Exxon Valdez Oil Spill
Restoration Project Final Report

Monitoring Environmental Contaminants in the Northern Gulf of Alaska: Workshop and Literature Compilation

Restoration Project 00567
Final Report DRAFT

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Study History: This was a project with two separate complementary elements; (1) to conduct and report on a workshop to develop recommendations about long-term monitoring of contaminants in the Gulf of Alaska and, (2) to compile literature about marine pollutants in the Northern Gulf of Alaska and areas affected by the *Exxon Valdez* oil spill.

Abstract: A one-day workshop was conducted to assess needs and priorities for discuss possible long–term monitoring of contaminants in the Gulf of Alaska. Thirteen contaminant specialists from various agencies participated. Two components were drafted and provided to the *Exxon Valdez* Oil Spill office for participants of the Gulf Ecosystem Monitoring workshop to be held 12-13 October 2000, in Anchorage, AK. Recommendations also were developed for long-term monitoring of specific contaminants, species and other indicators of pollution in the marine environment. An extensive literature survey was compiled, with abstracts, and formatted for distribution as a compact disk.

Key words: contaminants, persistent organic pollutants, POPs, persistent bioaccumulative toxics, PBTs, Gulf of Alaska, HCBs, HCHs, heavy metals, monitoring, PAHs, PCBs, pollution, radionuclides, recommendations, Gulf Ecosystem Monitoring

Project Data: *Description of data – Workshop:* Notes were taken during the meeting on laptop computer and by hand. The meeting was not tape-recorded. *Format* – Notes taken on computer were written using Microsoft Word 2000. *Custodian* - Contact Sue Hills, Institute of Marine Science, University of Alaska Fairbanks, Fairbanks Alaska 99775-7220, voice 907-474-5106, fax 907-474-5571. *Availability* – copies of the notes can be provided on diskette and photocopy.

Literature compilation: Literature was compiled along with abstracts and keywords. *Format:* All references were entered into Endnotes software. *Custodian* – Douglas Burrows, Environmental Assessment Program, National Marine Fisheries Service, Northwest Fisheries Science Center, 2725 Montlake Boulevard East, Seattle, Washington 98112, voice 206-860-3359, fax 206-860-3335. *Availability* – copies can be provided by compact disk or via e-mail.

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EXECUTIVE SUMMARY

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This project sponsored a workshop to assess needs and priorities for monitoring environmental contaminants in the northern Gulf of Alaska, including the area directly affected by the Exxon Valdez oil spill. Topics and resulting recommendations addressed contaminants that pose potentially adverse effects to the marine ecosystem and to human health, as well as marine and other species that are sensitive to or indicative of pollution. Workshop participants agreed that the long time horizon of the proposed Gulf Ecosystem Monitoring Program, under development by the *Exxon Valdez* Oil Spill Trustees Council would offer a unique opportunity for the future collection of contaminants data. Participants recognized, however, that the program would not likely encompass all the aspects of contaminants that were of interest to them, such as human health-related issues.

Participants agreed that key precedents and much valuable work had already been done in other parts of the world by other programs such as the international Arctic Monitoring and Assessment Programme, the Environmental Protection Agency's National Environmental Monitoring and Assessment Program, and the Canadian National Contaminants Program. These programs could help form the foundation for long-term monitoring of contaminants and environmental compartments in Alaska. As a core, the lists of chemicals from the first two programs were recommended, as well as the list of species from the Arctic Monitoring and Assessment Programme. Specific considerations regarding proposed core measures were also discussed. Participants noted that additional collaborative effort is needed to further define the scope of key elements to monitor. The development of the Gulf Ecosystem Monitoring program and the contaminants portion should result in clearly articulated objectives that build on and coordinate with ongoing programs while focusing on unique Alaska objectives. Specific recommendations were developed regarding proposed core measures that should be considered.

INTRODUCTION

Alaska, the nation's largest coastal state, currently has no long-term program to monitor environmental pollutants such as petroleum hydrocarbons in marine organisms. In the northern Gulf of Alaska and areas of the *Exxon Valdez* oil spill, scientists, managers and concerned citizens have been challenged by the absence of background levels or trends to compare with effects of exposure to the chemical constituents of crude oil and other pollutants. Chemicals of particular interest include persistent organic pollutants (POPs), pesticides, heavy metals and petroleum constituents that accumulate in marine organisms and are known collectively as persistent bioaccumulative toxics (PBTs). These pollutants are of concern for their potential effects on animal populations, as well as potential health concerns for humans using local traditional or subsistence food resources. Although some of the chemicals of concern have been detected at generally low levels in some Alaskan marine biota, there is increasing public concern and scientific interest in understanding the potential levels, trends, and associated effects to organisms.

Polyaromatic hydrocarbons (PAHs), constituents of natural and manmade petroleum products, have been increasingly detected in marine organisms and have been documented in EVOS field

research. Persistent organic pollutants such as polychlorinated byphenyls (PCBs) and organochlorine pesticides have been found throughout the world and can be detected in the environment in trace quantities. They can be transported great distances on wind and ocean currents following their accidental release from industrial countries. Mercury and other metals such as inorganic arsenic, mercury, cadmium, and selenium are naturally present in the environment in low amounts, and industrial sources can contribute additional quantities. It is well established that persistent bioaccumulative toxic chemicals can accumulate in top carnivores in marine ecosystems. Pollutants may also act synergistically with other stressors, such a climate change, ultraviolet radiation, disease, or habitat degradation to adversely affect species and ecosystem structure.

Pollutants entering marine waters have the potential to affect resources and human uses injured by the oil spill. Human population growth, industrial activities and waste disposal are increasingly contributing pollutants form local regional and international sources. Faced with these pressures, resource managers need accurate, up to date information on conditions and changes over time to protect resources from harm, and to guide restoration decisions. The public needs accurate information to make informed recommendations and choices. Because local residents rely heavily on the abundance, quality and safety of marine species used as food, communities affected by the spill need assurance that local conditions are being monitored. Consumers need current information to assess benefits and issues associated with a marine-based subsistence diet.

The specific goals of long-term monitoring of contaminants in the northern Gulf of Alaska and the area affected by the spill , while not yet defined in detail, may include:

- Determine the extent, persistence, and effects of remaining oil spilled by the T/V *Exxon Valdez* in the environment.
- Provide periodic measurements of contaminants levels in species used for subsistence foods, for subsequent use in human health assessments to evaluate potential benefits and risks.
- Identify changes in the Gulf of Alaska Marine ecosystem structure and potential environmental stressors.

Currently there is very little baseline monitoring information from Alaska's marine ecosystems to assess possible trends, associated variability, and combined effects from contaminants. To help develop future monitoring priorities, this project was developed as a step toward evaluating current knowledge and data gaps, and formulating recommendations. These results are being provided for the Exxon Valdez Oil Spill Trustee Council to incorporate and further refine into a more comprehensive proposal for a long-term Gulf Ecosystem Monitoring program.

Consistent with the *Exxon Valdez* Oil Spill Trustee Council's November 1994 Restoration Plan, the primary geographic focus of this project is the oil spill region in the northern Gulf of Alaska including Prince William Sound, Cook Inlet, Kodiak, and the Alaska Peninsula, as well as eastward to Yakutat. Communities with potential to directly benefit from this project and the eventual GEM program for contaminants monitoring include Valdez, Cordova, Chenega, Tatitlek, Whittier, Tyonek, Nanwalek, Port Graham, Seldovia, Homer, Soldotna, Anchorage, Kodiak, Pt. Lions, Ouzinkie, Old Harbor, Akhiok, Chiniak, Karluk and Larsen Bay.

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OBJECTIVES

The objectives for Project 00567 were as follows:

1) Determine current data sources on environmental contaminants, including data for water quality and sediments in the regions affected by the oil spill.
2) Asses what we have learned about contaminants from EVOS and other research on levels, trends and sensitivities in marine species.
3) Assess the greatest concerns to the northern Gulf of Alaska Marine ecosystem, and to human consumers of marine organisms.
4) Identify data gaps and priorities.
5) Develop recommendations for long-term monitoring of environmental contaminants.

The literature compilation addresses the first objective. Further details about this part of the project are contained in Appendix C.

As a means to focus specifically on objectives 2-5, the specific goal of the workshop was to identify and discuss issues related to designing a contaminant monitoring program for the Gulf of Alaska that could be incorporated into the new Gulf Ecosystem Monitoring Program (GEM) of the *Exxon Valdez* oil spill (EVOS) Trustee Council. Under previous EVOS guidelines, only petroleum-related contaminants had been addressed in research and trend studies. Under GEM, the list may be expanded to a broader suite of pollutants (e.g., persistent organic pollutants or POPs, heavy metals).

Specific objectives of the workshop discussion were to:

1) List proposed contaminants to be monitored and the rationale for their selection.
2) List proposed environmental compartments to be sampled (e. g., water, sediment, tissues) and the rationale for their selection;
3) Indicate the relative importance of the selected indicator or sentinel compartments or species;
4) Make recommendations in a document to be circulated widely for further use.

METHODS

A total of 17 contaminants specialists from various agencies were contacted and asked to participate in the workshop. Twelve either came or sent representatives (Appendix A), plus the project manager and the facilitator. The goal and objectives were sent to participants as well as a list of contaminants as a starting point for Objective 1 (Table 1). Because many participants had not been closely involved in GEM planning, representatives of the GEM program were asked to provide an overview of their timelines and plans. Resources available at the workshop included an annotated bibliography of 738 references to studies conducted in the Gulf of Alaska and North Pacific Ocean or on species found in that area. The bibliography, funded by this project and developed separately by Dr. Margaret Krahn of the National Marine Fisheries Service, is available as an electronic version from ARLIS and from the Alaska Department of Environmental Conservation.

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Notes and recommendations of workshop participants were recorded on laptop with a screen projector for viewing by participants during the meeting and by hand. The meeting was not tape-recorded.

Table 1. List of contaminants for possible inclusion in monitoring program (Arctic Monitoring and Assessment Program (AMAP) 1997).

Hexachlorobenzenes (HCBs)
Hexachlorocyclohexanes (HCHs)
Chlordanes
Heptachlor
DDT (DDE, DDD)
Mirex
Toxaphene
Dieldrin/aldrin
Furans
Polychlorinated biphenyls (PCBs)
Brominated biphenyls
Dioxins
Polycyclic Aromatic Hydrocarbons (PAHs)
Tributylin (TBT)
Mercury
Cadmium
Selenium
Petroleum Hydrocarbon constituents of crude oil.

RESULTS

The GEM program overview

The *Exxon Valdez* Trustee Council is developing a long-term (~100 yrs) Gulf Ecosystem Monitoring Program in the Northern Gulf of Alaska, north of 53°N (EVOS 2000). Long-term monitoring will be complemented with shorter-term research projects to clarify critical linkages. The primary mission is to monitor the productivity of the Gulf ecosystem and factors (human-caused and other) that affect or can explain changes in populations of animal species in which the EVOS Trustee Council is interested. Priorities will be organized by themes and by answering questions related to detecting changes. The issue of contaminants crosses disciplines and thus is seen as part of other themes rather than being a theme in itself.

GEM is being developed over three years; this workshop occurred in the second year. The workshop in mid October 2000 further developed a draft monitoring plan then sent to the National Research Council in February 2001. That plan addresses components to be sampled, location and frequency of sampling, and not include detailed statistical sampling designs or budgets. Thus, objectives of the contaminants workshop fit into the GEM timeline and

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participants developed two specific components for the 12-13 October 2000 GEM workshop (Appendix B).

With coordination, integration, and synthesis as watchwords of GEM, it is expected that other partners will work together to ensure that GEM projects are collaborative and will have combined funding. It is hoped that GEM can be an incentive for organizations to work together in monitoring and research. The GEM synthesis theme will include a periodic "State of the Gulf" index as a "report card." The State of the Gulf index is seen as a way to track the "whole big picture," that is, not to lose connections and larger trends that might not be recognized on individual projects.

Workshop participants noted that long-term projects are critical but difficult to implement. They agreed that research projects of two to four years are common and can be useful but that long-term monitoring is crucial. For example, the 15-yr national status and trends Musselwatch program has already proved to be very valuable. The long time-horizon of the GEM program might allow different kinds of analyses, such as investigating multiple stressors and combined or synergistic effects (cumulative impacts). Multiple overlapping stressor analysis could help identify important areas to be examined ("hot spots"). A program focus on endpoints is crucial to doing other work such as toxicology.

Contaminants to be monitored

Workshop participants noted that chronic, low concentrations of mixtures of chemicals are likely to be found in the study area. They agreed that the international Arctic Monitoring and Assessment Programme (AMAP) list of chemicals (Table 1) was the minimum to be measured and should be included in any monitoring scheme for the Gulf to allow comparison with the circumarctic data of AMAP. The U.S. Environmental Protection Agency's national Environmental Monitoring and Assessment Program (EMAP) tracks more chemicals (Table 2) than does AMAP; that list was also discussed. EMAP is proposed to begin in Alaska in the future. Participants recommended that additional sites within the GEM area could be proposed for inclusion in EMAP, and the few additional analyses needed for AMAP chemicals (Table 2) added to the EMAP analytes. Note that the geographical areas included in GEM, AMAP, EMAP, and the previous EVOS projects are not the same.

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Table 2. Comparison of chemicals monitored under the Arctic Monitoring and Assessment Program (AMAP) and the U.S. Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP). From AMAP (1997), and EPA (2000).

Chemical or chemical group	AMAP	EMAP
Chlordanes (alpha chlordane for EMAP)	Y	Y
Dieldrin/aldrin	Y	Y
Endosulfan I	N	Y
Endosulfan II	N	Y
Endosulfan sulfate	N	Y
Endrin	N	Y
Heptachlor	Y	Y
Heptachlor epoxide	N	Y
Hexachlorobenzenes (HCBs)	Y	Y
DDT (DDE, DDD)	Y	Y
2,4'-DDD	N	Y
4,4'-DDD	N	Y
2,4'-DDE	N	Y
4,4'-DDE	N	Y
2,4'-DDT	N	Y
4,4'-DDT	N	Y
Hexachlorocyclohexanes (HCHs)	Y	N
Lindane	Y	N
Mirex	Y	Y
Toxaphene	Y	Y
Trans-Nonachlor	N	Y
Furans	Y	N
Polychlorinated biphenyls (PCBs)	Y	Y
21 PCB congeners (see EPA 2000 for complete list)	N	Y
Brominated biphenyls	Y	N
Dioxins	Y	N
Polycyclic Aromatic Hydrocarbons (PAHs)	Y	Y
Acenaphthene	N	Y
Anthracene	N	Y
Benz(a)anthracene	N	Y
Benzo(a)pyrene	N	Y
Biphenyl	N	Y
Chrysene	N	Y
Chrysene (C1-C4)	N	Y
Dibenz(a,h) anthracene	N	Y
Dibenzothiophene	N	Y
Dibenzthiophene (C1-C3)	N	Y
2,6-dimethylnaphthalene	N	Y
Fluoranthene	N	Y
Fluorene	N	Y
Fluorene (C1-C3)	N	Y

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Table 2. Continued.

Chemical or chemical group	AMAP	EMAP
2-methylnaphthalene	N	Y
1-methylnaphthalene	N	Y
1-methylphenanthrene	N	Y
2,6-dimethylnaphtalene	N	Y
Naphthalene	N	Y
Naphtalene (C1-C4)	N	Y
Pyrene	N	Y
Benzo(b)fluoranthene	N	Y
Acenaphthylene	N	Y
Benzo(k)fluoranthene	N	Y
Benzo(g,h,I)perylene	N	Y
Ideno(1,2,3-c,d)pyrene	N	Y
2,3,4-trimethylnaphthalene	N	Y
Tributylin (TBT)	Y	N
Aluminum	N	Y
Antimony (sediment only)	N	Y
Arsenic	N	Y
Cadmium	Y	Y
Chromium	N	Y
Copper	N	Y
Iron	N	Y
Lead	N	Y
Manganese (sediment only)	N	Y
Mercury	Y	Y
Nickel	N	Y
Selenium	Y	Y
Silver	N	Y
Tin	N	Y
Zinc	N	Y

If additional funding were available or additional funding partners could be found, workshop participants listed other factors that should be monitored: radionuclides, ultraviolet light (UV), phthalates, selected pathogens (e.g., clostridium spores, coliform bacteria), xenobiotic species, and human-generated noise. They identified the problem of nutrients from sewage or agricultural runoff causing unusual phytoplankton blooms but did not specify which nutrients should be monitored. Although PAHs were present on both the AMAP and EMAP lists, other toxic properties of mixtures of crude and refined oils may exist. Participants felt strongly that some mechanism must to be built in to the process periodically to update analysis methods and to evaluate the list of substances being monitored. The understanding of contaminants and their effects is changing relatively rapidly and chemicals formerly thought to be harmless may be shown in the future to have previously unsuspected effects. A recent example of this is phthalates, chemicals used to make plastics flexible, and also used in cosmetics and other products.

Biological response products should be monitored and may be more important to assess than the level of the pollutant alone. Biomarkers or biological response products should be monitored such as markers of reduced immune systems; metabolic markers of exposure to POPs or other contaminants (e.g., P450); or indicators of endocrine disruption. Microbial genetic markers (e.g. genes for methylating mercury), although not well developed at this time, may prove useful in the future.

It was recognized that other data would be needed to interpret contaminants monitoring information. Those data could include water quality measures including as dissolved oxygen, salinity, temperature, pH; sediment data such as grain size and total organic carbon; and various community structure indices. Such data would likely be collected by other GEM projects but should be scrutinized in relation to contaminants monitoring to ensure the data are available for the appropriate places, times, and scales.

Compartments to be monitored

Although water, air, sediments, and living organisms were considered, the majority of the discussion was on the use of living organisms as bioindicators. The use of bioindicators has been justified in other marine pollution monitoring programs because 1) they assess bioavailable pollutants; 2) they can show effects of contaminant levels below current chemical analytical detection limits (due to chronic, low level pollution or short-term pulses); and 3) they assess the mixture of chemicals in the environment with synergistic or additive antagonistic relationships, or the influence of abiotic factors (e.g., photoactivation). The choice of organism for monitoring can be based on the importance of that organism itself or because it is a surrogate for something else of importance. Underlying the discussion were generally understood or assumed principles for selection of appropriate compartments. Some characteristics of a suitable or "good" indicator organism (and by extension a "good" compartment) are:

- Abundant throughout the monitoring area
- Easy to sample in an objective, quantitative manner
- Has a stable taxonomy, easily taught to non-specialists
- Sensitive enough to provide early warning of sublethal effects
- Concentrates the chemical above background levels
- Slow to eliminate the chemical
- Clear food chain linkages
- Easily assessed
- Reliably indicates the presence of chemical if it is present
- Clear temporal or spatial relationship to the source of the chemical because they are:
  - Sessile, or have a
  - Known home range, or a
  - Known life span (e.g., squid that live 1-2 years)
- Highly valued by the public as food or for cultural importance (e.g., salmon, sea otters)
- Higher trophic level organisms for bioaccumulating or biomagnifying chemicals
- Lower trophic level organisms for chemicals that do not accumulate in higher levels of food chains.

Lists of possible organisms to be monitored can then be further reduced by specifying the system of interest, e.g., pelagic/benthic, coastal/offshore, resident/migrant, piscivore/planktivore (Table 3). For example, mussels indicate that a pollutant is mediated through waterborne transport, probably in the nearshore/surface water column, and are particularly effective indicators for lipophilic contaminants such as POPs, and PAHs. The hyponeuston layer in the oceans has been shown to concentrate pollutants in pelagic offshore areas. The Japanese Squid Watch program (Hashimoto et. al. 1999) monitors squid that live for 1-2 years and are found across much of the North Pacific Ocean. Migratory animals such as salmon or birds may carry contaminants into the study area that are not found in water, sediments or lower trophic organisms in the study area. Microbial species abundance and diversity may change with pollutant loads, and thus may influence biogeochemical cycling.

Rather than developing a new list of indicator organisms, workshop participants endorsed the use of the AMAP list of organisms (Table 4) as a starting point. That list would be modified during the synthesis activity proposed for GEM sponsorship (Appendix B). Selection of appropriate bioindicators depends upon the objectives of the program, as well as financial, level-of-expertise, and time considerations. Participants also agreed in principle with the AMAP model of not sampling every species every year for every chemical.

GEM program representatives stated that effects of environmental change on humans are not part of GEM. However, workshop participants felt strongly that humans should be included in the contaminants components because of their status as top trophic level indicators. If humans, especially those dependent on wild organisms ("subsistence" or "country" food) from the study area were to be included, careful dietary surveys would be needed. Several kinds of information would be available for humans that would be difficult or impossible to get from non-human top trophic level consumers. For example, possible indicators of human health status include:

- maternal blood in the first trimester of pregnancy
- umbilical cord blood
- infections in first year of life
- birthweight, head circumference, occurrence of malformations
- human biomarkers (not yet well developed)

Workshop participants discussed desirability of assessing contaminants in food after it has been prepared for eating (i.e., end-of-fork studies). Although some such studies have been done in other areas (AMAP 1997, Han and Adare 1997) the results have been highly variable and difficult to interpret with limited value toward understanding bioavailability. Such studies were not specifically recommended by the workshop participants for inclusion in the GEM program.

The group recommended very strongly that water NOT be sampled because concentrations of pollutants are likely to be low, necessitating filtering of large volumes of water with sensitive handling/holding requirements.

Sediments can be a repository for pollutants and become a long-term source. Chemical analyses of pollutants in sediments may be of increasing interest over time. Once an early baseline is established for the study area, they can be sampled at longer intervals (e.g., 1/10 yrs).

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Air should be sampled with dry and wet deposition monitors during all seasons. It was recognized that spring river runoff, ice melt, and glacial inputs can be important sources of contaminants but no specific monitoring recommendation was made.

Table 3. General types of compartments to be included in a Gulf of Alaska contaminants monitoring plan

General description	Example	Comments
Top trophic level consumers as integrator species	Harbor seal	
	Killer whales	Compare to polluted populations
Lower trophic level consumers	Mussels	National Status and Trends program
Near shore integrator	Sea otter	Compare west-southeast populations
Species with known effects of particular pollutant	Eagles and pesticides	Compare west-east populations
	Seabirds	Used by humans, but source may not be in nesting area
Top trophic level piscivore	Beluga	Compare with arctic populations
Subsistence species with regional exposures	Locally resident fish	Used for benefit/risk analyses
Pelagic, offshore integrator with known life span	Squid with 1-2 year life span	Potential to add Gulf of Alaska to international/Japanese squid watch program
Migratory species (trans-boundary)	Migratory birds	Specific sources outside Alaska
Effects of selection on a short time scale	Microbial community composition	Only the species/individuals that can tolerate the levels of contaminants survive

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Table 4. An overview of compartments and species common to several AMAP Trends and Effects subprograms but excluding the terrestrial subprogram (AMAP 2000).

Subprogram	Media/Species
Atmosphere	Air/aerosol
	Bulk precipitation
	Snow pack
	Glacial cores
Marine	Surface sediment
	Sediment cores
	Seawater /
	Sea ice
	Macro-algae
	Blue mussels
	Whelks
	Sculpin
	Other fish (cod, capelin, flounder, etc.)
	Ringed seal
	Harbor porpoise
	Pilot whale
	Beluga
	Walrus
	Polar bear
	Arctic fox
	Eider
	Black guillemot/Alcids
	Kittiwake
	Glaucous gull
Freshwater	Surface sediment
	Sediment cores
	Lake / river water
	Ice
	Arctic char
	Burbot / Lake trout / Pike
	Loon
Human health	Blood
	Other human media
	Traditional food items (marine, freshwater, terrestrial)

Relative importance of the selected indicator or sentinel species

Workshop participants felt it was premature to recommend a priority list of indicator species or compartments at this time.

What is next

Two components were included in the materials prepared for the discussions at the GEM workshop 12-13 October 2000 (Appendix B). This report will be further distributed for adaptation and use in developing a contaminants monitoring plan for the Gulf of Alaska that will be well integrated with existing and planned national and international programs. Concerns raised at the workshop about the lack of human related studies, bioindicators as food, and synergies of contaminants need to be addressed in future iterations of the draft plan. Workshop participants noted that the bibliography provided at the workshop was an excellent start. Some noted that they would like to see more references that would be outside the original geographic or subject criteria, such as those from Canadian studies as well as human health references. Shorter-term research project areas need to be identified to link with the monitoring program. One specific example of a possible research project is to explore the distinct difference in PCBs loads compared between bowhead and beluga whales inhabiting the same areas. These animals feed at very different trophic levels, thus having different potential exposures. However, another possibility to explore is that microbes in the foregut of bowhead whales may break down the pollutants.

DISCUSSION

The stated mission of the GEM program is to "*sustain a healthy and biologically diverse marine ecosystem in the northern Gulf of Alaska and the human use of the marine resources in that ecosystem through greater understanding of how its productivity is influenced by natural changes and human activities*" (EVOS 2000). Within the GEM framework, contaminants are seen as a possible explanation of changes in productivity of the study area. The mission statements of two existing arctic contaminants programs, AMAP and the Canadian Northern Contaminants Program (NCP) are quite different. The responsibility of eight-nation AMAP is to "*monitor the levels and assess the effects of selected anthropogenic pollutants in all compartments of the Arctic*" (AMAP 1997). The goal of the NCP is to "*reduce or eliminate contaminants in traditional/country food...[with an] emphasis on providing northerners with the information they need to make their own decisions, participate in the issues, and contribute to solutions*" (NCP 1997). The goal of EPA's national scorecard system, known as EMAP, is perhaps the closest to that of GEM: "*EMAP is designed to monitor indicators of pollution and habitat condition and seek links between human-caused stressors and ecological condition*" (EPA 2000).

At the intersection of these different types of programs are data on contaminant levels in the area of interest and their effects on living organisms. Whether those data are then used to explain changes in productivity or to raise source and abatement/mitigation issues depends on the objectives of the individual program. However, the questions to be answered may affect

sampling protocols such as recommended sampling time and place. For example, assessment of the safety of traditional foods would be unlikely to have the same sampling program as the assessment of the effects of contaminants on ecosystem health. Workshop participants agreed that objectives and hypotheses of a Gulf of Alaska monitoring program and linked research must be carefully examined and integrated. A clear statement of objectives is especially necessary in the area of contaminants and human health.

Workshop participants were particularly aware of the gap between a potential contaminants monitoring program under GEM and the needs for contaminant monitoring at a larger scale. It was recognized that it would be appropriate for GEM to sponsor a round table or working group to coordinate work and synthesize information but that a multi-agency agreement would probably be necessary to provide a funding partnership (some GEM support) to extend the program to other areas. For example, human health issues would not be fully incorporated into a GEM program. Another example is that surveys for harbor seals have been funded from other sources but EVOS has paid for analysis of tissues taken incidental to other activities. Thus it would be possible for a project to be driven by contaminants issues but not fully funded by GEM. Another advantage to a coherent, well-articulated program and coordination among agencies is that if GEM has sufficient funds in a particular year, they could be used, for example, to address an ongoing need such as analyzing contaminants in archived samples.

CONCLUSIONS

Workshop participants agreed that the long time horizon of the proposed GEM program offers a unique opportunity for the collection of contaminants data although the program does not propose to encompass all the aspects of contaminants that were of interest to participants (e.g., human health issues). It was agreed that much work had already been done elsewhere by other programs (e.g., AMAP, EMAP, and the Canadian NCP) serving as important examples which should be considered as a foundation for designing monitoring for contaminants and compartments. Further collaborative work is needed to define the scope of core monitoring objectives and priorities, which in turn relies partly upon clear objectives emerging from the overall proposal for the GEM program. The program will need to build upon and coordinate with ongoing programs while focusing on its unique objectives.

ACKNOWLEDGMENTS

Thanks to EVOS and ADEC for sponsoring this forum to specifically address contaminants. Thanks especially to the participants who efficiently focused their expertise and knowledge on the task to be able to accomplish so much in a short time. Thanks also to Doug Dasher, (ADEC Fairbanks) for access to useful background materials. This study was funded through the *Exxon Valdez* Trustees Council, under agreement between ADEC and the Institute of Marine Science, University of Alaska Fairbanks.

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APPENDIX A. List of Participants at the EVOS/GEM Contaminants Discussion Group, Anchorage, AK, September 18, 2000.

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APPENDIX B. TITLES AND DESCRIPTIONS OF DRAFT GEM COMPONENTS SUBMITTED FOR INCLUSION IN BACKGROUND NOTEBOOKS FOR THE 12-13 OCTOBER 2000 GEM WORKSHOP, ANCHORAGE, ALASKA.

Title: Sources, Effects, Fates and Trends of Contaminants

Description:

1) Synthesize contaminants information to assess interactions of contaminants and effects, and contaminants and sources. Compile existing data, assess ongoing work and sampling, and, from this material, determine data gaps and formulate research and monitoring needs. Use information from various sources including AMAP, EMAP, regional and data collection programs to develop long-term priorities and direction. Classify major sources as known, probable, or unknown.
2) Develop a state of the Gulf index (SGI) to detect changes.
3) Develop collaborative commitment and process to integrate results from ongoing contaminants monitoring into interdisciplinary research, monitoring, and analysis, for example, through periodic assessment roundtables and electronic database access.

Title: Monitoring Environmental Contaminants

Description:
Monitoring strategies to address key questions regarding origin and fate of environmental contaminants from both regional and point sources in the northern GOA in concert with programs in adjacent geographic regions and cooperating agencies within the geographic scope of GEM. Support for sampling and long-term storage of samples is provided in cooperation with concerned agencies.

APPENDIX C. LITERATURE COMPILATION

(To be provided by NOAA/NMFS/NWFSC/Environmental Assessment Division)

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The 16th Northeast Pacific Pink and Chum Salmon Workshop was held in Juneau, Alaska 24-26 February 1993. Over 100 scientists, resource managers, harvesters, and processors attended. The workshop has been held biennially since the early 1960s, not by any formal organization but by volunteer hosts who have traditionally had the meeting in Alaska, British Columbia, or Washington.

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The Exxon Valdez oil spill in Prince William Sound, Alaska, in March 1989, was the largest crude spill to date in US waters. It prompted many studies on the fate, transport and effects of the oil on biota in Alaskan waters, as well as on archaeological sites. This book consists of 25 research papers presented at an ASTM Symposium in April 1993. This introductory chapter summarizes topics and highlights of those papers, covering chemistry and fate, shoreline impacts, effects on fish, fisheries and wildlife, and impacts on archaeological sites, and discusses some of the issues arising from the study of this spill. Some lessons learned from this research included: The need for accurate identification of the spilled oil-derived hydrocarbons in all samples, the extensive movement of the oil down the Alaskan coast, with its unique fate characteristics, the strong chemical basis required for interpreting the biological significance of sedimented hydrocarbons, the difficulty of separating oil effects on biological populations from changes due to other variables (biotic and abiotic), the need for sensitive hydrocarbon biomarkers, and the need to have established definitions and criteria to determine whether biological recovery had occurred. To provide a context for the papers in this volume, other published literature and symposia on this spill are discussed. Some of the more important remaining issues include: The duration of effects of the residual oil, the extent of intertidal impact and recovery, and the extent and duration of impacts of the spill on fisheries and wildlife populations, including seabirds and sea otters. Additional issues, of considerable importance, but not concerned primarily with the fate and effects of the spilled oil, include: The need for the oil spill community as a whole to agree ahead of time on how to study such accidental spills, and select appropriate monitoring tools. The effect of impending litigation on the type and extent of the research conducted. This volume provides the reader with detailed insights into the ecological impacts of such accidents in cold sub-arctic waters, and some of the outstanding scientific issues on the effects and recovery patterns after such spill events.

Agler, B. and S. Kendall (1999). Marine Bird and Sea Otter Population Abundance of Prince William Sound, Alaska: Trends Following the T/EXXON VALDEZ Oil Spill, 1989-96. Restoration Project 96159. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service,

Anchorage, AK. Nongame Bird Project.: 242p.

The authors conducted small boat surveys to estimate marine bird and sea otter (Enhydra lutris) populations in Prince William Sound, Alaska during March and July 1996, using methods developed in 1989-91. During 1996, the authors recorded 83 bird and 13 mammal species. To examine population trends from 1989-96, the authors assumed that in the absence of the oil spill, population estimates in the oiled zone would change at the same rate as those in the unoiled zone. To reduce the effect of annual variation on the trends of marine bird populations in Prince William Sound from 1989-96, the authors determined a ratio of a species' or species groups' population estimate from the oiled zone to the estimate in the unoiled zone by year. For Prince William Sound as a whole, the authors examined population trends from 1989-96, using regression analyses. See also PB96-194881.

Agler, B., S. Kendall, et al. (1999). "Declines in Marine Bird Populations in Prince William Sound, Alaska Coincident with a Climatic Regime Shift." Waterbirds **22**(1): 98-103.

Analyses of marine bird surveys conducted in Prince William Sound, Alaska in July 1972 were compared to surveys in July 1989, 1990, 1991, and 1993 and indicated that populations of several taxa of marine birds that prey on fish have declined in Prince William Sound, but most taxa that feed on other prey species, such as benthic invertebrates, have not declined. Red-throated Loon (Gavia stellata), Pacific Loon (G. pacifica), cormorant (Phalacrocorax spp.), Surf Scoter (Melanitta perspicillata), Bonaparte's Gull (Larus philadelphia), terns (Sterna spp.), Pigeon Guillemot (Cepphus columba), Brachyramphus murrelets (Brachyramphus marmoratus and B. brevirostris), Parakeet Auklet (Cyclorrhynchus psittacula), Tufted Puffin (Fratercula cirrhata), and Horned Puffin (Fratercula corniculata) populations declined by >50%. Most of these are piscivores, feeding on schooling fish. Some non-piscivorous taxa, such as Harlequin Ducks (Histrionicus histrionicus), goldeneyes (Bucephala clangula and islandica), and Black Oystercatchers (Haematopus bachmani), have increased in Prince William Sound between 1972 and 1989-1993, although a portion of the population was killed by the T/V Exxon Valdez oil spill. Declines in piscivorous bird populations also have been documented in the Gulf of Alaska, the Bering Sea, and along the California coast in the past two decades and have been coincidental to changes in forage fish species in the North Pacific Ocean. Many of the declines appear to be related to changes in forage fish abundance that occurred during a climatic regime shift in the north Pacific Ocean, although some taxa were also affected by the Exxon Valdez oil spill.

Agler, B., S. Kendall, et al. (In press). "Changes in marine bird populations in Prince William Sound, Alaska between 1972 and 1989 to 1993." Colonial Waterbirds.

Ambrose, S., A. Matz, et al. (In preparation). Environmental Contaminants in American and Arctic Peregrine Falcon Eggs in Alaska, 1979-95. Anchorage, AK, U.S. Fish and

Wildlife Service, Northern Alaska Ecological Services.

Amoroso, F. and L. Keenan (1994). The Environmental Economic Impact Of Vessel Oil Spills. Contributions in Economics and Economic History, No. 153. J. E. J. Hickey and L. A. Longmire, Greenwood Press Inc.: Westport, Connecticut, USA.: 131-156.

Andres, B. (1996). Consequences of the Exxon Valdez oil spill on black oystercatchers inhabiting Prince William Sound, Alaska. Columbus, OH, Ohio State University. Thesis

Andres, B. (1996). Effects of the EXXON VALDEZ Oil Spill on Black Oystercatchers Breeding in Prince William Sound, Alaska. Bird Study Number 12. Restoration Study Number 17. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Marine and Coastal Bird Project.

Black oystercatchers (Haematopus bachmani) were studied in central Prince William Sound, Alaska, to determine the effects that the Exxon Valdez oil spill had on their population, reproductive biology, and behavioral ecology. Estimates of direct mortality of black oystercatchers varied widely among the methods used to assess losses and ranged from 4% to 57% of the population inhabitating the spill zone; mortality probably did not exceed 20% of the population. Although the black oystercatcher population appears to be recovering in some areas of the Sound, delayed reproduction in the species precludes determination of the total effect of the spill on the population until at least 1994.

Andres, B. (1997). "The Exxon Valdez oil spill disrupted the breeding of black oystercatchers." Journal of Wildlife Management **61**(4): 1322-1328.

I evaluated the effects of the Exxon Valdez oil spill on black oystercatchers (Haematopus bachmani) by comparing the breeding success of pairs inhabiting oiled and unoiled islands in Prince William Sound, Alaska. I hypothesized that direct and indirect consequences of shoreline oiling would disrupt the breeding and foraging behavior of oystercatchers. Fewer pairs occupied (36%) or maintained nests on (34%) oiled Green Island after the spill in 1989 than in 1991, whereas the number of pairs and nests remained similar on unoiled Montague Island during the same period. In 1989, chicks disappeared from nests at a greater rate (42%) on Green Island than from nests on Montague Island; disturbance associated with cleanup operations also reduced productivity on Green Island in 1990. By 1991, productivity on Green Island (1.3 chicks/pair) exceeded that on Montague Island (0.6 chicks/pair). In 1989, mortality of bay mussels (Mytilus trossulus) was significantly higher (P = 0.003), and feeding rates of oystercatchers were significantly lower (P = 0.0002), on Green Island than on Montague Island. I concluded that the breeding of black oystercatchers was disrupted during 1989 and 1990 but had substantially recovered by 1991. Additional, intensive restoration actions probably are not needed for black

oystercatchers to recover in areas affected by the spill.

Andres, B. (1998). "Shoreline habitat use of black oystercatchers breeding in Prince William Sound, Alaska." Journal of Field Ornithology **69**(4): 629-634.

To guide habitat acquisition for species negatively affected by the Exxon Valdez oil spill, I quantified habitat use of Black Oystercatchers (Haematopus bachmani) breeding in Prince William Sound, Alaska. I used local counts of breeding pairs and Sound-wide transect counts of individuals to determine shoreline features that explained variation in oystercatcher density. Density of pairs, and occurrence of individuals, was greater in areas dominated by shorelines of gradual slopes than in areas dominated by steep shorelines. Within areas dominated by steep, rocky shorelines, breeding density increased as the proportion of mixed sand and gravel beaches and as the number of rocks and small islands increased. Shoreline features that explained variation in local pair density were corroborated by data from Soundwide surveys. I incorporated information from other studies to construct a general, qualitative decision-tree model that predicts that disturbance-free shorelines of gradual slopes should support the highest densities of breeding Black Oystercatchers. Qualitative and quantitative models should be tested to determine their applicability to shoreline habitat throughout the oystercatcher's range.

Andres, B. (1999). "Effects of persistent shoreline oil on breeding success and chick growth of black oystercatchers." Auk **116**(3): 640-650.

Anon (1990). "Installation Restoration Program. Stage 1. King Salmon Airport , King Salmon, Alaska." Govt Reports Announcements & Index **08**.

TD3: Four investigations areas at King Salmon Airport were tested for over 146 inorganic, volatile organic, semivolatile organic, and pesticide contaminants. Of these 146, 31 potential contaminants of concern have been identified. These contaminants are addressed in this report because they exceed federal or state criteria for the protection of human health and the environment, are consistently present in site media (soil, sediment, surface,and ground waters), and are potentially toxic to humans and the environment. Suggested actions and the rationale for each investigation area are presented. An extensive appendix of field data is included as a separate volume. Keywords: Toxicity, Hazardous materials, Petroleum oils, Lubricants, Steel drums, Groundwater quality, Soil vapor gas, Aquifer, Geophysical survey, Sampling, Monitoring wells, Remedial investigation, Feasibility study. (RH) Final technical rept. See also Appendixes A-J, AD-A215 998.

Anon (1990). Shoreline segment characteristics handbook for smear model application (for microcomputers): 5 diskettes.

Five high-density floppy disks in R-Base format summarize the 6-volume 3,050 page data report which summarizes the data required to run the Coastline and

Surf Zone Oil Spill Transport Model (also known as the Smear Model or COZOIL) for the majority of the coast of Alaska. The model is used to predict the transport and weathering of spilled oil onto and along shorelines deterministically or stochastically, assuming the presence of a spill. The data are organized by the shoreline segments and subsegments corresponding to the segments used by the Minerals Management Service in oil spill risk analysis. Data are included for beach morphology, near-shore oceanographic conditions, meteorological conditions and ocean fetch as affected by the presence of sea ice.

Anon (1990). Alaskan Oil Spill Bioremediation Project. . Govt Reports Announcements & Index (GRA&I), Eastern Research Group, Inc., Arlington, MA. : 20p .

The U.S. Environmental Protection Agency's Office of Research and Development entered into a cooperative agreement with the Exxon Company to initiate a bio-remediation study as part of an effort to clean up oil on the shorelines of Prince William Sound, Alaska. The presence of oil was the result of an 11-million gallon spill of crude oil from the tanker, Exxon Valdez, on March 24, 1989. The study was designed to determine the feasibility of using nutrients to enhance microorganisms that live in the waters and sediments to degrade the oil and, thus, reduce its detrimental effects. Two types of fertilizer, a water soluble and an oleophilic, were applied on both physically cleaned and untreated beach sediments. Several sampling and field testing methods were used to observe changes in the composition of the oil, to monitor the movement of added nutrients in the test beaches, to detect changes in the number of bacteria present as the test proceeded and to assess the degradation of the oil. Based on available results of ORD's research, Exxon proposed to begin bioremediation on nearly 6,000 yards of shoreline in the Sound. The application began August 1, 1989. Color illustrations reproduced in black and white. Sponsored by Environmental Protection Agency, Cincinnati, OH. Center for Environmental Research Information.

Anon (1990). Outer Continental Shelf Environmental Assessment Program. Final Reports of Principal Investigators. Volume 67. . Govt Reports Announcements & Index (GRA&I), National Ocean Service, Anchorage, AK. Ocean Assessments Div. : 634p .

Contents: Distribution, abundance, and biology of blue king and Korean hair crabs around the Pribilof Islands; Distribution, abundance, and diversity of the epifaunal benthic organisms in Alitak and Ugak bays, Kodiak Island, Alaska; Distribution and abundance of some epibenthic invertebrates of the northeastern Gulf of Alaska with notes on the feeding biology of selected species; Reproductive success in Dungeness crab (Cancer magister) during long-term exposures to oil-contaminated sediments; Distribution and abundance of decapod larvae of the Kodiak shelf. See also Volume 63, PB90-115718. Sponsored by Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.

Anon (1990). Outer Continental Shelf Environmental Assessment Program. Final

Reports on Principal Investigators. Volume 66. . Govt Reports Announcements & Index (GRA&I), National Ocean Service, Anchorage, AK. Ocean Assessments Div. : 515p .

Contents: Early life history of Pacific herring: relationships of larval dispersal and mortality to environmental conditions. Final report of Port Moller planning study; Early life history of Pacific herring: relationships or larval dispersal and mortality to environmental conditions. Final report of 1989 Port Moller reconnaissance survey; Effects of petroleum contaminated waterways on spawning migration of Pacific salmon. Phase I. Laboratory studies; Effects of petroleum contaminated waterways on migratory behavior of adult pink salmon. Final rept. See also PB90-156217. Sponsored by Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.

Anon (1990). Outer Continental Shelf Environmental Assessment Program: Comprehensive Bibliography, June 1990. . Govt Reports Announcements & Index (GRA&I), National Ocean Service, Anchorage, AK. Ocean Assessments Div. : 648p .

The objectives of the Outer Continental Shelf Environmental Assessment Program (OCSEAP) are as follows: To provide information about the OCS environment that will enable the Department of the Interior (DOI) to make sound management decisions regarding the development of mineral resources on the OCS; To acquire information that will enable DOI to identify those aspects of the environment that might be affected by oil and gas exploration and development; To establish a basis for predicting the effects of OCS oil and gas activities on the environment; and To acquire impact data that may result in modification of leasing stipulations, operating regulations, and OCS operating orders in order to permit more efficient resource recovery with adequate environmental protection. The bibliography is a compilation of publications and reports that have resulted from research funded by OCSEAP since its inception in 1975 and is an updated version of the Comprehensive Bibliography published in January 1988. Certain other publications that have appeared in other government documents, books, or refered literature relating to environmental problems associated with oil and gas development are included in the bibliography. See also PB88-212030. Sponsored by Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.

Anon (1991). Toxic Release Inventory: microcomputers). Govt Reports Announcements & Index (GRA&I), Environmental Protection Agency, Washington, DC. Office of Toxic Substances.

The Toxic Chemical Release Inventory (TRI) data on diskette includes (1) the names, addresses, counties, and public contacts of facilities manufacturing, processing or using the reported chemicals; (2) the SIC code for the plants; (3) the chemical involved; and (4) the estimated quantity emitted into the air (point and non-point emissions), discharged into bodies of water, injected underground, released to land, or released to publicly owned treatment works. All releases are in pounds per year. Data file. System: Apple Macintosh. For use with Macintosh database management and spreadsheet programs. See also PB90-502964 and PB90-503509.

Anon (1991). "Prince William Sound, Alaska: The cleanup continues." GeoTimes **36**(3): 16-17.

The 1990 shoreline treatment season began in March with 20 Spring Shoreline Assessment Teams (SSAT) mapping the oil distribution remaining after the first storm season. These teams, made up of representatives from state and federal agencies and Exxon, surveyed more than 2,400 miles of shoreline from Prince William Sound to Kodiak Island. They found oil persisting along 400 miles, with 65 percent of the oiled shoreline in Prince William Sound. Things had improved significantly over the storm season. Comparison of fall 1989 and spring 1990 statistics showed the number of shoreline miles classified as heavily oiled was reduced 70 percent, moderately oiled shorelines 25 percent, and lightly oiled shorelines 37 percent.

Anon (1991). Outer Continental Shelf Environmental Assessment Program. Final Reports of Principal Investigators. Volume 69. . Govt Reports Announcements & Index (GRA&I), National Ocean Service, Anchorage, AK. Ocean Assessments Div. : 393p .

Content: Trace contaminants in surface sediment of the northern Bering Sea: a statistical review; Trace contaminants in the greater St. George Basin: a statistical review; Mercury in Alaska marine surface sediments: a review of the regional data; and Natural distribution and environmental background of trace heavy metals in Alaskan shelf and estuarine areas. See also Volume 68, PB90-272337. Sponsored by Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.

Anon (1992). Exxon Valdez HindCast (for microcomputers).: 1 diskette.

Once installed, the "HindCast Player" HyperCard stack displays the spill trajectory of the Exxon Valdez oil spill in the Prince William Sound in March of 1989. The product, "Exxon Valdez HindCast" contains one compressed file and one documentation file. The file containing the documentation is named "Read.me", and the compressed file is named "Exxon HindCasts". The compressed folder contains a moov file called "Exxon Valdez ", a Hyper Cord Stack called, "HindCast Player v/2", and Apples Quick Time TM extension file. System: Macintosh II or Quadra Family; System 6.0.5 or System 7.0 operating system. Language: HyperCord 2.1. Decompressed files require 5.5MB hard-disk space is required. The software is on one 3 is equivalent inch diskette, 1.44M high density.

Anon (1993). Exxon Valdez oil spill. (Latest citations from the Energy Data Base).

The bibliography contains citations concerning the environmental and economic impact of the Exxon Valdez oil spill. The citations examine the effect of the oil spill on marine wildlife, the Alaskan shoreline, the fishing industry and other natural resources. Topics also include oil spill persistence, clean-up, and emergency and contingency planning. (Contains a minimum of 119 citations and

includes a subject term index and title list.)

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment Final Report. Database Management. Fish/Shellfish Study Number 30. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Juneau. Commercial Fisheries Div.: 25p.

In order to evaluate the extent of damage and injury to natural resources as a result of the Exxon Valdez oil spill, the following types of data would need to be synthesized and carefully managed: (1) historical baseline data to establish conditions prior to the spill; (2) data generated by damage assessment projects to establish damage and extent of injury; and (3) data generated by ongoing monitoring projects to determine the effectiveness of restoration programs. The project was implemented to facilitate access to historical datasets maintained by the Alaska Department of Fish and Game, and to address the need to preserve the raw data generated by selected damage assessment projects associated with the Exxon Valdez oil spill.

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment. Assessment of Injury to Harbor Seals in Prince William Sound, Alaska, and Adjacent Areas Following the Exxon Valdez Oil Spill. Marine Mammal Study Number 5. Restoration Study Number 73. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Anchorage.

The goal of the project was to determine whether the Exxon Valdez oil spill (EVOS) had a measurable impact on harbor seals, Phoca vitulina richardsi, in Prince William Sound (PWS) and adjacent areas. During the EVOS, harbor seals were exposed to oil both in the water and on land. The study was designed to investigate and quantify, as possible, the effects of oil and the disturbance associated with cleanup on distribution, abundance, and health of harbor seals in the affected area. Final rept.

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment. Impact of the Oil Spill on Juvenile Pink and Chum Salmon and Their Prey in Critical Nearshore Habitats. Fish/Shellfish Study Number 4. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Juneau, AK. Alaska Region.: 340p.

The objective of the study was to determine the impact of the Exxon Valdez oil spill on juvenile pink and chum salmon during their initial period of residency in nearshore marine habitats of western Prince William Sound. In oiled locations, both pink and chum salmon fry in the nearshore marine environment observations and laboratory experiments indicated that ingestion of whole oil or oil-contaminated prey was an important route of contamination. Final rept.

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment. Injury to Demersal Rockfish and Shallow Reef Habitats in Prince William

Sound, 1989-1991. Subtidal Study Number 6. Fish/Shellfish Study Number 17. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Anchorage. Div. of Sport Fish.

Demersal rockfish (Sebastes spp.) in Prince William Sound were studied from 1989 through 1991 to assess injury due to the Exxon Valdez oil spill. Injury was assessed by establishing the exposure of rockfish to petroleum hydrocarbons and then determining if any histopathological lesions occurred with increased frequency in fish from sites with oil-exposed fish. Final rept.

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment. Injury to Salmon Eggs and Preemergent Fry in Prince William Sound. Restoration Study Number 60C. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Anchorage.: 91p.

The study is a continuing project designed to monitor recovery of pink salmon Oncorhynchus gorbuscha populations in Prince William Sound that were impacted by the Exxon Valdez oil spill. The report covers the work and findings for the period March 1, 1992 - February 28, 1993. Embryo mortality and embryo to preemergent fry survival were examined in intertidal and upstream areas of oil contaminated and unaffected (control) streams. Each of four stream zones in 31 streams were sampled for embryos and preemergent fry. Final rept.

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment. Technical Support Study for the Restoration of Dolly Varden and Cutthroat Trout Populations in Prince William Sound. Restoration Study Number 106. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Anchorage. Div. of Sport Fish.: 61p.

In order to restore populations of Dolly Varden and cutthroat trout, a closure of sport fisheries for these two species occurred in oiled areas. Sixty-one stream systems in non-oiled locations in Prince William Sound that support populations of Dolly Varden and cutthroat trout were identified and incorporated into a site selection matrix. Catch rate, size information, and information about stream morphology were collected during the ground surveys. Migration information was analyzed from four years of tag return data, as an initial effort to understand stock movement and definition. Final rept.

Anon (1995). EXXON VALDEZ Oil Spill Restoration Plan. . Govt Reports Announcements & Index (GRA&I), Exxon Valdez Oil Spill Trustee Council, AK. : 88p .

In 1989, the Exxon Valdez oil spill contaminated about 1,500 miles of Alaska's coastline. It killed birds, mammals, and fish, and disrupted the ecosystem in the path of the oil. The Exxon Valdez Restoration Plan provides long-term guidance for restoring the resources and services injured by the oil spill. It contains policies for making restoration decisions and describes how restoration activities will be implemented. Color illustrations reproduced in black and white. See also PB95-198792 and PB95-198800. Sponsored by Department of the Interior, Washington, DC.

Anon (1995). Exxon Valdez Oil Spill. Restoration Project. Injury to Salmon Eggs and Preemergent Fry in Prince William Sound. Restoration Project 93003. . Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Anchorage. : 49p .

The study is a continuing project designed to monitor recovery of pink salmon Oncorhynchus gorbuscha populations in Prince William Sound which were impacted by the Exxon Valdez oil spill. Embryo mortality and embryo to preemergent fry survival have been examined in intertidal and upstream areas of oil contaminated and unaffected (control) streams since the spring of 1989. The report covers work performed between March 1, 1993 and September 30, 1993. Final rept.

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment Final Report. Impacts of the Exxon Valdez Oil Spill on Bottomfish and Shellfish in Prince William Sound. Fish/Shellfish Study 18. . Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Juneau. Commercial Fisheries Management and Development Div. : 91p .

Trawl surveys were conducted in Prince William Sound and adjacent waters in 1989 and 1990 to assess impacts of the Exxon Valdex oil spill on commercial species of bottomfish and shellfish. The surveys (1) determined abundance, distribution, and year-class strength of important bottomfish and shellfish species and (2) assessed the incidence and distribution of oil contamination in fish bile.

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment Final Report. Sockeye Salmon Overescapement. Fish/Shellfish Study Number 27. . Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Soldotna. Commercial Fisheries Management and Development Div. : 72p .

The authors examined the effects of large escapements of sockeye salmon in to the Kenai River and into Red and Akalura Lakes on Kodiak Island. Estimated smolt numbers outmigrating from the Kenai River decreased from 30 million in 1989 to under 500,000 in 1992. Decreased overwintering survival of age-0 juvenile sockeye salmon rearing in Skilak and Kenai lakes is the major contributor to this decline. Preliminary examination of limnological data from Skilak and Kenai Lakes provided no obvious explanation for this major decline in winter survival of juvenile sockeye. Due to differences in diel vertical migration of zooplankton among glacial lakes on the Kenai Peninsula with varying planktivores levels, the authors hypothesize that behavioral changes of zooplankton induced by predation may be a major contributor to the juvenile sockeye decline.

Anon (1995). Exxon Valdez Oil Spill. State Federal Natural Resource Damage Assessment. Injury to Prince William Sound Spot Shrimp. Subtidal Study Number 5. . Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Anchorage. : 158p .

Since the grounding of the T Exxon Valdez caused an oil spill on March 24, 1989, four surveys have been conducted by the Alaska Department of Fish and Game (ADF&G) to assess possible damage done by the oil spill to spot shrimp Pandalus platyceros. The surveys were conducted November 1989, March 1990, and November 1990 as Fish/Shellfish Study 15, then November 1991 as Subtidal Study 5. The report incorporates results of all surveys, but emphasizes November surveys and their analysis. Final rept.

Anon (1995). Exxon Valdez Oil Spill: State Federal Natural Resource Damage Assessment Final Report. Effects of Pink Salmon (Oncorhynchus gorbuscha) Escapement Level on Egg Retention, Preemergent Fry, and Adult Returns to the Kodiak and Chignik Management Areas Caused by the Exxon Valdez Oil Spill. Fish/Shellfish . Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Kodiak. Commercial Fisheries Management and Development Div. : 106p .

As a result of the 1989 Exxon Valdez oil spill, commercial salmon fishing in and around the Kodiak and Chignik areas was severely restricted throughout the 1989 season. Consequently, pink salmon escapements for these areas greatly exceeded targeted escapement objectives. Investigations were conducted within the Kodiak and Chignik Management Areas during 1989 and 1990 to determine if negative impacts on future odd-year brood line pink salmon production occurred as a result of overescapement in 1989. Final rept.

Anon (1996). Superfund Record of Decision (EPA Region 10): Standard Steel and Metals Salvage Yard, (USDOT), Superfund Site, Anchorage, AK., July 16, 1996. . Govt Reports Announcements & Index (GRA&I), Environmental Protection Agency, Washington, DC. Office of Emergency and Remedial Response. : 111p .

The decision document presents the selected remedial action for the Standard Steel and Metals Salvage Yard, in Anchorage, Alaska. This is the final remedial action for the site. The site was not divided into operable units. The Removal Action utilized treatment as a principle element for the principle sources.

Anthony, R. G., A. K. Miles, et al. (1999). "Productivity, diets, and environmental contaminants in nesting bald eagles from the Aleutian Archipelago." Environmental Toxicology and Chemistry **18**(9): 2054-2062.

We studied productivity, diets, and environmental contaminants in nesting bald eagles from the western Aleutian Islands, Alaska, USA, during the summers of 1993 and 1994. Productivity on Adak, Tanaga, and Amchitka Islands ranged from 0.88 to 1.24 young produced per occupied site and was comparable to that of healthy populations in the lower 48 United States. However, productivity on Kiska Island was depressed, averaging 0.67 young per occupied site. The lower reproductive success on Kiska was associated with elevated levels of dichlorodiphenyldichloroethylene and other organochlorine pesticides. Many of the organochlorine pesticides were elevated in bald eagle eggs from the four islands, but concentrations of these contaminants and Hg were significantly higher in eggs from Kiska Island than in eggs from the other islands. In contrast,

polychlorinated biphenyl concentrations were higher in eggs from Adak, Amchitka, and Kiska (where military facilities have been installed) than in those from Tanaga (which has had little military activity). The most likely source of these contaminants in bald eagles was from their diets, which were variable spatially and temporally. Fish made up most (56%) of the eagles' diet on Adak and Tanaga Islands, followed by birds (25%) and mammals (19%). In contrast, birds comprised the majority (60%) of bald eagle diets on Amchitka and Kiska Islands, followed by mammals (30%) and fish (10%). The high proportion of seabirds in the diet of eagles from Kiska Island could be the major source of organochlorine and Hg contamination. Elevated concentrations of organochlorines in bald eagle eggs from the Aleutian Archipelago was surprising, because of the distance to agricultural areas. The results indicate that these contaminants can be transported long distances and affect wildlife populations in remote and pristine areas. We also discuss potential sources and transport mechanisms of these contaminants to the Aleutian Islands.

Antrim, L., R. Thom, et al. (1995). "Effects of petroleum products on bull kelp (Nereocystis luetkeana)." Marine Biology (Berlin) **122**(1): 23-31.

Although research has been conducted on the effects of oil on the giant kelp Macrocystis pyrifera, no similar studies have been completed on bull kelp, Nereocystis luetkeana, the dominant kelp in Washington State, British Columbia, and Alaska. The effects of three petroleum products (diesel fuel, intermediate fuel oil (IFO), and crude oil) were tested before and after weathering on N. luetkeana. Whole plants were exposed to petroleum product for 4 or 24 h and then transferred to the field; observations on the condition of the plants were made daily for 7 d. In addition, controlled bioassays were performed to measure the effects of petroleum exposure on net photosynthetic rate (NP) and respiration rate (R), using light- and dark-bottle techniques. These experiments verified the susceptibility of N. luetkeana tissue to the damaging effects of direct exposure to several oil types. The 4 h exposures to weathered diesel and unweathered IFO, and 24 h exposures to unweathered and weathered diesel and IFO resulted in moderate to severe damage to kelp tissue (i.e., clearly delineated bleached line accompanied by tissue necrosis). Weathered diesel was more toxic than unweathered diesel. The most severe damage to bull kelp was concentrated at the meristematic zone (junction of stipe and bulb) where new tissue growth occurs. Petroleum type significantly affected stipe and blade NP, R, and NP:R ratios. Diesel treatments had a greater negative effect on NP than did the IFO treatments. Based on these experiments, the relative ranking of the damaging effects of petroleum treatment on bull kelp are weathered diesel >unweathered IFO > unweathered diesel > weathered IFO > unweathered crude> weathered crude.

Armstrong, D., P. Dinnel, et al. (1995). Status of selected bottomfish and crustacean species in Prince William Sound following the EXXON VALDEZ oil spill. ASTM Special Technical Publication, No. 1219. EXXON VALDES oil spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-EXXON

VALDEZ Oil Spill Atlanta, Georgia, USA, April 26-28, 1993. P. G. Wells, J. N. Butler and J. S. Hughes, ASTM (American Society for Testing and Materials): Philadelphia, Pennsylvania, USA.: 485-547.

Exposure and possible adverse effects of the Exxon Valdez oil spill (EVOS) at depth were studied between 1989 and 1991 on several species of crustaceans, molluscs, and finfish that are characterized by ontogenetic shifts in distribution from meroplanktonic larvae to benthic and demersal juveniles and adults. Our approach was to search for 1) evidence of exposure to Exxon Valdez crude oil (EVC) at depth (generally between 20 to 150 m) and 2) measurable perturbations at both the individual and population levels. Primary species targeted were Tanner crab (Chionoecetes bairdi), several pandalid shrimps (Pandalus platyceros, P. hypsinotus, P. borealis), flathead sole (Hippoglossoides elassodon), and several bivalves including scallops (Chlamys rubida) and infaunal clams (Nuculana, Yoldia, and Macoma spp.). Our survey design provided a comparison between variables measured in "oiled" bays around Knight Island and "non-oiled" bays at other locations within Prince Williams Sound. "Oiled" was defined in terms of degree of shoreline oiling, sediment and tissue hydrocarbon concentrations with the EVC signature, elevated concentrations of fluorescent aromatic compounds (FACs) in bile of flathead sole, and frequency of oil in benthic trawls. Statistical analyses of catch-per-unit-of-effort (CPUE; relative abundance determined by pots and trawls) were focused on detection of differences in trends through time (that is, "time-by-oil" interaction) rather than on magnitude of differences, thereby avoiding the problem of inherent differences in baseline CPUE levels between bays and the influence of non-random application of oil to bays. Polycyclic aromatic hydrocarbons (PAHs) of petrogenic origin were measured in all bays sampled in this study and levels of PAHs derived from EVC were elevated in the "oiled" bays following the spill, yet attenuated to less than 200 ng/g sediment by 1991. Total PAHs in scallop tissues were higher in "oiled" bays in 1989 but decreased 15-fold to a mean of 16 ng/g by 1990. Clam tissues from "oiled" bays in 1991 had higher PAH concentrations, but only samples from Bay of Isles had alkylated PAHs (about 90 ng/g) indicative of EVC exposure. Mean concentrations of FACs in flathead sole bile were significantly higher in "oiled" than "non-oiled" bays (about 27 and 14 ng/g, respectively) in both 1990 and 1991, and corresponded to elevated tissue levels of PAHs in clams, which are the major prey of sole in these bays. Virtually no evidence of significant adverse effects was detected at either the individual or population levels across all the life history stages sampled. Larval Tanner crabs were widely distributed in the plankton in early summer of 1989 and 1990; adult female fecundity and trends in CPUE of juveniles did not differ significantly between the two categories of bays. In spring of 1990, 16 dead juvenile Tanner crabs were caught in three "oiled" bays and mortality was significantly correlated with elevated FACs in bile of flathead sole. Such mortality was likely linked to inordinately low bottom-water salinity that spring, and dead crabs were not found on any other cruise prior to or after this event. Pandalid shrimp were ubiquitous throughout the study area, and no significant differences were measured between "oiled" and "non-oiled" bays in trends of CPUE of P. borealis (the best quantified) and fecundity of P. platyceros. Fecundity in the case of P. hypsinotus was reduced in 1990

compared with 1989 irrespective of bay, but fecundity was also about 30% lower among females from the "oiled" compared with "non-oiled" bays. In the case of flathead sole, mean abundance of young-of-the-year fish declined significantly in "non-oiled" bays and mean abundance of older fish increased significantly in "oiled" bays. In contrast to lack of evidence of adverse effects on target species caused by the EVOS, substantial declines in fishery landings of several crabs and shrimps had occurred in PWS, some to the point of closure, prior to the spill. Long-term trends in abundance of populations of these species due to natural environmental causes or fishing pressures are likely to be far more important than fluctuations attributable to EVOS.

Atlas, R. (1995). "Bioremediation of petroleum pollutants. ." International Biodeterioration & Biodegradation **35**(1-3): 317-327. .

Hydrocarbon-degrading microorganisms are ubiquitously distributed in soil and aquatic environments. Populations of hydrocarbon-degraders normally constitute less than 1% of the total microbial communities, but when oil pollutants are present these hydrocarbon-degrading populations increase, typically to 10% of the community. With regard to rates of natural degradation, these typically have been found to be low and limited by environmental factors. Rates reported for pristine marine waters typically are less than 0.03 g/m3/day. In adapted communities rates of hydrocarbon degradation of 0.5-50 g/m3/day have been reported. Bioremediation tries to raise the rates of degradation found naturally to significantly higher rates. The two general approaches that have been tested for the bioremediation of marine oil spills are the application of fertilizer to enhance the abilities of the indigenous hydrocarbon-Utilizing bacteria and the addition of naturally, occurring adapted microbial hydrocarbon-degraders by seeding. Bioremediation, accomplished by the application of fertilizer to enhance the abilities of the indigenous hydrocarbon-utilizing bacteria, was successfully applied for the treatment of the 1989 Alaskan oil spill in Prince William Sound, Alaska. Seeding with adapted nonindigenous microbial hydrocarbon degraders was tested on smaller spills in Texas-such as the Mega Borg spill-but bioremediation to remove petroleum pollutants by seeding has yet to be demonstrated as efficacious in field trials. The spill of more than 200,000 barrels of crude oil from the oil tanker Exxon Valdez in Prince William Sound, Alaska, as well as smaller spills in Texas-such as the Mega Borg spill-have been treated by bioremediation to remove petroleum pollutants. The Exxon Valdez spill formed the basis for a major study on bioremediation through fertilizer application and the largest application of this emerging technology. Three types of nutrient supplementation were tested: water-soluble (23:2 N:P garden fertilizer formulation): slow-release (Customblen); and oleophilic (Inipol EAP 22). Each fertilizer was tested in laboratory simulations and in field demonstration plots to determine the efficacy of nutrient supplementation. The use of Inipol EAP22 (oleophilic microemulsion with urea as a nitrogen source, laureth phosphate as a phosphate source, and oleic acid as a carbon source) and Customblen (slow-release calcium phosphate, ammonium phosphate, and ammonium nitrate within a polymerized vegetable oil coating) was approved for shoreline treatment and was used as a major part of the cleanup effort. Multiple regression models

showed that nitrogen applications were effective in stimulating the rates of biodegradation.

Babcock, M., P. Harris, et al. (1997). "Restoration of oiled mussel beds in Prince William Sound Alaska five years after the EXXON VALDEZ oil spill." Journal Of Shellfish Research **16**(1): 258.

The persistence of Exxon Valdez crude oil underlying some sense mussel (Mytilus trossulus) beds was measured 2-4 years post-spill. These beds were intentionally left untreated during cleanup activities, 1989-1991, because they provided physical stabilization and mussels were a food source for higher consumers. In 1992 and 1993, we documented 31 beds in Prince William Sound with sediment concentrations in excess of 10,000 mu g/g total petroleum hydrocarbons. Mussel concentrations of polynuclear aromatic hydrocarbons ranged to 10.0 mu g/g. Samples from these beds contained the highest oil concentrations seen since 1990, the year following the Exxon Valdez disaster. Beds were not recovering rapidly naturally and oil from these mussels could be incorporated into the food chain. Our purpose was to evaluate a simple, manual technique for removing oil that was in close contact with overlying mussels. In 1994, cooperatively with the Alaska Department of Environmental Conservation and residents from Chenega, twelve mussel beds were restored. Mussels were removed and allowed to wash one tidal cycle on absorbent pads. Oiled sediment underlying the mussels was removed, uncontaminated sediment substituted, and mussels replaced. Bed stability and hydrocarbon concentrations were measured periodically. Short-term evaluation of the process indicated successful removal of oil from close contact with overlying mussels. By August, 1995, sediments underlying the restored bed showed an average decrease in total petroleum hydrocarbons of 98%. Our results show that this simple method, although labor-intensive, is successful by providing a buffer of uncontaminated sediment underneath mussels, thereby reducing the body burden of petroleum hydrocarbons in these mussels. (DBO)

Babcock, M., G. Irvine, et al. (1996). Persistence of oiling in mussel beds three and four years after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society: Bethesda, Maryland, USA. **18:** 286-297.

Dense beds of the mussel *Mytilus trossulus* affected by Exxon Valdez crude oil in Prince William Sound and along the Kenai and Alaska peninsulas were intentionally left untreated during shoreline cleanup activities in 1989-1991. In 1992 and 1993, mussels and sediments from 70 mussel beds in Prince William Sound and 18 beds along the Kenai and Alaska peninsulas were sampled to establish the geographic extent and intensity of Exxon Valdez oil persisting in mussel beds. Sediments collected in 1992 and 1993 from 31 of the oiled mussel beds in the sound had total petroleum hydrocarbon (TPH) concentrations greater than 10,000 mu g/g wet weight. The highest concentrations were in sediments collected from Foul Bay (62,258 plus or minus 1,272 mu g TPH/g, mean plus or minus SE). Five of the 18 beds sampled along the Kenai Peninsula showed

sediment TPH concentrations greater than 5,000 mu g/g. The mean concentration of total polynuclear aromatic hydrocarbons (TPAH) in mussels from these same beds ranged up to 8.30 plus or minus 0.26 mu g/g (Squirrel Island) in Prince William Sound and 4.01 plus or minus 1.54 mu g/g along the Kenai Peninsula (Morning Cove, Pye Islands). Polynuclear aromatic hydrocarbon fingerprints of mussel tissue collected from surveyed sites indicated the contaminant source was Exxon Valdez oil. In 1993, mean TPH concentrations in sediments and mean TPAH concentrations in mussels were lower by more than 50% compared with these concentrations in 1992. Some beds showed little reduction in oil. Almost all the beds showing only small decreases in hydrocarbons were in protected, low-energy areas, where there probably was little remobilization of residual oil underlying the beds. This study has produced analytical evidence showing that substantial residual Exxon Valdez oil persists in sediments underlying mussel beds in the area affected by the spill. Residual crude oil is a source of chronic contamination of mussels and their predators. In the more-protected intertidal areas, natural flushing and remobilization of Exxon Valdez oil will be slow; some of these mussel beds potentially can be manually cleaned.

Babcock, M. and J. Short (1996). Prespill and Postspill Concentrations of Hydrocarbons in Sediments and Mussels at Intertidal Sites in Prince William Sound and the Gulf of Alaska. Coastal Habitat Study Number 1B. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Auke Bay, AK. Auke Bay Lab. : 156p .

The authors compared hydrocarbon concentrations in mussels (Mytilus trossulus) and sediments from beaches before and after oil contaminated beaches in the Sound and the Gulf of Alaska. Mussels and sediments collected outside the path of floating oil or before it became beached, indicated that other sources of hydrocarbons were negligible compared with the spilled oil. In sediments from stations away from the spilled oil, polynuclear aromatic hydrocarbons were usually less than 100 ng/g. Results for stations not impacted by the Spill can be used to determine quantitative restoration criteria for oiled beaches.

Bacon, C., W. Jarman, et al. (1999). "Comparison of Organochlorine contaminants among sea otter (Enhydra lutris) populations in California and Alaska." Environmental Toxicology and Chemistry **18**(3): 452-458.

Organochlorine pesticides, polychlorinated biphenyls (PCBs) including non-ortho PCBs, polychlorinated dibenzo-p-dioxins (PCDDs), and polychlorinated dibenzofurans (PCDFs) were measured in sea otter liver tissue from California, southeast Alaska, and the western Aleutian archipelago collected between 1988 and 1992. Average total dichlorodiphenyltrichloroethane concentrations for California otters (850 mu g/kg wet weight) were over 20 times higher than in Aleutian otters (40 mu g/kg) and over 800 times higher than otters from southeast Alaska (1 mu g/kg). Levels for total PCBs in Aleutian otters (310 mu g/kg) were 1.7 times higher than levels in California otters (190 mu g/kg) and 38

times higher than otters from southeast Alaska (8 mu g/kg). Levels for PCDD and PCDF were extremely low in all otter populations. Levels of PCBs in Aleutian and Californian otters are abnormally high when compared with southeast Alaskan otters. The source of PCBs to the Aleutian Islands remains unclear and vital to understanding the potential impacts to sea otters.

Baker, B. (1990). The wreck of the Exxon Valdez . North American Wildlife and Natural Resources Conference, Denver, CO (USA), 16-21 Mar 1990.

For America's fish and wildlife to be protected, it's imperative that the oil industry be required to internalize the costs of oil spill safeguards in calculating their bottom line. Weather conditions at the time of the March 24, 1989 grounding of the Exxon Valdez were ideal by Alaska standards. Seas were fairly calm, temperatures were mild, and day length was favorable. It's fortunate that the disaster did not occur in the long, subzero darkness of a North Pacific winter storm. More than 257,000 barrels spewed into what had been one of the most pristine, biologically productive and environmentally sensitive marine ecosystems in the world. According to a February estimate 20-40 percent of the oil has evaporated, only 5-14 percent has been recovered, and 56-65 percent remains unrecovered. The combination of low oil recovery under highly favorable weather conditions shattered the assurance long fostered by the oil industry that spills can be contained and cleaned up year-round in open seas or in pack ice. The biological resources at stake in Prince William Sound included all five of Alaska's salmon species as well as halibut, shrimp, cod and shellfish.

Ballachey, B. (1996). Biomarkers of Damage to Sea Otters in Prince William Sound, Alaska, Following Potential Exposure to Oil Spilled from the EXXON VALDEZ. Marine Mammal Study 6-1. EXXON VALDEZ Oil Spill Stateederal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage.: 20p.

The study was conducted to evaluate several biomarkers of genotoxic damage in sea otters that had potentially been exposed to oil spilled from the Exxon Valdez. Thirteen adult male sea otters were captured in eastern (unoiled) Prince William Sound, and 14 in western (oiled) Prince William Sound in September and October 1991. Blood lymphocytes, sperm and testicular cells were collected from the otters for flow cytometric analyses to measure: (1) DNA content of lymphocytes, (2) nuclear chromatin structure of sperm, and (3) subpopulations of cell types in the testis. Additionally, sperm cells were examined by light microscopy for morphological abnormalities. The DNA content of blood lymphocytes from sea otters in the oiled vs. unoiled areas was not significantly different, although there was greater variation among samples from the oiled area. One measure of sperm cell quality was poorer for male sea otters from the unoiled area, and may have been associated with differences in the age and breeding status of the two groups sampled. Other measures of sperm and testicular cells did not differ between areas.

Ballachey, B. and K. Kloecker (1997). Hydrocarbon Residues in Tissues of Sea Otters

('Enhydra Lutris') Collected Following the EXXON VALDEZ Oil Spill. Marine Mammal Study 6-16. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage.
Alaska Science Center, Anchorage. Biological Resources Div. : 62p .

Ten moderately to heavily oiled sea otters were collected in Prince William Sound during the Exxon Valdez oil spill and up to seven tissues from each were analyzed for hydrocarbons. Aliphatic and aromatic hydrocarbons were detected in all tissues. Concentrations of aromatic hydrocarbons in fat samples were an order of magnitude higher than in other tissues. The patterns of distribution of these hydrocarbons suggested crude oil as the source of contamination. However, there was variation among oiled otters in the concentrations of individual hydrocarbons, which may be due to differing proximate causes of mortality and varying lengths of time and sea otters survived following oil exposure. The concentrations of both aliphatic and aromatic hydrocarbons in the tissues of the ten oiled sea otters generally were higher than in tissues from 7 sea otters with no external oiling that were collected from prince William Sound in 1989 and 1990, or from 12 sea otters collected from an area in southeast Alaska which had not experienced an oil spill. See also PB97-205652, PB96-198577, PB96-198536, and PB96-198544. Prepared in cooperation with Alaska Science Center, Anchorage. Biological Resources Div.

Ballachey, B. and K. Kloecker (1997). Hydrocarbons in Hair, Livers and Intestines of Sea Otters ('Enhydra lutris') Found Dead along the Path of the EXXON VALDEZ Oil Spill. Marine Mammal Study 6-3. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage.
Alaska Science Center, Anchorage. Biological Resources Div. : 56p .

Aliphatic and aromatic hydrocarbons were analyzed in hair, liver and intestinal samples taken from dead sea otters (Enhydra lutris) collected in spring and summer 1989 from Prince William Sound, the Kenai Peninsula and Kodiak Island, along the path of the Exxon Valdez oil spill. Hair showed significant differences in hydrocarbon concentrations among the three locations, but few significant differences were noted for liver or intestine samples. The highest concentrations of both aliphatic and aromatic hydrocarbons were measured in hair samples from Prince William Sound. Hydrocarbon concentrations in intestine and liver samples from the three locations were generally similar and low, suggesting that uptake into the tissues was limited, or that hydrocarbons within the tissues had been metabolized by the time samples were collected. See also PB97-205645, PB96-198577, PB96-198536, and PB96-198544. Prepared in cooperation with Alaska Science Center, Anchorage. Biological Resources Div.

Barber, W., L. McDonald, et al. (1995). "Effect of the Exxon Valdez oil spill on intertidal fish: A field study." Transactions of the American Fisheries Society **124**(4): 461-476.

The purpose of this study was to evaluate the impact of the March 1989 Exxon

Valdez oil spill and subsequent cleanup activities on density, biomass, and species diversity of intertidal fishes in Prince William Sound, Alaska. Intertidal fish were sampled in a quasi-experimental, matched-pairs (oiled-cleaned versus reference sites) design stratified by three habitat types with random selection of oiled-cleaned (O-C) sites. Site pairs were sampled twice in 1990 and in 1991. Of 21 fish taxa, 5 made up 98% and 1 made up 74% of total abundance. There were no significant differences in species diversity between reference and O-C sites. Density, however, was significantly greater at reference sites for all habitats combined for both visits in 1990. In contrast, density in 1991 was about equal at reference and O-C sites. Total biomass for all habitats combined was greater at reference than O-C sites during both visits in 1990, but differences were not statistically significant. In 1991, however, the total biomass at reference and O-C sites was about equal. Forward stepwise multiple logistic regression models indicated that presence of oil was a significant predictor of reduced density at mid-intertidal levels in 1990 but not in 1991. From the general pattern of lower density and biomass on O-C sites in 1990 followed by no significant differences in 1991 and corroborating evidence of multiple-regression modeling, we conclude that the presence of oil and subsequent cleanup activities had a negative impact on intertidal fishes in 1990 and that there was evidence that recovery was underway in 1991.

Barinaga, M. (1989). "Alaskan oil spill: health risks uncovered [news] [see comments]." Science **245**(4917): 463.

Barker, D. (1992). Nearly three years after the spill: An update on the conditions in Alaska. High Altitude Revegetation Workshop, Fort Collins, CO (USA), 4-6 Mar 1992, Colorado Water Resour. Res. Inst., Colorado State Univ., Fort Collins, CO 80523 (USA).

The tanker Exxon Valdez ran aground on Bligh Reef in Prince William Sound, Alaska on March 24, 1989. The result was a spill of nearly 11 million gallons of crude oil, some of which moved through Prince William Sound into the Gulf of Alaska, oiling shorelines in the western Sound, along the Kenai Peninsula, and in the Kodiak Island area. Under the direction of federal and state authorities, Exxon initiated and continued intensive cleanup activities during the months of April through mid-September of 1989, in 1990, and in 1991. Additional work may be done in the summer of 1992 if conditions warrant it. This cleanup was the largest and most expensive oil spill cleanup program ever done in the world. Ecological recovery is well under way in areas impacted by the spill, thanks to nature's own cleansing power and man's efforts. Much has been learned about how to prevent and respond to such an event in the future.

Bayha, K. and J. Kormendy (1990). Proceedings of a Symposium to Evaluate the Response Effort on Behalf of Sea Otters After the T EXXON VALDEZ Oil Spill into Prince William Sound. Sea Otter Symposium: Proceedings of a Symposium to Evaluate the Response Effort on Behalf of Sea Otters After the T EXXON VALDEZ Oil Spill into

Prince William Sound, Anchorage, Alaska on April 17-19, 1990, Fish and Wildlife Service, Anchorage, AK.
National Fish and Wildlife Foundation, Washington, DC.

The T/V Exxon Valdez grounded on Bligh Reef in Prince William Sound, Alaska, in the early morning of 24 March 1989, spilling 11 million gallons of toxic crude oil into pristine Prince William Sound. As part of the response effort, a sea otter (Enhydra lutris) rescue was begun. The effort continued until 11 September 1989 at a cost reported to be in excess of $8 million. The rescue was precedent setting in several ways: the magnitude of the effort-as many as 14 capture crews at one time were spread over 400 nautical miles from the spill site to the Shelikof Strait, the number of animals handled (454) and people involved (more than 430), the techniques and equipment tested, and the apparent success-197 sea otters released into the wild. The U.S. Fish and Wildlife Service, with assistance from nearly every sector that participated in the response, evaluated the rescue effort in a symposium in April 1990. The papers presented and the five concurrent workshop syntheses serve to document the effort, evaluate what was learned, and offer recommendations. The summary table included here is intended to provide the reader ready access to the number of sea otters handled. (Prepared in cooperation with National Fish and Wildlife Foundation, Washington, DC.)

Becker, P., B. Koster, et al. (1990). "Alaskan Marine Mammal Tissue Archival Project." Biol Trace Elem Res **26-27**: 329-34.

A project to establish an archive of Alaskan marine mammal tissues was conceived in 1987 to be a part of the National Biomonitoring Specimen Bank (NBSB). Protocols and field collection of marine mammals, long-term storage, and analysis are summarized in this paper. Instrumental neutron activation analysis has been used for an initial evaluation of trace element content in samples of northern fur seal (Callorhinus ursinus) from the Pribilof Islands. The findings agree with previously observed trace element levels in northern fur seals. The archived specimens can be used in future studies when comparison of past and present pollution levels are needed.

Becker, P., E. Mackey, et al. (1995). "Relationship of silver with selenium and mercury in the liver of two species of toothed whales (Odontocetes)." Marine Pollution Bulletin **30**(4): 262-271.

Liver specimens archived in the National Biomonitoring Specimen Bank from beluga whales, Delphinapterus leucas, and from Alaska and pilot whales, Globicephala melas, from the North Atlantic were analysed for silver, selenium and total mercury. Silver concentrations in beluga whales were one to three orders of magnitude higher than the concentrations in pilot whales and those reported elsewhere for other marine mammals. The concentrations of silver in the livers of beluga whales were the same or in some instances higher than the concentrations of selenium or mercury. Like mercury, silver was positively correlated with selenium in both pilot and beluga whales. This suggests a possible role for selenium in the accumulation and storage of silver in both

species of whales, and raises questions about the potential for silver at such high concentrations to affect radical-scavenging enzyme systems in these marine mammals.

Becker, P. and C. Manen (1988). Natural Oil Seeps in the Alaskan Marine Environment. . Govt Reports Announcements & Index (GRA&I), National Ocean Service, Anchorage, AK. Ocean Assessments Div. : 123p .

The report is a synthesis of information on the marine and coastal oil seeps in Alaska, and on the effects of chronic oil pollution on Arctic marine biotic communities and ecological processes. Of 29 oil seepage areas reported along the Alaskan coast, 14 have been confirmed as containing actual oil seeps. Large areas of coastal seepage have been identified in the central Gulf of Alaska and Arctic regions. When compared to known seepage rates on the California coast, the amount of oil entering the Alaska marine environment from known coastal seeps is probably rather small. Also, the organic enrichment of the benthic communities demonstrated at California seeps might not be as evident at Arctic seeps because of slower rate of oil degradation in the latter. Additional hypotheses on the effects of natural seeps on biological communities and ecosystems are discussed. Final rept., Sponsored by Minerals Management Service, Washington, DC.

Becker, P., S. Wise, et al. (1992). Alaska Marine Mammal Tissue Archival Project: Sample Inventory and Results of Analyses of Selected Samples for Organic Compounds and Trace Elements. Govt Reports Announcements & Index (GRA&I), National Inst. of Standards and Technology (CSTL), Gaithersburg, MD. National Ocean Service, Anchorage, AK. Arctic Environmental Assessment Center.: 139p.

In 1987, the Alaska Marine Mammal Tissue Archival Project (AMMTAP) was established as part of the National Biomonitoring Specimen Bank (NBSB) program at the National Institute of Standards and Technology (NIST).The purpose of the AMMTAP was to establish a representative collection of Alaska marine mammal tissues for future contaminant analyses and documentation of long-term trends in environmental quality. Since 1987, specimens have been collected from 65 animals (seven species) from six different sites. The report contains the current sample inventory and the results of the analysis of selected samples for the measurement of inorganic and organic compounds. See also PB88-199732 and PB91-184796. Prepared in cooperation with National Ocean Service, Anchorage, AK. Arctic Environmental Assessment Center.

Becker, P. R., B. J. Koster, et al. (1993). "Biological specimen banking in Arctic research: an Alaska perspective." Sci Total Environ **139-140**: 69-95.

The cryogenic archival of biological specimens for retrospective analysis is of significant value for present and future research on population genetics, pathology, systematics, toxicology and environmental monitoring. This realization is emphasized by the increasing support of this activity by various government

agencies, institutions and international groups. The international Arctic community is no exception. Canada has been conducting such activities in association with environmental monitoring programs for many years. Similar efforts appear to be underway in other polar nations. From the perspective of the United States Arctic, the Alaska Marine Mammal Tissue Archival Project (AMMTAP) was the earliest organized effort to develop an environmental specimen bank specifically designed for longterm archival of biological specimens under cryogenic conditions. The AMMTAP emphasizes use of standardized rigorous sampling and archival protocols, procedures that minimize contamination of samples during collection and maintaining a detailed record of sample history. The development of this specimen bank, recent activities of this project and other cryogenic specimen banks being developed in Alaska are described.

Becker, P. R., E. A. Mackey, et al. (1997). "Concentrations of chlorinated hydrocarbons and trace elements in marine mammal tissues archived in the U.S. national biomonitoring specimen bank." Chemosphere **34**(9-10): 2067-2098.

The U.S. National Biomonitoring Specimen Bank (NBSB) provides for the long term storage fo well documented and preserved specimens representing several types of environmental matrices. A major part of this inventory consists of marine mammal tissues (e.g., blubber, liver, kidney, and muscle). Within the NBSB selected specimens are periodically analyzed for chlorinated hydrocarbons and trace elements. Although only 20 percent of the 560 marine mammal specimens in the NBSB have been analyzed, the database is of value in evaluating the stability of analytes and sample degradataion during storage, for comparing with results from samples collected in the future for long-term monitoring, and for comparing with analytical results from other laboratories on samples collected at the same time for monitoring purposes. The NBSB analytical database contains results for 37 elements, many of which are not analyzed routinely by conventional analytical techniques used in monitoring programs, and the follwing organic compounds: selected PCB congeners, DDT compounds, alpha- and gamma-HCH, HCB, heptachlor epoxide, oxychlordane, cis-chlordane, trans-chlordane, cis-nonachlor, trans-nonachlor, and dieldrin in 9 marine mammal species: northern fur seal (Callorhinus ursinus), ringed seal (Phoca hispida), spotted seal (P. largha), bearded seal (Erignathus barbatus), pilot whale (Globicephala melas), harbor porpoise (Phocoena phocoena), white-sided dolphin, (Lagenorhynchus acutus), beluga whale (Delphinapterus leucas), and bowhead whale (Balaena mysticetus). Analyses of beluga whale blubber for toxaphene and additional chlorinated hydrocarbons are obtained through collaboration with the Department of Fisheries and Oceans, Canada.

Becker, P. R., National Institute of Standards and Technology (U.S.), et al. (1995). Concentrations of chlorinated hydrocarbons, heavy metals and other elements in tissues banked by the Alaska Marine Mammal Tissue Archival Project. Gaithersburg, MD, U.S. Dept. of Commerce Technology Administration National Institute of Standards and Technology: v, 115.

Becker, P. R., B. J. Porter, et al. (1999). National Marine Mammal Tissue Bank and Quality Assurance Program: Protocols, Inventory and Analytical Results, NIST.

Becker, P. R., S. A. Wise, et al. (1997). "Specimen banking of marine organisms in the United States: current status and long-term prospective." Chemosphere **34**(9-10): 1889-906.

A major part of the activities conducted over the last decade by the National Biomonitoring Specimen Bank (NBSB) has involved the archival of marine specimens collected by ongoing environmental monitoring programs. These archived specimens include bivalves, marine sediments, and fish tissues collected by the National Status and Trends and the Exxon Valdez Oil Spill Damage Assessment programs, and marine mammal tissues collected by the Marine Mammal Health and Stranding, Response Program and the Alaska Marine Mammal Tissue Archival Project. In addition to supporting these programs, the specimens have been used to investigate circumpolar patterns of chlorinated hydrocarbon concentrations, genetic separation of marine animal stocks, baseline levels of essential and nonessential elements in marine mammals, and the potential risk to human consumers in the Arctic from anthropogenic contaminants found in local subsistence foods. The NBSB specimens represent a resource that has the potential for addressing future issues of marine environmental quality and ecosystem changes through retrospective analysis; however, an ecosystem-based food web approach would maximize this potential. The current status of the NBSB activities related to the banking of marine organisms is presented and discussed, the long-term prospective of these activities is presented, and the importance of an ecosystem-based food web monitoring approach to the value of specimen banking is discussed.

Bence, A. and W. Burns (1995). Fingerprinting hydrocarbons in the biological resources of the Exxon Valdez spill area. ASTM Special Technical Publication, No. 1219. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials): Philadelphia, Pennsylvania, USA.

A procedure has been developed that discriminates Exxon Valdez crude from other sources of hydrocarbons found in Prince William Sound and the Gulf of Alaska. The procedure uses polycyclic aromatic hydrocarbon (PAH) distributions, measured by gas chromatography/mass spectrometry (GC/MS), to fingerprint sample extracts. The relative abundances of alkylated phenanthrenes, dibenzothiophenes, and chrysenes are used to differentiate Exxon Valdez crude and its weathering products from other hydrocarbons. Saturate fraction distributions are used to confirm the PAH identification whenever possible. The procedure has been applied to the more than 1 500 PAH analyses of tissues reported by the Oil Spill Health Task Force, formed

after the spill to assess subsistence food safety, and nearly 4 700 PAH analyses of biological samples in PWSOIL, the government's damage-assessment chemistry database. These two datasets constitute the largest collection of hydrocarbon analyses of biological samples from the spill-impact zone. Excluding shellfish, only a small fraction of the samples contain recognizable Exxon Valdez crude residues, and most of those are samples that were collected in 1989. Only rarely is Exxon Valdez crude identified in samples collected in 1990, and never in 1991 samples. The majority of samples containing Exxon Valdez crude residues are associated either with external surfaces (e.g., eggshells, skin, hair, carcasses) or with the gastrointestinal tract (e.g., stomach contents, intestines). Many of these samples contain diesel in various stages of weathering, as do sediment samples also archived in the database. For example, diesel is observed on approximately one-half of the bald eagle and common murre eggshells collected in both 1989 and 1990.

Berg, C., T. Gerlach, et al. (1997). The Exxon Valdez Oil Spill Habitat Protection as a Restoration Strategy. American Association for the Advancement of Science. Arctic Science and Resource Management: Exploring the Issues; 48th American Association for the Advancement of Science: Arctic Division Science Conference, Valdez, Alaska, USA, September 24-27,1997, Alaska Sea Grant College Program, University of Alaska Fairbanks; Fairbanks, Alaska, USA.

Bergmann, P. (1995). Cultural resources protection: How prepared are federal and state agencies in 1994 to deal with potential impacts to cultural resources during a spill response? . Prevention, Response and Oversight Five Years after the Exxon Valdez Oil Spill. Proceedings of an International Conference. R. Dearborn, E. Piper, H. Baderet al. Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science . **95 :** 261-267.

Alaska's coastline and its interior contain important archaeological and historic heritage sites. At the same time, oil exploration, development, production, and transportation (via pipeline) occur both onshore and offshore. Furthermore, offshore waters serve as passageways for oil tankers and other ocean vessels, which carry petroleum products and/or hazardous substances. Marine or inland spills of those substances, and associated response activities, result in injury to archaeological and historical resources. Since 1988, the U.S. Department of the Interior has worked with Alaska Regional Response Team members and on-scene coordinators to help ensure that the protection of cultural resources is considered following oil spills and hazardous substance releases. As a result, since 1988, the Alaska Regional Response Team and on-scene coordinators have begun to recognize that: (1) oil spills and hazardous substance releases may impact cultural resources, and (2) they have a statutory responsibility to ensure that appropriate actions are taken to protect those resources following a spill. Because of this groundwork, steps were taken following the T/V Exxon Valdez oil spill to minimize injury to cultural resources during the 4-year response effort.

Bergmann, P. (1995). Wildlife protection strategies: How prepared is Alaska in March 1994 to deal with oiled or potentially oiled wildlife? . Prevention, Response and Oversight Five Years after the Exxon Valdez Oil Spill. Proceedings of an International Conference. R. Dearborn, E. Piper, H. Baderet al. Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science . **95 :** 231-241.

Following the T/V Exxon Valdez oil spill, the federal and state governments, including the State of Alaska, passed legislation that emphasized oil spill prevention, contingency planning, and response capabilities. At the same time, the oil industry reevaluated its preparedness in each of these areas. As a result, progress has been made in Alaska by federal and state agencies and the oil industry in their respective abilities to deal with wildlife that are contaminated, or are at risk of being contaminated, as a result of an oil spill.

Bernatowicz, J., P. Schempf, et al. (1996). Bald eagle productivity in south-central Alaska in 1989 and 1990 after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 785-797.

Nesting surveys of bald eagles *Haliaeetus leucocephalus* were conducted in 1989 and 1990 in coastal south-central Alaska, including Prince William Sound, Kenai Peninsula, Kodiak Archipelago, Katmai National Monument, and Alaska Peninsula-Becharof National Wildlife Refuge, to assess the effects of the Exxon Valdez oil spill on reproductive success. Nesting success was appreciably lower only in 1989 within the spill area in western Prince William Sound, located at the upstream end of the spill trajectory. Productivity in western Prince William Sound in 1990 increased to levels that we believe are normal for the region. Reproductive success for regions outside of the sound appeared to be normal in both 1989 and 1990. Because of the lack of prespill data, survey biases, and the potential for wide natural fluctuations in reproductive success, only a substantial reduction in productivity would have been evident in this study. This study provides the first estimates of bald eagle productivity for many areas in south-central Alaska.

Bickham, J., J. Mazet, et al. (1998). "Flow cytometric determination of genotoxic effects of exposure to petroleum in mink and sea otters." Ecotoxicology **7**(4): 191-199.

Three experiments were conducted to investigate the genotoxic effects of crude oil on American mink (Mustela vison) and sea otters (Enhydra lutris). In the first experiment, the effects on mink of chronic exposure to weathered Prudhoe Bay crude oil were studied. Female mink were fed a diet that included weathered crude oil for a period of 3 weeks prior to mating, during pregnancy and until weaning. Kits were exposed through lactation and by diet after weaning until 4 months of age. Kidney and liver tissues of the kits were examined using flow cytometry (FCM) and it was found that the genome size was increased in kidney samples from the experimental group compared to the control group. This effect was probably due to some type of DNA amplification and it could have been

inherited from the exposed mothers or have been a somatic response to oil exposure in the pups. No evidence of clastogenic effects, as measured by the coefficient of variation (CV) of the G sub(1) peak, was found in kidney or liver tissue. In the second experiment, yearling female mink were exposed either by diet or externally to crude oil or bunker C fuel oil. Evidence for clastogenic damage was found in spleen tissue for the exposure groups, but not in kidney tissue. No evidence of increased genome size was observed. In the third experiment, blood was obtained from wild-caught sea otters in Prince William Sound. The sea otters represented two populations: one from western Prince William Sound that was potentially exposed to oil from the Exxon Valdez oil spill and a reference population from eastern Prince William Sound that did not receive oil from the spill. The spill had occurred 1.5 years prior to obtaining the blood samples. Although the mean CVs did not differ between the populations, the exposed population had a significantly higher variance of CV measurements and five out of 15 animals from the exposed population had CVs higher than the 95% confidence limits of the reference population. It is concluded that FCM is a sensitive indicator of the clastogenic effects of oil exposure and that haematopoietic tissues and blood are best for detecting clastogenic damage. Moreover, the observed differences in the genome size of the kidney cells were possibly heritable effects, but this needs further investigation. Lastly, sea otters exposed to spilled oil 1.5 years earlier showed evidence of clastogenic damage in one-third of the individuals sampled.

Bienert, R. and W. Pearson (1995). "Application of ecological risk assessment principles to questions of oil exposure in Pacific herring following the Exxon Valdez spill." Canadian Technical Report of Fisheries and Aquatic Sciences(2060): 219-225.

Blajeski, A., L. Duffy, et al. (1996). "Differences in fecal levels of phorphrin among river otters exposed to the Exxon Valdez oil spill." Biomarkers(1): 262-266.

Blanchard, A. and H. Feder (1997). "Reproductive timing and nutritional storage cycles of Mytilus trossulus Gould, 1850, in Port Valdez, Alaska, site of a marine oil terminal." Veliger **40**(2): 121-130.

Mytilus trossulus was investigated to determine the reproductive and nutritive cell storage cycles for this mussel in Port Valdez, a fjord within Prince William Sound, Alaska. Three intertidal sites within the boundaries of a marine terminal, and four sites remote from the terminal area were sampled. Mussels from Port Valdez exhibit a distinct annual cycle with gametogenic development throughout winter, during periods with freezing air and water temperatures, and demonstrate a summer-long spawning period. Nutritive cells generally decrease throughout late winter as gametogenesis proceeds to spawning, reaching minimal values during early summer. No differences between sites attributable to the proximity of mussels to the terminal area were apparent. The effects of stress, likely related to silt-laden waters derived from a nearby glacier, were observed at one site remote from the marine terminal. Regional differences in the reproductive cycles

of Mytilus spp. are discussed.

Bodkin, J., D. Mulcahy, et al. (1996). Age-Specific Reproduction in Female Sea Otters ('Enhydra lutris') from Southcentral Alaska: Analysis of Reproductive Tracts. Marine Mammal Study 6-4. EXXON VALDEZ Oil Spill State Federal Natural resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage. : 17p .

We estimated age of sexual maturity and age-specific reproductive rates by examining carcasses and reproductive tracts from 177 female sea otters (Enhydra lutris). Carcasses were recovered from southcentral Alaska, primarily western Prince William Sound, following the T Exxon Valdez oil spill in 1989. Our estimates of the reproductive characteristics of female sea otters obtained by examination of reproductive tracts were similar to those in the literature based on in situ observations of marked individuals.

Bodkin, J. and M. Udevitz (1994). An intersection model for estimating sea otter mortality along the Kenai Peninsula. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 81-95.

The interseciton approach seemed to provide and adequate estimate of relative exposure to oil for a case where suitable data on oill abundance and movement and on the abundance and distribution of sea otters were available. Our examples of loss estimates generated with the models demonstrated its sensitivity to the assumed relation between exposure to oils and mortality rates. The mean exposure values in HB and PWP were 38 to 8.5 times greater than those at Kenai Peninsula. Refinement fo the model should include better definition of the expsosure-mortality relation, particularly at low exposure levels. Mortaility rates of otters subjected to rehabilitation should not be used to estimate this relation unless the effects of the interaction between rehabilitation and degree of oiling on mortality can be quantified. Further development of the model should also focus on obtaining an estimate of the precision of loss estimates. It is likely that bootstrap procedures will be required because of the conplex nature of the loss estimator.

The need for a theoretical approach to estimate acute losses of sea ottters arose because complete baseline data on sea otter abundace before the spill were lacking. This linited our ability to quantify the acute mortality of sea otters from the spill beyond the number of recovered carcasses. Direct estimates of losses from well designed pre- and post-spill surverys would be preferable to those provided by models such as the intersextion. Therefore, we recommend development and implementation of rigorous survey protocols in areas shared by otters and oil recovery, storage, and transportation. The most effective uses of the intersection model may be predictive modeling of the effects of future spills and quantifying exposure in a spill area.

Bodkin, J. and M. Udevitz (1996). Intersection Model for Estimating Sea Otter Mortality

from the EXXON VALDEZ Oil Spill Along the Kenai Peninsula, Alaska. Marine Mammal Study 6-5. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage. : 21p .

The authors developed an analytical model (intersection model) to estimate the exposure of sea otters (Enhydra lutris), to oil from the Exxon Valdez oil spill. The authors applied estimated and assumed exposure dependent mortality rates to the Kenai Peninsula sea otter population to provide examples of the application of the model in estimating sea otter mortality. The intersection model requires three distinct types of data: (1) distribution, abundance, and movements of oil, (2) abundance and distribution of sea otters, and (3) sea otter mortality rates relative to oil exposure. Initial output of the model is an estimate of exposure of otters to oil. Exposure is measured in amount and duration of oil near an otter's observed location (intersections). The authors provide two examples of the model using different assumptions about the relation between exposure and mortality. Because of an apparent non-linear relation between the degree of oiling and survival of otters from rehabilitation, output from the authors' examples are likely biased.

Bodkin, J. and M. Udevitz (1999). An aerial survey method to estimate sea otter abundance. Marine Mammal Survey and Assessment Methods. G. Garner, S. Amstrup, J. Laakeet al, A.A. Balkema, 3000 BR.

Sea otters (Enhydra lutris) occur in shallow coastal habitats and can be highly visible on the sea surface. They generally rest in groups and their detection depends on factors that include sea conditions, viewing platform, observer technique and skill, distance, habitat and group size. While visible on the surface, they are difficult to see while diving and may dive in response to an approaching survey platform. We developed and tested an aerial survey method that uses intensive searches within portions of strip transects to adjust for availability and sightability biases. Correction factors are estimated independently for each survey and observer. In tests of our method using shore-based observers, we estimated detection probabilities of 0.52-0.72 in standard strip-transects and 0.96 in intensive searches. We used the survey method in Prince William Sound, Alaska to estimate a sea otter population size of 9,092 (SE = 1422). The new method represents an improvement over various aspects of previous methods, but additional development and testing will be required prior to its broad application.

Bodkin, J. and F. Weltz (1990). Evaluation of sea otter capture after the T/V Exxon Valdez oil spill, Prince William Sound, Alaska. Sea Otter Symposium: Proceedings of a Symposium to Evaluate the Response Effort on Behalf of Sea Otters After the T/V Exxon Valdez Oil Spill into Prince William Sound, U.S. Fish and Wildlife Service.

Boehm, P. (1998). Sediment Quality in Depositional Areas of Shelikof Strait and Outermost Cook Inlet: Final Literature Synthesis, Minerals Management Service: 84.

This literature synthesis provides the initial step to begin the Minerals Management Serivce (MMS) Program 'Sediment Quality in Depositional Areas of Shelikof Strait and Outermost Cook Inlet' by first defining the available information and background, or baseline, data from the study are. This report includes a description of oceanographic processes relevant to pollutant transport to and in outermost Cook Inlet and Shelikof of Strait and an analysis of sources of regional and local contaminants for this area.

Boehm, P., G. Douglas, et al. (1997). " Application of petroleum hydrocarbon chemical fingerprinting and allocation techniques after the Exxon Valdez oil spill." Marine Pollution Bulletin **34**(8): 599-613.

Advances in environmental chemistry laboratory and data interpretation techniques (i.e. chemical fingerprinting) contributed to a better understanding of the biological impact of the 1989 Exxon Valdez oil spill and the fate of the spilled oil. A review of the evolution of petroleum chemical fingerprinting techniques is presented followed by a summarization of how new approaches were used to characterize and differentiate among different petroleum sources in the Prince William Sound region after the spill. An assessment of the initial data suggested that multiple sources of polycyclic aromatic hydrocarbons (PAH) were present. These findings were further substantiated, even in samples of low part-per-billion PAH concentrations, by using refined and extended laboratory techniques including the analysis of saturate biomarkers. To interpret these mixtures of sources, fingerprint-analysis flow charts and source allocation techniques were developed and applied to the data, leading to the quantification of the spilled oil as a small increment on the natural hydrocarbon background in subtidal sediments.

Boehm, P., P. Mankiewicz, et al. (1996). "Characterization of mussel beds with residual oil and the risk to foraging wildlife 4 years after the Exxon valdez oil spill. ." Environmental Toxicology and Chemistry **15**(8): 1289-1303.

The grounding of the Exxon Valdez on March 24,1989, released about 41 million L of crude oil into the waters of Prince William Sound, Alaska, USA, and oiled about 16% of the Prince William Sound shoreline to various degrees. Although winter storms, cleanups, and natural biodegradation have removed the majority of the oil on the shorelines, some residual oil still remains trapped in sediments immediately below mussel beds. This oil was protected from wave action by the dense covering of mussels. Field surveys found that mussels in such beds constituted less than 3% of the mussels available for foraging in two areas that had been extensively oiled in 1989. Levels of polycyclic aromatic hydrocarbons (PAHs) in these mussels were also measured. Mean PAH concentrations in mussel tissues ranged between 20 and 4,000 ng/g dry weight and in sediments between 20 and 26,000 ng/g dry weight. Assuming that the species considered most at risk (i.e., harlequin ducks, black oystercatchers, and sea otters) consumed the mussel proportion of their diets exclusively from such beds (at either the median or 95th percentile of mussel tissue PAH concentration), the estimated PAH dosage they would receive was one to three orders of magnitude

below doses known to cause sublethal effects in surrogate species. Considering the low frequency of mussel beds with residual oil, the patchy distribution of remaining weathered oil residues, and the relatively low PAH concentrations in the mussels, the risk of quantifiable injury at the level of an individual bird or otter, or at the population level, is minimal. Furthermore, based on a review of the mussel PAH data in Prince William Sound, the risk to wildlife has been minimal since 1990, 1 year after the spill.

Boehm, P., D. Page, et al. (1998). "Study of the fates and effects of the Exxon Valdez oil spill on benthic sediments in two bays in Price William Sound, Alaska. 1. Study design, chemistry, and source fingerprinting." Environmental Science and Technology **32**(5): 567-576.

This study was conducted to assess the subtidal effects of the Exxon Valdez oil spill in a large embayment in Prince William Sound, AK. A stratified random-sampling design was used to compare stations in an oiled bay, the Bay of Isles, with stations in Drier Bay, a bay that received little impact from the spill. The study included sediment chemistry, benthic ecology, and bioaccumulation elements. Only the results on chemistry of the oil in the bottom sediments are reported here. Analyses of sediment samples revealed four types of polycyclic aromatic hydrocarbons (PAH) in the two bays: (1) Alaska North Slope (ANS) crude oil attributable to the spill, (2) natural oil seep-derived background, (3) pyrogenic, and (4) diagenetic. The Bay of Isles subtidal sediments contained significantly higher levels of weathershed ANS-PAH attributable to the spill than did Drier Bay. However, the levels of ANS-PAH in the Bay of Isles were generally lower than those of the petrogenic background PAH naturally present in the subtidal sediments of the sound. This natural petrogenic background PAH component increased in concentration with increasing depth zone (and increasing sediment clay content) for each bay. Drier Bay, a location of past cannery and mining activity, had significantly greater concentrations of pyrogenic PAH than did the Bay of Isles. All sediment PAH concentrations were well below the effects range-low (ER-L) sediment toxicity threshold value of 4000 ng/g for total PAH. The highest sediment total PAH concentration (1500 ng/g) occurred in Drier Bay, and the highest sediment ANS (spill)-PAH concentration (201 ng/g) occurred in the Bay of Isles. There is no evidence for large-scale offshore transport of Exxon Valdez crude to the subtidal sediments.

Boehm, P., D. Page, et al. (1995). Shoreline Ecology Program for Prince William Sound Alaska following the Exxon Valdez oil spill part 2. Chemistry and toxicology. ASTM Special Technical Publication, No. 1219. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993. P. G. Wells, J. N. Butler and J. S. Hughes. Philadelphia, Pennsylvania, USA, ASTM (American Society for Testing and Materials). **1219:** 347-397.

Part two of a three-part series, this paper describes chemical and toxicological results of a comprehensive shoreline ecology program that was designed to assess recovery in Prince William Sound following the Exxon Valdez oil spill of

March 24, 1989. The program is an application of the "sediment quality triad" approach, combining chemical, toxicological, and biological measurements. Other parts of the program are described in Part 1: Study Design and Methods (Page et al., this volume) and Part 3: Biology (Gilfillan et al., this volume). The study was designed so that results could be extrapolated to the entire spill zone in the sound and projected forward in time. It combined one-time sampling of 64 randomly chosen study sites representing four major habitats and four oiling levels (including unoiled reference sites), with periodic sampling at 12 subjectively chosen "fixed" sites. Sediment samples-or when conditions required, filter-wipes from rock surfaces-were collected in each of three intertidal zones and from subtidal stations up to 30-m deep. Oil removal was generally quite rapid: by 1991 the concentration of oil spilled from the Exxon Valdez had been dramatically reduced on the majority of shorelines by both natural processes and cleanup efforts. Moderate concentrations of petroleum residues remain only in limited, localized areas; however, most of these residues are highly asphaltic, not readily bioavailable, and not toxic to marine life. Acute sediment toxicity from oil (as measured by standard toxicity tests) was virtually absent by 1990-'91, except at a small number of isolated locations. The petroleum residues had degraded below the threshold of acute toxic effects. Measurable polycyclic aromatic hydrocarbon (PAH) levels are, in general, well below those conservatively associated with adverse effects, and biological recovery has been considerably more rapid than the removal of the last chemical remnants. The remaining residues continue to degrade and are, in general, predicted to become indistinguishable from background hydrocarbon levels by 1993 or 1994. Localized residues of weathered oil will no doubt exist beyond 1994 at certain locations, but their environmental significance will be negligible compared with other stresses ongoing in the sound. Samples of nearshore subtidal sediments showed surprisingly low concentrations of oil residue, as an increment to the natural petrogenic hydrocarbon background. Sediment toxicity tests showed that they were essentially non toxic. It appears that most of the oil leaving the shoreline was swept away and dissipated at sea. It is concluded that long-term ecological effects resulting from shoreline oiling or subtidal contamination are highly unlikely.

Boersma, P., J. Parrish, et al. (1995). Common murre abundance phenology and productivity on the Barren Islands, Alaska: The Exxon Valdez oil spill and long-term environmental change. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill. P. G. Wells, J. N. Butler and J. S. Hughes. Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials): Philadelphia, Pennsylvania, USA. **1219:** 820-853.

The Exxon Valdez oil spill in 1989 caused substantial seabird mortality. By 1 August, more than 30 000 seabird carcasses (74% murres) were recovered, and it was initially estimated that between 100 000 and 300 000 seabirds were killed. The Barren Islands, in particular East Amatuli Island, support the largest seabird colonies within the path of the spill. With respect to murres nesting on the Barren Islands, claims were made that the population suffered at least a 50%

loss and that the remaining population underwent a change in breeding phenology, a breakdown in breeding synchrony, and a widespread failure to fledge chicks in the years following the spill. As a result of these effects, it was projected that the population would take 20-70 years to recover. Principally because of the paucity of prespill data on the Barren Islands murre population size and reproductive success, it is impossible to quantify any effect of the spill on these populations. Available prespill data (1976-1978) on the East Amatuli murre population size ranges from 19 000 to 61 000 birds. These data are not systematic, replicated counts but rather are estimates indicating a broad range within which the true attendance figure probably resided. Our postspill attendance counts range from 31 041 to 37 128 (1990-1992). Comparisons between matched historical and 1990s photographs showed nearly identical attendance patterns, although there were significantly more murres in the 1990s photographs. Postspill attendance data from multiply censused areas suggest a recovery may have been taking place because of greater than expected annual increases (+25% from 1990 to 1991). Prespill data on reproductive activity of the murres nesting in the Barren Islands were collected from a single 5 x 5-m plot located in a dense, flat section of the East Amatuli Light Rock colony.

Bol'shakov, V. (1992). "Evaluating the consequences of the oil spills in Alaska on vertebrates." Ekologiya (Moscow)(6): 86-88.

Bolger, M. and C. D. Carrington (1999). Hazard and Risk Assessment of Crude Oil in Subsistence Seafood Samples from Prince William Sound: Lessons Learned from the Exxon Valdez. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 195-204.

Following the spill, Native Alaskans were gravely concerned that their seafood was contaminated by the petroleum. Concern for the presence of contaminants from petroleum spills in marine organisms should be primarily focused on the potential long-term health effects (i.e., carcinogenesis) of certain petroleum components, specifically PAHs. While toxic effects other than cancer are associated with other crude oil components-particularly in the case of direct exposure to petroleum mixtures-the high levels required (e.g., worker exposure) for these effects will not occur from secondary exposure through consumption of fish or shellfish unless there are obvious effects on the marine organisms themselves. In addition, because the methodology for relative cancer-risk assessment is inherently more conservative than that used for non- cancer endpoints, the focus on the PAH-induced cancer effects is the prudent and appropriate public health focus.

PAHs were not present to any significant extent in the subsistence samples that were collected and analyzed as part of the NOAA National Marine Fisheries Service subsistence survey,particularly for the numerous finfish samples. The risk associated with consumption of unsmoked salmon is insignificant compared with the risk associated with consuming smoked salmon, since smoking significantly

increases the PAH level.

Shellfish, particularly bivalves, deserve particular attention in any oil spill, because it has consistently been shown that components of petroleum accumulate to a much greater extent in bivalves than in finfish and thus represents the most likely point of passage of aquatic oil spillage into human consumption. The risk estimate presented for molluskan bivalves was predicated on the initial conservative assumption that persons at risk would consume molluskan bivalves contaminated at the level of PAH produced by the Exxon Valdez oil spill for a period of 10 years. Subsequent evidence gathered during the course of the study indicated that this was indeed a conservative assumption and that bivalves would not be expected to be contaminated with PAHs at this level for such an extended period of time. The lifetime carcinogenic risk is low for consumption of unsmoked salmon, other finfish, crustaceans, and even oil-contaminated molluskan bivalves.

Bolger, M., S. Henry, et al. (1996). Hazard and risk assessment of crude oil contaminants in subsistence seafood samples from Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993., American Fisheries Society: Bethesda, Maryland, USA. **18:** 837-843.

One year after the Exxon Valdez oil spill, the commissioner of the Food and Drug Administration (FDA) received a request from the Alaska Oil Spill Health Task Force to assess the risk of oil contaminants in the subsistence seafood supply. The long-term health hazards of an oil spill reflect the processes of biodegradation and bioaccumulation. Of all the components of crude petroleum, the polynuclear aromatic hydrocarbons (PAHs) are toxic at the lowest doses and are the most likely to be passed through the marine food chain. The ability of fish to metabolize PAHs makes fish of considerably less concern as a dietary source of PAHs as compared to molluskan bivalves. A risk assessment using an equivalency approach was used for PAH concentrations in fish and shellfish for several reasons. The National Oceanic and Atmospheric Administration (NOAA) analyzed hundreds of subsistence fish and shellfish samples from 13 subsistence fishing grounds used by native Alaskans in or near Prince William Sound for aromatic contaminants, including aromatic hydrocarbons and dibenzothiophenes. Two surveys of fish and shellfish consumption in Chenega Bay on Evans Island in Prince William Sound and on Kodiak Island were used to estimate the risks of exposure to PAHs. Here we report the FDA's conclusion that the risk of contracting cancer from eating finfish collected from the spill area was, for practical purposes, equal to zero. Advisory levels for benzo[a]pyrene equivalencies (BaPEs) in fish and shellfish that correspond to a 10 super(-6) risk were developed. As with all quantitative cancer risk assessments, this upper-bound risk estimate was produced with the knowledge that the true risk is somewhere between the upper-bound number presented and zero. Levels of BaPE in smoked salmon were shown to be higher than levels of BaPE in bivalve mollusks as a result of the oil spill. These conclusions were based on the higher levels of PAHs found in the 1989 samples. Recent samples have demonstrated a significant decrease in PAH levels since the oil spill.

Bowman, T. (1993). "Effects of the Exxon Valdez oil spill on bald eagles." J Raptor Research **27**(1): 64-65.

Bowman, T., P. Schempf, et al. (1995). "Bald eagle survival and population dynamics in Alaska after the Exxon Valdez oil spill." Journal of Wildlife Management **59**(2): 317-324.

We investigated age-specific annual survival rates for 159 bald eagles (Haliaeetus leucocephalus) radiotagged from 1989 to 1992 in Prince William Sound (PWS), Alaska. We monitored radio-tagged eagles for |3 years beginning 4 months after the Exxon Valdez oil spill. There was no difference (P > 0.10) in survival rates between eagles radiotagged in oiled areas and eagles radiotagged in unoiled areas of PWS. Pooled annual survival rates were 71% for first-year eagles, 95% for subadults, and 88% for adult bald eagles. Most deaths occurred from March to May. We found no indication that survival of bald eagles radiotagged >4 months after the oil spill in PWS was directly influenced by the spill and concluded that any effect of the spill on survival occurred before eagles were radiotagged. A deterministic life table model suggests that the PWS bald eagle population has an annual finite growth rate of 2%. Given the cumulative effects of direct mortality and reduced productivity caused by the oil spill, we predicted that the bald eagle population would return to its pre-spill size by 1992.

Bowman, T., P. Schempf, et al. (1997). "Bald eagle population in Prince William Sound after the Exxon Valdez oil spill." Journal of Wildlife Management **61**(3): 962-967.

We initiated studies to determine whether the Exxon Valdez oil spill influenced bald eagle (Haliaeetus leucocephalus) demography in Prince William Sound (PWS), Alaska. Using fixed-wing aircraft, we surveyed bald eagle populations within random plots once each year and censused nearly all islands in PWS in 1989-91 and 1995 to estimate population size. We calculated population indices (uncorrected for birds not seen) of 2,199; 1,935; 2,116; and 2,641 adult eagles for the 4 years studied. Subsequent to the 1989 oil spill, the eagle population returned to its estimated pre-spill size by 1995. The PWS bald eagle population has increased at an average annual rate of 3.7% from 1982 to 1995. The proportion of immatures in the population averaged 29% and did not vary significantly among years.

Bowyer, R., J. Testa, et al. (1995). "Habitat selection and home ranges on river otters in a marine environment : Effects of the Exxon Valdez oil spill." Journal of Mammalogy **76** (1): 1-11.

We studied habitat selection and home ranges of river otters (Lutra canadensis) living along the coastlines of Prince William Sound, Alaska, following the Exxon Valdez oil spill in late March 1989. Deposition of feces by otters at latrine sites that were heavily oiled was significantly less than for nonoiled sites in Herring Bay in June and July, but not during August 1989. Finer-scale measurements of habitat showed selection differed significantly on oiled (Herring Bay) and nonoiled (Esther Passage) study areas in 1990; otters selected steeper tidal slopes and sites with larger rocks on oiled than on nonoiled areas, based on

characteristics of latrines and random sites. We believe otters avoided shallower slopes and protected areas with smaller rocks and gravel where oil persisted the longest. Thus, differences in habitat selection ostensibly were the result of a reduction in habitat availability caused by oil contamination. Otters on both study areas strongly selected old-growth forest; commercially logged areas in Esther Passage had no otter latrines. River otters on both areas also selected vegetated slopes (approaches to latrine sites) that were less steep. Home ranges of otters were about twice as large on the oiled area as on the nonoiled area, again suggesting that habitat for otters was reduced as a result of the oil spill. These outcomes were detected >1 year after the oil spill and suggest that there may be chronic effects of the oil spill on river otters.

Bowyer, R., J. Testa, et al. (1994). "Changes in diets of river otters in Prince William Sound, Alaska: effects of the Exxon Valdez oil spill." Canadian Journal of Zoology **72**: 970-976.

We studied the effects of the Exxon Valdez oil spill on the diets of river otters (Lutra canadensis) from oiled and nonoiled areas of Prince William Sound, Alaska, U.S.A., in 1989 and 1990. On the basis of identification of prey remains in their feces, otters fed principally on marine, bottom-dwelling fishes. Marine gastropods, bivalves, and crustaceans composed most of the invertebrates in the diet of otters; freshwater and terrestrial food items seldom occurred in their feces. The diets of otters included 149 different taxa, most of which rarely occurred in their feces. Sixty-five taxa occurred greater than or equal to 5 times in our combined data set. Species richness and diversity of prey remains in otter feces were similar on oiled and nonoiled study areas in late winter (April) 1989 (before the oil spill) and during summer (June-October) 1989 following the spill. By summer (July-September) 1990, however, there were significant declines in the richness and diversity of species (mostly bony fish, molluscs, and bivalves) in otter diets on the oiled area. Likewise, the relative abundance of prey remains in otter feces showed strong differences between areas and years, and an area by year interaction. Members of the Perciformes and Archaeogastropoda declined from 1989 and 1990 on the oiled area while they increased on the nonoiled site; Malacostraca exhibited the opposite pattern. These outcomes, when considered with other data on body mass and blood chemistry, strongly suggest that some effects of the oil spill on otters were delayed.

Braddock, J., J. Lindstrom, et al. (1993). Microbial biodegradation of oil in sediments following the T/V Exxon Valdez oil spill. 93rd General Meeting of the American Society for Microbiology, Atlanta, Georgia, USA, May 16-20,1993.

Braddock, J., J. Lindstrom, et al. (1995). "Distribution of Hydrocarbon-Degrading Microorganisms in Sediments from Prince William Sound, Alaska, following the Exxon Valdez Oil Spill." Marine Pollution Bulletin **30**(2): 125-132.

Biodegradation by naturally occurring populations of microorganisms is a major mechanism for the removal of petroleum from the environment. Therefore,

measurements of microbial populations are an important component of contaminated site assessment studies. Over a 3 year period following the T Exxon Valdez oil spill in Prince William Sound, Alaska, we counted numbers of hydrocarbon-degrading microorganisms in intertidal and subtidal sediments affected by the spill. We found significantly higher numbers of hydrocarbon-degrading microorganisms at sites within the path of the oil slick than at reference sites, indicating rapid acclimation of the resident microbial populations. In offshore surface sediments, we saw a temporal increase in numbers of hydrocarbon-degrading microorganisms. Our data suggest that microbial measurements are good indicators of exposure of sediments in Prince William Sound to hydrocarbons and of mobilization of oil to surface sediments offshore over time.

Braddock, J., J. Lindstrom, et al. (1996). Patterns of microbial activity in oiled and unoiled sediments in Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 94-108.

Perturbations of microbial communities generally result in shifts in the composition of the microbial population and lead to differences in their activities. An increase in the biodegradation activity of naturally occurring populations of microorganisms can lead to substantial removal of petroleum from the environment. For these reasons, measurements of microbial populations are an important component of contaminated site assessment studies. Over a 3-year period following the Exxon Valdez oil spill in Prince William Sound, Alaska, we measured numbers of hydrocarbon-degrading microorganisms and hydrocarbon mineralization potentials of microorganisms in oiled and unoiled surface sediments from the shore through 100-m depth offshore. We used these techniques to assess the response of microbial populations to oiling. We present here the data from two oiled sites and two reference sites as an example of how these techniques can be used to monitor changes in sediment microbial populations with time after perturbation (oiling). We found both temporal and spatial variations in numbers and activity of hydrocarbon-degrading microorganisms, with higher values at the oiled sites than at reference sites.

Braddock, J. and K. McCarthy (1996). "Hydrologic and microbiological factors affecting persistence and migration of petroleum hydrocarbons spilled in a continuous-permafrost region." Environmental Science and Technology **30**(8): 2626-2633.

Fuel spills, totaling about 1300 m^3, occurred between 1976 and 1978 adjacent to Imikpuk Lake, a drinking water source near Barrow, AK. Substantial contamination of soils and groundwater near the lake persists. We examined the magnitude and direction of groundwater flux and the microbial activity at this site to understand the persistence of contamination and its effect on the lake. We found that groundwater flux is small due to shallow permafrost, which restricts the cross-sectional area available for flow, and to the short annual thaw season (ca. 90 days). The small flux and limited depth also constrain contaminant transport and dispersion, resulting in persistent, shallow contamination. The

numbers of hydrocarbon-oxidizing microorganisms and their laboratory mineralization potentials for benzene (at 10° C) were higher in samples from contaminated areas than in reference samples. Benzene mineralization potentials in groundwater samples were comparable to more temperate systems (0.1-0.5 mg of benzene mineralized L^{-1} day^{-1}) and were stimulated by nutrient additions. Field measurements of dissolved oxygen, nitrate, ferrous iron, and sulfide in groundwater provided evidence that biodegradation of petroleum hydrocarbons is occurring in situ. Despite evidence of an active microbial population, microbial processes, like contaminant transport, are likely limited at this site by the short annual thaw season.

Braddock, J., B. Rasley, et al. (1996). Hydrocarbon Mineralization Potentials and Microbial Populations in Marine Sediments Following the EXXON VALDEZ Oil Spill. Subtidal Study Number 1B. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks. Inst. of Arctic Biology and Museum. : 213p .

Following the Exxon Valdez oil spill in 1989, the authors measured numbers of hydrocarbon-degrading microoganisms and hydrocarbon mineralization potentials of microorganisms in oiled and unoiled surface sediments from the shore through 100 m depth offshore. The authors found both temporal and spatial variations in numbers and activity of hydrocarbon-degrading microorganisms with significant higher values at the oiled sites than at reference sites. The microbial data indicate mobilization between 1989 and 1990 of oil from the intertidal to surface sediments at 20, 40 and 100 m depths offshore.

Braddock, J. and Z. Richter (1996). Microbiology of Subtidal Sediments: Monitoring Microbial Populations. Restoration Project 93047-2. EXXON VALDEZ Oil Spill Restoration Project Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks. Inst. of Arctic Biology. : 54p .

Following the Exxon Valdez oil spill in 1989, the authors measured numbers of hydrocarbon-degrading microorganisms and hydrocarbon mineralization potentials of microorganisms in oiled and unoiled surface sediments from the shore through 100 m depth offshore. The authors found both temporal and spatial variations in numbers and activity of hydrocarbon-degrading microorganisms with statistically significant higher values at the oiled sites than at reference sites. In the summer of 1993, the authors returned to ten study sites within Prince William Sound to monitor the changes in the numbers and activities of hydrocarbon-degrading microorganisms at these sites with time. In 1993 the numbers and activities of hydrocarbon-degrading microorganisms were generally very low at all sites although elevated populations and activities were measured in intertidal sub-surface samples at several sites (Northwest Bay, Herring Bay and Sleepy Bay) with observable sub-surface oiling.

Bradley, P. and F. Chapelle (1995). "Rapid toluene mineralization by aquifer microorganisms at Adak, Alaska: Implications for intrinsic bioremediation in cold

environments." Environmental Science and Technology **29**(11): 2778-2781.

Sediments from a relatively cold (5° C), petroleum hydrocarbon-contaminated aquifer in Adak, AK, mineralized [^{14}C]toluene at an aerobic rate (16.3% day^{-1} at 5° C) comparable to that (5.1% day^{-1} at 20° C) of sediments from a more temperate aquifer at Hanahan, SC. In addition, rates of overall microbial metabolism in sediments from the two aquifers, as estimated by [1-^{14}C]acetate mineralization, were similar (similar to 10.6% h^{-1}) at their respective in situ temperatures. These results are not consistent with the common assumption that biodegradation rates in cold groundwater systems are depressed relative to more temperate systems. Furthermore, these results suggest that intrinsic bioremediation of petroleum hydrocarbon contaminants in cold groundwater systems may be technically feasible, in some cases.

Bragg, J. and E. Owens (1994). Clay-oil flocculation as a natural cleansing process following oil spills: Part 1. Studies of shoreline sediments and residues from past spills. Arctic and Marine Oil Spill Program Technical Seminar, Vancouver, BC (Canada), 8-10 Jun 1994, ENVIRONMENT CANADA, OTTAWA, ON (CANADA).

Part 1 of this paper summarizes interim results from ongoing studies of the effect of clay-oil flocculation on natural cleansing of oil residues following oil spills on marine shorelines. In this study, completed since publication of earlier work (Bragg and Yang 1994) that first reported the significance of clay-oil flocculation as a natural cleansing process following the Exxon Valdez spill, the existence of clay-oil flocculation is documented to have occurred after other oil spills that have been investigated. As part of this study, sediments and oiled sediment samples were collected and analyzed from the following spills: Arrow (1970 - Nova Scotia, Canada), Metula (1974 - Straits of Magellan, Chile), Baffin Island Experiment, "BIOS" (1980 - Cape Hatt NWT, Canada), Nosac Forest (1993 - Tacoma, WA), and Fred Bouchard (1993 - Tampa Bay, FL). Results show that fine mineral sediments needed to form clay-oil floc are present at most locations, but the rate of flocculation and later speed of removal of the flocculated oil from shorelines is highly dependent on oil viscosity as well as hydraulic energy available from water motion. Highly viscous Bunker C fuel oil was found to flocculate, but unlike low viscosity oil, requires days, not seconds, to visually show flocculation. Further, where high concentrations of oil are not first removed by manual or mechanical cleaning, such as at the site of the Arrow spill, asphalt pavements or highly viscous mousse can form that then essentially shut down or significantly retard natural cleansing processes such as clay-oil flocculation or bioremediation.

Bragg, J., R. Prince, et al. (1994). "Effectiveness of bioremediation for the Exxon Valdez oil spill." Nature **368**(6470): 413-418.

The effectiveness of bioremediation for oil spills has been difficult to establish on dynamic, heterogeneous marine shorelines. A new interpretative technique used following the 1989 Exxon Valdez spill in Alaska shows that fertilizer applications significantly increased rates of oil biodegradation. Biodegradation rates depended mainly on the concentration of nitrogen within the shoreline, the oil

loading, and the extent to which natural biodegradation had already taken place. The results suggest ways to improve the effectiveness of bioremediation measures in the future.

Bragg, J. and S. Yang (1995). Clay-oil flocculation and its role in natural cleansing in Prince William Sound following the Exxon Valdez oil spill. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill. P. G. Wells, J. N. Butler and J. S. Hughes. Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA. **1219:** 178-214.

Natural interactions of fine mineral particles with residue oil and seawater, in a process called clay-oil flocculation, were found to create solids-stabilized oil-in-water emulsions on shoreline sediments at numerous locations in Prince William Sound following the Exxon Valdez spill. In laboratory tests using oiled sediment samples from Prince William Sound, these emulsions were shown to facilitate natural cleansing and dispersion of oil from sediments by moving water. Microscopic examination showed that the emulsions consisted of complex and varied floc aggregates of about 1-100 microns in diameter. Fluorescence under ultraviolet light revealed that the interior of these particles consisted of numerous spheres of oil surrounded by mineral fines and seawater. X-ray diffraction and scanning electron microscope studies showed the minerals to consist of clays, quartz, and feldspar-typical components of glacial flour. Chemical analyses of the oil revealed a correlation between the fraction of polar hydrocarbons present and the amount of mineral fines bound with the oil. These factors were also treated to the ease by which the oil could be removed from substrate sediments by hydrodynamic forces. To investigate the effect of flocculation on natural cleansing, studies were conducted to determine the hydrodynamic energy needed for seawater to remove flocculated oil residues from sediments sampled from shorelines. Water was pumped at different velocities through a column packed with oiled sediment, and the amount and composition of oil removed from the sediment were measured as functions of water velocity and sediment movement. In separate tests, oil removal was observed in a wave tank that generated wave heights less than and greater than needed to move sediments. These tests demonstrated that, with clay-oil flocculation, substantial amounts of the oil could be removed at wave energies less than those needed to cause sediment movement and abrasion, which helps to explain observed removal of oil from the subsurface and from low energy shorelines where waves were not large enough to move sediments. Further, the large hydraulic cross section and nearly neutral buoyancy of floc particles removed from the sediment help to explain their efficient dispersal. The flocculation process also significantly increases the oil-water interfacial area, enhancing access to the oil by bacteria for biodegradation. Clay-oil flocculation was found to be a beneficial process that we believe accelerated the removal of oil from shoreline sediments following the Exxon Valdez spill. The physical properties of the floc should have facilitated dispersion of the oil over large distances, thus helping to reduce buildup of hydrocarbons in subtidal sediments. Clay-oil flocculation, therefore, is another natural cleansing process that must be

considered when studying the fate of oil spilled on shorelines.

Braley, S. (1994). Local participantion in the development of oil spill contingency plans. Coastal Zone Canada '94, Cooperation in the Coastal Zone. Conference Proceedings. P. Wells and P. Ricketts. Halifax, NS (Canada), 20-23 Sep 1994, Coastal Zone Canada Assoc., Dartmouth, NS (Canada). **2:** 475-483.

The state of Alaska has established an oil pollution control program which contains some of the strictest measures for response capability and prevention in the world, including specific standards for oil spill contingency planning. The review and approval process for industry oil spill contingency plans includes public notice and comment, as well as review of the plans through the Alaska Coastal Management Program procedures for facilities and vessels operating within the coastal zone of Alaska. The importance of local participation in the review of oil spill contingency plans is recognized both in regulation and participation through the state coastal zone management process. Local knowledge must be incorporated into a contingency plan for response actions to be timely and effective. Additionally, local priorities should be established and identified before a spill ever occurs.

Brannon, E. and A. Maki (1996). "The Exxon Valdez oil spill: Analysis of impacts on the Prince William Sound pink salmon." Reviews in Fisheries Science **4**(4): 289-337.

In the 6 years following the Exxon Valdez oil spill in March 1989, a number of field and laboratory studies have been conducted to assess spill-related effects on all critical life stages of the Prince William Sound pink salmon population. In many cases, the results of these studies are in close agreement, but in others they are not. The conclusions arrived at by various investigators must be resolved because both an understanding of oil-spill effects in the marine environment and the response of the pink salmon population to such spills are critical to comprehending and responding to spills in the future. This paper examines results from all available studies of the Exxon Valdez oil spill and summarizes the extent of documented effects. Results show that the low concentrations of petroleum that actually entered the water column, the limited number of streams actually oiled, and the flushing of the intertidal incubation areas of those streams kept the hydrocarbon concentrations in the water and stream sediments well below the toxicity threshold for pink salmon. These data and the fact that 3 of the 6 postspill years have established all-time record adult run sizes indicate that the Exxon Valdez spill posed only a low level of risk to this species, and support the conclusion that specific oil-related effects on the pink salmon population in Prince William Sound are not detectable.

Brannon, E., L. Moulton, et al. (1995). An assessment of oil spill effects on pink salmon populations following the Exxon Valdez oil spill: Part 1. Early life history. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill. P. G. Wells, J. N. Butler and J. S. Hughes. Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA. **1219:** 548-584.

Pink salmon, Oncorhynchus gorbuscha, is the main salmon species of commercial importance in Prince William Sound. Unlike other Pacific salmon, they have a two-year life cycle and have adapted to spawn in the intertidal reaches of numerous small streams throughout the oil-spill area. Thus, they represent the species at highest potential risk for spill-related injury. This paper discusses results of field programs initiated within a few days of the spill and designed to assess

spill effects on critical early life stages of pink salmon in postspill years. Samples of water and stream sediments from throughout the spill area were used to define the exposure of pink salmon to residual hydrocarbons from the spill. Mean sediment concentrations of polycyclic aromatic hydrocarbons (PAH) up to 300 ppb were measured in oiled streams in 1989 and generally followed a downward trend toward background in 1990 and 1991. These PAH concentrations were then used in regression analyses of potential effects on key early life stages of pink salmon. Water samples taken from both nearshore feeding and rearing areas and offshore migratory areas show that hydrocarbon concentrations were from one to four orders of magnitude lower than concentrations reported in the literature to cause acute or chronic effects on fish species.

Bristol Environmental and Engineering Services, I. and I. OASIS Environmental (1999). Installation Restoration Program: Statistical analysis of sampling events; revision of post-closure monitoring plan. North and South Bluffs, King Salmon Airport. Anchorage, AK, United States Air Force, 611th Air Support Group, 611th Civil Engineer Squadron, 21885 Second Street, Elmendorf AFB, Anchorage, AK 99506-4420

U.S. Army Engineer District, Alaska, Engineering Branch, P.O. Box 898, Anchorage, AK 99506-0898.
The U.S. Air Force 611th Civil Engineering Squadron, under the military's Installation Restoration Program, tasked the U.S. Army Corps of Engineers, Alaska District, to implement the Post-Closure Monitoring Plan (PCMP) for the North and South Bluffs, former military wast disposal sites in king Salmin, Alaska. The PCMP was developed to evaluate the applicable regulations, and provide and early warning system for detecting contaminant releases. Groundwater, surface water, and sediment monitoring began in June1996.

This report is designed to function as an addendum to the PCMP. Changes in relevant information about the bluff sites (e.g., applicable regulations and three years of post-closure monitoring data) were analyzed to accomplish the following goals:

- Update the regulatory basis for PCMP, based on revisions to the potentially applicable regulations since the PCMP was completed in 1995;
- Establish an updated list of contaminants of potential concern (COPCs) for each site;
- Perform temporal statistical analyses to evaluate trends in COPC detections, if possible;
- Perform spatial statistical analyses to evaluate patterns in COPC detection;
- Construct a decision guide to provide a framework for removal or addtion of monitoring points or analytical methods in the post-closure monitoring program.

Brodersen, C., J. Short, et al. (1999). Evaluation of oil removal from beaches 8 years after the Exxon Valdez oil spill. Proceedings of the Twenty-second Arctic and Marine Oilspill Program (AMOP) Technical Seminar, Ottawa, Ont, Environment Canada.

Brown, D., D. Burrows, et al. (1996). Survey of Alaskan subsistence invertebrate seafoods collected in 1989-1991 to determine exposure to oil spilled from the Exxon Valdez. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D.

Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 844-855.

In response to native Alaskans' concerns, subsistence seafoods were analyzed to determine levels of contamination and to assess the safety of consuming these foods after the Exxon Valdez oil spill. This article includes the results of analyses from approximately 1,000 samples of blue mussels Mytilus edulis, butter clams *Saxidomus giganteus*, Pacific littlenecks *Protothaca staminea*, and chitons (order *Neoloricata*). Between July 1989 and August 1991, samples of invertebrate species were collected from 80 stations near 22 native Alaskan subsistence seafood collection areas inside Prince William Sound and along the Kenai and Alaska peninsulas. Invertebrates were also collected from two sites far away from the spill to serve as reference samples. Samples were analyzed for aromatic contaminants consisting of aromatic hydrocarbons and dibenzothiophenes that are components of the Prudhoe Bay crude oil spilled by the Exxon Valdez. Samples from some stations at Chenega, Windy Bay, Kodiak (Village), and Old Harbor consistently had more than 100 ng/g wet weight of total aromatic contaminants (moderately or highly contaminated). Generally, molluscs sampled from the majority of stations and from the reference areas near Angoon and Yakutat were not contaminated or were only minimally contaminated with aromatic contaminants (concentrations were less than 100 ng/g wet weight). In an advisory opinion, the Food and Drug Administration, in conjunction with the Alaska Oil Spill Health Task Force, indicated that little risk was involved in consumption of the subsistence seafoods studied, as long as visibly oiled organisms were avoided. Because invertebrates can serve as sentinel organisms for evaluating the decline in concentrations of aromatic contaminants over time, continued analyses of these organisms are also important for monitoring recovery from oil contamination.

Brown, D., M. Krahn, et al. (1991). Metabolites of aromatic compounds in bile of fish exposed to weathered crude oil. 39th ASMS Conference on Mass Spectrometry and Allied Topics, Nashville, TN.

The Exxon Valdex spilled about 11 million gallons of Prudhoe Bay crude oil (PBCO) into Prince William Sound (PWS), AK, in March, 1989. Aromatic hydrocarbons and heterocyclic compounds such as dibenzothiophenes and their alkyl substituted homologs are abundant in PBCO. We wanted to determine if fish were exposed to these aromatic compounds (ACs) as a result of the spill.

Studies have shown that fish take up ACs from their environment. ACs are readily metabolized and the metabolites are excreted in bile. Our goal was to determine specific metabolites of petroleum-related ACs in bile as definitive evidence of exposure. A halibut was injected with weathered PBCO collected from PWS 11 days following the spill to serve as a positive control in the determination of oil exposure in feral fish. Bile was collected 48 hours post injection, and the metabolites in 100 microliters of bile were hydrolyzed using beta-glucuronidase with sulfatase activity. The hydrolyzed (non-conjugated) metabolites were extracted into dichloromethane andthe extract was cleaned up by HPLC size-exclusion cleanup (Krahn, et al., J. Chromatogr. 437: 161-175, 1988). The metabolite fraction was analyzed by GC/MS using a 30-m DB-5 capillary column.

Three microliters were injected splitless at 80 degrees C; the split valve was opened opened after 0.5 min; the oven programmed at 4 degrees per minute to 300 degrees C; 45-450 amu scanned per sec.

More than 150 metabolites were identified as alcohols or phenols in the PBCO-injected halibut; however, a solvent-injected halibut had low levels of a few metabolites. An ion chromatogram of the phenanthrene metabolites from the bile is shown in Figure 1. Spectra of 9-anthracenemethanol standard and of C1-, C2-, and C3-substituted phenanthrene-OHs (PHN-OH) from the bile are shown in Figure 2.

The work provided a reference pattern for the successful determination of metabolites of petroleum-related ACs in bile samples from fish captured in PWS.

Brown, D. W., D. G. Burrows, et al. (1999). Exposure of Alaskan Subsistence Shellfish to Oil Spilled from the Exxon Valdez. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 135-168.

The concentrations of petroleum related aromatic compounds (ACs) in four target mollusk species collected in 1989-1994 from 24 sampling areas (88 sampling stations) and 2 reference areas ranged from non-detect to 8,400 ± 8,800 ppb (n = 3, collected in 1989). It was shown from patterns of relative concentrations of ACs in samples and spilled oil that the Exxon Valdez was the source of ACs in mollusks from some sites but not from others. The concentrations of ACs in mollusks that resulted from the oil spill decreased with time at some stations, whereas at other stations where there was a continuing source of petroleum, such as a tar mat, concentrations did not decrease.

Brown, D. W., B. B. McCain, et al. (1999). "Status, correlations and temporal trends of chemical contaminants in fish and sediment from selected sites on the Pacific coast of the USA." Marine Pollution Bulletin **37**(1-2): 67-85.

The National Benthic Surveillance Project (NBSP), a component of NOAA's National Status and Trends Program, monitored sediment and bottomfish for chlorinated hydrocarbon pesticides (CHs), PCBs and polycyclic aromatic hydrocarbons (PAHs) at selected urban and nonurban sites along the west coast of the USA from 1984 to 1993. This project successfully generated an extensive data set to evaluate the recent status and trends of environmental quality in coastal waters. This article summarizes and interprets the status of selected PAHs, PCBs and CHs in surficial sediments and selected species of bottom-feeding fish for 50 sites in Alaska, Washington, Oregon and California for the first 7 years (1984-1990) of the NBSP. The highest concentrations of most sediment-associated organic contaminants were present in the most highly urbanized areas, and many of the organic contaminants were bioaccumulated by indigenous marine fish species. The concentrations of PAHs and CHs in sediments generally correlated with levels of these compounds or their

derivatives in bottomdwelling fish. Assessment of trends in the concentrations of chlordanes, dieldrin, DDTs, PAHs and PCBs for the 7-year period from 1984-1990 suggest that, since the mid-1980s, concentrations of the persistent CHs, such as PCBs and DDTs in sediment and fish, show no consistent temporal trends, whereas levels of PAHs, which are nonpoint source contaminants, showed consistent increases at both nonurban and urban near-coastal sites.

Brown, E. and T. Baker (1999). Injury to Prince William Sound Herring Following the EXXON VALDEZ Oil Spill. Fish Shellfish Study Number 11. EXXON VALDEZ Oil Spill State/Federal Natural Resource Damage Assessment. Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Cordova. Commercial Fisheries Management and Development Div. : 148p .

Studies were conducted in 1989 through 1991 to determine injury to herring in Prince William Sound following the Exxon Valdez oil spill. About half the herring eggs deposited in 1989 were exposued to Exxon Valdez oil. Survival to hatch was not impacted, but there were substantial sublethal effects (acceleration of embryo development, morphological deformities and cytogenetic abnormalities) in newly hatched larvae and reduced survival from hatch to free swimming. These correlated well with oil exposure in adjacent mussels and paralleled experimental laboratory observations. The relationship of oil to histopathological lesions in feeding larvae from oiled areas was supported by laboratory studies. Severe focal hepatocellular necrosis in 20% of adult herring examined from oiled areas (none in unoiled areas) was probably due to viral hemorrhagic septicemia induced by exposure of carrier fish to Exxon Valdez oil, and consistent with later laboratory studies. Polynuclear aromatic hydrocarbons, probably Exxon Valdez oil in origin, were detected in adult herring tissues. Sponsored by Exxon Valdez Oil Spill Trustee Council, Anchorage, AK.

Brown, E., T. Baker, et al. (1996). Injury to the early life history stages of Pacific herring in Prince William Sound after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 448-462.

The Exxon Valdez oil spill occurred a few weeks before Pacific herring *Clupea pallasi* spawned in Prince William Sound. About half of the egg biomass was deposited within the oil trajectory, and an estimated 40 to 50% sustained oil exposure during early development. The resulting 1989 year-class displayed sublethal effects in newly hatched larvae, primarily premature hatch, low weights, reduced growth, and increased morphologic and genetic abnormalities. Genetic endpoints, especially anaphase aberration rates, were highly correlated with site-specific Exxon Valdez oil concentrations. Responses were specific and sensitive to this oil exposure. In newly hatched larvae, anaphase aberration rates were elevated at oiled sites, and in pelagic larvae genetic damage was greatest near oiled areas of southwestern Prince William Sound. Genetic damage in larvae from oiled areas progressively decreased during the 6-week study, but site-specific measures of instantaneous mortality suggest that a

significant reduction (52.3%) in larval production occurred in 1989. Although approximately equal egg biomass was deposited in non-oiled and oiled areas, we estimated that oiled areas produced only 0.016 x 10 super(9) pelagic larvae compared with 11.82 x 10 super(9) non-oiled areas. Despite the estimated substantial decrease in larval production, reduced abundance in the 1989-year class recruiting as 4-year-old adults in 1993 could not be estimated because natural processes affecting recruitment are poorly understood; however, the 1989 year-class was a minority of the 1993 spawning population, one of the smallest cohorts observed in Prince William Sound, and it returned to spawn with an adult herring population reduced by approximately 75%, apparently because of a widespread epizootic.

Brown, E. and M. Carls (1998). Pacific herring. Restoration Notebook, Exxon Valdez Oil Spill Trustee Council: 1-8.

Brown, E., B. Norcross, et al. (1996). "An introduction to studies on the effects of the Exxon Valdez oil spill on early life history stages of Pacific herring, Clupea pallasi, in Prince William Sound, Alaska." Canadian Journal of Fisheries and Aquatic Sciences **53** (10): 2337-2342.

On March 24, 1989, the tanker vessel Exxon Valdez spilled 42,000 000 L of crude oil after grounding on Bligh Reef in the northeastern part of Prince William Sound, Alaska. On the basis of knowledge of oil effects, Pacific herring (Clupea pallasi) damage assessment was studied. Long-term (prespill) fisheries base-line data and detailed information collected from oiled and un-oiled sites following the spill were used. The early life stages are the most sensitive to the toxic effects of oil and therefore were emphasized in damage assessment studies. One of the most challenging tasks for damage assessment was the establishment of the level of exposure at each of the life stages examined. To understand how oil spread through the PWS ecosystem and how herring were potentially exposed, it is important to understand the oceanography of the region.

Brown, E., S. Resnick, et al. (1991). "UAF Radiorespirometric Protocol for Assessing Hydrocarbon Mineralization Potential in Environmental Samples." Biodegradation **2**: 121-127.

Following the EXXON Valdez oil spill, a radiorespirometric protocol was developed at the University of Alaska Fairbanks (UAF) to assess the potential for microorganisms in coastal waters and sediments to degrade hydrocarbons. The use of bioremediation to assist in oil spill cleanup operations required microbial bioassays to establish that addition of nitrogen and phosphorus would enhance biodegradation. A technique assessing 1-^{14}C-n-hexadecane mineralization in seawater or nutrient rich sediment suspensions was used for both of these measurements. Hydrocarbon-degradation potentials were determined by measuring mineralization associated with sediment microorganisms in sediment suspended in sterilized seawater and/or marine Bushnell-Haas broth. Production of $^{14}CO_2$ and CO_2 was easily detectable during the first 48 hours with added

hexadecane levels ranging from 10 to 500 mg/l of suspension and dependent on the biomass of hydrocarbon degraders, the hydrocarbon-oxidation potential of the biomass and nutrient availability. In addition to assessment of the hydrocarbon-degrading potential of environmental samples, the radiorespirometric procedure, and concomitant measurement of microbial biomass, has utility as an indicator of hydrocarbon contamination of soils, aqueous sediments and water, and can also be used to evaluate the effectiveness of bioremediation treatments. (Copyright (c) 1991 Kluwer Academic Publishers.) Prepared in cooperation with Alaska Univ., Fairbanks. Inst. of Northern Engineering, and Technical Resources, Inc., Gulf Breeze, FL.

Buderi, R. (1989). "Alaskan oil spill: survivors return to the wild [news]." Nature **340** (6233): 421.

Bue, B., S. Fried, et al. (1998). "Estimating salmon escapement using area-under-the curve, aerial observer efficiency, and stream-life estimates: The Prince William Sound pink salmon example." Bull. NPAFC , North Pacific Anadromous Fish Comm., Vancouver, BC [Canada] **1**: 240-250.

Accurate estimates of Pacific salmon (Oncorhynchus spp.) spawners are needed to set spawning escapement goals and regulate harvests. Estimating the number of pink salmon Oncorhynchus gorbuscha spawning in Prince William Sound, Alaska, is difficult since annual runs have ranged between 2.2 million and 19.6 million and spawning occurs in over one thousand individual freshwater systems. Escapement monitoring is accomplished by surveying a collection of 208 index creeks several times over a period of weeks from fixed wing aircraft. Unadjusted survey counts are used to monitor escapements during the commercial fishing season, while estimates of the total number of spawners are calculated after the season using area-under-the-curve methods. The accuracy was examined of area-under-the-curve estimates by using information obtained on creeks with intertidal weirs: 3 creeks in 1990, 8 creeks in 1991, and 7 creeks in 1992. Aerial observer efficiency and stream-life values, calculated for each study creek each year of the study, used in conjunction with aerial observations, produced pink salmon escapement estimates that were on average within 10% of weir counts for these same creeks. Currently used methods, using only the area-under-the-curve and a constant stream life of 17.5 days, produced escapement estimates that were on average less than 50% of the corresponding weir counts. The use of a correction for aerial observer efficiency provided the greatest improvement in escapement estimates, although, the adjustment for stream life also provided substantial improvement. An investigation of the effect of survey frequency on area-under-the-curve estimates indicated that accuracy deteriorated when the survey interval exceeded 7 days.

Bue, B., S. Sharr, et al. (1994). Assessment of injury to pink salmon eggs and fry. Proceedings of the 16th Northeast Pacific Pink and Chum Salmon Workshop, Juneau, Alaska, USA, February 24-26,1993, University of Alaska; Fairbanks, Alaska, USA.

Bue, B., S. Sharr, et al. (1996). Effects of the Exxon Valdez oil spill on pink salmon embryos and preemergent fry. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 619-627.

We examined pink salmon *Oncorhynchus gorbuscha* preemergent fry mortality, embryo mortality, and survival from embryo to preemergent fry in intertidal and upstream areas of Prince William Sound that were affected by the Exxon Valdez oil spill. No change in preemergent fry density or increase in numbers of dead fry was detected within 1 month of the spill. Pink salmon embryo mortality was elevated in oil-affected streams during fall of each year from 1989 through 1992 ($P < 0.023$ for all years). In 1989 increased embryo mortality was detected in the lower intertidal zones, and in 1990 elevated mortalities were observed at the highest intertidal zone. In 1991 embryo mortality was significantly higher in all intertidal zones, as well as upstream of oil contamination. The same patterns of mortalities were observed in 1992, although they were not as extreme as that observed in 1991. However, no difference in survival of embryo to preemergent fry was detected for the 1989-1991 brood years.

Bue, B., S. Sharr, et al. (1998). "Evidence of damage to pink salmon populations inhabiting Prince William Sound, Alaska, two generations after the Exxon Valdez oil spill." Transactions of the American Fisheries Society **127**(1): 35-43.

Our investigations into the effects of the 1989 Exxon Valdez oil spill in Prince William Sound, Alaska, suggest that chronic damage occurred to some populations of pink salmon Oncorhynchus gorbuscha. Significantly elevated embryo mortalities were observed from 1989 through 1993 in populations inhabiting streams previously contaminated by oil. No statistically detectable difference in embryo mortality was observed in 1994 and 1995. We assessed the possible influence of the natural environment on these findings by collecting gametes from adults returning to contaminated and to uncontaminated streams, transporting the gametes to a hatchery where intrastream crosses were made, and incubating the resulting embryos under identical environmental conditions. Significantly increased embryo mortality was detected for embryos originating from the oil-contaminated lineages in 1993 but not in 1994, which indicated that the significant differences detected in the field in 1989-1993 were not induced by naturally occurring environmental variables.

Buell, J. (1991). Consequences of episodic exposure of chum salmon eggs/alevins to expected A-J mine tailings pond concentrations of Ag, Cd, Cu, Pb, and Zn . Proceedings of the Seventeenth Annual Aquatic Toxicity Workshop: Threshold Biological Response: Predicting and Determining Ecological Relevance, Vancouver, BC (Canada), 5 Nov 1990.

The preferred tailings disposal alternative for the A-J Mine, Juneau, AK, would episodically interrupt the water supply to a chum salmon (Oncorhynchus keta) hatchery, requiring the use of tailings pond water for egg/alevin incubation. A bioassay using five metals (Ag, Cd, Cu, Pb and Zn) produced excess mortality of experimental eggs/alevins over controls of 0.4% (98.7% experimental survival,

99.1% control survival), well within tolerable limits. Body burden and body compartment analyses tracked metals uptake during exposure and depuration during an extended (8-wk) salt water challenge.

Buhl, K. and S. Hamilton (1991). "Relative sensitivity of early life stages of Arctic grayling, coho salmon, and rainbow trout to nine inorganics." Ecotoxicology & Environmental Safety **22**(2): 184-197.

The acute toxicity of nine inorganics associated with placer mining sediments to early life stages of Arctic grayling (Thymallus arcticus), coho salmon (Oncorhynchus kisutch), and rainbow trout (O. mykiss) was determined in soft water (hardness, 41 mg liter-1 CaCO3) at 12ÍC. The relative toxicities of the inorganics varied by four orders of magnitude; from most toxic to least toxic, the rank order was cadmium, silver, mercury, nickel, gold, arsenite, selenite, selenate, and hexavalent chromium. In general, juvenile life stages of the three species tested were more sensitive to these inorganics than the alevin life stage. Among juveniles, no single species was consistently more sensitive to the inorganics than another; among alevins, Arctic grayling were generally more sensitive than coho salmon and rainbow trout. Based on the results of the present study, estimated no-effect concentrations of arsenic and mercury, but not cadmium, chromium, gold, nickel, selenium, or silver, are close to their concentrations reported in streams with active placer mines in Alaska. Thus, arsenic (as arsenite(III)) and mercury may pose a hazard to Arctic grayling and coho salmon in Alaskan streams with active placer mines.

Burden, P., J. Isaacs, et al. (1990). Economic impacts of the S.S. Glacier Bay oil spill: Social and economic studies. Outer Continental Shelf Report, U.S. Mineral Management Service: 148.

On July 2, 1987, an oil spill occurred in Cook Inlet when the S.S. Glacier Bay hit a submerged obstacle while enroute to Kenai Pipeline Company facilities to offload oil. The 1987 commercial fishery in Cook Inlet was barely underway when the S.S. Glacier Bay oil spill occurred, and the largest salmon return in history was moving up the inlet. The sockeye salmon run alone totaled over 12 million, providing a seasonal catch of 9.25 million salmon. The 1987 sport fishery in Cook Inlet was in mid-season at the time of the spill. The S.S. Glacier Bay oil spill represents an opportunity to study the economic impacts of an oil spill event in Alaska, particularly with regard to commercial fishing impacts and the public costs of cleanup. The report evaluates the existing information on the spill, response measures, and economic impacts, and adds discussions with individuals and groups involved in or affected by the spill to this data base. The report reviewed accounts of the oil spill and its costs; identified types and sources of data, developed protocol, and contacted groups and people for data collection and verification; and described, analyzed, and prepared reports of the economic effects of the S.S. Glacier Bay oil spill. (Contract DI-14-35-0004-60133. Sponsored by Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.)

Burn, D. (1999). Boat-Based Population Surveys of Sea Otters ('Enhydra lutris') in Prince William Sound, Alaska, Following the EXXON VALDEZ Oil Spill. Marine Mammal Study 6-6. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Marine Mammals Management. : 42p .

Following the Exxon Valdez oil spill, boat-based population surveys of marine birds and sea otters were periodically conducted within Prince William Sound, Alaska, between June 1989 and July 1991. The purpose of this research was to estimate post-spill sea otter density and abundance for comparison with pre-spill data in order to determine the injury to the population. Within the oiled area, sea otter density within shoreline stratum (defined as a 200m-wide strip adjacent to the shore) was 35% lower than the pre-spill density, suggesting a significant oil effect. Sea otter density in the shoreline stratum of unoiled areas was not significantly different than pre-spill density. Declines in shoreline sea otter density between 1989 and 1990 in both oiled and unoiled areas suggested a possible Sound-wide decline in the sea otter population. However, comparison of abundance estimates of all survey strata combined showed that the sea otter population in both oiled and unoiled areas of Prince William Sound were not significantly different between July of 1989,1990, and 1991. See also PB96-194956 and PB98-136898.

Burns, K. (1993). "Evidence for the importance of including hydrocarbon oxidation products in environmental assessment studies." Marine Pollution Bulletin **26**(2): 77-85.

To provide evidence for the importance of including hydrocarbon oxidation products in environmental assessment studies, 10 samples of bivalve tissue from Prince William Sound, collected as part of the assessment of the 1989 Valdez Oil Spill were extracted and separated into fractions based on polarity, by normal (HPLC). Each fraction was analysed by ultraviolet fluorescence spectroscopy (UVF) and examined for evidence of the presence of oxidation products of aromatic hydrocarbons (O-PAHs). Fluorescence in the wavelengths characteristic of O-PAHs was present in the bivalve extracts and intensity correlated with the amount of petroleum hydrocarbons as determined by gas chromatography (GC). The percentage of UVF intensity in polar fractions compared to the hydrocarbon fractions ranged from 7-85% and corresponded with degree of weathering the oil residues had undergone as determined by their GC patterns. Thus, although UVF is only a semi-quantitative method, these results support the contention that photo and bacterial degradation processes create a complex assemblage of intermediate oxidation products of hydrocarbons that are bioaccumulated in marine organisms. Analytical methodologies applied to marine monitoring and hazard assessments must be extended to include some of the oxidation products formed from the toxicants spilled into the marine environment.

Burns, W., P. Mankiewicz, et al. (1997). "A principal-component and least-squares method for allocating polycyclic aromatic hydrocarbons in sediment to multiple sources." Environmental Toxicology and Chemistry **16**(6): 1119-1131.

A method was developed to allocate polycyclic aromatic hydrocarbons (PAHs) in sediment samples to the PAH sources from which they came. The method uses principal-component analysis to identify possible sources and a least-squares model to find the source mix that gives the best fit of 36 PAH analytes in each sample. The method identified 18 possible PAH sources in a large set of field data collected in Prince William Sound, Alaska, USA, after the 1989 Exxon Valdez oil spill, including diesel oil, diesel soot, spilled crude oil in various weathering states, natural background, creosote, and combustion products from human activities and forest fires. Spill oil was generally found to be a small increment of the natural background in subtidal sediments, whereas combustion products were often the predominant sources for subtidal PAHs near sites of past or present human activity. The method appears to be applicable to other situations, including other spills.

Button, D. K., B. R. Robertson, et al. (1992). "Interactions between marine bacteria and dissolved-phase and beached hydrocarbons after the Exxon Valdez oil spill." Appl Environ Microbiol **58**(1): 243-51.

Turnover times for toluene in Resurrection Bay after the Exxon Valdez grounding were determined to be decades, longer than expected considering that dissolved hydrocarbons were anticipated to drift with the current and stimulate development of additional hydrocarbon- utilizing capacity among the microflora in that downcurrent location. These turnover times were based on the recovery of 14CO2 from added [14C]toluene that was oxidized. The concentrations of toluene there, 0.1 to 0.2 microgram/liter, were similar to prespill values. Oxidation rates appeared to be enhanced upstream near islands in the wake of the wind-blown slick, and even more within the slick itself. Specific affinities of the water column bacteria for toluene were computed with the help of biomass data, as measured by high-resolution flow cytometry. They were a very low 0.3 to 3 liters/g of cells.h-1, indicating limited capacity to utilize this hydrocarbon. Since current- driven mixing rates exceeded those of oxidation, dissolved spill components such as toluene should enter the world-ocean pool of hydrocarbons rather than biooxidize in place. Some of the floating oil slick washed ashore and permeated a coarse gravel beach. A bacterial biomass of 2 to 14 mg/kg appeared in apparent response to the new carbon and energy source. This biomass was computed from that of the organisms and associated naphthalene oxidation activity washed from the gravel compared with the original suspension. These sediment organisms were very small at approximately 0.06 microns 3 in volume, low in DNA at approximately 5.5 g per cell, and unlike the aquatic bacteria obtained by enrichment culture but quite similar to the oligobacteria in the water column.(ABSTRACT TRUNCATED AT 250 WORDS)

Calkins, D., E. Becker, et al. (1994). Impacts on Steller sea lions. T. B. M. M. a. t. E. V. Loughlin. San Diego, CA, Academic Press: 119-139.

None of the data presented and analyzed provided conclusive evidence of an effect of the Exxon Valdez oil spill on Steller sea lions. Predicted values generated by regression models were not significantly different from actual

counts. Data collected on premature pupping showed significantly higher premature pupping ratios at a haulout sire nearer the oil spill compared to a haulout site farther away. However, an oil spill effect cannot be shown based on this evidence alone. This investigation was designed to detect large changes in premature pupping ratios which should have been coupled with a reduction in pup production, but numbers of premature pups were relativly small which complicated the analysis.

The data collected and analyzed in this study showed that the previously observed decline continued throughout the period. The rate of decline was as predicted by the regression models. Data from previous counts allowed only very low power statistical analysis and no significant oil spill effect was detected.

When all tissures from a single individual were compared, toxicant levels were not consistently high enough to confirm contamination. However, contamination cannot be determined by looking for aromatic compounds in tissues only, becasue the hepatobiliary is very efficient and eliminates the metaboolized AC compounds via bile. As a result, ACs are only found at relatively low levels in other tissues. Our studies showed that some sea lions were exposed to oil and that thery were metabolizing and excreting metabolites of aromatic hydrocarbons into the bile. No lesions related to hydrocarbon contamination were found during histological examinations. No evidence indicated damage caused to sea lions from toxic effects of oil.

Carls, M., M. Babcock, et al. (submitted). "Persistence of oiling in mussel beds after the Exxon Valdez oil spill." Marine Environmental Research.

Carls, M., L. Holland, et al. (1996). Growth, feeding and survival of pink salmon fry exposed to food contaminated with crude oil. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 608-618.

Growth of pink salmon fry *Oncorhynchus gorbuscha* was reduced by oil-contaminated food in an 8-week laboratory experiment, and feeding and survival were reduced at high oil concentrations (34.8 mg total oil per gram of food). Total concentrations of Alaska North Slope crude oil in the food ranged from 0.00 (control) to 34.8 mg/g. In the highest oil treatment, mortality became significant after 2 weeks and increased rapidly until fry began feeding on clean food. Growth reductions in exposed fry were significant after 1 week in mid- (2.8 mg/g) and high-oil treatments and became more pronounced over time. The estimated feeding rate was inhibited only in the highest oil treatment, but increased in the lowest oil concentration (0.37 mg/g). Although feeding rate did not decline in the low- and mid-oil treatments, growth was significantly reduced in these groups. This suggests that changes in growth caused by oil were not caused simply by starvation, but rather were the result of increased metabolic demand or reduced assimilation efficiency. Results of this experiment support the hypothesis that juvenile

pink salmon in Prince William Sound were contaminated with hydrocarbons from the 1989 Exxon Valdez oil spill by ingesting oiled prey and that this contamination was responsible for reduced growth of fry in oiled habitats.

Carls, M., G. Marty, et al. (Submitted). "Synthesis of the toxicological and epidemiological impacts of the Exxon Valdez oil spill on Pacific herring in Prince William Sound, Alaska." Can. J. Fish. Aquat. Sci.

Carls, M., G. Marty, et al. (1998). "Expression of viral hemorrhagic septicemia virus in prespawning Pacific herring (Clupea pallasi) exposed to weathered crude oil." Canadian Journal of Fisheries and Aquatic Sciences **55**(10): 2300-2309.

Expression of subclinical viral infection in response to toxicant exposure has not previously been reported, but evidence presented herein indicates that activation of viral hemorrhagic septicemia (VHSV) may occur in Pacific herring (Clupea pallasi) exposed to crude oil encountered after an oil spill. Decreased incidence of hepatic inflammmatory cells as a function of total polynuclear aromatic hydrocarbon (TPAH) concentration was evidence for immunosuppression in exposed fish, and decreased immune surveillance is a possible mechanism by which subclinical VHSV could be reactivated. Adult Pacific herring of unknown status regarding infection by VHSV were captured from the wild and exposed to weathered crude oil for 16-18 days. TPAH concentration in tissue, VHSV prevalence, and mortality were correlated with dose. Histopathologic lesions were significantly correlated with TPAH concentration and prevalence of VHSV, but not gender or length. Significant lesions included increased hepatocellular necrosis, splenic thrombosis, and decreased inflammation in the liver.

Carls, M. and S. Rice (1988). "Sensitivity differences between eggs and larvae of walleye pollock (Theragra chalcogramma) to hydrocarbons." Marine Environmental Research **26**(4): 285-297.

Exposure of embryonic and larval walleye pollock (Theragra chalcogramma) to the water-soluble fractions (WSF) of Cook Inlet crude oil during embryonic development caused mortality and a variety of morphological abnormalities. Median WSF concentrations (1 multiplied by 8 ppm) which caused mortality after hatch did not differ significantly from those causing morphological abnormalities (1 multiplied by 6 ppm). Pollock larvae exposed to WSF did not develop abnormalities, but swimming and survival were significantly affected within 4 h of exposure. The LC sub(50) for larvae dropped from 1 multiplied by 9 ppm on day 4 to 0 multiplied by 9 ppm on day 10.

Carls, M. and S. Rice (1990). "Abnormal development and growth reductions of pollock, Theragra chalcogramma, embryos exposed to water-soluble fractions of oil." U S National Marine Fisheries Service Fish Bulletin **88**(1): 29-38.

Exposure of developing pollock Theragra chalcogramma embryos to static water-soluble fractions (WSF) of Cook Inlet crude oil in seawater slower initial

development, produced shorter larvae, and caused morphological abnormalities including membranous vesicles; body curvatures; deformations of yolk, eye, brain, jaw, intestine, and pericardial sac; absence of lower jaw; fin erosion; yolksac bloating; and light pigmentation. These abnormalities were retained after hatch, and in many cases became more pronounced as developing structures failed to form properly. The median concentration of WSF that caused abnormalities (AB50) was 2.1 | 0.1 ppm. Exposure during embryonic development reduced prehatch survival by a maximum of 26%, and caused high mortality after hatch. The median lethal concentration (1.8 | 0.6 ppm) was not significantly different than the AB50. Although exposed pollock embryos generally survived to hatching, larvae were malformed, smaller, and had poorer survival potential than controls.

Carls, M., S. Rice, et al. (1999). "Sensitivity of fish embryos to weathered crude oil: Part I. Low level exposure during incubation causes, malformations, genetic damage, and mortality in larval Pacific herring (Clupea pallasi)." Environmental Toxicology and Chemistry **18**(3): 481-493.

Pacific herring eggs were exposed for 16 d to weathered Alaska North Slope crude oil. Exposure to an initial aqueous concentration of 0.7 parts per billion (ppb) polynuclear aromatic hydrocarbons (PAHs) caused malformations, genetic damage, mortality, and decreased size and inhibited swimming. Total aqueous PAH concentrations as low as 0.4 ppb caused sublethal responses such as yolk sac edema and immaturity consistent with premature hatching. Responses to less weathered oil, which had relatively lower proportions of high molecular weight PAH, generally paralleled those of more weathered oil, but lowest observed effective concentrations (LOECs) were higher (9.1 ppb), demonstrating the importance of composition. The LOEC for more weathered oil (0.4 ppb) was similar to that observed in pink salmon (1.0 ppb), a species with a very different development rate; by inference, other species may be similarly sensitive to weathered oil. Our methods simulated conditions observed in Prince William Sound (PWS) following the Exxon Valdez oil (EVO) spill. Biological effects were identical to those observed in embryolarval herring from PWS in 1989 and support the conclusion that EVO caused significant damage to herring in PWS. Previous demonstration by our laboratory that most malformed or precocious larvae die corroborates the decreased larval production measured after the spill.

Carls, M., J. Thomas, et al. (In press). "Exposure of Pacific herring to weathered crude oil: assessing effects on ova." Environ. Toxicol. Chem. **19**(6).

Carls, M., A. Wertheimer, et al. (1996). Contamination of juvenile pink and chum salmon by hydrocarbons in Prince William Sound after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 593-607.

Juvenile pink salmon *Oncorhynchus gorbuscha* and chum salmon *O. keta* were collected

from oiled nearshore marine habitats in Prince William Sound in 1989 and 1990 to determine if they were contaminated by exposure to Exxon Valdez crude oil. For comparison, fish were also collected from non-oiled, control areas located as close as possible to oiled areas. Mussels were routinely sampled to obtain site-specific measures of biological availability of hydrocarbons. Mussels were contaminated with polynuclear aromatic hydrocarbons (PAHs) in oiled areas in 1989 (6,942 plus or minus 1,427 ng/g); much lower concentrations were observed in control locations (25 plus or minus 13 ng/g). Contamination of mussel tissues persisted into 1990, but at greatly reduced concentrations. In 1989, PAH concentrations were significantly greater in pink salmon tissues from oiled areas (181 plus or minus 28 ng/g) than from non-oiled areas (54 plus or minus 8 ng/g). In 1990, PAH concentrations (51 plus or minus 7 ng/g) were not significantly different in oiled and non-oiled locations. Most of the PAHs detected in pink salmon and mussel tissues were also found in Exxon Valdez crude oil. As may be expected after a single perturbation, PAH concentrations in mussels and pink salmon increased to peak levels after the spill and then declined. Cytochrome P4501A was significantly induced in juvenile pink and chum salmon from oiled locations in 1989 but not in 1990. Based on these observations, we conclude that Exxon Valdez crude oil caused these differential changes in PAH concentrations and induced cytochrome P4501A enzyme activity. The degree of contamination of visceral tissues and the frequency of tissue types staining for P4501A indicated that ingestion of whole oil was an important route of contamination for juvenile pink and chum salmon. We believe contamination of juvenile salmon was physiologically significant and contributed to the reduced growth observed in juvenile pink salmon from oiled areas of Prince William Sound in 1989.

Carlson, P. and (ed) (1991). Sediment of Prince William Sound, beach to deep Fjord floor, a year after the Exxon Valdez oil spill. Anchorage, AK, U.S. Geological Survey: 98 pp.

Carlson, P. and K. Kvenvolden (1992). Sediment of Prince William Sound: the aftermath of the Exxon Valdez oil spill. 43rd Arctic Science Conference, Valdez, AK, University of Alaska Fairbanks Geophysical Institute.

Carlson, P. and K. Kvenvolden (1996). Tracking Exxon Valdez oil from beach to deepwater sediments of Prince William Sound, Alaska. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 109-120.

Prince William Sound is a large fjord-type estuary system containing rugged bedrock islands dominated by coarse gravel beaches. The insular submarine slopes are covered with gravelly to muddy sediment. Bedrock and morainal ridges separate deep basins containing Holocene diatom-rich mud. Since the Exxon Valdez oil spill in the sound in March 1989, we have participated in four sediment-sampling cruises. Two months after the spill, oil had not reached the deepwater sediment at 19 sample sites. Reoccupation of

nine sites, 14 months after the spill, produced no visible oil and no compelling evidence for oil contamination. Beaches and shallow-water sediments were sampled 17 months after the spill. Oil was present in various forms on all beaches visited. Geochemical characterizations indicate that tar found on two beaches was not from Exxon Valdez oil. At 11 shallow-water stations, geochemical markers suggest spilled oil in the sediment. In June 1992 (38 months after the spill), minor amounts of Exxon Valdez oil, as well as tar from earlier spills, were found on several beaches. In addition, sediment at two deepwater sites contained geochemical markers indicating trace amounts of the spilled Exxon Valdez oil.

Carlson, P., K. Kvenvolden, et al. (1995). Two oil spills, 25 years apart, in Prince William Sound, Alaska. Geological Society of America.

Carlson, P., K. Kvenvolden, et al. (1997). Fate of spilled oil in Prince William Sound: Diary of a Forensic Geology study, U.S. Geological Survey: 88 pp.

Carlson, P., E. Reimnitz, et al. (1990). Bottom sediment along the oil spill trajectory in Prince William Sound and along the Kenai Penninsula, Alaska. Anchorage, AK, U.S. Geological Survey: 100 pp.

Carter, H. and K. Kuletz (1995). Mortality of marbled murrelets due to oil pollution in North America, Pac. Southwest Res. Stn: 261-269.

Mortality of Marbled Murrelets (Brachyramphus marmoratus) due to oil pollution is one of the major threats to murrelet populations. Mortality from large spills and chronic oil pollution has been occurring for several decades but has been documented poorly throughout their range; it probably has contributed to declines in populations, in conjunction with loss of nesting habitat and mortality in gill nets. The 1989 Exxon Valdez oil spill in Alaska caused the largest single mortality of murrelets (about 8,400 birds) in the world and contributed to decline in murrelet populations in Prince William Sound. Due to inadequate baseline data, low recovery of oiled carcasses, and other factors, the full impacts of this extensive mortality have not been determined. Restoration activities have included acquisition of murrelet nesting areas in old-growth forests in southcentral Alaska. Similar acquisition of old-growth forests will occur as restoration for mortality from the 1986 Apex Houston oil spill in California. Future oil spills will continue to threaten the viability of small, declining populations, especially in California, Oregon and Washington where a single large spill could extirpate an entire population. Efforts must be expanded to: better document mortalities during large and small spills, develop better baseline data to assess impacts, identify old-growth forests for acquisition for restoration, and reduce oil pollution.

Celewycz, A. and A. Wertheimer (1996). Prey availability to juvenile salmon after the

Exxon Valdez Oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 564-577.

The impact of the Exxon Valdez oil spill on potential prey resources of juvenile salmon was studied from April to June 1989 (zooplankton and epibenthic crustaceans) and 1990 (zooplankton only). Eight locations were sampled: two each in oiled and non-oiled bays, and two each in oiled and non-oiled corridors in western Prince William Sound. Zooplankton were sampled at each location with 20-m vertical hauls. Epibenthic crustaceans were sampled with 10-m hauls of an epibenthic sled at three nearshore habitat types: low-, medium-, and steep-gradient beaches. We did not detect any reduction in abundance of either zooplankton or epibenthic crustaceans important in the diet of juvenile salmon as a result of the Exxon Valdez oil spill. Density, biomass, and diversity (number of taxa) of zooplankton did not differ significantly between oiled and non-oiled locations in either 1989 or 1990. Biomass of harpacticoid copepods and all epibenthic crustaceans was significantly greater in oiled than in non-oiled locations. Diversity of epibenthic crustaceans, however, was similar in oiled and non-oiled locations. We conclude that the *Exxon Valdez* oil spill did not reduce the available prey resources of juvenile salmon in western Prince William Sound.

Chapman, P., J. Bridgman, et al. (1996). "Science and common sense in Port Valdez, Alaska." Marine Pollution Bulletin **32**(3): 254-356.

Based on past history, reissuance of the effluent discharge permit for the Ballast Water Treatment Plant at the Valdez Terminal of the Trans Alaska Pipeline System should have been highly contentious and divisive. This has not been the case due to what the authors believe could be a model for progress through co-operation.

Chianelli, R. (1991). "Bioremediation technology development and application to the Alaskan spill." Bulletin of Ecological Society of America **72**(2 Suppl): 86-87.

Childress, J. and J. Hall (1998). "Oil-spill ecology." Science Teacher **65**(7): 32-35.

Christie, H., L. Foeyn, et al. (1991). Oljesoelet i Prince William Sound, Alaska. (Oil spill in Prince William Sound, Alaska). Govt Reports Announcements & Index (GRA&I), Selskapet for Industriell og Teknisk Forskning, Trondheim (Norway).: 61p.

The report gives an evaluation of the clean-up work after the Exxon Valdez oil spill. Further, it gives an evaluation of the research plan attached to the fate of the oil in the nature, the effects on biological resources and the socio-economic impacts. Proposals for Norwegian follow-up initiatives are given. 27 refs., 3 figs. In Norwegian.

Clark, J., R. Prince, et al. (1991). Monitoring ecological/toxicological effects of oil spill

bioremediation treatments. 2nd International Marine Biotechnology Conference (IMBC '91), Baltimore, MD (USA), 13-16 Oct 1991.

Bioremediation treatments have the potential for direct or indirect adverse impacts on aquatic biota. As part of our involvement with monitoring bioremediation treatments used in the Exxon Valdez oil spill clean-up, we have measured water-column hydrocarbons and tissue residues in biota from treated areas to monitor for potential enhancement of oil solubility or oil dispersion resulting from bioremediation activities. Changes in dissolved oxygen concentration or chlorophyll content of ambient waters also have been monitored to detect potential stimulation of bacterial or algal populations by nutrient additions. No adverse ecological effects were observed following carefully controlled bioremediation treatments in Alaska.

Claxton, L., V. Houk, et al. (1991). "Effect of bioremediation on the mutagenicity of oil spilled in Prince William Sound, Alaska." Chemosphere **23**(5): 643-650.

On 24 March 1989 approximately 11 million gallons of Prudhoe Bay crude oil spilled into the waters of Prince William Sound, Alaska ultimately contaminating nearly 1000 miles of shoreline. Approximately 300 miles of contaminated beach were considered amenable to cleanup by bioremediation. To determine whether or not bioremediation would be effective in this geophysicl setting and under such climatic conditions and to identify potential deleterious effects, the U.S. Environmental Protection Agency (EPA) conducted one of the world's largest in situ bioremediation field demonstration research projects. One of the methods used to assess potential health effects associated with this and similar efforts was the examination of mutagenicity associated with the oil spill and the products of bioremediation. Salmonella mutagenicity was assessed using a semi-automated plating device (spiral plater) that requires less sample than the standard assay. Both the Prudhoe Bay crude oil and its weathered counterpart collected from oil-impacted water were weakly mutagenic. The mutagenicity of samples collected from the contaminated beaches (undergoing both enhanced and natural bioremediation) declined over time.

Cochrane, J. F. and K. A. Trust (1996). Contaminant Case Report: Spectacled Eider (Somateria fischeri) Eggs and Feathers from the Yukon-Kuskokwim Delta, Alaska. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services: 19pp.

Coffin, R., L. Cifuentes, et al. (1997). "Assimilation of oil-derived carbon and remedial nitrogen applications by intertidal food chains on a contaminated beach in Prince William Sound, Alaska." Marine Environmental Research **44**(1): 27-39.

Beaches in Prince William Sound, Alaska were heavily oiled by the Exxon Valdez spill in March 1989. Fertilizer supplements designed to stimulate oil degradation by indigenous bacteria were applied to beaches in the rocky intertidal zones. We used stable carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotopes to monitor trophic interactions following these treatments. Representative

macroalgae and consumer organisms were sampled during the summers of 1989 and 1990. Microcosm experiments were conducted to trace bacterial assimilation of fertilizer nitrogen and to compare relative uptake of oil and indigenous substrates during 1990. Fertilizer nitrogen was the dominant source of bacterial nitrogen in the microcosm experiments. Bacteria preferentially assimilated indigenous substrates and used oil as a substrate only after more labile substrates were depleted. Following depletion of indigenous substrates, nitrogen supplements appeared to enhance assimilation of carbon from oil. The $\delta^{13}C$ and $\delta^{15}N$ values of bacteria growing on oil and fertilizer nitrogen were distinct in the rocky intertidal environment, providing a tracer to examine the link between bacterial production and higher trophic levels. No evidence however, was found for a transfer of carbon or nitrogen assimilated by bacteria to higher trophic levels.

Cohen, M. (1995). "Technological disasters and natural resource damage assessment: An evaluation of the Exxon Valdez oil spill." Land Economics **71**(1): 65-82.

Ex post analysis can enhance assessment of the social costs of technological disasters. This paper employs a market model to evaluate the economic losses of the 1989 Exxon Valdez oil spill on southcentral Alaska's fisheries. The upper bound of the accident's first-year social costs on these resources is $108 million, approximately 27 percent of ex-vessel value. Second-year effects may have been as high as $47 million. More probable estimates of the oil spill's actual social costs are likely less than these amounts. Precise determination of the accident's impacts is constrained by the dynamic interaction of numerous biological and economic variables.

Collier, T., M. Krahn, et al. (1993). Oil exposure and effects in subtidal fish following the Exxon Valdez oil spill. Proceedings of the 1993 International Oil Spill Conference: Prevention, Preparedness, Response, Tampa, Florida, March 29-April 1, 1993, Washington, D.C.

The assessment of oil exposure and resulting biological effects in subtidal fish following marine oil spills is a rather challenging task, due to difficulty in sampling and a lack of methodologies that allow direct determination of petroleum exposure. Because fish can rapidly metabolize petroleum hydrocarbons, standard chemical analyses are of little use for assessing exposure of fish to oil. However, there are now methods available for measuring the metabolites of petroleum hydrocarbons in fish, as described by Krahn et al. in this volume. There have also been advances in determining early biochemical effects, such as induction of the cytochrome P450 system, and more severe biological effects, such as histopathological alterations and reproductive dysfunction, in fish species following exposure to petroleum hydrocarbons and related compounds. Accordingly, following the Exxon Valdez oil spill, we have been using these approaches and methodologies to measure oil exposure in subtidal fish species, together with associated biological effects. These studies have been conducted at sites inside Prince William Sound and along the Kenai and Alaska Peninsulas. Our results show a continuing exposure of several fish species, including benthic

species, which indicates petroleum contamination of subtidal areas. We have also assessed reproductive function and histopathological alterations in several of these species, and while major effects have not been documented, there is some suggestion of histopathological alterations of gill in one species of benthic fish. Still to be determined are the potential impacts on fishery resources of long-term exposure to petroleum, albeit at moderate to low levels.

Collier, T., C. Krone, et al. (1996). Petroleum exposure and associated biochemical effects in subtidal fish after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 671-683.

After the *Exxon Valdez* oil spill, petroleum exposure in subtidal fish species was assessed by determining levels of fluorescent aromatic compounds (FACs) in fish bile. The biochemical effects of this exposure were assessed by measuring induction of a specific cytochrome P-450, cytochrome P-4501A (CYP1A), and levels of deoxyribonucleic acid (DNA) adducts by "P-postlabeling. These studies were conducted at sites inside Prince William Sound and along the Kenai and Alaska peninsulas. The species examined were Dolly Varden Salvelinus malma, yellowfin sole Pleuronectes asper, rock sole P. bilineatus, flathead sole Hippoglossoides elassodon, and walleye pollock Theragra chalcogramma. For the Dolly Varden, a littoral-zone species, exposure was greatest in the 1989 sampling and dropped considerably by 1990; however, for nearshore benthic species (i.e., yellowfin, rock, and flathead soles), exposure continued into 1990 and 1991. Walleye pollock showed evidence of exposure when they were first sampled in 1990, at sites more than 640 krn from where the F-uon Valdez went aground. Generally, CYP1A induction showed temporal trends that were similar to trends in FAC data, and was shown to be a useful measure of oil exposure; however,- in two of the most heavily exposed species, there was no evidence of increased formation of petroleum-derived DNA adducts. Overall, the results show a continuing exposure of several subtidal fish species, suggesting that petroleum contamination of subtidal areas needs to be considered in assessing the impacts of major oil spills. Still to be determined are the potential impacts on fishery resources of long-term exposure to petroleum, albeit at moderate to low levels.

Commission, M. M. (1995). Annual report to Congress, 1994. Marine Mammal Commission. Annual Report. Marine Mammal Commission, Marine Mammal Commission: 283.

This 22nd annual report reviews domestic and international activities affecting marine mammals. It contains the following main sections: reauthorization of the Marine Mammal Protection Act; principles for wildlife conservation; species of special concern; marine mammal-fisheries interactions; international aspects of marine mammal protection and conservation; marine mammal strandings and die-offs; impacts of marine debris; marine mammal management in Alaska; outer continental shelf oil and gas exploration and development; research and studies program; permits for marine mammal research, public display and enhancement; and marine mammals in captivity.

Coon, M. and G. Knoke (1990). Performance and compatibility analysis of oil weathering and transport-related models for use in the environmental assessment process., Minerals Management Service: 61.

OCSEAP has developed and verified a suite of models to study the transport and fate of oil spills in the Alaskan outer continental shelf. The objectives of the study are to analyze four specific oil spill models and to recommend modifications allowing their sequential or integrated use in defining the fate of an oil spill. The project consisted of a comprehensive review of the model characteristics and physical assumptions incorporated into existing models and a study of how they can be effectively combined to support environmental assessment using microcomputers. Redundant model features and missing model features were identified. Various methods for combing the computer codes were compared. A low cost combined code is to develop the I/O software with simple architecture, combine the existing oil spill models in the simplest manner, and prepare a database, without addressing the missing features. The top of the line combined code is to develop menu-driven I/O software, develop a new integrated oil spill model, add code to address the missing features, and to prepare a database. (Sponsored by Minerals Management Service, Washington, DC.)

Cooney, R. (1995). Sound ecosystem assessment sea understanding processes constraining the production of pink salmon and herring in Prince William Sound Alaska. Landscapes: Human Ecology, Landscape Ecology, Earth System Science; 46th AAAS Arctic Division Science Conference, Fairbanks, Alaska, USA, September 19-22,1995, AAAS Arctic Division; Fairbanks, Alaska, USA.

Crawford, M. (1990). "Bacteria effective in Alaska cleanup [news]." Science **247**(4950): 1537.

Crock, J., R. Severson, et al. (1992). "Determining baselines and variability of elements in plants and soils near the Kenai National Wildlife Refuge, Alaska." Water Air Soil Pollut. **63**: 253-271.

Crowley, D. (1993). Breeding habitat of harlequin ducks in Prince William Sound, Alaska. Corvallis, OR, Oregon State University.

Thesis

Dahlheim, M. (1996). Assessment of Injuries and Recovery Monitoring of Prince William Sound Killer Whales Using Photo-Identification Techniques. Restoration Project 93042/94092. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Seattle, WA.

Alaska Fisheries Science Center: 39p.

Photo-identification studies of individual killer whales inhabitating Prince William Sound were collected from 1989-91 and from July to September 1993 to determine the impact of the spill on whale abundance and distribution (1989-1991) and monitor recovery (1993). Concurrent photo-identification studies were also conducted in Southeast Alaska to determine if PWS killer whales were displaced to other areas between 1989 and 1991. Despite increased effort, the number of encounters with PWS killer whales appears to be decreasing. The authors assume, that the whales are dead from natural causes, a result of interactions with fisheries, from the spill, or a combination of these causes.

Dahlheim, M. and C. Matkin (1994). Assessment of injuries to Prince William Sound killer whales. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 163-171.

The cause(s) for 14 killer whales missing from the AB pod is unknown. We are confident that: (1) whales have not been misidentified; (2) adequate effort was made in PWS to locate the missing animals ; and (3) the number of times the pod was encountered was sufficient to evaluate the presence or absence of an individual whale. It is unlikely that the whales left their pod and moved elsewhere. Therefore, we assume that some of the whales may have died of natural causes and the remainder are dead from either, or a combination or, a result of interactions with fisheries or the EVOS. The highest mortality rates ever reported for North Pacific resident killer whales occurred in 1989 and 1990, coinciding with the EVOS. There is a spatial and temporal correlation between the loss of the 14 whales and the EVOS, but there is no clear cause-and-effect relationship.

Dahlheim, M. and C. Matkin (1996). Assessment of Injuries to Killer Whales in Prince William Sound. Marine Mammal Study Number 2. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Seattle, WA. Alaska Fisheries Science Center
North Gulf Oceanic Society, Homer, AK: 27p.

Photo-identification studies of individual killer whales inhabiting Prince William Sound were collected from 1989-91 to determine the impact of the spill on whale abundance and distribution. Concurrent photo-identification studies were also conducted in Southeast Alaska to determine if PWS killer whales were displaced to other areas. Despite increased effort, the number of encounters with PWS killer whales appears to be decreasing. The authors assume, that the whales are dead from natural causes, a result of interactions with fisheries, from the spill, or a combination of these causes. Prepared in cooperation with North Gulf Oceanic Society, Homer, AK.

Dahlheim, M. and O. Von Ziegesar (1996). Effects of the EXXON VALDEZ Oil Spill on the Abundance and Distribution of Humpback Whales (Megaptera novaeangliae) in

Prince William Sound. Marine Mammal Study Number 1. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Seattle, WA. Alaska Fisheries Science Center
North Gulf Oceanic Society, Homer, AK: 28p.

Photo-identification studies of Prince William Sound humpback whales were conducted from May to September in 1989 and 1990 to assess the impact on the spill on humpback whale life history and ecology. In 1989, concurrent studies were conducted in Southeast Alaska on humpback whales to determine if whales avoided contaminated waters of Prince William Sound and moved to other northern feeding areas. In 1989, photographic analysis of Prince William Sound humpbacks resulted in the identification of 59 whales. In 1990, 66 whales were documented. The increase in whale sightings may have been due to the increase in effort during the 1989 and 1990 season. Because of the difference in survey effort before and after the spill, it is impossible to determine if there was a difference in the number of humpback whales using the Sound. Distribution varied among years and may be related to prey distribution. Prepared in cooperation with North Gulf Oceanic Society, Homer, AK.

Davis, R., T. Williams, et al. (1988). "The effects of oil contamination and cleaning on sea otters Enhydra lutris II. Metabolism thermoregulation and behavior." Can J Zool **66** (12): 2782-2790.

The purpose of this study was to develop a method to clean and rehabilitate sea otters (Enhydra lutris) that might become contaminated during an oil spill and to determine which physiological and behavioral factors were important in restoring the insulation provided by the fur. Tests were conducted on 12 sea otters captured in Alaska and brought to the Sea World Research Institute in San Diego. Under base-line conditions in water at 13 degree C, average metabolic rate was 8.0 W/kg, core body temperature was 38.9 degree C, and whole body thermal conductance was 10.7 W(m super(2) multiplied by degree C). Otters spent 35% of their time grooming, 45% resting, 10% swimming, and 10% feeding. The squalene concentration on the fur averaged 3.7 mg/g fur. Oiling increased thermal conductance 1.8 times. To compensate for the loss of insulation and maintain a normal core body temperature (39 degree C), the otters increased average metabolic rate (1.9 times) through voluntary activity and shivering; the time spent grooming and swimming increased 1.7 times. Using Dawn detergent, the authors were able to clean the oiled fur during 40 min of washing and rinsing. Squalene was removed by cleaning and did not return to normal levels in the oiled area after 7 days.

Davis, R., T. Williams, et al. (1994). Sea otter oil spill contingency planning. PREVENTION, RESPONSE AND OVERSIGHT FIVE YEARS AFTER THE EXXON VALDEZ OIL SPILL. PROCEEDINGS OF AN INTERNATIONAL CONFERENCE., Anchorage, AK (USA), 23-25 Mar 1994, SEA GRANT COLL. PROGRAM REP. ALASKA UNIV. INST. MAR. SCI.

The Alaska Regional Response Team's Wildlife Protection Guidelines specify

the response strategy for marine mammals, migratory birds, and terrestrial mammals that are threatened as a result of an oil spill. The response strategy is divided into three parts. The primary response emphasizes controlling the release and spread of spilled oil at the source to prevent or reduce contamination of potentially affected species and/or their habitat. The secondary response strategy emphasizes keeping potentially affected wildlife away from oiled areas through the use of deterrent techniques. Preemptive capture and relocation of sea otters may be feasible if only a small number are in danger of being oiled. The tertiary response involves the capture and rehabilitation of oiled animals. Tertiary response is initiated only when primary and secondary response activities fail and the trustee agency (i.e., USFWS in conjunction with ADF&G) deem that it is appropriate to capture and rehabilitate oiled sea otters. Any secondary or tertiary response activities must have the approval of appropriate federal and state wildlife trustee agency representatives.

Day, R., S. Murphy, et al. (1997). "Effects of the Exxon Valdez oil spill on habitat use by birds along the Kenai Peninsula, Alaska." Condor **99**(3): 728-742.

We examined habitat use by 34 species of marine-oriented birds along the Kenai Peninsula, Alaska, in 1989-1991 to measure effects of the Exxon Valdez oil spill of March 1989 outside of the immediate spill area in Prince William Sound. Overall, 22 species (65%) did not exhibit statistically significant initial negative impacts on their use of oil-affected habitats. Of the 12 species that did exhibit significant negative impacts on habitat use, 6 showed evidence of recovery by the end of the study in late 1991. Of the 6 species that failed to show clear evidence of recovery, two (Common Merganser and Glaucous-winged Gull) showed no evidence of recovery by 1991, three (Common Loon, Double-crested Cormorant, and Sharp-shinned Hawk) may have begun recovery by 1991, and evaluation of recovery of the sixth species (Ancient Murrelet) was precluded by a lack of data. On individual surveys, the proportion of species recorded that exhibited negative impacts declined through time, from 36% on the first survey after the spill in 1989 to 19% in late 1991. These results indicate that the Exxon Valdez oil spill had significant initial effects on habitat use by some marine-oriented birds along the Kenai, although the majority of species analyzed showed no obvious spill-related effects on habitat use and impacts on several other species were not prolonged.

Day, R., S. Murphy, et al. (1995). Use of oil-affected habitats by birds after the Exxon Valdez oil spill. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

This study investigated the effects of the Exxon Valdez oil spill on the use of oil-affected habitats by birds during 1989-1991. We measured densities of birds in bays that had been subjected to various levels of oiling from the spill during survey cruises that were conducted throughout the year in Prince William Sound (PWS) and during summer along the Kenai Peninsula. Overall, 23 of 42 (55%)

species in PWS and 22 of 34 (65%) species on the Kenai showed no evidence of oiling impacts on their use of habitats. Most species that did show initial negative impacts had recovered by late summer 1991 when our study concluded, although 6 of the 19 species initially impacted in PWS and 6 of the 12 species initially impacted along the Kenai did not exhibit clear signs of recovery by this time. A Principal Components Analysis of species examined from PWS revealed extensive overlap in ecological attributes among species that were and were not negatively impacted in their use of oil-affected habitats. Species that did not show clear evidence of recovery tended to be intertidal feeders and residents of PWS, but other ecologically similar species evidenced either no initial impacts or rapid recovery. These similarities suggest that the prognosis is good for the species for which we were unable to document recovery in habitat use. Our findings, together with the rapid rates of recovery in habitat features reported in other studies, suggested that impacts of the Exxon Valdez oil spill on avian use of oil-affected habitats generally were not persistent.

Day, R., S. Murphy, et al. (1997). "Effects of the Exxon Valdez oil spill on habitat use by birds in Prince William Sound, Alaska." Ecological Applications **7**(2): 593-613.

Oil spills may affect species through direct effects on population size and structure and direct and indirect (toxicological) effects on reproduction. Spill effects on the habitats these organisms occupy have received less attention, but they are no less important. For 2.5 yr following the Exxon Valdez oil spill in Prince William Sound, Alaska, we studied the use of oil-affected habitats by 42 species of marine-oriented birds. On 11 survey cruises, we surveyed bays that had received different levels of initial oiling. We related the abundance of individual species in the bays to the oiling gradient, using regression models that included habitat measures to control for variations among the sites in features other than oiling level. We defined a spill-induced impact as a statistically significant relationship between the abundance of a species and values along the oiling gradient, after accounting for the effects of variations in habitat features. We used among-year comparisons of regressions between oiling levels and abundance, controlled for season, to assess recovery. We concluded that recovery from a spill-induced impact had occurred when we no longer could detect a significant relationship between a species' abundance and oiling levels. Overall, 23 (55%) of the 42 species exhibited no initial negative impacts on their use of oil-affected habitats. Of the 19 species that did exhibit negative impacts, 13 (68%) showed evidence of recovery within 2.5 yr (the final survey in 1991). Six species (Homed Grebe, Red-necked Grebe, Barrow's Goldeneye, Bufflehead, Mew Gull, and Northwestern Crow) showed no clear evidence of recovery by our final survey. The proportion of species recorded on individual surveys that exhibited negative impacts at that time declined over the study, from 54% on the first survey after the spill in 1989 to 10% in late 1991. A principal components analysis revealed extensive ecological overlap between species that were negatively impacted in their use of oil-affected habitats and those that were not. The six species that had not recovered by late 1991 tended to be intertidal feeders and residents, but these traits also characterized some species that did

not exhibit initial impacts and some species that subsequently recovered from impacts. We detected no obvious ecological differences between species that suffered spill impacts on habitat use and those that apparently were not affected, or between impacted species that later recovered in their use of habitats and species that had not yet recovered. These results indicate that the Exxon Valdez oil spill had clear initial negative impacts on habitat use by nearly half of the species examined, suggesting substantial initial effects on habitat suitability for these species. These impacts persisted for <2.5 yr for most affected species. This rate of recovery in habitat use parallels the rapid recovery (usually <2 yr) documented for other oil-affected communities (e.g., intertidal invertebrates, fishes, and birds) that have been studied in Alaska and elsewhere.

de Marty, G., J. Hose, et al. (1997). "Histopathology and cytogenetic evaluation of Pacific herring larvae exposed to petroleum hydrocarbons in the laboratory or in Prince William Sound, Alaska, after the Exxon Valdez oil spill." Canadian Journal of Fisheries and Aquatic Sciences **54**(8): 1846-1857.

Following the 1989 Exxon Valdez oil spill in Prince William Sound, Alaska, USA, Pacific herring (Clupea pallasi) larvae sampled from oiled sites had ascites, pericardial edema, and genotoxic damage. Laboratory study confirmed that these lesions were consistent with oil exposure. Pacific herring larvae were trawled from two oiled and two unoiled sites in Prince William Sound in May 1989. Larvae from oiled sites were shorter, had ingested less food, had slower growth (oiled, 0.07-0.10 mm/day; unoiled, 0.15-0.18 mm/day), and had higher prevalence of cytogenetic damage (oiled, 56-84%; unoiled, 32-40%) and ascites (oiled, 16%; unoiled, 1%) than from unoiled sites. In the laboratory experiment, Pacific herring eggs were exposed to an oil-water dispersion of Prudhoe Bay crude oil (initial concentrations of 0.0, 0.10, 0.24, 0.48, and 2.41 mg) and sampled for histopathology <24 h after hatching. Effects were significant at the 0.48 mg/L dose (Dunnett's procedure, $P < 0.05$). Lesions included ascites; hepatocellular vacuolar change; and degeneration or necrosis of skeletal myocytes, retinal cells, and developing brain cells. Lesions in field-sampled larvae were consistent with higher mortality rates documented in larvae from oiled sites.

de Vogelaere, A. and M. Foster (1994). "Damage and recovery in intertidal Fucus gardneri assemblages following the 'Exxon Valdez' oil spill." Marine Ecology Progress Series **106**(3): 263-271.

In March 1989, the 'Exxon Valdez' spilled over 10 million gallons (ca 38 million l) of crude oil into Prince William Sound, Alaska, USA. The spill was followed by massive clean-up using hot sea-water at high pressure as well as other mechanical and chemical techniques. We studied initial damage and subsequent recovery in the upper margin of the Fucus gardneri assemblage on protected shores by comparing sites that were unoiled, oiled and cleaned with hot water at high pressure, and oiled but less intensely cleaned. F. gardneri cover averaged 80% on unoiled sites but <1% on all oiled and cleaned sites 18 mo after the spill. The abundances of barnacles, littorine snails and limpets varied among sites and

species, and this variation was associated in part with differences in their life histories. F. gardneri cover was still extremely low on oiled and cleaned sites 2.5 yr after the spill. Holdfasts that persisted after cleaning did not resprout. F. gardneri recruitment was lowest at intensely cleaned sites, and most recruits occurred in cracks near adults. Recruits were less abundant under canopies but placing canopies over recruits did not decrease their survivorship over 5 mo. Natural weathering of tar was rapid, with most marked patches gone in less than 1 yr. We conclude that intense mechanical cleaning following this oil spill increased damage and slowed recovery. Such methods should be avoided if reduction of environmental damage is the primary objective of post-spill management decisions. The recovery of F. gardneri at its upper margin might be enhanced by devices that retain moisture and increase substratum rugosity.

de Vries, S. and M. Giger (1998). Contaminants Survey: Island Bay Barrel Cache. Alaska Peninsula/Becharof National Wildlife Refuge. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services: 16 pp + appendix.

de Vries, S. and M. Giger (1998). Contaminants Survey: Bear Creek Well Number 1. Alaska Peninsula/Becharof National Wildlife Refuge. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services: 19 pp + appendix.

de Vries, S. and M. Giger (1999). Urban Contaminants Project: Fish and Hood Creeks, Anchorage, Alaska. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services: 49 pp + appendix.

Dean, T., S. Jewett, et al. (1996). Injury to epibenthic invertebrates resulting from the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 424-439.

Injuries to subtidal populations of epibenthic invertebrates in Prince William Sound were assessed by comparing densities of dominant species at oiled versus non-oiled (control) sites between 1990 and 1993. Dominant taxa included five species of sea stars and one species of crab. Population densities of leather star *Dermasterias imbricata*, and helmet crab *Telmessus cheiragonus* were smaller at oiled sites than at controls in 1990. The same general pattern was observed in most habitats and depths sampled. There was possible injury to slender arm stars *Evasterias troschelii*, although the evidence for this was less convincing. The sunflower sea star *Pycnopodia helianthoides* was found in greater abundance at control sites within eelgrass beds, but in greater abundance at oiled sites in other habitats. Densities of two other species of sea stars did not differ between sites and were apparently unaffected by oiling. In shallow portions of bays, populations of *Dermasterias* and *Telmessus* were fully recovered by 1993; however, recovery was less than complete within eelgrass beds. There were no significant differences in the density of either *Dermasterias* or *Telmessus* between oiled and control eelgrass sites in

1993, but average densities remained more than twice as high at the controls. Polycyclic aromatic hydrocarbon (PAH) concentrations were higher at oiled sites, confirming our classification of sites with respect to oiling. There was a general correspondence between level of injury to epifaunal invertebrates and PAH concentrations. Injury was greatest and PAH levels were highest in shallow waters in eelgrass beds and bays. Levels of both injury and PAHs declined between 1990 and 1993. It was unclear whether the injuries were the result of acute toxicity of oil, sublethal effects of oiling, collateral injury from cleanup activities, or a combination of these factors.

Dean, T., L. McDonald, et al. (1993). Damage assessment of coastal habitats: lessons learned from Exxon Valdez. Proceedings of the 1993 International Oil Spill Conference: Prevention, Preparedness, Response, Washington, D.C.

Dean, T., M. Stekoll, et al. (1998). "Eelgrass (Zostera marina L.) in Prince William Sound, Alaska: Effects of the Exxon Valdez oil spill." Marine Pollution Bulletin **36**(3): 201-210.

Possible injury to, and recovery of, populations of eelgrass, Zostera marina L., in Prince William Sound were assessed following the Exxon Valdez oil spill by comparing populations at oiled vs reference sites between 1990 and 1995. Eelgrass beds in heavily oiled bays were exposed to moderate concentrations of hydrocarbons. In 1990, a year after the spill, concentrations of total polycyclic aromatic hydrocarbons averaged nearly 4000 ng g-1 dry weight of sediment at oiled sites compared to less than 700 ng g-1 at reference sites. Injuries to less than 700 ng g-1 at reference sites. Injuries to eelgrass, if any, appeared to be slight and did not persist for more than a year after the spill. There were possible effects on the average density of shoots and flowering shoots, as these were 24 and 62% lower at oiled than at reference sites in 1990 ($p < 0.10$ for both). However, there were no differences between oiled and reference sites with respect to eelgrass biomass, seed density, seed germination or the incidence of normal mitosis in seedlings, and there were no signs of the elimination of eelgrass beds. Populations recovered from possible injuries by 1991, as there was a sharp decline in hydrocarbon concentrations and there were no differences in shoot or flowering shoot densities between oiled and reference sites in 1990 or subsequent years.

Dean, T., M. Stekoll, et al. (1996). Kelps and oil: The effects of the Exxon Valdez oil spill on subtidal algae. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 412-423.

This study examined possible changes in the subtidal macroalgal populations as a result of the Exxon Valdez oil spill. The abundance and size distribution of dominant subtidal algae were measured in Prince William Sound 1 year after the spill. Population density, biomass, and cover were compared between oiled and control sites within each of three habitats: sheltered bays, moderately exposed points, and very exposed points with a

surface canopy of *Nereocystis luetkeana*. Dominant macroalgae in these habitats were the kelps *Agarum cribrosum, Laminaria saccharina, L. groenlandica*, and *N. luetkeana*. There were no differences in the total density, biomass, or percentage cover of macroalgae between oiled and control sites. However, at least one of the dominant kelp species within each habitat was more abundant at the oiled sites. In addition, there were generally more small plants at oiled sites, suggesting recent recruitment or slower growth there. Recruitment at oiled sites may have been indicative of recovery from recent oil-related disturbance. Although these data suggest possible injury to kelps as a result of the spill, there were no apparent long-term impacts on subtidal populations of macroalgae.

Dearborn, R., E. Piper, et al. (1995). Prince William Sound Community College and fishing vessel oil spill response training. Prevention, Response and Oversight Five Years After the Exxon Valdez Oil Spill. Proceedings of an International Conference, Anchorage, Alaska (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University, Institute of Marine Science.

The conference participants looked at the many local, state, and federal changes made in the United States since 1989 to assess whether enough as been accomplished regarding oil spill prevention and response preparedness for the next spill. The conference was sponsored by the Alaska Sea Grant Program, University of Alaska Fairbanks in cooperation with the Alaska Department of Environmental Conservation, Cook Inlet Regional Citizens' Advisory Council, Exxon Valdez Oil Spill Trustee Council, Hazardous Substance Spill Technology Review Council, Regional Citizens' Advisory Council of Prince William Sound, U.S. Coast Guard, and U.S. Environmental Protection Agency.

DeGange, A., A. Doroff, et al. (1994). "Experimental recovery of sea otter carcasses at Kodiak Island, Alaska following the Exxon Valdez oil spill." Marine Mammal Science **10** (4): 492-496.

On 24 March 1989, the T/V Exxon Valdez ran aground in Prince William Sound, Alaska, spilling approximately 11 million barrels of crude oil. Oil was deposited on beaches nearly 700 km from the spill site, affecting thousands of hectares of sea otter (Enhydra lutris) habitat. Two of the principal limitations in determining the initial effects of the Exxon Valdez oil spill on sea otter populations were a lack of recent population data, and a lack of information on the proportion of the total number of sea otters killed by the spill that were actually recovered. In late April and early May oil spread to the Kodiak Archipelago. With the oil came wildlife rescue, beach cleanup, and other spill-response activities including searches for dead birds and mammals. We took this opportunity to assess experimentally the recovery of sea otter carcasses in the Kodiak Island area. Specifically, we were interested in the proportion of the total number of dead sea otters the recovered carcasses represented.

DeGange, A. and C. Lensink (1990). Distribution age and sex composition of sea otter carcasses recovered during the response to the T-V Exxon Valdez oil spill. Symposium to Evaluate the Response Effort on Behalf of Sea Otters after the T/V Exxon Valdez Oil

Spill into Prince William Sound. K. Bayha and J. Kormendy. Anchorage, Alaska, USA, April 17-19,1990., U S Fish and Wildlife Service. **90:** 124-129.

DeGange, A., D. Monson, et al. (1990). Distribution and relative abundance of sea otters in south-central and south-western Alaska before or at the time of the T/V Exxon Valdez oil spill. Sea Otter Symposium: Proceedings of a Symposium to Evaluate the Response Effort on Behalf of Sea Otters After the T/V Exxon Valdez Oil Spill into Prince William Sound.

Doroff, A. and J. Bodkin (1994). Sea otter foraging behavior and hydrocarbon levels in prey. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 193-208.

Sea otter foraging success, in terms of the percentage of successful dives or mean number of prey items captured per dive, was not affected in the oiled area 2 years after the EVOS. Prey composition (primarily clam, mussel, and crab) was similar among the oiled and nonoiled study sites and to prespill data from the western PWS region. Adult sea otters foraged primarily in the subtidal region, while juveniles foraged more frequently intertidally. Tissues of subtidal bivalve prey tested for hydrocarbon content did not differ regardless of the degree of shoreline oiling. Mussel tissue sampled in 1989-1992 in the intertidal regions exhibited, in site-specific areas, hydrocarbon concentrations similar to crude oil. Contamination of mussels and other intertidal prey species may be of concern for juvenile sea otters and for adults specializing in the use of intertidal prey.

Doroff, A. and J. Bodkin (1998). Sea Otter Foraging Behavior and Hydrocarbon Concentrations in Prey Following the EXXON VALDEZ Oil Spill in Prince William Sound, Alaska. Marine Mammal Study 6-8. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage. : 50p .

In summer 1991, sea otter foraging success and prey composition were determined by visual observation at 2 sites affected by shoreline oiling during the Exxon Valdez oil spill and at a non-oiled site in western Prince William Sound, Alaska. Prey species were also determined petroleum hydrocarbon concentrations in sea otter prey.

Doroff, A. and A. DeGange (1994). "Sea otter, Enhydra lutris, prey composition and foraging success in the northern Kodiak Archipelago." Fishery Bulletin **92(4):** 704-710.

During 1987 and 1988, sea otter, Enhydra lutris, prey composition and foraging success were studied by observing foraging otters in the northern Kodiak Archipelago. Study areas differed in the number of years in which they were occupied by sea otters and were categorized as established (occupied >25 years), intermediate (occupied 5-15 years), and frontal (occupied <5 years). Clams were the most frequently identified sea otter prey (57-67%) in all study areas, and of the clams

identified to species, Saxidomus giganteus was the most frequently observed. Mussels, Mytilus spp., crabs (primarily Telmessus spp.), and green sea urchins, Strongylocentrotus droebachiensis, contributed less than or equal to 25% to the total prey within each study area. Adults did not differ in the proportion of clams, mussels, or crabs captured as prey among study areas. Adults captured clams with a greater frequency and mussels with lesser frequency than did juvenile sea otters for all study areas combined. Forage success did not differ among study areas for adults nor between adults and juveniles for all study areas combined. Adult sea otters in the established area appear to have compensated for reduced prey size by retrieving more prey items per dive; however, they obtained less clam biomass per dive than otters in the intermediate and frontal areas.

Douglas, G., A. Bence, et al. (1996). "Environmental stability of selected petroleum hydrocarbon source and weathering ratios." Environmental Science & Technology **30** (7): 2332-2339.

Weathering and biodegradation alter the composition of spilled oil, making it difficult to identify the source of the release and to monitor its fate in the environment. Using intertidal sediment and terrestrial soil data that cover a wide range of oil weathering states, we show that ratios of alkylated dibenzothiophenes and phenanthrenes are useful for source identification even up to 98% depletion of total polycyclic aromatic hydrocarbons (PAHs). Furthermore, we find that some ratios of alkylated naphthalenes, phenanthrenes, and chrysenes can qualitatively assess the extent of weathering an oil has undergone since a spill. These source and weathering ratios appear to successfully describe oil depletion and to identify sources in subtidal sediment data from the M Haven spill in Italy, the Exxon Valdez spill in Alaska, and a North Sea oil spill.

Dragoo, D., G. Byrd, et al. (1996). Population Levels and Reproductive Performance of Murres Based on Observations at Breeding Colonies Four Years After the EXXON VALDEZ Oil Spill. Restoration Study Number 11. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. . Govt Reports Announcements & Index (GRA&I), Alaska Maritime National Wildlife Refuge, Homer. .

An assessment of the damage to murre populations and reproductive performance due to the 1989 Exxon Valdez oil spill was conducted from 1989 to 1991. In 1992, we continued monitoring these parameters at three murre (Uria aalge and U. lomvia) nesting colonies located in the path of the oil in an effort to begin measuring recovery. Numbers of murres were significantly reduced at all three study colonies following the spill. We found no recovery to prespill numbers. Timing of breeding and productivity of murres at the Barren Islands and Puale Bay returned to near normal levels in 1992.

Driskell, W., A. Fukuyama, et al. (1996). Recovery of Prince William Sound intertidal infauna from Exxon Valdez oiling and shoreline treatments 1989 through 1992. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and

B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 362-378.

In 1989, following the massive crude oil spill from the T/V Exxon Valdez, a sampling program was established to assess effects on and track the recovery of low-intertidal infauna from mixed gravel-sand-silt (mixed-soft) beaches. At some sites, effects from oiling were compounded by impacts from high-pressure hot-water washing used in shoreline cleanup. Total abundance, species richness, species diversity, and abundance of several major taxa (polychaetes, bivalves, and gastropods) were significantly lower in hot-water-washed beaches than in unoiled beaches. Infauna at oiled sites that were not hot-water washed rebounded quickly following the disturbance. Although all study sites showed some degree of recovery by 1992, recovery of infauna at sites that were cleaned still lagged significantly behind the oiled sites.

Du Lac, D. (1990). The Exxon Valdez oil spill: A land manager's view. North American Wildlife and Natural Resources Conference, Denver, Colorado, USA, March 16-21, 1990, Wildlife Management Institute; Washington, D.C., USA.

Duffy, L. (2000). Mercury in Alaska: The Need for Monitoring. Global Glimpses, Center for Global Change & Arctic System Research. **8:** 1-3.

Duffy, L., R. Bowyer, et al. (1998). Intertidal Effects of Pollution: Assessment of Top-Trophic Level Predators as Bioindicators. . Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks. Inst. of Arctic Biology and Museum. **:** 82p .

Growth rate, foraging ecology and breeding biology of nesting Pigeon Guillemots were studied during the breeding seasons of 1994 through 1996, in Kachemak Bay, Alaska. large differences were observed in diet, growth rates, and nest success among locations within Kachemak Bay. Differences in mean levels of biomarkers were observed between years, and between juvenile and adults, as well as among locations within Kachemak Bay. In a controlled dose response experiment, site-specific differences in some blood variables were observed among treatments. Given the doses, which were low, the lack of a dramatic growth rate effect was in agreement with not observing a constant effect in the biomarkers selected. Final rept. See also PB98-140742. Sponsored by Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office., Alaska Dept. of Fish and Game, Sitka. and Alaska Univ., Fairbanks. Coastal Marine Inst.

Duffy, L., R. Bowyer, et al. (1993). Acute phase proteins and cytokines in Alaskan mammals as markers of chronic exposure to environmental pollutants. Exxon Valdez Oil Spill Symp., Anchorage, AK (USA), 2-5 Feb 1993, BETHESDA, MD (USA), American Fisheries Society.

We examine the usefulness of developing acute phase proteins and cytokines as markers of biological effects for free-ranging Alaskan mammals. Blood assays

for these markers are already in widespread use as indicators of chemical pollution exposure, disease, and stress in humans. The acute phase response includes fever and changes in the plasma concentration of several proteins that originate in the liver. The acute phase response is mediated by cytokines, such as interleukin-1 and interleukin-6, which are released by macrophages and other cells. The few data available indicate that these biochemical markers are valuable for documenting chemical exposure when used in conjunction with an overall biostatistical model. Additional baseline studies using this nonlethal, analytical method for mammal populations are needed to characterize age, sex, and season as sources of variation.

Duffy, L., R. Bowyer, et al. (1994). "Chronic effects of the Exxon valdez oil spill on blood and enzyme chemistry of river otters." Environmental Toxicology and Chemistry **13**(4): 643-647.

River otters (Lutra canadensis) living in marine environments of Prince William Sound, Alaska, and exposed to crude oil from the Exxon Valdez spill in March 1989 showed elevated levels of blood haptoglobins, and interleukin-6 it, as well as elevated activities of aspartate aminotransferase, alanine aminotransferase, and creatine kinase in summer 1991. Stepwise logistic regression, using a subset of these and other blood proteins and enzyme activities as potential independent variables, correctly classified 86.4% of 22 otters as inhabiting oiled or nonoiled areas. River otters abandoned latrine sites (an index to their abundance) over three times more often in oiled than in nonoiled areas, suggesting there may have been a delayed response in river otter populations to exposure to crude oil. Ours is the first clear model for the long-term effects of an oil spill on blood parameters of a free-ranging mammal using a nonlethal methodology. These effects occurred two years after the spill and following a major effort to clean oil from the shorelines of Prince William Sound.

Duffy, L., R. Bowyer, et al. (1996). Acute phase proteins and cytokines in Alaskan mammals as markers of chronic exposure to environmental pollutants. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 809-813.

We examine the usefulness of developing acute phase proteins and cytokines as markers of biological effects for free-ranging Alaskan mammals. Blood assays for these markers are already in widespread use as indicators of chemical pollution exposure, disease, and stress in humans. The acute phase response includes fever and changes in the plasma concentration of several proteins that originate in the liver. The acute phase response is mediated by cytokines, such as interleukin-1 and interleukin-6, which are released by macrophages and other cells. The few data available indicate that these biochemical markers are valuable for documenting chemical exposure when used in conjunction with an overall biostatistical model. Additional baseline studies using this nonlethal, analytical method for mammal populations are needed to characterize age, sex, and season as sources of variation.

Duffy, L., M. Hecker, et al. (1999). "An analysis of the fur of river otters in Prince William Sound, Alaska: oil related hyrdrocarbons eight years after the Exxon Valdez oil spill." Polar Biology **21**: 56-58.

Duffy, L., E. Scofield, et al. (2000). A field test of Hsp70 and Hsp 60 as biomarkers of effect to Hg in freshwater fish of western Alaska. International Conference on Arctic Development, Pollution, and Biomarkers fo Human Health, Anchorage AK.

Increased awareness by subsistence users to the health risks associated with local mining activity and natural deposits of cinnabar prompted the Yukon-Kuskokwim Health Corporation (YKHC) to implement a mercury survey. People in the area surveyed by YKHC are dependent on these fish for a large portion of their subsistence diet. There was concern and questions that mining activity and natural geological depositis in the area may lead to elevated levels of mercury (Hg) in these fish. This concern is based on Canadian research that suggested elevated Hg levels in arctic and subarctic fish. Heat shock proteins (Hsp) may be suitable boimarkers of exposure for the effects of Hg on protein structure.

In subsistence fish; northern pike (Esox lucius), burbot (Lota lota), whitefish (Coregonus nelsoni), grayling (Thymallus arcticus) and sheefish (Stenodus lencicthys), we determined the Hsp 60 and Hsp 70 levels in 31 samples from adult fish gills. A dot-blot analysis using antibodies to either Hsp 60 or Hsp 70 showed the average Hsp 70 concentration was 9.1 microgram per gram of protein, while the average Hsp 60 concentration was 147.4 microgram per gram protein extracts. Mercury levels in muscle tissue in these fish averaged 0.382 ppm. No correlation was observed between the Hsp 60 or Hsp 70 expression in gill tissue and mercury concentrations in muscle tissue. Hsp 60 and Hsp 70 protein levels in the gills were correlated.

Duffy, L. K., R. T. Bowyer, et al. (1993). "Differences in blood haptoglobin and length-mass relationships in river otters (Lutra canadensis) from oiled and nonoiled areas of Prince William Sound, Alaska." Journal of Wildlife Diseases **29**(2): 353-9.

Significant differences in levels of blood haptoglobin occurred between river otters (Lutra canadensis) inhabiting oiled (mean = 361 mg/100 ml, SD = 38, n = 6) and nonoiled (mean = 306 mg/100 ml, SD = 87, n = 8) areas of Prince William Sound, Alaska (USA) following the Exxon Valdez oil spill in 1989. Additionally, male river otters from oiled areas had significantly lower body mass (1.13 kg) than male otters from nonoiled areas. We propose oil-related causes for these differences.

Duffy, L. K., R. T. Bowyer, et al. (1994). "Evidence for recovery of body mass and haptoglobin values of river otters following the Exxon Valdez oil spill." Journal of Wildlife Diseases **30**(3): 421-428.

Levels of blood haptoglobin (Hp) and interleukin-6 immunoreactive protein (IL-6

ir) were significantly elevated in river otters (Lutra canadensis) inhabiting oiled areas of Prince William Sound, Alaska (USA) following the Exxon Valdez oil spill in 1989. By May and June 1992, however, such differences were not apparent. Mean body mass of otters, adjusted for sex, age-class, and total length with analysis of covariance, differed between oiled and non-oiled areas from 1990 to 1992, but were nearly identical by May and June 1992. We propose that river otters may be recovering from chronic effects that we observed in 1990 and 1991 following the 1989 Exxon Valdez oil spill, but further research is necessary to test this hypothesis.

Duncan, P. and A. Hooten (1996). Influence of residual and applied oil on intertidal algal recruitment. Proceedings of the Exxon Valdez Oil Spill Symposium, Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA.

We studied the effect of stranded oil on algal recruitment in rocky intertidal communities in two locations in Prince William Sound, Alaska, between 1989 and 1992. Rocks collected from two oiled beaches and ceramic tiles were used as substrates for recruitment, and tarred and clean substrates were paired for each experiment. Two other treatments - caged tiles and tiles painted black - were used to examine how grazers and dark color affected recruitment. Recruitment of biota was consistently reduced on tarred substrates (by 50-100%), despite changes in location, experimetnal methods. and year. In all cases, tarred halves of rocks and tarred tiles had signifiantly lower algal cover than did clean surfaces. Similar reductions were observed for limpets and checkered periwinkles Littorina scutulata, indicating that the depressed algal recruitment was not caused by grazers feeding preferentially on tarred substrates. Cages did not sucessfully exclude grazers. Inside the cages, littorines, algae, and rockweed germlings Fucus sp. were more abundant and their recruitment was again significantly reduced on tarred tiles. Paint had no effect on recruitment, indicating that dark coloration could not account for the inhibition of recruitment by tar. The relationship between redsidual tar and recruitment success can be used in cleanup decisions for rocky shores if consideration is given to substrate composition, exposure to weathering, potential effects of cleaning on the established community, and availability of dispersing propagules.

EA Engineering, S., and Technology (1997). Tier II Ecological Risk Assessment for Piscivorous Wildlife Inhabiting Eskimo Creek. King Salmon, Alaska, Armstrong Laboratory, 2404 E Street, Brooks Air Force Base, TX 78235-5114
Earth Technology, Inc., Suite 600, 1420 King Street Alexandria VA 22314.

In August 1995, a Tier I ecological risk assessment (ERA; EMCON 1995a) was conducted for the United States Air Force installation at King Salmon Airport (KSA), in King Salmon, Alaska. The Tier I ERA was conducted as part of an Installation Restoration Program (IRP) remedial investigation/feasibility study (RI/FS) and provided quantitative estimates of the potential effects of chemical-impacted soil, surface water, and sediment on fish and wildlife at several areas within the installation, including Eskimo Creek.

In 1996, EA Engineering, Science, and Technology (EA) was contracted by Armstrong Laboratory through Earth Technologies (Prime Contract No. F41624-95-D-9016/0013) to conduct fish tissue sampling and analyses to refine the Tier I risk assessment model and provide a Tier II assessment (Wenstel, et al. 1994) of the potential for ecological risks posed by contamination possibly entering Eskimo Creek. This technical report presents the results of the fish tissue sampling and analyses, and the Tier II ERA.

Ebert, T. and D. Lees (1996). Growth and loss of tagged individuals of the predatory snail Nucella lamellosa in areas within the influence of the Exxon Valdez oil spill in Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium, Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA.

Growth and recapture rates of tagged individuals of the predatory frilled dogwinkle *Nucella lamellosa* were studied at areas in Prince William Sound, Alaska, that were within the influence of the Exxon Valdez oil spill. Snails were individually tagged with small plastic fish tags in spring and summer 1991, measured with calipers, and released at three types of sites: (1) unoiled, (2) oiled, and (3) oiled and washed with hot water. Sites were searched again in September 1991 and in July 1992 and all tagged individuals were measured. The Brody-Bertalanffy function was used as the basic growth model and was modified to accommodate seasonal variation in growth. Analysis showed a strong seasonal component to growth, with minimum growth during the winter. Growth was highest at sites that had not experienced oiling and was lowest at oiled locations. When growth of frilled dogwinkle was adjusted for degree of exposure to open sea conditions, growth was similar at unoiled and "oiled-and-washed" sites and higher than at oiled sites. Recapture rates of tagged snails were highest at unoiled sites and lowest at oiled locations; recapture rates at sites washed with hot water were intermediate. We conclude that oil from the Exxon Valdez depressed growth and recapture rates of tagged frilled dogwinkle in Prince William Sound and that treatment of oiled beaches with hot water improved growth conditions for frilled dogwinkle but did not return the sites to an unoiled state with respect to recapture rates.

Edgar, B. (1993). "Has Alaska recovered?" American Birds **47**(3): 352-361.

Edmundson, J., G. Kyle, et al. (1997). "Trophic-level responses to nutrient treatment of meromictic and glacially influenced Coghill Lake." Alaska Fishery Research Bulletin **4** (2): 136-153.

Prior to a 1990-1994 run decline, Coghill Lake consistently produced the highest single-system sockeye salmon Oncorhynchus nerka catches in Prince William Sound. Although limnological and juvenile fisheries data are not available before the run declined, we hypothesized that sockeye salmon fry produced from 3 consecutive years of high escapements (1980-1982) might have overgrazed the zooplankton forage base and reduced the lake's sockeye salmon rearing capacity. In 1993 the Exxon Valdez Oil Spill Trustee Council approved and

helped fund a nutrient enrichment stock restoration project for Coghill Lake to mitigate the oil-damaged fishery resources. During 4 years of nutrient enrichment (1993-1996), the seasonal mean phosphorus concentration increased 22%, algal biomass of mainly genera edible by zooplankton increased 220%, and the standing stock (density) of the prevalent zooplankton (Cyclops) increased 117% compared to pre-enrichment years (1988-1992). The sockeye salmon population averaged 263,604 smolts before enrichment compared to 940,411 during treatment. This increased smolt production is attributed to increases in primary and secondary production because the number of smolts produced per spawner also increased during enrichment. The trophic-level responses to nutrient enrichment in meromictic, glacially influenced Coghill Lake were similar to those observed for other clearwater holomictic and meromictic lakes treated in Alaska.

Elston, R., A. Drum, et al. (1997). "Health and condition of Pacific herring Clupea pallasi from Prince William Sound, Alaska,1994." Diseases of Aquatic Organisms **31**(2): 109-126.

This study determined baseline health and condition values of Pacific herring Clupea pallasi in 1994 in Prince William Sound (PWS), Alaska. In April 1994, 134 herring were collected from 3 spawning sites in PWS, including a sequential sampling from 1 site. For each herring, morphometric characteristics, sex and presence of gross external and internal lesions were documented, and samples were processed for aging, virological, bacteriological and histological analysis. The study did not reveal trends in herring health and condition in 1994 that could reasonably be attributed to the 'Exxon Valdez' oil spill in 1989. No viruses or pathogenic bacteria were detected, but herring worms, a coccidian parasite and a systemic and virulent fungal infection were found in the herring. The degree of vacuolation in liver cells, previously thought to indicate exposure of fish to oil, varied significantly with the stage of reproductive development of the herring. Similarly, the liver melanomacrophage index, also believed to be correlated with environmental toxicant exposures, varied significantly among sample locations and with collection date. In this study, significant differences in age distribution of spawning herring populations occur in close geographic proximity and collection time intervals in PWS. Based on our results, the use of condition factor, disease and indices of liver function to indicate pollutant exposure are likely to be invalid unless other factors unrelated to pollutant exposure are taken into account, such as reproductive stage of the herring, spawning behavior and location, age of herring and collection date. Thus, we conclude that various hypotheses advanced regarding impacts of the 'Exxon Valdez' oil spill as well as other cases of environmental contamination cannot be supported without rigorous statistical evaluation of natural variations in indices of fish health and condition.

Erikson, D. (1995). Surveys of murre colony attendance in the northern Gulf of Alaska following the Exxon Valdez oil spill. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for

Testing and Materials); Philadelphia, Pennsylvania, USA.

Field surveys were conducted in July and August 1991 on 32 of the 36 murre (Uria spp.) colonies in the northern Gulf of Alaska to assess colony attendance (number of birds present at a colony) two years after the Exxon Valdez oil spill. The surveys focused on murre colonies because murres represented 74% of the recovered seabird carcasses and because it had been claimed that there was large-scale mortality of murres, leading to 60% to 70% decreases at some large colonies and population recovery periods of 20 to 70 years. Murres were present at all 32 colonies, and colony attendance estimates were generally similar to those from historical (prespill) surveys, particularly for those colonies in the direct path of the spill, i.e., the Barren Islands and Chiswell Islands. Colony attendance levels in 1991 do not support the contention that murre colony attendance in the study area was drastically lower than historical levels. When colonies were grouped according to risk of oil exposure, the mean changes in attendance between 1991 and historical murre surveys did not differ significantly among the groups. Factors that could account for the observed similarity of 1991 and historical murre counts despite the high estimated mortality are (1) overestimation of mortality or (2) replacement of lost breeders through either recruitment of formerly nonbreeding individuals into the breeding population at spill-affected colonies or immigration of murres from nonaffected colonies. The findings of this study suggest that impacts of the Exxon Valdez oil spill on murre colony attendance in the northern Gulf of Alaska were relatively short-term.

Estes, J. (1998). "Concerns about rehabilitation of oiled wildlife." Conservation Biology **12**(5): 1156-1157.

The Exxon Valdez oil spill was a precedent-setting event because of the seemingly limitless resources invested in environmental cleanup, rehabilitation of oiled wildlife, and a host of related post-spill activities. Sea otters were the centerpiece of rehabilitation efforts, in large part because of their vulnerability, local abundance, and public appeal. In an earlier commentary I questioned whether this effort was in the best interest of conservation. Eight years have passed since the Exxon Valdez spill, during which time concern over marine oil spills has grown to the point of creating its own culture. Our society's need for cheap energy has made spill prevention an elusive goal, thereby elevating rehabilitation to a position of considerable importance in spill response programs. But just what are the benefits of rehabilitation and what are its likely costs? The developing polarity of views on wildlife rehabilitation makes this a timely issue.

Estes, J., C. Bacon, et al. (1997). "Organochlorines in sea otters and bald eagles from the Aleutian Archipelago." Marine Pollution Bulletin **34**(6): 486-490.

In summary, these findings demonstrate that potentially harmful OC levels occur in the Aleutian Islands, one of the most remote areas of North America. Sources of these compounds should be determined, because the likely alternatives have substantially different implications to the conservation and management of fisheries, seabirds and marine mammals. If the high OC levels in the Aleutian chain are from one or several local sources, mitigation may be in order.

Conversely, the possibility of more distant sources raises a larger suite of issues including health risks to wildlife and humans, the practicability of mitigation, and policy implications for the non-purposeful transport of environmentally harmful stubstances across national borders.

Estes, J., M. Tinker, et al. (1998). "Killer whale predation on sea otters linking oceanic and nearshore ecosystems." Science (Washington) **282**(5388): 473-476.

After nearly a century of recovery from overhunting, sea otter (Enhydra lutris) populations are in abrupt decline over large areas of western Alaska. Increased killer whale (Orcinus orca) predation is the likely cause of these declines. Elevated sea urchin density and the consequent deforestation of kelp beds in the nearshore community demonstrate that the otter's keystone role has been reduced or eliminated. This chain of interactions was probably initiated by anthropogenic changes in the offshore oceanic ecosystem.

Evers, D., J. Kaplan, et al. (1998). "Geographic trends in mercury measured in common loon feathers and blood." Environmental Toxicology and Chemistry **17**(2): 173-183.

The common loon (Gavia immer) is a high-trophic-level, long-lived, obligate piscivore at risk from elevated levels of Hg through biomagnification and bioaccumulation. From 1991 to 1996 feather (n = 455) and blood (n = 381) samples from adult loons were collected between June and September in five regions of North America: Alaska, northwestern United States, Upper Great Lakes, New England, and the Canadian Maritimes. Concentrations of Hg in adults ranged from 2.8 to 36.7 mug/g (fresh weight) in feathers and from 0.12 to 7.80 mug/g (wet weight) in whole blood. Blood Hg concentrations in 3 to 6-week-old juveniles ranged from 0.03 to 0.78 mug/g (wet weight) (n = 183). To better interpret exposure data, relationships between blood and feather Hg concentrations were examined among age and sex classes. Blood and feather Hg concentrations from the same individuals were significantly correlated and varied geographically (r2 ranged from 0.03 to 0.48). Blood and feather Hg correlated strongest in areas with the highest blood Hg levels, indicating a possible carryover of breeding season Hg that is depurated during winter remigial molt. Mean blood and feather Hg concentrations in males were significantly higher than concentrations in females for each region. The mean blood Hg concentration in adults was 10 times higher than that in juveniles, and feather Hg concentrations significantly increased over 1 to 4-year periods in recaptured individuals. Geographic stratification indicates a significant increasing regional trend in adult and juvenile blood Hg concentrations from west to east. This gradient resembles U.S. Environmental Protection Agency-modeled predictions of total anthropogenic Hg deposition across the United States. This gradient is clearest across regions. Within-region blood Hg concentrations in adults and juveniles across nine sites of one region, the Upper Great Lakes, were less influenced by variations in geographic Hg deposition than by hydrology and lake chemistry. Loons breeding on low-pH lakes in the Upper Great Lakes and in all lake types of northeastern North America are most at risk from Hg.

Falkenberg, C. and R. Kulkarni (1995). Using spatial access methods to support the visualization of environmental data. Proceedings of Visualization '95, IEEE Computer Society Press.

Fall, J. (1990). "The Division of Subsistence of the Alaska Department of Fish and Game: an overview of its research program and findings: 1980-1990." Arctic Anthropology **27**(2): 68-92.

Fall, J. and L. Field (1996). Subsistence uses of fish and wildlife before and after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 819-836.

The *Exxon Valdez* oil spill fouled waters and beaches used for subsistence hunting, fishing, and gathering by 2,200 residents of 15 Alaska Native communities. In the year after the spill, subsistence harvests declined by as much as 77% compared to pre-spill averages in 10 of these villages, primarily because of the villagers' uncertainty about the safety of using subsistence foods that might have been contaminated by the oil. An Oil Spill Health Task Force formed to respond to these concerns. The task force coordinated a subsistence foods testing program and communicated the program's findings to the affected users. During the 3 years of these studies, marine invertebrate, fish, and marine mammal tissue samples were analyzed by gas chromatography-mass spectrometry for aromatic contaminants (ACs). Most samples had AC concentrations less than 10 parts per billion (ppb). An expert toxicological committee convened to review the study findings. The committee concluded that finfishes from all areas were safe to eat, but that intertidal invertebrates from specific areas, which had reported concentrations of greater than 1,000 ppb, should not be consumed. The success of the risk communication program in the villages was mixed, in part because of the limited number of sampling locations and samples and the long intervals between the collection of samples and communication of the interpreted results. By the end of the third year after the spill, subsistence harvest levels had rebounded but remained below pre-spill norms in several communities, especially those of Prince William Sound. Although there was evidence of recovery of subsistence uses, some households returned to using subsistence foods despite continued misgivings because of economic and cultural reasons.

Fall, J. A. (1999). Patterns of Subsistence Uses of Fish and Wildlife Resources in the Area of the Exxon Valdez Oil Spill. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 21-32.

The Exxon Valdez oil spill of March 1989 fouled waters and beaches used for subsistence hunting, fishing, and gathering by 15 predominantly Alaska Native communities of Prince William Sound, Lower Cook Inlet, the Kodiak Island archipelago, and the Alaska Peninsula of south-central and southwest. At the

time of the spill, about 2000 people, most of Alutiiq descent and cultural heritage, lived in these 15 villages. Additionally, in 1989 another 13,000 people, who were eligible to engage in subsistence activities under state and federal regulations, lived in three larger communities of the region.

Subsistence uses of wild, renewable resources are of fundamental economic, social, and cultural importance to the communities of the oil-spill area. The potential effects on fish, marine invertebrates, birds, and mammals of the 11 million gallons of oil spilled by the Exxon Valdez were of primary concern to the people and communities in the spill area who have traditionally relied upon these natural resources. The patterns of subsistence uses before the oil spill provide an overview that explains the basis for great concern of these residents. The survival of these communities and their way of life continues to depend directly on the food that subsistence activities provide and the strength of the cultural traditions that subsistence activities support.

Fall, J. A. (1999). Changes in Subsistence Uses of Fish and Wildlife Resources following the Exxon Valdez Oil Spill. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 51-104.

Subsistence uses of fish, marine invertebrates, birds, and mammals are of fundamental economic, social, and cultural importance to the residents of the communities of the area affected by the Exxon Valdez oil spill of March 1989. The oil spill severely disrupted patterns of subsistence use. In the 12 months after the spill, subsistence harvest quantities dropped, the variety of wild resources used for food was much reduced, people directed far less time than normal to subsistence activities, and traditional sharing was curtailed. Although many households in all 15 Alaska Native communities in the spill area suffered reduced subsistence uses in the first post-spill year, the greatest effects were in Prince William Sound, Lower Cook Inlet, and in some Kodiak Island Borough communities.

The large majority of households whose subsistence uses declined in 1989 pointed to oil-contamination concerns as the reason for their unusually low use levels. Little specific information was available to subsistence users until most subsistence harvest opportunities in the spring, summer, and early fall of 1989 had passed. Advice from health officials that sight, smell, and taste were reliable indicators of subsistence food safety was rejected by many subsistence users in these villages because it contradicted their own observations of dead and dying wildlife. Further, despite generations of traditional knowledge about the natural environment, the potential unseen effects of the spilled oil on subsistence resources could not be interpreted without assistance from health officials and scientists. The experience of the oil spill cast doubt on subsistence users' own abilities to understand their environment and make informed decisions about subsistence resources. The changes in use of subsistence foods from village to village by year and the reasons expressed by villagers are included.

Fall, J. A., L. J. Field, et al. (1999). Overview of Lessons Learned from the Exxon Valdez Oil Spill: A 10-Year Retrospective. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 237-270.

The legacy of the Exxon Valdez oil spill (EVOS) includes a better understanding of ecological relationships and an enhanced preparedness to respond to future spills. The intent of this book has been to contribute to the lessons learned from the EVOS by focusing on an important aspect of environmental disaster response that is often ignored or neglected: the human dimension. And while the nutritional and cultural significance of subsistence uses of fish and wildlife is especially noteworthy in Alaska, these lessons apply to any human population that uses local natural resources for food. From the standpoint of technical program development, the procedures for collecting, testing, and evaluating samples of subsistence resources for contamination and food safety may serve as modest models for future disaster response and environmental monitoring. From the perspective of risk communication, two key themes stand out. The first is the importance of a collaborative, multidisciplinary approach from the earliest stages of response. The second is the necessity of an effective, interactive communication process that develops a credible message and delivers it well and is flexible and reflexive enough to adapt as its audience responds. Crosscutting both of these themes is the importance of sound science, local knowledge and observations, a public process above suspicion, and sensitivity to the cultural context in which the issues are defined and the message is received. These lessons must be applied to each stage of the process, from contingency planning, to spill response, to long-term restoration.

Faro, J., R. Bowyer, et al. (1996). Assessment of Injury to River Otters in Prince William Sound, Alaska, Following the EXXON VALDEZ Oil Spill. Terrestrial Mammal Study Number 3. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks.: 88p.

River otters (Lutra canadensis) were killed by direct effects of the Exxon Valdez oil spill, but the magnitude of that loss is unknown due to lack of pre-spill data. A time lag in spill effects is reflected by the reduction in species richness and diversity in the summer diets of otters in oiled areas between 1989 and 1990. Otters from oiled areas had higher haptoglobin levels in both 1990 and 1991. Male otters captured in oiled areas in 1990 had significantly lower body mass than otters from nonoiled areas. Otters from oiled areas had home ranges that were twice as large as those from a non-spill area. Differences in rates of fecal deposition between oiled and nonoiled latrine sites in 1989 suggest otters used heavily oiled areas less often. Otters avoided shorelines with shallow slopes on the oiled area, whereas they strongly preferred these slopes on nonoiled sites, suggesting that otters lost habitat as a result of the spill. Sponsored by Alaska Dept. of Fish and Game, Soldotna.

Faro, J., R. Bowyer, et al. (1996). River Otter Component of the Oiled Mussel-Bed Study. Restoration Study Number 103-3. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks.: 17p.

The authors' objective was to determine if physiological and morphological differences previously detected in river otters from oiled and nonoiled areas could be affected by mussel beds, and whether these differences would persist or subside with time. Differences in levels of blood haptoglobin and Interleukin-6 ir, which previously were elevated in river otters (Lutra canadensis) inhabiting oiled when compared to nonoiled areas of Prince William Sound, Alaska, were not observed in summer 1992. River otters from oiled areas continued to regain body size from levels noted in 1990; adjusted mean body mass of otters from oiled and nonoiled areas were nearly identical by summer 1992. Consequently, no adverse effects in 1992 could be attributed to oiled mussel beds from areas where river otters were captured. Likewise, oiled mussel beds may not have been a factor contributing to documented differences in these variables in 1990 and 1991. Sponsored by Alaska Dept. of Fish and Game, Soldotna.

Feder, H. (1996). Injury to Deep Benthos. Subtidal Study Number 2B (Airater Study Number 2). EXXON VALDEZ Oil Spill State/Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks. Inst. of Marine Science.: 125p.

This study was designed to assess the possible injury by petroleum, derived from the Exxon Valdez oil spill to benthic infaunal resources within Prince William Sound in water deeper than 20 m. Analyses of benthic biological data collected from 14 bays in Prince William Sound in 1990 at 40, 100 and > 100 m, by univariate and multivariate techniques, demonstrated no obvious disturbance effects on the benthic biota 16 months after the oil spill. In all multivariate analyses, the major environmental variables related to the composition of benthic assemblages were sediment parameters such as percent silt, clay, mud, percent water and amount of nitrogen and carbon in sediment. Although limited amounts of petroleum hydrocarbons and presence of hydrocarbon degrading bacteria were detected at some sites at 40 and 100 m in 1989 and 1990, minor or no impact was sustained by benthic fauna of the deep benthos within the Sound. Sponsored by Alaska Dept. of Fish and Game, Anchorage. Habitat and Restoration Div.

Feder, H. and A. Blanchard (1998). "The deep benthos of Prince William Sound, Alaska, 16 months after the Exxon Valdez oil spill." Marine Pollution Bulletin **36**(2): 118-130.

In 1990, 16 months after the T Exxon Valdez oil spill (EVOS) in Prince William Sound, Alaska, an assessment of the benthic macrofauna and associated environmental parameters at 40 and 100 m was made. Assessment of the biota and environmental data demonstrated patterns in deep benthic assemblages reflective of oceanographic conditions, as indicated by sediment differences, rather than EVOS toxicity. Comparison of polynuclear aromatic hydrocarbons

(PAH) and $\delta^{13}C$ values in sediments between stations within the oil trajectory and reference stations outside of the trajectory showed no significant differences. This investigation uncovered no signals of disturbance 16 months after the EVOS. These results agree with conclusions of studies of intertidal and shallow subtidal regions following the EVOS that demonstrated disturbance effects decreasing with depth.

Feder, H., A. Naidu, et al. (1990). "Trace element and biotic changes following a simulated oil spill on a mudflat in Port Valdez, Alaska (USA)." Marine Pollution Bulletin **21**(3): 131-137.

A mudflat in Port Valdez, Alaska, was examined to determine effects of experimental additions of Prudhoe Bay crude oil on metal chemistry and harpacticoid copepod abundance. Hydrocarbon concentrations were at background levels 30 days after final addition of oil. The short residence time of oil added to sediments is attributable to physical removal of oil by tides, low sediment permeability, and low affinity of hydrocarbons for periglacial clay surfaces. Elemental concentrations, except Si, were lower in oiled than in unoiled sediments. Elemental depletion in oil-impacted sediments is attributable to mobilization of metals from oxide/hydroxide sediment phases or to desorption from clay due to lowering of Eh-pH of sediments subsequent to oil addition. In oiled sediments, abundance of the harpacticoid copepods Harpacticus uniremis. Halectinosoma gothiceps, and Heterolaophonte sp. was similar to or higher than values within unoiled plots. The resons for lack of deleterious effects of oil on copepods in Port Valdez are not yet understood.

Field, L. J. (1999). Developing a sampling strategy for assessing potential contamination of subsistence seafood resources following the Exxon Valdez oil spill. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 115-134.

The primary goal of the subsistence sampling program was to provide subsistence users with information to assist them in making informed decisions about the consumption of subsistence resources. Subsistence users wanted to know whether subsistence resources were safe to eat and made it clear that they would not be satisfied with assurances from public health officials that were based on sensory evaluations. They wanted samples of subsistence resources collected and tested for oil contamination using current analytical chemical procedures and instrumentation to determine whether subsistence resources were contaminated with oil following the spill. More specifically, were concentrations of ACs (considered to be the components of crude oil most likely to cause long-term health effects) elevated in subsistence resources? If subsistence resources were found to be contaminated, other questions became important: Are the concentrations high enough to represent a significant health concern? Are concentrations declining? Is the Exxon spill the source of the contamination? The subsistence sampling program was designed to provide

information to subsistence collectors that could be used to supplement their own observations. The way the program plan was developed and how it evolved over the duration of the study (inlcuding the basis for sample location selection, target species selection, sampling frequencey, and collection and analysis methods) are presented.

Field, L. J., J. A. Fall, et al., Eds. (1999). Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. SETAC Technical Publication Series. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC).

Field, R., M. North, et al. (1993). "Nesting activity of yellow-billed loons on the Colville River delta, Alaska, after the Exxon Valdez oil spill." Wilson Bulletin **105**(2): 325-332.

During the summer after the Exxon Valdex oil spill in Prince William Sound in March 1989, we surveyed Yellow-biled Loons (Gavia adamsii) on lakes in the Colville River delta in northern Alaska (USA). A study in 1983-1984 documenting nesting activity in the same area provided a baseline for comparisons of possible effects of the spill on nesting activity. Density of adult loons in 1989 was similar to densities in 1983-1984. We located 26 pairs of yellow-billed Loons in 29 nesting territories. However, only 42% of the loon pairs nested in 1989, compared to 76% nesting pairs in 1983 and 79% in 1984.

Fleeger, J., T. Shirley, et al. (1996). Meiofaunal recolonization experiment with oiled sediments. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 271-285.

To gain insight into long-term studies of the effects of the Exxon Valdez oil spill on the meiobenthos, a colonization experiment was initiated in 1990. Unweathered Exxon Valdez crude oil was mixed with azoic sediment to prepare low (26 plus or minus 3 mu g/g total aromatics) and high (210 plus or minus 12 mu g/g total aromatics) treatments of oiled sediments. The resulting mixtures, and azoic sediment without oil as a control, were added to triplicate colonization trays and buried flush with the surface of two beaches near mean low water in Herring Bay, Prince William Sound, Alaska. Hydrocarbon concentrations tended to decline with time. Trays and ambient sediments were sampled by coring and harpacticoid copepod species enumerated on days 0, 1, 2, and 28. Harpacticoids (more than 40 species) were mostly phytal associates from surrounding eelgrass beds. Colonization was rapid (approaching ambient levels in 1-2 d), especially in control and low-oil treatments. High-oil treatments exhibited significantly reduced densities of total harpacticoids and of two rapidly colonizing species (*Halectinosoma* sp. and *Mesochra pygmaea*) especially on days 1 and 2. Two slower colonizers (*Paralaophonte perplexa* and *Amphiascus minutus*) were unaffected by oil additions. Detrended correspondence analysis identified oil effects on the harpacticoid assemblage among the treatment-date collections. Ambient samples from all dates segregated from experimentals and were tightly clustered. Day 1 and 2 low- and high-oil

treatments clustered together as did control, low-, and high-oil sediments from day 28. Control day 1 and 2 collections were intermediate. Thus, results suggest that an oil effect on migration and colonization was detectable, but for fewer than 28 d.

Flint, P., M. Petersen, et al. (1997). "Exposure of spectacled eiders and other diving ducks to lead in western Alaska." Canadian Journal of Zoology **75**(3): 439-443.

Lead poisoning, resulting from ingestion of spent shot, has been identified as a cause of mortality in Spectacled Eiders (Somateria fischeri) on the Yukon-Kuskokwim Delta, Alaska. We examined lead-exposure rates of adult and juvenile Spectacled Eiders and other diving ducks, using atomic absorption spectrophotometry of blood samples. Additionally, we X-rayed birds in the field to identify ingested shot. We detected shot in the gizzards of 11.6% of Spectacled Eiders X-rayed. During the period from arrival through incubation, 13.0% of adult females and 6.6% of adult males had elevated blood lead levels when captured. During the brood-rearing period, 35.8% of adult females and 12.2% of ducklings were exposed to lead when captured. There was an increase in the probability of exposure of adult females with date sampled. We predict that 50% of the successfully breeding hens were likely exposed to lead, and 25-37% of the Spectacled Eider breeding population was exposed to lead. The long-term effects of sublethal doses on Spectacled Eiders are unknown; however, exposure of nesting females and young birds to lead may result in reduced over-winter survival and (or) reduced fecundity.

Ford, R., M. Bonnell, et al. (1996). Total direct mortality of seabirds from the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 684-711.

An estimate of total mortality of seabirds from the Exxon Valdez oil spill was derived from numbers of carcasses collected on shore. The processes leading to carcass collection were modeled to account for sinking of oiled birds at sea, removal from the beach by scavengers, and incomplete search effort. To determine rates of loss of oiled birds at sea, radio-tagged carcasses were tracked by aircraft and boat. Eight groups totaling 184 carcasses were tracked in spring and summer 1990; four groups were released in Prince William Sound and four in the Gulf of Alaska off Kodiak Island. Values of median persistence time for groups released in Prince William Sound ranged from 15 to 20 d, whereas those of releases in the Gulf of Alaska ranged from 7 to 18 d. Assuming that birds drifted passively with the oil, the rate function for loss of birds at sea was applied to probable point-of-oiling and time to landfall at a particular beach. Concentrations of birds subject to oiling were located with survey data gathered in the Outer Continental Shelf Environmental Assessment Program and by the U.S. Fish and Wildlife Service. Point of oiling and path of drift to each beach were determined with the National Oceanic and Atmospheric Administration (NOAA) HAZMAT oil trajectory model and NOAA overflights. Scavenging rates were estimated from field studies in Prince William Sound and on the outer coast of the Olympic Peninsula, Washington, in which oiled carcasses were monitored daily. In each study, it was found that about 50%

of carcasses were removed by scavengers within 2 d and most of the remainder were taken within 5 d. To model beach search effort and its relation to scavenging rate, it was assumed that (1) carcasses were deposited with equal frequency on any nonreflective substrate, (2) that all carcasses on nonreflective but unsearched beaches were missed, and (3) that a fraction of those on searched beaches were lost as a result of scavenging. Estimates of proportion of carcasses lost because of scavenging were made considering the interval between deposition of oiled birds and initial search and the interval between successive searches of a given beach. Based on best estimates of model parameters, 375,000 birds were directly killed by the Exxon Valdez oil spill. Uncertainty in model parameters was examined by randomly selecting from the probability distribution of possible values. Among 1,250 model runs, the 5% lower bound and 95% upper bound were 300,000 and 645,000 birds, respectively. Uncertainty in parameters tended to skew model results toward higher estimates of total mortality.

Freese, J. and C. O'Clair (1996). Injury to Crabs Outside Prince William Sound. Fish Shellfish Study Number 22. EXXON VALDEZ Oil Spill State/Federal Natural Resources Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Auke Bay, AK. Auke Bay Lab.: 22p.

Commercial Dungeness crab fisheries exist near Kodiak Island and the eastern Alaska Peninsula. Both areas lie within the trajectory of the 1989 Exxon Valdez oil spill. Thirty nine sites in the region were sampled in 1989 and 1990 to assess petroleum hydrocarbon contamination of crab tissues and benthic sediments with which crabs were associated. Female crabs were found in small numbers at 15 sites. Eight of these sites exhibited low levels of petroleum hydrocarbons in the sediments. Only two of the eight sites showed oil contamination that could be linked convincingly to the Exxon Valdez oil spill. None of the crab tissue samples showed evidence of contamination by petroleum hydrocarbons.

Frost, K., B. Ballachey, et al. (1993). Effects of the Exxon Valdez Oil Spill on Marine Mammals in Prince William Sound. Exxon Valdez Oil Spill Symposium, Anchorage, AK.

Findings of the major studies of the effects of spilled oil on different marine mammals in Prince William Sound are presented.

Frost, K. and L. Lowry (1996). Assessment of Injury to Harbor Seals in Prince William Sound, Alaska and Adjacent Areas Following the EXXON VALDEZ Oil Spill. Marine Mammal Study Number 5. (Restoration Study Number 73). EXXON VALDEZ Oil Spill, State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Fairbanks. Wildlife Conservation Div.: 173p.

In the weeks following the Exxon Valdez oil spill (EVOS) harbor seals, Phocavitulina richardsi, swam through oil and inhaled aromatic hydrocarbons as they breathed at the air/water interface. Concentrations of fluorescent aromatic compounds in bile clearly indicated that most seals from oiled areas had been exposed to hydrocarbons. Before the EVOS, harbor seals in Prince William

Sound were declining at an average annual rate of 12% in both oiled and unoiled areas. Aerial surveys in 1989 indicated a 43% decline at oiled sites versus an 11% decline at unoiled sites. By 1992, there were still 34% fewer seals at oiled sites than before the spill. Supersedes PB95-966007.

Frost, K., L. Lowry, et al. (1999). "Monitoring the trend of harbor seals in Prince William Sound, Alaska, after the Exxon Valdez oil spill." Marine Mammal Science **15**(2): 494-506.

We used aerial counts to monitor the trend in numbers of harbor seals, Phoca vitulina richardsi, in Prince William Sound, Alaska, following the 1989 Exxon Valdez oil spill. Repetitive counts were made at 25 haul-out sites during the annual molt period each year from 1990 through 1997. A generalized linear model indicated that time of day, date, and time relative to low tide significantly affected seal counts. When Poisson regression was used to adjust counts to a standardized set of survey conditions, results showed a highly significant decline of 4.6% per year. Unadjusted counts indicated a slight, but not statistically significant, decline in the number of seals. The number of harbor seals on the trend-count route in eastern and central PWS has been declining since at least 1984, with an overall population reduction of 63% through 1997. Programs to monitor long-term changes in animal population sizes should account for factors that can cause short-term variations in indices of abundance. The inclusion of such factors as covariates in models can improve the accuracy of monitoring programs.

Frost, K., L. Lowry, et al. (1994). Impacts on distribution, abundance, and productivity of harbor seals. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 97-118.

EVOS response and cleanup activities resulted in and intensive activity in what is normally relatively undisturbed harbor seal habitat. Pre- and post-spill count data for oiled and unoiled sites in PWS enabled us to estimate directly the number of seals missing in these areas following the EVOS. Calculations indicated that 135 seals were missing at the seven oiled sites that were surveyed, and that a minimum of 302 seals were missing in PWS as a whole. We conclude that it is likely that these missing seals died as a result of the EVOS. There is no eveidence that seals were displaced from oiled sites by the spill and associated activities. Other components of the harbor seal damage assessment study showed that seals became coated with oil, oil was incorporated into some of their tissues, they behaved abnormally, and there was pathological damage in their brains. Our calculations of mortality are likely and underestimate of the total impact of the EVOS on harbor seals since only seals counted on haulout sites were included in the mortatilty estimate and the calculations do not include seals in the Gulf of Alaska, which were also impacted by the EVOS.

Available data indicate that pup production and survival were also affected by the EVOS. In oiled areas pups were found both before and during the normal pupping period. Aerial counts indicated that 26% fewer pups were produced at oiled sites in 1989 than would have been expected without the spill.

The trend in harbor seals in PWS since the EVOS is unclear, with molting counts indicating relative stability but pupping counts showing a steady decline. Nonetheless, harbor seal numbers in PWS and adjacent parts of the Gulf of

Alaska are greatedly reduced compared to historical levles. Other factors must also have contributed to the overall decline in this region. The harbor seal population is not likely to recover until limiting factors are identified and mitigated.

This study has demonstrated the importance of historical data in evaluatong the effects of human-caused perturbations, such as oil spills, on the enviornment. Wihtout historical data on distribution and abundance it would not have been possible to measure the impacts of the EVOS on harbor seals. We strongly recommend that population monitoring studies for key sepcies be implemented or continued whin areas where significant industrial activities are likely to occur, so that if an accident happens it will be possible to compare the changes that result with historical patterns.

Frost, K., L. Lowry, et al. (1998). Monitoring, habitat use, and trophic interactions of harbor seals in Prince William Sound, Alaska: Restoration Project 97064 Annual Report. Fairbanks, AK, USA, Alaska Department of Fish and Game: 149 pp.

Frost, K., C.-A. Manen, et al. (1994). Petroleum hydrocarbons in tissues of harbor seals from Prince William Sound and the Gulf of Alaska. Marine Mammals and the Exxon Valdez. T. R. Loughlin. San Diego, California, USA
London, England, UK, Academic Press, Inc.: 331-358.

As a consequence of the EVOS, harbor seals in PWS and in parts of the Gulf of Alaska (GOA) were exposed to petroleum-related hydrocarbons. Harbor seal tissue samples collected for chemical analyses following the spill and presently archived at the National Marine Mammal Laboratory in Seattle form the most extensive collection of tissues and data from phocid seals exposed to crude oil that is currently available. Over 1300 samples representing 15 tissues from 44 seals are archived and constitute an unparalleled resource for the study of marine contaminants in this species.

Some tissues from seals found dead or collected in oiled areas of PWS in 1989 contained elevated concentrations of petroleum-related hydrocarbons (i.e., phytane in brain samples and PAH in blubber samples) when compared to tissues from seals collected in the GOA of our of the path of the spilled oil. Concentrations of AC metabolites in the bile of oiled seals collected in oiled areas of PWS in 1989 were significantly higher than concentrations in the bile of seals collected in the GOA and near Ketchikan. One year after the EVOS, none of the tissues from seals collected in the spill area showed significantly elevated concentrations of petroleum-related hydrocarbons. However, average concentrations of AC metabolites in bile were still significantly higher than those observed for seals frm the GOA or unoiled PWS areas. These data support the hypothesis that harbor seals in PWS were exposed to high concentrations of petroleum-related hydrocarbons in the spring and summer of 1989. The level of this exposure in PWS declined in 1990 but was still greater than exposure in the GOA or outside of the spill path.

The implications of the results of hydrocarbon analyses for the health of the seals are unknown. Levels of hydrocarbons in seal tissues were very low. However, since seals metabolize hydrocarbons very efficiently, the levels remaining in some tissues when they were sampled underestimate the actual degree of exposure. Essentially, no information is available on the likely effects of the hydrocarbons on seals for anything other than short-term experimental exposure. It is important to note that chemical analyses did not measure the most volatile and acutely toxic C5-C8 hydrocarbons, which have been documented to cause mortality in other rmammals and which were most likely the cause of the nerve damage that we observed in oiled seals.

The poor correlation between different indicators of exposure to and metabolism of petroleum hydrocarbons, particularly in seals collected several months or more after the spill, complicates interpretation of the data from the EVOS. Although the prevalence of each of the indicators was greater in the oiled group than the other seals, no one indicator adequately indicated exposure in all seals. While this was not unexpected because of the different exposure histories of each seal, it makes it very difficult to recommend a simple sampling proticol or a single parameter to use as a measure of exposure in the event of a future spill. Based on the data form this study, we recommend that a suite of indicators be measured, including fluorescent AC metabolites in bile, PAHs in blubber (and milk when available), and phytane in brain. Because of the very efficient metabolism of hydrocarbons by seals, it is probably not very informative to analyze tissues other than blubber and milk for PAHs. It is essential that chemical analyses be accomanied by careful necropsy and histopathology of affected seals, with particular emphasis on the brain.

Fukuyama, A. and W. Driskell (1995). Changes in intertidal infaunal assemblages following the Exxon Valdez oil spill 1989-1994 . Twenty-third Benthic Ecology Meeting, New Brunswick, NJ (USA), 17-19 Mar 1995.

Lower intertidal infauna were sampled with cores following the Exxon Valdez oil spill in Prince William Sound, Alaska. Comparisons were made between reference unoiled sites, oiled and treated with hot-water high-pressure wash sites, and oiled and untreated sites from 1989 to 1994. Total abundance, species richness, species diversity, and abundances of most major taxa (polychaetes, crustaceans, gastropods, and bivalves) were significantly lower at the oiled and treated beaches than at unoiled beaches. At oiled untreated sites, infauna recovered quickly following oiling and abundances of all major taxa are now similar to or exceed abundances at unoiled sites.

Gage, T. (1998). Effects of invertebrate predators on clam populations in Prince William Sound, Alaska, with implications for the recovery of sea otters from the Exxon Valdez oil spill. Seattle, WA, University of Washington.

Thesis

Galt, J., W. Lehr, et al. (1991). "Fate and transport of the Exxon Valdez oil spill: Part 4

of a five-part series." Environ Sci Technol **25**(2): 202-209.

The floating oil distribution can be summarized as follows. Heavy amounts of floating oil were present in southwest Prince William Sound for about two weeks. Some shorelines were heavily oiled during this time. Significantly reduced amounts (by an order of magnitude) were present for another two weeks. After this time, light sheens--often caused by leaching from oiled beaches--were observed, but represented minor amounts of pollutant. An estimated 35% of the oil evaporated or dispersed into the water column in the Sound. An additional 40% affected the shoreline inside Prince William Sound. Perhaps 25% of the original spill left the Sound as floating oil. Only about 10% of the oil made it beyond Gore Point, and 2% actually got as far as Shelikof Strait.

Galt, J. and D. Payton (1990). Movement of oil spilled from the T/V Exxon Valdez. Symposium to Evaluate the Response Effort on Behalf of Sea Otters after the T/V Exxon Valdez Oil Spill into Prince William Sound, Anchorage, Alaska, USA, April 17-19,1990.

GAO (1993). Natural resources restoration: Use of Exxon Valdez oil spill settlement funds. GAO, Washington, DC (USA), Government Accounting Office, Washington, DC (USA): 34.

Under the civil settlement stemming from the 1989 grounding of the supertanker Exxon Valdez - the largest oil spill in U.S. history - Exxon agreed to pay a total of $900 million in 11 annual payments. Under the criminal settlement, Exxon was fined $150 million and required to pay $50 million each to the federal government and the state of Alaska to help restore areas damaged by the spill. This briefing report provides information on the amount and distribution of money that Exxon has paid through December 1992 under the settlements. GAO also discusses issues surrounding the functioning of the Trustee Council, which was created to coordinate damage assessments and to seek funds from responsible parties to clean up natural resources. GAO concludes that Alaska and federal trustees managing the oil spill settlement funds will have to address several issues before there can be confidence that the money is being spent for natural resources restoration and other intended purposes.

GAO (1993). Oil spill prevention: Progress made in developing Alaska demonstration projects. GAO, Washington, DC (USA), Government Accounting Office, Washington, DC (USA): 33.

In the wake of the 1989 Exxon Valdez oil spill, Congress established demonstration programs to spur local citizen oversight of oil and tanker operations in Prince William Sound and Cook Inlet. A citizen advisory council funded by the oil industry was set up at each location to monitor the environmental impact of crude oil transport. In GAO's view, the demonstration programs produced many positive changes, significantly boosting citizen participation in environmental oversight. The programs have yet to evolve, however, into the effective citizen-industry-government partnership that

Congress initially envisioned. Early disagreements, along with continuing dissension and mistrust, have slowed the development of the partnerships and have limited further improvements to environmental oversight and safety. In addition, participation by a key federal agency - the Environmental Protection Agency - is still lacking in one of the councils. Recent steps taken to improve the partnership are encouraging and should improve relations among the councils, industry, and government. It is premature, however, to conclude that communication and trust will improve to the point that the long-term success of the programs is ensured. If the programs are successful, they could serve as useful models for further program expansion. Periodic reports to Congress on the model programs' status, however, are not required.

Garnett, R. and D. Ellis (1995). "Tailings disposal at a marine placer mining operation by WestGold, Alaska." Marine Georesources & Geotechnology **13**(1-2): 41-57.

From 1985 to 1990 WestGold managed a marine placer mining operation with substantial documentation concerning its submarine tailings disposal (STD) system. For 5 years the operation involved the use of a floating bucket-ladder dredge with an integrated, gravity-based treatment plant to extract free particulate gold from the seabed gravels. Three-quarters of the throughput was disposed of at 1.5 m below sea level through two pipes, each of 0.51-m diameter. The system's design resulted from considerable trial and error and modeling studies to achieve regulated seawater conditions. The information is publicly available as a result of a very open permitting and operating process. The mining permit specified waste discharge controls and environmental impact limits for topics of local concern: the dredge's effluents, the red king crab population (an important fishery resource), seawater turbidity, and bioaccumulation of trace metals, especially mercury (a remnant of prior beach mining).

Garrott, R., L. Eberhardt, et al. (1993). "Mortality of sea otters in Prince William Sound following the Exxon Valdez oil spill." Marine Mammal Science **9**(4): 343-359.

This paper presents an estimate of the total number of sea otters that died as a direct consequence of the oil spill that occurred when the T Exxon Valdez grounded in Prince William Sound, Alaska on 24 March 1989. We compared sea otter counts conducted from small boats throughout the Sound during the summers of 1984 and 1985 to counts made after the spill during the summer of 1989. We used ratio estimators, corrected for sighting probability, to calculate otter densities and population estimates for portions of the Sound affected by the oil spill. We estimated the otter population in the portion of Prince William Sound affected by the oil was 6,546 at the time of the spill and that the post-spill population in the summer of 1989 was 3,898, yielding a loss estimate of approximately 2,650. Bootstrapping techniques were used to approximate confidence limits on the loss estimate of about 500-5,000 otters. The wide confidence limits are a result of the complex scheme required to estimate losses and limitations of the data. Despite the uncertainty of the loss estimate it is clear that a significant fraction of the otters in the spill zone survived. We observed

otters persisting in relatively clean embayments throughout the oil spill zone suggesting that the highly convoluted coastline of Prince William Sound produced refuges that allowed some sea otters in the oil spill area to survive.

Garshelis, D. (1997). "Sea otter mortality estimated from carcasses collected after the Exxon Valdez oil spill." Conservation Biology **11**(4): 905-916.

Large numbers of sea otters (Enhydra lutris) died following the 1989 Exxon Valdez oil spill. Two previous studies estimated spill-related mortality, one from the difference between counts of otters before and after the spill, and the other from the recovery rate of tagged carcasses that had been released at sea. I used a derivative of the second approach, but revised it to account for (1) moribund otters that had hauled out on shore; (2) carcasses that were collected at sea; and (3) differences in search effort in different areas of the spill-considerations that were not addressed previously. The mortality estimation procedure presented here, and applied to Prince William Sound, Alaska, had six input parameters, two with fixed values (the number of spill-related carcasses collected (391) and the number of otters taken alive that died in captivity (84)) and four that were assigned a range of values (the recovery rate for carcasses on the beach (60-90%), the proportion of recovered carcasses that were onshore (70-95%)), the proportion of offshore deaths recovered onshore (20-50%), and the proportion of moribund otters that hauled out (20-60%). Empirical estimates for these parameters were not available after the spill, but a range of plausible values for each was delimited using other available data. Randomly-selected combinations of values within these ranges produced mortality estimates for the sound (x = 750, 5-95% quantiles = 600-1000) that were lower than indicated by previous studies. These lower estimates do not diminish the tragic nature of the mortality, but instead highlight the significance of both the process and informational basis in producing estimates of catastrophic loss. Estimates of loss based on faulty or inadequate data may mislead investigations of population recovery and may jeopardize public trust in scientific assessments of future catastrophes.

Geiger, H., B. Bue, et al. (1996). A life history approach to estimating damage to Prince William Sound pink salmon caused by the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 487-498.

The 1989 *Exxon Valdez* oil spill resulted in contamination of the habitat of juvenile pink salmon *Oncorhynchus gorbuscha,* including approximately 31% of the spawning streams and much of the nearshore marine rearing habitat in the southwest portion of Prince William Sound. In this study we combined the results of other studies to evaluate the loss of returning wild adult pink salmon attributable to the *Exxon Valdez* oil spill. We estimated that approximately 1.9 million wild adult pink salmon fafled to return to Prince William Sound in *1990,* primarily because of a lack of growth in the critical nearshore life stage when they entered seawater in spring *1989* during the height of the spill. This number of fish was approximately *28%* of the potential wild-stock production from the

southwestern part of the sound returning in *1990.* We estimated that 60,000 wild adult pink salmon failed to return in *1991* and 70,000 in *1992* because of direct poisoning of salmon in the embryo stage. In both *1991* and *1992* this was 6% or less of the potential wild-stock production in the southwestern part of the sound and less than *2%* of the potential wild production in the entire sound.

Geiselman, J., H. Armstrong, et al. (1990). Mercury in the Marine Environment. Mercury in the Marine Environment: Workshop Proceedings, Held in Anchorage, Alaska on November 29-December 1,1988.

The U.S. Department of the Interior, Minerals Management Service (MMS) proposes to lease portions of the Outer Continental Shelf(OCS) lands in Norton Sound, Alaska for the mining of mineral resources. The Draft Environmental Impact Statement identified mercury in the marine environment as a central issue. From 29 November to 1 December 1989, the MMS Alaska OCS Region Office sponsored a workshop entitled 'Mercury in the Marine Environment.' The purpose of the workshop was to review current knowledge on mercury levels in seawater, sediments, and organisms and to discuss the findings in relation to water quality criteria and health concerns. The workshop was conducted to provide the Alaska OCS Region staff with additional information pertinent to the review and preparation of the Final EIS on the proposed OCS Mining Program, Norton Sound Lease Sale for gold dredging. The report includes the talks presented by the experts, the discussion periods after each talk, general discussions, and summary presentations to the Coordination Team on the last day of the workshop. Sponsored by Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.

Gibeaut, J. and E. Piper (1999). Shoreline Oiling Assessment of the EXXON VALDEZ Oil Spill,1993. EXXON VALDEZ Oil Spill Restoration Project 93038 Final Report. Govt Reports Announcements & Index (GRA&I), Texas Univ. at Austin. Bureau of Economic Geology.: 72p.

During the summer of 1993, the Alaska Department of Environmental Conservation surveyed 59 shoreline sites in Prince William Sound, Alaska that were oiled by the March 1989 Exxon Valdez oil spill. The data describe the oil's visual properties and extent. Comparisons of commonly measured locations through the years provide estimates of oil reduction. From 1991 to 1993, the amount of asphalt, surface oil residue, and surface mousse decreased by about one-half. By 1991, and still in 1993, most of the surface oil resided between mid- to upper intertidal large boulders and in bedrock fractures along the low-, moderate, and even high-energy shorelines. Asphalt was also present on the upper intertidal surfaces of sheltered pebble and cobble beaches and bedrock. Recalcitrant subsurface oil was typically below clean surface sediments along boulder-dominated limbs of pocket beaches and in bedrock- and boulder-shelter areas along otherwise high-energy shorelines. In some areas, sediment surface armor has prevented natural or unnatural physical removal. Subsurface oil also remained in some very-low wave energy settings. See also PB98-126501. Sponsored by Alaska Dept. of Environmental Conservation, Juneau. Office of

Restoration and Damage Assessment.

Gibeaut, J., E. Piper, et al. (1998). Kodiak Shoreline Oiling Assessment of the EXXON VALDEZ Oil Spill,1995. Restoration Project Final Report. Restoration Project 95027. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Environmental Conservation, Juneau. Office of Restoration and Damage Assessment.: 26p.

A shoreline survey team visited 24 sites in the Kodiak archipelago that had shoreline oiling in 1990 and 1991 to determine the persistence of that oiling through the summer of 1995. The survey team concentrated on Shuyak and northwest Afognak Island, selected areas between Sturgeon Head and Chief Cove (Spiridon Bay) on the Shelikof Straight coast of Kodiak Island, and seven sites of community concern near the village of Larson Bay inside Uyak Bay. Surveyors found no oil at sites south of Chief Cove, trace amounts at Chief Cove, and only widely spaced trace amounts at the sites on Shuyak Island. The area of shoreline affected with any amount of oil decreased by 75% within specific locations that were surveyed in 1990 or 1991 and resurveyed in 1995. Shoreline oil in Kodiak is not persisting as in PWS largely due to the lack of recalcitrant subsurface oil. Kodiak shorelines were initially affected by oil that had been floating for at least seven days. Other important reasons for the lack of shoreline oil in the Kodiak region include the patchy distribution of initial oiling and the overall high-wave energy settings of shorelines in the spill's path.

Giger, M. (1994). Baseline Data for Metals in Sediments and Water of Braided Creek and Landlocked Creek/Bluff Creek, Alaska Peninsula National Wildlife Refuge. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services: 37 pp + appendix.

Giger, M. and K. A. Trust (1997). Tissue Concentrations of Elemental and Organochlorine Compounds in Sea Otters from Two Aleutian Islands in Alaska. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services: 11 pp.

Gilfillan, E., D. Page, et al. (1995). Shoreline ecology program for Prince William Sound Alaska following the Exxon Valdez oil spill: Part 3. Biology. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

This study describes the biological results of a comprehensive shoreline ecology program designed to assess ecological recovery in Prince William Sound following the Exxon Valdez oil spill on March 24, 1989. The program is an application of the "Sediment Quality Triad" approach, combining chemical, toxicological, and biological measurements. The study was designed so that results could be extrapolated to the entire spill zone in Prince William Sound. The spill affected four major shoreline habitat types in Prince William Sound: pebble/gravel, boulder/cobble, sheltered bedrock, and exposed bedrock. The study design had two components: (1) one-time stratified random sampling at 64 sites representing four habitats and four oiling levels (including

unoiled reference sites) and (2) periodic sampling at 12 nonrandomly chosen sites that included some of the most heavily oiled locations in the sound. Biological communities on rock surfaces and in intertidal and shallow subtidal sediments were analyzed for differences resulting from to oiling in each of 16 habitat/tide zone combinations. Statistical methods included univariate analyses of individual species abundances and community parameter variables (total abundance, species richness, and Shannon diversity), and multivariate correspondence analysis of community structure. The communities of animals and plants inhabiting the bedrock and coarse sediments on Prince William Sound's shorelines responded much differently to oiling than communities in soft-sediment environments that were the subject of a majority of shoreline studies conducted after other oil spills.

Gilfillan, E., T. Suchanek, et al. (1995). Shoreline impacts in the Gulf of Alaska region following the Exxon Valdez oil spill. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

Forty-eight sites in the Gulf of Alaska region (GOA-Kodiak Island, Kenai Peninsula, and Alaska Peninsula) were sampled in July/August 1989 to assess the impact of the March 24, 1989, Exxon Valdez oil spill on shoreline chemistry and biological communities hundreds of miles from the spill origin. In a 1990 companion study, 5 of the Kenai sites and 13 of the Kodiak and Alaska Peninsula sites were sampled 16 months after the spill. Oiling levels at each site were estimated visually and/or quantified by chemical analysis. The chemical analyses were performed on sediment and/or rock wipe samples collected with the biological samples. Additional sediment samples were collected for laboratory amphipod toxicity tests. Mussels were also collected and analyzed for hydrocarbon content to assess hydrocarbon bioavailability. Biological investigations at these GOA sites focused on intertidal infauna, epifauna, and macroalgae by means of a variety of common ecological techniques. For rocky sites the percentage of hard substratum covered by biota was quantified. At each site, up to 5 biological samples (scrapes of rock surfaces or sediment cores) were collected intertidally along each of 3 transects, spanning tide levels from the high intertidal to mean-lowest-low-water (zero tidal datum). Organisms (down to 1.0 mm in size) from these samples were sorted and identified. Community parameters including organism abundance, species richness, and Shannon diversity were calculated for each sample. As expected for shores so far from the spill origin, oiling levels were substantially lower, and beached oil was more highly weathered than in Prince William Sound (PWS). Samples of oiled GOA shoreline sediment were not statistically more toxic in bioassay tests than sediment from unoiled reference sites. As a consequence of the lower oil impact, the biological communities were not as affected as those in the sound. Biological impacts, although present in 1989 in the GOA, were localized, which is consistent with the patchy and discontinuous nature of much of the oiling in GOA. Some organisms were locally reduced or eliminated in oiled patches but survived in unoiled patches nearby. In areas where oiling occurred, impacts were generally limited to middle and upper intertidal zones. Analyses of mussel samples indicate that by 1990 little of the shoreline oil remained bioavailable to epifauna. Quantifiable measures of the overall health and vitality of shoreline biological communities, such as organism abundance, species richness,

and Shannon diversity for sediment infauna, show few significant differences between oiled and reference sites in 1990.

Groff, J., J. Blake, et al. (1990). Necropsy observations in Alaskan sea otters Enhydra lutris from Prince William Sound affected by the Exxon Valdez oil spill. 21st Annual IAAAM Conference, Vancouver, B.C.

Grumbles, B. and J. Manley (1995). "The Oil Pollution Act of 1990: Legislation in the wake of a crisis ." Nat. Resour. Environ. **10** (2): 35-42.

The pattern is nothing new. Congress, like any other institution, needs nudging--sometimes gentle, sometimes jolting--before it responds. An environmental crisis prompts a congressional reaction, sometimes an overreaction. The discovery of contamination at Love Canal prompted enactment of Superfund; the disaster at Bhopal, India, led to the Emergency Planning and Community Right to Know Act; and the collision of the Exxon Valdez brought about the enactment of the Oil Pollution Act of 1990. For better or for worse, the pattern of environmental crisis and legislative response remains. March 24, 1989, marked the beginning of a new age in federal and state oil spill law. After the Exxon Valdex ran aground on Bligh reef and spewed 11 million gallons of crude oil into Prince William Sound, Alaska congressional debate on comprehensive federal legislation would never be the same. The stalemate that characterized previous congressional efforts seemed to disappear overnight.

Gundlach, E., E. Pavia, et al. (1991). Shoreline surveys at the Exxon Valdez oil spill: the state of Alaska response. Proceedings of the 1991 International Oil Spill Conference: Prevention, Behavior, Control, Cleanup, Washington, D.C.

Haebler, R., R. Harris, et al. (1990). Pathological examination and collection of toxicological samples from sea otters. Symposium to Evaluate the Response Effort on Behalf of Sea Otters after the T/V Exxon Valdez Oil Spill into Prince William Sound,, Anchorage, Alaska, USA, April 17-19,1990, U S Fish and Wildlife Service.

Haines, J., S. McCutcheon, et al. (1990). Importance of hydraulic behavior of subsurface water in affecting biodegradation of crude oil on oiled beaches in Prince William Sound. 90th Annual Meeting of the American Society for Microbiology 1990, Anaheim, California, USA, May 13-17,1990.

Hann, R. J. (1992). The Alaska Coastal Communities Cooperative: The concept and feasibility. Proceedings of the Fifteenth Arctic and Marine Oil Spill Program Technical Seminar. Edmonton, AB (Canada), 10-12 Jun 1992: 281-291.

In late 1991 the Prince William Sound Regional Citizens' Advisory Council commissioned a feasibility study for a community-based oil spill cooperative and

an associated spill school. A draft report was completed for the RCAC in January of 1992 and the final report has just been submitted. This paper describes the concept of the Alaska Coastal Communities Cooperative as presented in these two documents.

Hansen, D. J. (1992). Potential effects of oil spills on marine mammals that occur in Alaskan waters. Anchorage, AK, U.S. Department of the Interior, Minerals Manangement Service, Alaska OCS Region: 25 pp.

Contact with an oil spill can result in direct effects on marine mammals in Alaskan waters, causing mortality of some marine mammals and having no apparent effect on others. If extensive oil-spill contanct occurs, lethal effects on sea otters, polar bears, northern fur seals, and young ice-seal pups are expected from loss of thermal insulation, ingestion, and/or inhalation of toxic hydrocarbons, and from increased physiological stress associated with oiling and hydrocarbon intoxication. Other marine mammal species my suffer less serious or sublethal effects such as eye and skin irritation that might contribute to the death of highly stressed animals. Population-level effects on sea otters and Northern fur seals in Alaskan waters could occur if a large spill contacted large concentrations of these species.

Indirect effects of oil spills on marine mammals through changes in the availability of food organisms from contamination of habitats are difficult ot differentiate from natural changes in the environment and may be inconsequential in comparison to natural variability within the ecosystem. To date, no long-term oil-spill effects on marine mammals from bioaccumulation of hydrocarbons have been demonstrated. Marine mammals probably have adapted to the low levels of naturally ocuureing hydrocarbon components present in crude oil that can accumulate somewhat in the food web.

Harris, P., S. Rice, et al. (1996). Within-bed distribution of Exxon Valdez crude oil in Prince William Sound Blue mussels and underlying sediments. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 298-308.

The distribution of Exxon Valdez crude oil in sediments and its relationship to oiling in blue mussels *Mytilus trossulus* was examined in six Prince William Sound mussel beds in 1992. Distribution of oil in sediments within each bed was patchy and was related to several factors, including sample location on the beach, sample depth, and sediment grain size. Concentrations of total petroleum hydrocarbons as high as 30,000-40,000 mu g/g wet weight were found within a few meters of concentrations two orders of magnitude less. The distribution of total polynuclear aromatic hydrocarbons (TPAH) in mussels overlying the sediments was also patchy. Concentration levels in mussels roughly followed concentrations in underlying sediments, but correlation at specific sampling points was low. Generally, TPAH in mussels averaged 1% or less of the TPAH in shallow sediments from the same area of the bed. Similar proportions of individual

analytes relative to TPAH in mussels, shallow sediments, and Exxon Valdez crude oil indicate that the latter was the source of contamination in sediment and mussels, that the oil in the sediments has only moderately weathered, and that oil taken in by mussels was particulate. Mussels depurate petroleum hydrocarbons rapidly if not chronically exposed; the contaminated sediments were the continuous source of Exxon Valdez crude oil in mussel tissues. The pattern of oil distribution in mussels and in sediments within a mussel bed implies that it was dispersed from sediments into surrounding water and was taken up by nearby mussels. The chronic recontamination of mussels by Exxon Valdez crude oil in the sediments underlying them and the uneven distribution of this oil throughout mussel beds have important implications for studies monitoring concentrations and effects of oil remaining in mussel beds and for any mussel-bed restoration.

Hartung, R. (1995). Assessment of the potential for long-term toxicological effects of the Exxon Valdez oil spill on birds and mammals. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

This paper assesses the potential for direct long-term toxicological effects of exposures to oils in birds and mammals by tracing exposures and effects from the initial acute phases through the sub-chronic to the eventual long-term exposures. The immediate effects of oil spills are physical, the oil acting on the plumage of birds or the fur of mammals. This causes a loss of entrained air and a concomitant reduction in buoyancy and thermal insulation. Animals that escape the immediate impacts may be isolated from their food supply and often ingest large amounts of oil while attempting to clean themselves. At the comparatively high dose levels involved, these exposures can result in toxicologically significant responses in many organ systems. In the course of an oil pollution incident, the amounts of biologically available oils decrease steadily, and simultaneously the composition of the oils shifts towards those components that have low volatility, and that resist photo- and bio-degradation. As this occurs, the primary pathways of exposure change from direct intakes to indirect routes involving the food supply. Although laboratory studies often report finding some adverse effects, the dose rates employed in many of these studies are extremely high when compared with those that are potentially available to animals in the wild, and very few actually use weathered oils. An assessment of the toxicological literature and of the available empirical data on the Exxon Valdez oil spill leads to the conclusion that long-term sub-lethal toxic effects of crude oils on wildlife in such marine spills appear to be very unlikely.

Harvey, J. and M. Dahlheim (1994). Cetaceans in oil. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 257-264.

Daily vessel surveys of PWS were conducted from 1 to 9 April 1989 to determine the relative abundance and behavior of cetaceans in response to the EVOS. Two observers scanned the forward quarter of a vessel and recorded species,

number, location, time, behavior, and presence or absence of oil for each marine mammal sighting. Observations were also obtained from other researchers working in the area. During nine surveys (72.8 hours), 80 Dall's porpoise, 18 killer whales, and 2 harbor porpoise wer observed. Swimming speed of the Dall's porpoise was independent of the amount of oil present. We observed oil only on one individual, a Dall's porpoise. This individual had oil on the dorsal half of its body and appeared stressed because of its labored breathing pattern. In no case did cetaceans alter their behaviors when in areas with oil. These observations are consistent with other reports of cetaceans behaving normally in the presence of oil.

Harvey, S., I. Elashvili, et al. (1990). "Enhanced removal of Exxon Valdez spilled oil from Alaskan gravel by a microbial surfactant." Biotechnology (N Y) **8**(3): 228-30.

Remediation efforts for the oil spill from the Exxon Valdez tanker in Alaska have focused on the use of pressurized water at high temperature to remove oil from the beaches. We have tested a biological surfactant from Pseudomonas aeruginosa for its ability to remove oil from contaminated Alaskan gravel samples under various conditions, including concentration of the surfactant, time of contact, temperature of the wash, and presence or absence of xanthan gum. The results demonstrate the ability of the microbial surfactant to release oil to a significantly greater extent (2 to 3 times) than water alone, particularly at temperatures of 30 degrees C and above.

Hatch, S., P. Meyers, et al. (1997). Seasonal Movements and Pelagic Habitat Use of Murres and Puffins Determined by Satellite Telemetry. Restoration Project 95021. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), National Biological Service, Anchorage, AK. Alaska Science Center.: 105p.

In July 1995, implantable satellite transmitters were deployed in 10 common nurres and 5 tufted puffins at the Barren Islands, Gulf of Alaska. In a related study, 20 transmitters were deployed in common and thick-billed murres (Uria Lomvia) at two colonies in the Chukchi Sea.

Hayes, D. (1996). Recovery Monitoring of Pigeon Guillemot Populations in Prince William Sound, Alaska. Restoration Project 94173. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK.: 83p.

The population of pigeon guillemots in Prince William Sound decreased from about 15,000 (1970's) to about 5,000 (present). Some local populations were affected by the U Exxon Valdez oil spill in 1989, but there is evidence suggesting the Sound-wide population was already declining. Predation was the cause of numerous nesting failures. Abandonment of eggs was also high. Changes in the relative proportions of benthic and schooling fish in the diet of guillemot chicks might represent a key change in the ecosystem that is affecting other species of marine birds and mammals in the Sound.

Hayes, D. and K. Kuletz (1996). Decline of pigeon guillemot populations in Prince William Sound, Alaska, and apparent changes in distribution and abundance of their prey. Int. Symp. on the Role of Forage Fishes in Marine Ecosystems, Anchorage, Alaska (USA), 13-16 Nov 1996.

Pigeon guillemots (Cepphus columba) are cavity-nesting, pursuit-diving seabirds that forage in the nearshore environment on both demersal and schooling fishes. The population of pigeon guillemots in Prince William Sound (PWS) decreased from approximately 15,000 in the early 1970s to less than 5,000 in the 1990s. The populations at Naked Island6 nd four neighboring islands in PWS have shown a similar trend since the late 1970s. During this same period, the diet of pigeon guillemot chicks on Naked Island also changed. We believe there is a link between the change in diet and the population decline. We studied the chick-feeding patterns and reproductive success of pigeon guillemots at Naked Island over 8 years. In the years 1979-1981 Pacific sand lance (Ammodytes hexapterus) made up the single largest component (mean = 42.1%, SD = 17.3%) of chick diet, while in the 5 years 1989-1990 and 1994-1996, sand lance accounted for a much smaller fraction (mean = 12.9%, SD = 3.2%;). Demersal fishes such as gunnels (Pholidae), pricklebacks (Stichaeidae), and sculpins (Cottidae) have always been an important component of chick diet, and their relative contribution has increased since 1989. The proportions of Gadidae and schooling fishes such as Pacific herring (Clupea pallasi) and capelin (Mallotus villosus) have varied widely from year to year, but gadids were not a major component of chick diet until 1989.

Hayes, M. and J. Michel (1999). "Factors determining the long-term persistence of Exxon Valdez oil in gravel beaches." Marine Pollution Bulletin **38**(2): 92-101.

The largest amounts of, and the least weathered, oil found eight years after the Exxon Valdez oil spill occurred at depths of 25-50+ cm under the protective cover of a well-sorted cobble/boulder armor on intermittently exposed, coarse-grained gravel beaches within Prince William Sound, Alaska. In addition to the armoring, other factors enhancing the retention of the oil include flat slopes of the middle beach and a thick sediment veneer over a bedrock platform. Natural cleaning of the subsurface distribution which lasted for up to six years.

Hecker, M., L. Duffy, et al. (1997). Preliminary studies on river otter fur as an indictator of pollution in Alaska. Arctic Science and Resource Management: Exploring the Issues; 48th American Association for the Advancement of Science: Arctic Division Science Conference, Valdez, Alaska, USA, September 24-27,1997, Alaska Sea Grant College Program, University of Alaska Fairbanks; Fairbanks, Alaska, USA.

Hecker, M., L. Duffy, et al. (1997). River otters as a sentinel species: effect and detection of crude oil on the fur of river otters. Effects of Oil on Wildlife: Proceedings of the Fifth International Conference on Oil Spills.

Heintz, R., S. Rice, et al. (1996). Field and laboratory evidence for reduced fitness in pink salmon that incubate in oiled gravel. Proceedings of Contaminant Effects on Fish Symposium, International Congress on the Biology of Fishes, San Francisco State University.

Heintz, R., J. Short, et al. (1999). "Sensitivity of fish embryos to weathered crude oil: Part II. Incubating downstream from weathered Exxon Valdez crude oil caused increased mortality of pink salmon (Oncorhynchus gorbuscha) embryos." Environmental Toxicology and Chemistry **18**(3): 494-503.

We incubated pink salmon embryos under three exposure conditions, direct contact with oil-coated gravel, effluent from oil-coated gravel, and direct contact with gravel coated with very weathered oil (VWO). Embryo mortalities and polynuclear aromatic hydrocarbon (PAH) accumulation in embryo tissues during the direct-contact and effluent exposure experiments were not significantly different, indicating that PAH accumulation was mediated by aqueous transport. Mortality rates for embryos exposed initially to a total PAH concentration (TPAH) of 1.0 ppb were significantly higher than controls when the PAH were derived from VWO. The same aqueous TPAH concentration failed to increase mortality rates when the PAH were derived from less weathered oil, indicating that toxicity of effluents from the VWO was primarily associated with the larger PAH. We conclude that water quality standards for TPAH above 1.0 ppb may fail to protect fish embryos. Further, pink salmon embryos incubating in Prince William Sound after the Exxon Valdez oil spill may have accumulated lethal concentrations of PAH from interstitial water that was contaminated when it percolated through oil reservoirs located upstream from salmon redds.

Heintz, R., A. C. Wertheimer, et al. (1998). Long term effects of incubating in oiled gravel reduce average fitness in exposed pink salm (Oncorynchus gorbuscha) populations. 1998 SETAC Conference (Society of Environmental Toxicology and Chemistry), Chralotte, NC.

Long term effects on average fitness may be an overlooked consequence to pink salmon populations exposed to crude oil during embryonic development. We examined this hypothesis by incubating pink salmin in gravel contaminated with crude oil and measuring mortality (1) during embryonic development; (2) from emergent fry (juvenile) to adult return. Integrating the mortality estimates provided a model describint the effect of embryonic exposure on the average fitness in the exposes population. Evaluation of this method for two separate broods indicated a pink salmon population exposed to 15 ppb of polynuclear aromatic hydrocarbons in water will produce 40% fewer reproducing adults than an unexposed population. This reduction resulted from significantly elevated mortality throughout the life history of the fish. We also observed delayed sublethal effectcs, such as reduced growth of juvenile fish, and impaired homing fidelity and smaller size of mature adults exposed during embryonic development. Reduced size of females at maturity suggests further reductions in average fitness because fecundity of pink salmon id sirectly related to size. The results reported here are from a simulation of the exposure mechanism poited

for pink salmon in Prince William Sound after the Exxon Valdez oil spill. We incubated embryos up to 191 days downstream from weathered oil sources whose concentrations decreased logarithmically throughout the exposure period. The effective concentration in our simulation is 100 times lower than that reported in studies based on short-term bioassays involving acute exposures to unweathered oil. Because long-term effects are not detected by short-term bioassays, we conclude that short-term bioassays underestimate the risk imposed on these organisms.

Heintz, R., M. Wiedmer, et al. (1996). Laboratory evidence for short and long-term damage to pink salmon incubating in oiled gravel. Proceedings of the 17th Northeast Pacific Pink and Chum Salmon Workshop, Bellingham, WA, March 1-3, 1995.

Hendrick, M. and J. Jadamec (1991). Evaluating the relative performance of ASTM methods in the laboratory and the field . Monitoring Water in the 1990's: Meeting New Challenges. J. Hall and G. Glysson. Denver, CO (USA), 11-14 Jun 1990, American Society for Testing and Materials, Philadelphia, PA (USA): 567-577.

In order to establish legal responsibility for an oil spill and recover clean-up costs, the U.S. Coast Guard Oil Identification Laboratory compares spilled and suspected source oil samples using a multi-method approach based primarily on ASTM standards. This paper describes a computerized evaluation of whether improvements in technology and subsequent method development have improved the relative performance of the analytical methods. Artificial intelligence software capable of analyzing data bases containing qualitative as well as quantitative information was employed. Results of this on-going laboratory study indicate that the revised Gas Chromatography method performs better, relative to the Fluorescence, Infrared, High Performance Liquid Chromatographic and Thin Layer Chromatographic methods. A field study was conducted during the deployment of the Coast Guard Research and Development Center's Mobile Lab to Alaska where it was used to assist in assessing the environmental impact of the spilled EXXON VALDEZ oil.

Henny, C. J., D. D. Rudis, et al. (1995). "Contaminants and sea ducks in Alaska and the circumpolar region." Environmental Health Perspectives **103 Suppl 4**: 41-9.

We review nesting sea duck population declines in Alaska during recent decades and explore the possibility that contaminants may be implicated. Aerial surveys of the surf scoter (Melanitta perspicillata), white-winged scoter (M. fusca), black scoter (M. nigra), oldsqaw (Clangula hyemalis), spectacled eider (Somateria fischeri), and Steller's eider (Polysticta stellei) show long-term breeding population declines, especially the latter three species. The spectacled eider was recently classified threatened under the Endangered Species Act. In addition, three other diving ducks, which commonly winter in coastal areas, have declined from unknown causes. Large die-offs of all three species of scoters during molt, a period of high energy demand, were documented in August 1990, 1991, and 1992 at coastal reefs in southeastern Alaska. There was no evidence of

infectious diseases in those scoters. The die-offs may or may not be associated with the long-term declines. Many scoters had elevated renal concentrations of cadmium (high of 375 micrograms/g dry weight [dw]). Effects of cadmium in sea ducks are not well understood. Selenium concentrations in livers of nesting white-winged scoters were high; however, the eggs they laid contained less selenium than expected based on relationships for freshwater bird species. Histological evaluation found a high prevalence of hepatocellular vacuolation (49%), a degenerative change frequently associated with sublethal toxic insult. Cadmium and selenium mean liver concentrations were generally higher in those birds with more severe vacuolation; however, relationships were not statistically significant. We do not know if sea duck population declines are related to metals or other contaminants.

Hepler, K., P. Hansen, et al. (1996). Impact of oil spilled from the Exxon Valdez on survival and growth of Dolly Varden and cutthroat trout in Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 645-658.

When crude oil spilled from the grounded tanker Exxon Valdez into Prince William Sound, Alaska, in late March 1989, anadromous Dolly Varden *Salvelinus malma* and cutthroat trout *Oncorhynchus clarki* were residing in lakes. Five populations of each species were intercepted with five weirs in 1989, 1990, and 1991 during their annual seaward emigration in the spring. Two populations emigrated into the wake of the spill, while three emigrated into waters free of spilled crude oil. Because anadromous Dolly Varden and cutthroat trout feed during the summer near the shores of Prince William Sound, fish emigrating into the path of the spill spent their summers near stranded oil and possibly ingested contaminated food. Of the 11,995 Dolly Varden and cutthroat trout marked at weirs in 1989 and the 41,550 marked in 1990, 24% and 18% were recaptured in 1990 and 1991. Almost all (97%) recaptured emigrants were recaptured at the same weirs in 1990 and 1991 at which they were released 1 year earlier. However, on average an estimated 39% of survivors of both species evaded recapture in 1990 at fish-tight weirs that year. In populations associated with spilled oil, growth from 1989-1990 was 24% and 22% slower for recaptured subadult and adult Dolly Varden, respectively, and 36%-43% slower for subadult and adult cutthroat trout, respectively. These differences persisted through 1991 for cutthroat trout, but not for Dolly Varden; growth was slower during 1990-1991 for recaptured Dolly Varden in populations not associated with oil. Estimates of mean length by age-group for emigrating cutthroat trout in 1989 indicated that their growth had been uniform across Prince William Sound before the spill. Although averages of estimated survival rates from 1989 to 1990 are less in study populations associated with spilled oil (32% and 22% less for subadult and adult Dolly Varden, respectively, and 28% less for adult cutthroat trout), none of the differences are statistically significant. Chronic starvation and direct exposure to petrogenic hydrocarbons are hypothesized as the pathways by which spilled crude oil could have slowed the growth of Dolly Varden and cutthroat trout.

Hepler, K., P. Hansen, et al. (1996). Impact of Oil Spilled from the EXXON VALDEZ on

Survival and Growth of Dolly Varden and Cutthroat Trout in Prince William Sound, Alaska. Fishhellfish Study Number 5 (Restoration Study Number 90). EXXON VALDEZ Oil Spill State/Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Anchorage. Div. of Sport Fish.: 30p.

Five emigrating populations of Dolly Varden and cutthroat trout were intercepted in 1989-1991 during seaward migration to Prince William Sound following the Exxon Valdez oil spill; two into the spill area, three into non-spill areas. Study populations were comprised of tagged adults and subadults. Survival rates were estimated with log-linear models of capture histories of tagged fish. We used a two-stage simulation based on bootstrapping and Monte Carlo techniques to compare average survival rates in study populations that were and were not associated with spilled oil. Growth and survival rates were significantly lower in study populations associated with spilled oil. Results are consistent with the occurrence of a deleterious impact on growth and survival of emigrating species, although unable to be confirmed as results emanated from observation, not experiment.

Hetrick, J., P. Schwalenberg, et al. (1997). "Nanwalek, Port Graham and Tatitlek subsistence clam restoration." Journal of Shellfish Research **16**(1): 264-265.

Clams were once a major subsistence resource in the Native communities of Nanwalek and Port Graham in lower Cook Inlet and Tatitlek in Prince William Sound. Local clam populations have been decreasing in recent years and their contribution to the subsistence harvest has been greatly reduced. There are probably several reasons for this including changes in current and beach patterns, increasingly heavy sea otter predation and the Exxon Valdez oil spill. The oil spill impacted the wild clam populations and their importance as a subsistence food in two ways. First, some clam beds suffered from direct oiling. Second, even though many clams were not directly impacted by the oil, they have a tendency to accumulate, concentrate, and store the toxic contaminants from non-lethal amounts of oil. This has badly eroded the confidence of the villagers in the helpfulness of the remaining wild clam populations as a subsistence food. This project will attempt to restore local shellfish populations for subsistence use. (DBO)

Highsmith, R., T. Rucker, et al. (1996). Impact of the Exxon Valdez oil spill on intertidal biota. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 212-237.

The Coastal Habitat Injury Assessment (CHIA) study was initiated to assess injury to biological resources in intertidal habitats affected by the Exxon Valdez oil spill. Intertidal communities were subjected to the most intense impacts of the spill and of subsequent cleanup operations. An understanding of the effects of the oil spill and cleanup on the intertidal zone is critical in determining the extent of injury and the recovery potential of the affected areas. The CHIA study encompassed the three major geographic areas affected by the spill: Prince William Sound, Cook Inlet-Kenai Peninsula, and Kodiak-

Alaska Peninsula. Randomly selected oiled sites from various habitats were matched with non-oiled, reference sites. All epibenthic organisms and infauna were sampled and quantified. The results indicate that injury occurred to a wide range of taxa and community types. This article only reports the effects on the dominant taxa in the intertidal zone. The affected dominant taxa were the brown alga Fucus gardneri, the limpet Tectura persona, the barnacles Chthamalus dalli, Semibalanus balanoides, and Balanus glandula, the mussel Mytilus trossulus, two species oflittorines-Sitka periwinkle Littorina sitkana and checkered periwinkle L. scutulata-and oligochaetes. Although abundances and biomasses of C. dalli and oligochaetes were enhanced after the spill, other major taxa were negatively affected by the spill either as a direct result of exposure or treatment or indirectly because of loss of habitat or food. Observed differences between oiled and reference populations varied across regions, habitats, and tidal heights. Differences for several taxa were still apparent as of our last observation in 1991, implying incomplete recovery.

Highsmith, R., M. Stekoll, et al. (1999). Comprehensive Assessment of Coastal Habitat: Coastal Habitat Study Number 1A. EXXON VALDEZ Oil Spill, State Federal Natural Resource Damage Assessment Final Report. Volume 1. Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks. School of Fisheries and Ocean Sciences. Western EcoSystems Technology, Inc., Cheyenne, WY.: 782p.

The Coastal Habitat Injury Assessment Study was initiated to assess injury to intertidal habitats impacted by the Exxon Valdez oil spill. The study, conducted from 1989-1991, encompassed three major geographic areas impacted by the spill: Prince William Sound, Cook Inlet-Kenai Peninsula and Kodiak-Alaska Peninsula. Oiled sites were selected randomly and matched with non-oiled sites and classified into sheltered rocky, coarse textured or estuarine habitat. Statistically significant differences between oiled and non-oiled sites were interpreted as impact due to the spill and/or clean-up activities. Most observed differences varied across regions, habitats and tidal heights. Although intertidal communities showed widespread impact from oiling/clean-up activities for algal, invertebrate and fish components, data revealed that most habitats were recovering but had not fully recovered by 1991. See also PB96-194824. Prepared in cooperation with Western EcoSystems Technology, Inc., Cheyenne, WY.

Highsmith, R., M. Stekoll, et al. (1996). Herring Bay Experimental and Monitoring Studies. Restoration Study Number 102. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks. School of Fisheries and Ocean Sciences. Juneau Center for Fisheries and Ocean Sciences, AK.
Western EcoSystems Technology, Inc., Cheyenne, WY.
Coastal Resources Associates, Vista, CA.: 217p.

Intertidal studies were established in 1990 in Herring Bay, Prince William Sound in response to the T Exxon Valdez oil spill and have continued through the 1992 field season. Examination of the dominant intertidal alga, Fucus gardneri, has

shown that larger plants were removed from the intertidal in areas affected by the spill/clean-up. Where Fucus cover was reduced, an increase in the abundance of ephemeral alage often occurred. Populations of intertidal grazing invertebrates, such as limpets and periwinkles showed reduced densities at oiled sites. Initially, barnacle recruitment was lower in quadrats on tar-covered rocks, compared to scraped quadrats, but differences disappeared at most sites over time. However, Fucus germlings and filamentous algae contineud to have lower densities and percent cover on oiled than non-oiled substrates. Recovery is taking place in lower and middle intertidal zones and normal community interactions are returning. Prepared in cooperation with Juneau Center for Fisheries and Ocean Sciences, AK., Western EcoSystems Technology, Inc., Cheyenne, WY. and Coastal Resources Associates, Vista, CA. Sponsored by Alaska Dept. of Fish and Game, Anchorage.

Hilborn, R. (1996). Detecting Population Impacts from Oil Spills: A Comparison of Methodologies. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 639–644.

Five alternative methods for determining oil spill impacts at the population level are compared: (1) counts of dead animals, (2) pre- and postspill comparison of abundance, (3) oiled versus non-oiled comparison of abundance, (4) oiled versus non-oiled comparison of vital rates, and (5) direct experimental oiling. Counts of dead animals do not provide evidence of population-level impact. Pre- and postspill comparisons of abundance have very low statistical power and require substantial baseline data. Oiled versus non-oiled comparisons suffer from lack of randomization of oiling treatments. Experimental oiling must be shown to be comparable to the actual infield oil exposure. A strong case for oil impacts will usually require several of these types of data. It is suggested that traditional hypothesis tests are inappropriate for determination of oil spill impacts and that explicit calculation of the likelihood of different levels of impact is more appropriate.

Hill, K. and P. Tuomi (1990). Field test for detecting crude oil on the fur of sea otters. Symposium to Evaluate the Response Effort on Behalf of Sea Otters after the T/V Exxon Valdez oil spill into Prince William Sound, Anchorage, Alaska, USA, April 17-19,1990, U S Fish and Wildlife Service.

Hillman, S. (1994). "Prince William Sound, Alaska SERVS implementing the new age of spill prevention and response." Environ Toxicol Chem **1**(3): 401-410.

Alyeska Pipeline Service Company, Ship Escort Response Vessel Service (SERVS) is the primary response action contractor for Trans Alaska Pipeline System (TAPS) laden tankers within Prince William Sound. During the last five years, SERVS has implemented a world class spill prevention and response organization in this area. This paper provides an overview of the world class nature of the SERVS prevention and response organization. A review of the

supporting activities, equipment, planning, training and drill activities will be provided. The report will also address the response planning for nearshore spill response; fishing vessel support and area response center development; dispersant use strategies; in-situ burning techniques; waste management; coastal resource and sensitive environment inventory; and, wildlife protection and rehabilitation. All of these areas have been the subject of contingency planning and response updates as well as close coordination with ship operators, agencies and the public through citizen advisory groups.

Holloway, M. (1999). "Oil on water." Scientific American **280**(3): 38.

Studies arising from the Exxon Valdez oil spill suggest that fish are more sensitive to hydrocarbons than previously thought.

Ten years ago this month the Exxon Valdez tanker crashed into Bligh Reef, releasing at least 11 million gallons or so of crude oil into Prince William Sound in Alaska. The spill had enormous implications not only for the environment and people of the surrounding area but for public perceptions of oil pollution and for the federal law governing oil spills as well. The spill also created a massive experiment.

Despite many scientific conflicts, ongoing studies have led to some important insights. Researchers now have a better understanding of the impact of cleanup and of how an ecosystem recovers. They also have a clearer picture of how hydrocarbons--the building blocks of oil--affect certain species. Of these latter studies, work on pink salmon has recently produced some surprising results that, if they hold up, could have widespread implications for water-quality standards.

As a commercially critical fish, pink salmon received much attention after the spill. For years, biologists have documented the size and health of salmon populations returning to oiled and unoiled sites in the sound and have conducted laboratory experiments to decipher the precise dangers of hydrocarbons. Such studies are proving to be eye-opening. "Now we believe that oil pollution has much longer effects at much lower concentrations and with different compounds than we had thought," says Ronald A. Heintz, a biologist at the Nationa Marine Fisheries Service's Auke Bay Laboratory in Juneau.

Oil is composed of thousands of compounds, including polynuclear aromatic hydrocarbons, or PAHs. PAHs are not regulated in the aggregate nor for their impact on aquatic life. The Environmental Protection Agency issues water-quality recommendations only for human consumption of specific PAHs--such as naphthalene and chrysene--although states can devise their own regulations.

What Heintz and his team did was to expose pink salmon eggs and embryos to different amounts of total PAHs. In previously published papers, the researchers reported that postspill concentrations of PAHs--from a high of 51.5 parts per billion to a low of 4.4 ppb--can, variously, kill the fish, impair their ability to reproduce and lower their growth rates. "Exposing an embryo to oil is like taking a shotgun to its DNA," Heintz describes. It has lots of different effects, he adds, and "over the whole life cycle, those little effects really add up."

Now Heintz and his colleagues have determined that PAH levels as low as 1 ppb harm both pink salmon and Pacific herring. In their most recent studies, which appear in this month's Environmental Toxicology and Chemistry, the

scientists found that mortality increased for both species of fish exposed to 1 ppb. And they discovered that the effects of very weathered oil were the same as those of fresh oil--which means that the old oil persisting under gravel in some parts of Prince William Sound could still be harmful.

The fact that 1 ppb is damaging to two species suggests that intertidal organisms everywhere may be affected by the chronic pollution brought about by small spills or leaks. "You'd be hard-pressed to find any coastal area where you wouldn't get total PAH concentrations of that magnitude," asserts Judith E. McDowell of the Woods Hole Oceanographic Institution in Massachusetts.

If more researchers determine that PAHs at 1 ppb are damaging fish and other organisms, new regulations may be needed to ensure water quality-- which could affect oil exploration offshore and ballast-water discharges. Even Alaska, which has the strictest criteria in the world at 15 ppb, might have to rethink its standards, observes Jeffrey W. Short, a chemist at the Auke Bay Laboratory. But it could prove virtually impossible to regulate the many nonpoint sources of PAHs, such as storm-water runoff and people's sloppiness with their motor oil. "The consciousness has got to change with the public and the way that we set standards," says Usha Varanasi of the Northwest Fisheries Science Center in Seattle. "It is not always a company."

For now, as Heintz and both his supporters and critics point out, much more work is needed. "You need replication by an outside group," notes Paul D. Boehm, a petroleum expert at the consulting firm Arthur D. Little who has worked in the sound for Exxon. In addition, other species need to be studied to see if the observations extend beyond salmon and herring--although there is some evidence to support the Auke Bay findings. For instance, a 1991 study from Prince William Sound found that growth rates of capelin were affected at PAH concentrations of 4 ppb. And researchers in Puget Sound are finding similar effects in juvenile salmon, Varanasi remarks.

But in general, low-level PAH analyses remain uncharted terrain. Many intertidal regions are polluted, and discerning the specific effects of PAHs against a background of other contaminants is difficult. Heintz notes that his findings came to light because Prince William Sound had been a pristine area. "The Exxon Valdez is the stimulus that motivated a new way of looking at it for us," he says. "It has radically changed the way we think about oil pollution."

Holmes, K. (1990). "The Exxon Valdez spill: One year later. ." National Fisherman **71** (3): 14-16, 36.

An examination is made of the current situation in Alaskan waters 1 year following the Exxon Valdez oil spill. Beaches still show signs of oil and many problems exist regarding clean-up efforts and their effects on the environment and wildlife.

Hom, T., D. W. Brown, et al. (1999). Measuring the Exposure of Subsistence Fish and Marine Mammal Species to Aromatic Compounds Following the Exxon Valdez Oil Spill. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S.

Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 169-194.

Fish and mammals rapidly metabolize policyclic aromatic hydrocarbons (PAHs, primary components of petroleum) and excrete the metabolites in their bile. To assess recent exposure of fish and marine mammals to spilled oil, bile was collected and analyzed for metabolites of PAHs. The presence of metabolites of PAHs in bile showed that fish had been exposed to petroleum, however analyses of corresponding edible tissue from the fish showed that negligble concentrations of oil related PAH compounds had bioaccumulated. In general, the concentration of PAHs metabolites in bile of salmon collected in 1990 were lower than for those collected in 1989.

With few exceptions, the concentrations of PAHs in tissues of marine mammals (as in fish) were relatively low whereas the concentrations of metabolites in bile of harbor seals and sea lions collected in 1989 showed evidence of exposure to petroleum hydrocarbons.

Hom, T., U. Varanasi, et al. (1996). Assessment of the exposure of subsistence fish to aromatic compounds after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 856-866.

Previous research has shown that fish have the capacity to biotransform many aromatic compounds (ACs) to polar metabolites that are readily accumulated in the gall bladder for excretion and to greatly limit the deposition of ACs or their metabolites in edible muscle tissue. Accordingly, a rapid and sensitive method, developed in our laboratory for screening bile for fluorescent aromatic compounds (FACs) that are components of petroleum, was used to assess exposure of fish to Acs after the *Exxon Valdez* oil spill. The results of analysis of bile from nearly 500 fish provided evidence that many fish were exposed to ACs after the oil spill. Edible flesh samples from fishes showing a range of biliary FACs were analyzed for the presence of ACs by gas chromatography-mass spectrometry. Concentrations of FACs in bile of bottomfishes and salmon from areas affected by oil ranged from 10 to 17,000 ng phenanthrene equivalents/mg bile protein; however, no appreciable concentrations of ACs were detected in muscle of bottomfishes (<1 ng/g wet weight, parts per billion [ppb]), and, although concentrations of ACs in muscle of salmon were somewhat higher (most samples ranged from 0 to 20 ppb), they rarely exceeded 100 ppb. These findings were used by the Alaskan Oil Spill Health Task Force in arriving at an advisory opinion that consumption of the flesh of fish from areas affected by the oil spill posed minimal risk to native Alaskans. Furthermore, these results were used to verify findings of earlier laboratory studies on the pathways of metabolism and disposition of ACs in fish that were important in formulating a focused, scientific basis for the present investigation of oil-impacted subsistence fisheries.

Hooten, A. and R. Highsmith (1996). Impacts on selected intertidal invertebrates in Herring Bay, Prince William Sound, after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright.

Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 249-270.

Population densities of several species of invertebrates were determined at seven pairs of matched oiled and control sites in Herring Bay, Knight Island, Prince William Sound, from 1990 to 1993. Significantly lower population densities were observed for two limpet species and the Sitka periwinkle *Littorina sitkana* in the middle and upper intertidal zones of oiled sites, especially during 1990 and 1991. The predatory snails *Nucella* spp. and the six-armed seastar *Leptasterias hexactis* were either not present or were found in very low densities, and no differences were observed between site pairs. Recovery of invertebrate density had occurred by the end of 1993 at oiled sites in the lower and middle intertidal zones but remained incomplete in the upper intertidal zone for the limpet, *Tectura persona* at sheltered rocky and coarse-textured sites and for the Sitka periwinkle at sheltered rocky sites.

Hose, J. (1994). "Large-scale genotoxicity assessments in the marine environment." Environmental Health Perspectives **102**(Suppl 12): 29-32.

There are a number of techniques for detecting genotoxicity in the marine environment, and many are applicable to large-scale field assessments. Certain tests can be used to evaluate responses in target organisms in situ while others utilize surrogate organisms exposed to field samples in short-term laboratory bioassays. Genotoxicity endpoints appear distinct from traditional toxicity endpoints, but some have chemical or ecotoxicologic correlates. One versatile end point, the frequency of anaphase aberrations, has been used in several large marine assessments to evaluate genotoxicity in the New York Bight, in sediment from San Francisco Bay, and following the Exxon Valdez oil spill.

Hose, J., E. Biggs, et al. (In press). "Genetic damage in larval herring following the Exxon Valdez oil spill." Canadian Journal of Fisheries and Aquatic Sciences.

Hose, J., M. McGurk, et al. (1996). "Sublethal effects of the Exxon Valdez oil spill on herring embryos and larvae: Morphological, cytogenetic, and histopathological assessments, 1989-1991." Canadian Journal of Fisheries and Aquatic Sciences **53**(10): 2355-2365.

Following the Exxon Valdez oil spill in Prince William Sound, Alaska, in March 1989, Pacific herring (Clupea pallasi) larvae were evaluated for sublethal damage. From 1989 to 1991, egg masses were collected from oiled and unoiled beaches and incubated to hatch. Newly hatched herring larvae were assessed for morphological (skeletal, craniofacial, and finfold) deformities, cytogenetic abnormalities (anaphase-telophase aberrations), and histopathological lesions. In 1989, herring larvae from both oiled areas (Rocky Bay on Montague Island and Naked Island) had significantly more morphological deformities and cytogenetic abnormalities than did larvae from the unoiled location (Fairmont Bay). The extent of morphological and cytogenetic damage was correlated with oil exposure in adjacent native bay mussels. Larvae had no oil-related

histopathological lesions. In 1990 and 1991, oil-related developmental and genetic effects were undetectable.

Hose, J. E. and E. D. Brown (1998). "Field applications of the piscine anaphase aberration test: lessons from the Exxon Valdez oil spill." Mutation Research **399**(2): 167-78.

Several large-scale genotoxicity assessments have been performed in coastal marine areas that have demonstrated either localized or widespread genetic effects resulting from human activity. One common assessment method is the anaphase aberration test, a measurement of abnormal chromosome division, using embryolarval fishes. It can be used to detect the presence of mutagens within a poorly characterized complex mixture or monitor specific genotoxins and is easily adapted for laboratory screening. One comprehensive marine genotoxicity assessment was conducted using Pacific herring (Clupea pallasi) following the Exxon Valdez oil spill (EVOS) in Prince William Sound (PWS), AK in late March 1989. In early May, genetic damage was detected at many sites within the oil trajectory and was correlated with concentrations of polycyclic aromatic hydrocarbons characteristic of Exxon Valdez oil (EVO) in intertidal mussels. Effects were related spatially and temporally to oil exposure. Anaphase aberration rates decreased throughout May and June 1989, and by 1991, genotoxicity was undetectable. The abundance of the 1989 herring year class in PWS is significantly reduced; this is the first reported example linking genotoxicity to subsequent population level effects. This review describes the methodology for the anaphase aberration test using fish eggs, its applications for large-scale assessments and supportive laboratory studies, and its limitations for prediction of higher level effects on populations.

Hostettler, F. and K. Kvenvolden (1994). "Geochemical transformation of crude oil spilled from the Exxon Valdez super tanker into Prince William Sound, Alaska." Organic Geochemistry **21**: 927-936.

Houghton, J., A. Fukuyama, et al. (1993). Evaluation of the Condition of Prince William Sound Littoral Biota Following the Exxon Valdez Oil Spill and Subsequent Shoreline Treatment. Volume 3. Appendices. NOAA Technical Memorandum NOAA-TM-NOS-ORCA-73-V3. Seattle, WA, National Ocean Service. Office of Ocean Resources Conservation and Assessment, Seattle, WA
Pentec Environmental, Inc., Edmonds, WA.
Ogden Environmental and Energy Services, Co., Inc., San Diego, CA.
Driskell (William B.), Seattle, WA.: 226p.

This report contains tables that provide an anlaysis of the effects of the Exxon Valdez oil spill cleanup efforts on aquatic life in various parts of Prince William Sound and the Gulf of Alaska. Technical memo. See also Volume 2, PB96-113295. Prepared in cooperation with Ogden Environmental and Energy Services, Co., Inc., San Diego, CA. and Driskell (William B.), Seattle, WA.

Houghton, J., D. Lees, et al. (1996). Recovery of Prince William Sound intertidal epibiota from Exxon Valdez oiling and shoreline treatments, 1989 through 1992. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 379-411.

Biological and chemical data from 4 years of quantitative monitoring have been analyzed for trends in recovery of biota inhabiting beaches in Prince William Sound from the effects of the 1989 Exxon Valdez oil spill and subsequent cleanup. Stratified random sampling was used from April 1989 through July 1992 to assess biota at sheltered rocky sites subjected to three degrees of disturbance (unoiled, oiled but not hot-water washed, and oiled plus hot-water washed) in 1989. Hot-water treatments used to remove crude oil from the beaches of the sound in 1989 have had severe short-term impacts on intertidal epibenthos. Some high-pressure hot-water treated rocky shores that were stripped of biota in 1989 showed little colonization by 1990. On other oiled rocky shores that were not high-pressure hot-water washed, the majority of the epibiotal community dominants, including rockweed, mussels, barnacles, limpets, drills, and littorines, survived. Several significant differences were noted between the epibiota on unoiled shores and on oiled shores that were not hot-water treated; an even greater number of significant differences in epibiota was noted between those oiled beaches that had not been treated and those that had been treated. In May 1991 epibiotal populations on oiled and untreated shores were still depressed below those on unoiled shores. By July 1991 most high-pressure hot-water washed rocky shores showed some recovery, having been colonized by opportunistic species with planktonic larvae; new growth from remnants of the original biota also contributed to recovery. No significant differences remained between unoiled stations and those that had been oiled and not treated; some significant differences remained between the biota of unoiled and hot-water washed shores. Effects of high-pressure hot-water treatments applied in 1989 remained visible in intertidal assemblages in some areas through 1992. By July 1992 recovery of most rocky shores hadprogressed considerably, and few differences remained between the unoiled and the high-pressure hot-water washed categories. Individual hot-water washed sites still showed altered community structure that is attributed to the treatment, however, and full recovery of intertidal epibiota is still several years away in these areas.

Irons, D. (1996). Size and productivity of black-legged kittiwake colonies in Prince William Sound before and after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 738-747.

Black-legged kittiwakes *Rissa tridactyla* are the most abundant colonial seabirds nesting in Prince William Sound, Alaska. Approximately 20,000 pairs nest at 27 colonies in the sound. I counted the number of breeding pairs and determined productivity at 24 colonies between 1984 and 1994. Areas adjacent to 10 of these colonies were oiled by the *Exxon Valdez* oil spill and the areas adjacent to 14 colonies were not oiled. Data from the non-oiled colonies and from prespill years were used to determine if the oil spill had negative effects on the birds from oiled colonies. The number of breeding pairs did not decline at colonies in the oiled area after the *Exxon Valdez* oil spill compared to prespill years.

Kittiwake productivity in 1989 in the oiled area was lower than expected, while productivity in the non-oiled area was the highest ever recorded. Low numbers of chicks in the oiled area appeared to be the result of low laying rate or low hatching success. Kittiwake productivity in the oiled area did not improve from 1989 to 1994 and productivity in the non-oiled area in Prince William Sound declined in postspill years. When compared to kittiwake colonies in other parts of the Gulf of Alaska, the dramatic difference in pre-and postspill productivity in Prince William Sound kittiwakes was unique. This indicates that factors regulating kittiwake productivity operated differently in Prince William Sound compared to other parts of the Gulf of Alaska.

Irvine, G., D. Mann, et al. (1999). "Multi-year persistence of oil mousse on high energy beaches distant from the Exxon Valdez spill origin." Marine Pollution Bulletin **38**(7): 572-584.

For at least 5 yr after the Exxon Valdez spill, relatively unweathered oil mousse has persisted on the exposed rocky shores of Shelikof Strait 500 km from Prince William Sound, Alaska. Previously it was thought that oil would be rapidly removed from such geomorphic settings by wave action. Oil mousse persists at sites in Katmai National Park and Preserve (NP&P) where it was stranded high in the intertidal zone under a lag of large boulders. These boulders armor the beach, preventing waves from disturbing the substrate and its included oil. Weathering of this stranded mousse has been slight - mousse sampled in 1989, 1992 and 1994 show negligible changes in polynuclear aromatic hydrocarbons compared to 11-day old Exxon Valdez crude. The preservation of this oil is due to its transport as mousse boli whose interiors largely escape weathering, followed by its sheltering in the interstices of boulder-armored beaches. The transport of mousse may allow for the long distance dispersal of less weathered, and hence still toxic oil. Our findings suggest that the low ecological sensitivity ratings previously applied to exposed, rocky shorelines need to be modified. The biological threat posed by oil stranded on the Katmai NP&P coast probably is slight because of its small amount and sequestered state. However, it still possesses the ability to be chemically toxic and could be released through disturbance of the armoring boulders by unusually high wave events.

Irvine, G., D. Mann, et al. (In press). "Geomorphic position, chemical degradation, and implication for biotic impacts of persistent stranded oil mousse on a high energy coastline distant from the Exxon Valdez spill origin." Marine Pollution Bulletin.

Iwata, H., S. Tanabe, et al. (1994). "Persistent organochlorine residues in sediments from the Chukchi Sea, Bering Sea and Gulf of Alaska." Marine Pollution Bulletin **28**(12): 746-753.

Three surface sediments and two sediment cores were collected from the Gulf of Alaska, Bering Sea and Chukchi Sea, and analysed for persistent organochlorines (OCs). The geographical distributions of OCs showed different patterns according to their physicochemical properties. The concentrations of HCHs and HCB revealed rather uniform distribution, suggesting their more

transportable nature in long-range atmospheric transport. On the other hand, DDTs and PCBs were predicted to be less transportable via the atmosphere due to the decreasing trends of residue levels in sediments from south to north. The OC profiles in the sediment core from the Gulf of Alaska which seemed to be preserved without turbation revealed the elevated residue levels from bottom to surface layers. This implies that the aerial inputs of OCs in the cold ocean are still continuing significantly. The accumulation rates of OCs into sediments were rather smaller than the atmospheric inputs, indicating that the residue levels in water bodies are unlikely to decrease rapidly in the near future.

Jason, N. (1989). Alaska Arctic Offshore Oil Spill Response Technology Workshop Proceedings. Alaska Arctic Offshore Oil Spill Response Technology Workshop, Anchorage, Alaska on November 29-December 1,1988.

The Proceedings of the Alaska Arctic Offshore Oil Spill Response Technology Workshop contains papers by keynote speakers on the following topics: Mechanical Containment and Recovery; Chemical Treatment; In-Situ Burning; Readiness; the Technology Assessment and Research Program and the OHMSETT Program; the Arctic and Marine Oil Spill Program; the Canadian Environmental Science Revolving Fund; the Alaskan Clean Seas Research and Development Program; the NOFO Program. These papers served as a stimulus to the discussions that followed in the various Panel sessions. The Panels were organized into broad research areas: Mechanical Containment; Mechanical Recovery; Chemical Treatment; In-Situ Burning; Readiness. Each Panel summary is included in the Proceedings and these recommendations reflect the combined input from experts in the field. The Proceedings will serve as a working document to the Minerals Management Service (MMS) to identify their future research program. Final rept., Also available from Supt. of Docs. Library of Congress catalog card no. 89-600731. Sponsored by Minerals Management Service, Herndon, VA.

Jewett, S. and T. Dean (1998). Effects of the EXXON VALDEZ Oil Spill on Eelgrass Communities in Prince William Sound, Alaska 1990-95. Restoration Project 95106. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks. School of Fisheries and Ocean Sciences.
Coastal Resources Associates, Vista, CA.: 330p.

Injuries to the shallow subtidal eelgrass community were observed in the heavily oiled portions of Western Prince William Sound following the Exxon Valdez oil spill. High PAH concentrations were associated with observed differences in communities at oiled vs. reference sites. Dominant taxa within the eelgrass community, including infaunal amphipods, infaunal bivalves, helmet crabs, and leather stars were less abundant at oiled than at reference sites in 1990. Other taxa, including several families of opportunistic or stress-tolerant infaunal polychaetes and gastropods, epifaunal polychaetes and mussels, and small cod, were more abundant at oiled sites. By 1995, there was apparent recovery of most community constituents. However, not all taxa had recovered fully. Some

evidence of slight hydrocarbon contamination still existed at some sites, and three infaunal bivalves, two amphipods, a crab, and a sea star were still more abundant at reference sites than at oiled sites. See also PB96-194865. .
Prepared in cooperation with Coastal Resources Associates, Vista, CA. Sponsored by Alaska Dept. of Fish and Game, Anchorage. Habitat and Restoration Div.

Jewett, S., T. Dean, et al. (1996). Effects of the Exxon Valdez oil spill on benthic invertebrates in an oxygen-deficient embayment in Prince William Sound Alaska. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 440-447.

The possible impacts of *the Exxon Valdez* oil spill on the infaunal and epibenthic community within a heavily oiled fjordic embayment in western Prince William Sound, Alaska, were examined. Initial observations within this embayment in fall 1989 revealed numerous dead and dying organisms. The infauna within the embayment was represented by a relatively rich assemblage of 24 taxa. By fall 1990, the infaunal community was reduced to only six taxa and was dominated by *a* single polychaete species. The observations of dead organisms in 1989 and the decline of the benthic community between 1989 and 1990 were coincident with high concentrations of hydrocarbons in the sediments. By 1991, hydrocarbon concentrations were greatly reduced, very few dead organisms were observed, and the benthic community had recovered to include 32 taxa. These data suggest a possible adverse impact of oiling in 1989 and 1990, followed by recovery. However, sampling in fall 1993 again revealed a greatly impoverished community (four taxa), concomitant with low hydrocarbon concentrations in the sediment and depleted dissolved oxygen in the bottom waters. These data suggest that although the *Exxon Valdez* oil spill may have been, in part, responsible for the dead organisms and the impoverished infaunal community in the years subsequent to the spill, such reductions of benthic infauna can occur as a result of natural hypoxia-anoxia.

Jewett, S., T. Dean, et al. (In press). "Exxon Valdez oil spill: impacts and recovery in the soft-bottom benthic community in and adjacent to eelgrass beds." Marine Ecology Series.

Jewett, S., T. Dean, et al. (1996). Effects of the EXXON VALDEZ Oil Spill on Shallow Subtidal Communities in Prince William Sound, Alaska,1989-93. Restoration Project 93047. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Univ., Fairbanks. School of Fisheries and Ocean Sciences.
Juneau Center for Fisheries and Ocean Sciences, AK.
California Univ., Santa Barbara. Marine Science Inst.
Western EcoSystems Technology, Inc., Cheyenne, WY.: 365p.

Injuries to several of the dominant taxa in the nearshore subtidal community were observed in the heavily oiled portions of western Prince William Sound following the Exxon Valdez oil spill of March 1989. The initial effects were most

pronounced in more protected eelgrass and silled fjord habitats, where PAH (polycyclic aromatic hydrocarbon) concentrations in sediments exceeded 1000 ng g-1 in 1990. By 1993, PAH concentrations in sediments declined to less than 100 ng g-1, and there were far fewer differences between oiled and control sites with respect to the abundance of dominant plant, invertebrate, and fish taxa. However, not all taxa had recovered fully.

Prepared in cooperation with Juneau Center for Fisheries and Ocean Sciences, AK., California Univ., Santa Barbara. Marine Science Inst. and Western EcoSystems Technology, Inc., Cheyenne, WY. Sponsored by Alaska Dept. of Fish and Game, Anchorage. Habitat and Restoration Div.

Johnson, C. and D. Garshelis (1995). Sea otter abundance distribution and pup production in Prince William Sound following the Exxon Valdez oil spill. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill. P. Wells, J. Butler and J. Hughes. Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA. **1219:** 894-929.

We investigated effects of the 1989 Exxon Valdez oil spill on the abundance, distribution, and pup production of sea otters (Enhydra lutris) in Prince William Sound (PWS) by comparing counts made during 1990 and 1991 with counts made by researchers 5-12 years before the spill. We observed no evidence of avoidance or attraction to spill-affected shorelines 1-2 years after the spill. Despite a substantial loss of sea otters immediately following the spill, we counted fewer otters than prespill investigators at only one of three heavily oiled islands, and from 1990 to 1991 our counts at this one site increased to a level equivalent to the latest (1985) prespill count. We followed the methods of prespill investigators and found close agreement between our counts of otters and those of two other concurrent investigations using the same survey technique. This agreement among counts, and our involvement in counts made prespill, suggested that inter-observer variability could not explain our unexpectedly high counts at oiled sites. Some otters killed in the spill were likely replaced by otters from other parts of PWS. However, we suggest that a modest population increase prior to the spill, but after the last prespill counts, is the most plausible explanation for the concurrence of our postspill counts and counts from the early 1980s. At three heavily oiled sites, pup production 1-2 years after the spill was as high or higher than witnessed before the spill. Although the increase in pupping observed at one island was greater in lightly oiled than in heavily oiled areas, no such trend occurred at another oil-affected island. Mortality, as indicated by the number of carcasses found on beaches a year after the spill, was similar to what had been observed historically. The diet also was unchanged. If the otter population indeed was growing before the spill, these results indicate the potential for renewed population growth.

Johnson, E. (1991). Effect on fishermen of the Valdez spill. Seaways: 8.

In January 1991, Mr Johnson visited Valdez and Cordova, Alaska, to get the views of fishermen and others on the impact that the Exxon Valdez oil spill had

on them. These extracts are taken from the report from the Come-By Chance Area Fishermen's Committee, Newfoundland, Canada, who saw many similarities between their area and Alaska.

Johnson, P., S. Rice, et al. (1992). Impacts of oil pollution and Prince William Sound studies: Bibliography of 1960-91 publications and reports, Auke Bay Laboratory. Auke Bay, AK (USA), National Marine Fisheries Serv., Auke Bay, AK (USA). Auke Bay Lab: 98.

The bibliography lists 137 publications and reports authored by staff members of the Auke Bay Fisheries Laboratory (ABL) and was compiled in response to the numerous information requests following the 1989 Exxon Valdez oil spill. It covers research done in the early 1960s from the Olsen Bay Field Station in Prince William Sound (including some post-1964 earthquake studies), work conducted along the Alaska Peninsula, and laboratory research on the effects of petroleum hydrocarbons on many of Alaska's fish and shellfish (primarily temperate or subarctic species). The listing is organized into three parts: Bibliography, Abstracts, and Indexes.

Johnson, S., M. Carls, et al. (1997). "Reproductive success of Pacific herring (Clupea pallasi) in Prince William Sound, Alaska, six years after the Exxon Valdez oil spill." Fishery Bulletin **95**: 368-379.

The Exxon Valdez oil spill occurred just prior to the spring migration of Pacific herring, Clupea pallasi, from offshore feeding grounds to nearshore spawning areas in Prince William Sound (PWS), Alaska. Most or all of the life stages of herring in PWS may have been exposed to oil after the March 1989 spill. Delayed impacts from the spill were suspected as one possible cause in the unprecedented crash of the adult herring population in 1993 and stimulated studies to assess reproductive success. In spring 1995, mature herring were collected from four sites in PWS and from three uncontaminated sites in southeast Alaska (SE) to determine if reproductive impairment was evident in PWS herring six years after the spill. Herring were artificially spawned and their eggs were reared in a laboratory until hatching. Observed response parameters included fertilization success, hatching times, hatching success, as well as larval viability, swimming ability, and spinal abnormalities. Responses of all year classes combined or those restricted to the same year class did not differ significantly between regions ($P>0.50$); the best and worst responses generally occurred in the SE. Within each site, response of the 1989 year class (most likely impacted by the oil spill in PWS) generally did not differ significantly from any other year class. To verify macroscopic observations, a subset of larvae from the 1989 year class was also inspected microscopically for yolk and pericardial abnormalities, and yolk volume was measured - but no significant regional differences were observed for any of these morphological categories. Based on the parameters examined in this study, evidence of reproductive impairment of Pacific herring in PWS by the spill was not detected in 1995, and the chances of detecting any oil-related effects against natural background variation appeared to be negligible.

Johnson, W., C. Marshall, et al. (1993). Oil-spill risk analysis: Cook Inlet/Shelikof Strait Outer Continental Shelf Lease Sale 149. Volume 1. The analysis. Final rept., Outer Continental Shelf Environmental Asessement Program (OCSEAP); Mineral Management Service: 455.

The Federal Government has proposed to offer Outer Continental Shelf lands in Cook Inlet/Shelikof Strait for oil and gas leasing. Because oil spills may occur from activities associated with offshore oil production, the Minerals Management Service conducts a formal risk assessment. In evaluating the significance of accidental oil spills, it is important to remember that the occurrence of such spills is fundamentally probabilistic. The effects of oil spills that could occur during oil and gas production must be considered. The report summarizes results of an oil-spill risk analysis conducted for the proposed Cook Inlet/Shelikof Strait OCS Lease Sale 149. The objective of the analysis was to estimate relative risks associated with oil and gas production for the proposed lease sale.

Juday, G. and N. Foster (1990). "A preliminary look at effects of the Exxon Valdez oil spill on Green Island Research Natural Area, Alaska, USA." Agroborealis **22**(1): 10-17.

The pristine island beaches of western and southwestern Prince William Sound stood in the path of the Exxon Valdez oil spill. Within two days they had received a very large dose of relatively unweathered crude oil. One of the islands on the southern edge of the massive oil slick was Green Island, where, in 1986, the authors had done some initial work in a long-term monitoring project along the beaches and in the intertidal zone. The authors did not originally intend to study an oil spill, but now that one has occurred we hope to learn as much as possible about changes in our area.

Juday, G. and N. Foster (1995). A return to Green Island, Prince William Sound, Alaska, USA. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill. P. Wells, J. Butler and J. Hughes. Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA. **1219:** 26-28.

Karinen, J., M. Babcock, et al. (1993). Hydrocarbons in Intertidal Sediments and Mussels from Prince William Sound, Alaska, 1977-1980: Characterization and Probable Sources. U.S. Department of Commerce, NOAA Technical Memorandum, National Marine Mammal Lab, Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, DOC: 69.

The oil spill that resulted from the March 1989 grounding of the oil tanker vessel Exxon Valdez provides a unique opportunity for the study of marine oil pollution effects because the spilled crude oil polluted a large geographic area that was previously considered pristine. The only sources of confounding hydrocarbons in the areas of Prince William Sound, Alaska, impacted by the spill are naturally

occurring hydrocarbons and anthropogenic hydrocarbons from occasional boating activity in the Sound or due to long-range atmospheric transport. The authors' objectives were to determine the levels, intra-annual variability, and interannual variability of selected alkane hydrocarbons and PAHs in intertidal sediments and in M. trossulus tissues at a network of sampling stations over the 4-year sampling period, and if possible to identify the likely sources of hydrocarbons found. Technical memo.

Kastelein, R. and F. Weltz (1991). "Distribution and behavior of Steller sea lions (Eumetopias jubatus) in Prince William Sound, Alaska (USA), June 1989." Aquat Mamm **17**(2): 91-97.

The distribution and behaviour of Steller sea lions (Eumetopias jubatus) on their rookeries and haul-out areas in Prince William Sound, Alaska were studied in June 1989. An aerial count at low tide showed mor animals hauled out than a similar survey, flown 9 days later at high tide. In this geographical area, and in this period of the year, the haul-out pattern of Steller sea lions seems influenced by the tide in varying degrees depending on the colony. A larger number of Steller sea lions were counted in the colonies in 1989 than in a similar study during the same period of the previous year. One colony was only used as a haul-out in 1988, but was used on a small scale as a rookery in 1989.

Kelso, D. and M. Kendziorek (1991). "Alaska's response to the Exxon Valdez oil spill." Environ Sci Technol **25**(1): 16-23.

When the tanker Exxon Valdez ripped its hull on Bligh Reef in Alaska's Prince William Sound, spilling nearly 11 million gallons of crude oil, it also shattered the confidence of many Americans in the technology and management systems used to prevent and respond to spills. The March 1989 oil spill killed more wildlife than any spill in history: an estimated 100,000-300,000 sea birds, thousands of marine mammals, and hundreds of bald eagles (1). The spill disrupted the herring and salmon harvests of commercial and subsistence fisheries that had consistently supported communities in the spill area. In villages scattered along more than a thousand miles of the affected coastlines, the spill devastated subsistence fishing, hunting, and gathering--essential parts of the rural economy and Native American culture.

Ketkar, K. (1995). "Protection of marine resources: The US Oil Pollution Act of 1990 and the future of the maritime industry." Marine Policy **19**(5): 391-400.

Media coverage of 1989 Exxon Valdez oil spill in US coastal waters enhanced public awareness of marine pollution and made Alaskan natural resources valuable for more individuals. Consequently, political pressures led the US Congress to enact comprehensive legislation - the Oil Pollution Act of 1990 (OPA90), with the aim of reducing the number and the volume of accidental oil spills and also minimizing damage to marine and coastal natural resources. A methodology is proposed which incorporates the impact of oil pollution regulations, public awareness, navigational risk and oil spills on the cost of oil

transfer to maritime industry. Estimated benefit-cost ratios of OPA90 regulations such as the double hull requirement and vessel response plans are found to be less than one even when natural resources are valued at post-Exxon Valdez levels.

Khan, R. (1990). "Parasitism in marine fish after chronic exposure to petroleum hydrocarbons in the laboratory and to the Exxon Valdez oil spill." Bulletin of Environmental Contamination and Toxicology **44**(5): 759-63.

Crude oil or its water soluble components are known to induce histopathological effects in fish following chronic exposure. Fish tend to harbor a variety of parasites, most of which under natural conditions cause little or no apparent harm. However, after chronic exposure to petroleum hydrocarbons, the prevalence and intensity of parasitism increases substantially. Trichodinid ciliates are mainly ectoparasitic protozoans on the gills of fish. A study was initiated to ascertain the relationship between trichodinid infections and exposure of fish to crude oil or its fractions in the laboratory and subsequently, in the Gulf of Alaska following the Exxon Valdez oil spill.

Khan, R. (1991). "Effect of oil-contaminated sediment on the longhorn sculpin (Myoxocephalus octodecemspinosus) following chronic exposure." Bulletin of Environmental Contamination and Toxicology **47**(1): 63-69.

The longhorn sculpin, Myoxocephalus octodecemspinosus , is one of the fish species that inhabits littoral areas adjacent to wharves and fish-processing plants where it feeds on discarded offal. Discharged crude oil has been reported to contaminate and persist in sediment for long periods and is known to affect fish in a variety of ways. The present study was conducted to ascertain the effect of oil-contaminated sediment, following long-term exposure, on body weight, organs, tissues and parasitofauna of the sculpin and the potential use of its parasites as indicators of pollution.

Khan, R. (1995). "Histopathology in winter flounder, Pleuronectes americanus, following chronic exposure to crude oil." Bulletin of Environmental Contamination and Toxicology **54**(2): 297-301.

Chronic exposure to crude oil has a profound affect on living organisms. These effects vary from reduced feed intake, behavioral, physiological, reproductive and pathological changes. Fish, which submerge themselves in sediment when not foraging for food are more likely to be affected than others that live in the water column. Flounders (Pleuronectidae), sediment-inhabiting fish, have been shown to be affected after exposure to oil-contaminated sediment. Two previous studies reported the effects of various concentrations of oil-contaminated sediment on winter flounder, Pleuronectes (= Pseudopleuronectes) americanus, following chronic exposure. The present study reports the histopathological changes in juvenile and adult winter flounder that survived following chronic exposure to crude oil.

Khan, R. and P. Ryan (1991). "Long term effects of crude oil on common murres (Uria aalge) following rehabilitation." Bulletin of Environmental Contamination and Toxicology **46**(2): 216-222.

The purpose of this communication is to report the long term effects of crude oil on common

murres.

Kim, G., S. Tanabe, et al. (1996). "Characteristics of butyltin accumulation and its biomagnification in Steller sea lion (Eumetopias jubatus)." Environmental Toxicology and Chemistry **15**(11): 2043-2048.

The present study was conducted to examine sex difference, age, and temporal trends of butyltin accumulation and its biomagnification in Steller sea lion (Eumetopias jubatus) collected from Alaska, USA, during 1976-1985 and from Hokkaido, Japan, during 1994-1995. Average concentration of total butyltin compounds (SIGMABTs) in the liver of Steller sea lion from Alaska (19 ng/g wet weight) was much lower than those from western and eastern Hokkaido, Japan (150 and 220 ng/g), respectively. This result suggests that Japanese coastal waters are contaminated with BTs in comparison with those of Alaska. In most samples, dibutyltin (DBT) residues were retained at higher levels than tributyltin (TBT), suggesting the degradation of TBT to DBT in the liver. Sex difference and age-dependent accumulation of BTs residues were not found in Steller sea lion. Similarly, no prominent temporal trend in BT concentrations was observed between 1976 and 1985. Nevertheless, the annual consumption of organotin compound was doubled in the United States during the same period. These results suggest that the butyltin compounds are degraded faster than the intake from diet in Steller sea lion. The biomagnification factor of BTs in Steller sea lion was low (0. 15-4.6; mean, 0.6), indicating that this animal is unlikely to magnify BTs due to rapid degradation and excretion.

Kline, T. J. (1998). Salmon Fry. A Trophic Mass-Balance Model of Alaska's Prince William Sound Ecosystem, for the Post-Spill Period 1994-1996. T. Okey and D. Pauly. Vancouver, Canada, Fisheries Centre, University of British Columbia. **6:** 26-31.

Klosiewski, S. and K. Laing (1997). Marine Bird Populations of Prince William Sound, Alaska, Before and After the EXXON VALDEZ Oil Spill. Bird Study Number 2. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Migratory Bird Management.: 104p.

We estimated the summer and winter abundance of marine birds in Prince William Sound, Alaska, following the 1989 Exxon Valdez oil spill, examined changes in population size between pre-spill and post-spill surveys, and compared pre- to post-oil spill population trends in the oiled zone of the Sound relative to trends in the unoiled zone. Ninety-nine species of birds were observed on surveys. Estimated populations of 15 to 32 species/species groups demonstrated declines over the 17-19 year period between pre- and post-spill surveys. However, because of the long time period between surveys, we could not directly associate overall population declines with the oil spill.

Kocan, R. (1996). Fish embryos as in situ monitors of aquatic pollution. Techniques in

Aquatic Toxicology. G. Ostrander. Boca Raton, FL, Lewis Publishers: 73-91.

Kocan, R., P. Hershberger, et al. (In press). "Effects of ovarian fluid and crude oil on survival of virual hemorrhagic septicemia virus in seawater." Diseases of Aquatic Organisms.

Kocan, R. and J. Hose (1997). Laboratory and field observations of sublethal damage in marine fish larvae: lessons from the effects of the Exxon Valdez oil spill. Chemically Induced Alterations in Functional Development and Reproduction of Fishes. R. Rolland, M. Gilbertson and R. Peterson. Pensacola, FL, Society for Environmental Toxicology and Chemistry.

Kocan, R. and J. Hose (In press). "Correspondence between laboratory and field observations of sublethal damage in marine fish larvae: lessons from the effects of the Exxon Valdez oil spill on Prince William Sound herring." Journal of Toxicology and Environmental Health.

Kocan, R., J. Hose, et al. (1996). "Pacific herring (Clupea pallasi) embryo sensitivity to Prudhoe Bay petroleum hydrocarbons: Laboratory evaluation and in situ exposure at oiled and unoiled sites in Prince William Sound." Canadian Journal of Fisheries and Aquatic Sciences **53**(10): 2366-2375.

Pacific herring (Clupea pallasi) embryos were exposed to oil-water dispersions of Prudhoe Bay crude oil in artificial seawater. Pilot studies demonstrated that over 85% of the low molecular weight hydrocarbons evaporated during the first 24 h of each exposure. Genetic damage was the most sensitive biomarker for oil exposure, followed by physical deformities, reduced mitotic activity, lower hatch weight, and premature hatching. Oil had its greatest effect on the blastsodisc and gastrula stages. Embryos deployed in Prince William Sound 3 years after the Exxon Valdez oil spill yielded a greater proportion of abnormal and lower weight larvae at previously oiled sites than at unoiled sites. Although there is no unequivocal evidence that oiled sites pose a long-term hazard to herring embryo or larval survival, a more comprehensive in situ study is warranted in light of the data obtained during this study.

Kocan, R., G. Marty, et al. (1996). "Reproductive success and histopathology of individual Prince William Sound Pacific herring 3 years after the Exxon Valdez oil spill." Canadian Journal of Fisheries and Aquatic Sciences **53**(10): 2388-2393.

Adult Pacific herring (Clupea pallasi) collected in 1992 from a site previously oiled by the Exxon Valdez oil spill exhibited a lower percent hatch and produced fewer morphologically normal larvae than fish from a previously unoiled site. Possible explanations for these reproductive differences include 1)exposure to residual oil, 2)homing of previously oil-injured fish, 3)homing of different strains of herring, 4) physical or chemical characteristics of each exposure site unrelated

to oil. Differences in microscopic tissue lesions were also observed and were marginally significant between sites. Granulomatous inflammation occurred only in females from previously oiled sites, and this plus increased splenic congestion were negatively correlated to production of normal larvae. Scores for macrophage aggregates in spleen, liver, and kidney were greater in fish from previously oiled sites, particularly in males, but differences were related to age rather than exposure history. Because most of the lesions related to reproductive success were acute or subacute, differences in tissue damage could not be directly related to previous oil exposure.

Koons, C. and H. Jahns (1992). The fate of oil from the Exxon Valdez - a perspective. . MTS '92: Global Ocean Partnership, Washington, DC (USA), 19-21 Oct 1992 , MTS, Washington, DC (USA) .

Several natural processes were at work in the sea and on the shoreline to insure the eventual dissipation and degradation of the oil released into Prince William Sound as a result of the grounding of the Exxon Valdez . These processes have been well documented in a large body of literature on the fate of previous spills, and were further confirmed by published information from the Valdez spill. The marine environment has the capacity to assimilate petroleum hydrocarbons by these natural processes, as demonstrated by a steady-state level of petroleum hydrocarbons in the oceans even in areas of submarine oil seeps.

Koster, B., S. Wise, et al. (1995). Alaska Marine Mammal Tissue Archival Project: Specimen Inventory. Govt Reports Announcements & Index (GRA&I), National Inst. of Standards and Technology (CSTL), Gaithersburg, MD. Organic Analytical Research Div.

National Marine Fisheries Service, Silver Spring, MD. Office of Protected Resources.: 78p.

The Alaska Marine Mammal Tissue Archival Project (AMMTAP) was initiated in 1987 to aid in the monitoring of contaminants in the Alaskan environment. The tissue samples are then archived in the National Biomonitoring Specimen Bank (NBSB) at the National Institute of Standards and Technology (NIST). In the NBSB, the tissues are stored in vapor phase liquid nitrogen freezers until required for analysis. This document contains the current inventory of the AMMTAP archive. Included in the inventory is information such as: species, location collected, morphometries, tissues collected and dispositions of the tissue, i.e., archived or homogenized for analysis. This document contains the records for the collection of tissue from 94 animals samples between July 87 - October 93. See also PB91-184796 and PB92-143718. Prepared in cooperation with National Marine Fisheries Service, Silver Spring, MD. Office of Protected Resources.

Krahn, M., D. Burrows, et al. (1992). "Mass spectrometric analysis for aromatic compounds in bile of fish sampled after the Exxon Valdez oil spill." Environmental Science and Technology **26**(1): 116-126.

After the Exxon Valdez oil spill, the exposure of marine organisms to petroleum had to be determined. Gas chlormatography/mass spectrometry was used to identify metabolites of aromatic compounds (ACs), such as alkylated naphthols, phenanthrols and dibenzothiophenols, in the hydrolyzed bile of five salmon (Oncorhynchus gorbuscha) and four pollock (Theragra chalcogramma) captured in Prince William Sound several months after the oil spill. These metabolites wre not found in the control fish sampled from areas not impacted by the oil. The metabolites were identified by comparison to those from the hydrolyzed bile of a halibut (Hippoglossus stenolepis) which had been injected with weathered Prudhoe Bay crude oil. The dibenzothiophenols are proposed as promising marker compounds for identifying the exposure of fish to certain crude oils. In addition, a high-performance liquid chromatographic method to screen bile for metabolites of ACs was validated for used in estimating the exposure of fish to petroleum.

Krahn, M., G. Ylitalo, et al. (1993). "Comparison of high-performance liquid chromatography/fluorescence screening and gas chromatography/mass spectrometry analysis for aromatic compounds in sediments sampled after the Exxon Valdez oil spill." Environmental Science and Technology **27**(4): 699-708.

After the grounding of the Exxon Valdez, sediment samples were collected to determine the degree and distribution of the oiling. Sixty sediments from 10 sites in Prince William Sound, AK, were analyzed for Prudhoe Bay crude oil (PBCO) using a rapid HPLC screening method that measured fluorescence at wavelength pairs specific for two- and three-ring petroleum-related aromatic compounds (ACs). Concentrations of individual ACs in the sediments were also determined by GC/MS to compare the results of the two methods. Concentrations of ACs measured by HPLC screening were highly correlated with the sums of ACs determined by GC/MS, thus validating the screening method as an effective tool for estimating concentrations of petroleum-related ACs in sediments. Moreover, differences in HPLC chromatograms suggested different sources of contamination, e.g., crude oil or diesel fuel. Finally, GC/MS analyses confirmed that PBCO was a primary source of contamination in many sediments.

Krahn, M., G. Ylitalo, et al. (1993). Screening methods for assessing damage to natural resources following the Exxon Valdez oil spill. Proceedings of the 1993 International Oil Spill Conference: Prevention, Preparedness, Response, Washington, D.C.

Evaluating the extent of the damage to natural resources after a major oil spill, such as the Exxon Vladez spill in Prince William Sound, Alaska, requires the analysis of thousands of samples of sediment and biota. Threfore, the use of rapid, low-cost methods -- generally known as screening methods -- to estimate concentrations of petroleum-related aromatic hydrocarbons in samples is vitally important to the production of timely information in an emergency response. These screening procedures can rapidly process large numbers of samples to yield semiquantitative estimates of contaminant concentrations and allow ranking of samples by degree of contamination. Thus, the most contaminated samples can be located rapidly by screening, and detailed analyses, for example, gas

chromatography/mass spectrometry (GC/MS) can be focused on selected samples to confirm the presence of contamination.

Krahn, M. M., P. R. Becker, et al. (1997). "Organochlorine contaminants in blubber of four seal species: integrating biomonitoring and specimen banking." Chemosphere **34** (9-10): 2109-21.

Blubber samples from four Alaska seal species (bearded seal, Erignathus barbatus, harbor seal, Phoca vitulina, northern fur seal, Callorhinus ursinus, ringed seal, P. hispida) were collected for inclusion in the US National Biomonitoring Specimen Bank, as well as for immediate analysis as part of the contaminant monitoring component of the US National Marine Fisheries Service's Marine Mammal Health and Stranding Response Program. The blubber samples were analyzed for organochlorine (OC) contaminants (e.g., PCB congeners, pesticides, DDTs). Results for bearded and ringed seals from the Alaska Arctic revealed low blubber concentrations of OC contaminants. Harbor seals from Prince William Sound. Gulf of Alaska, had somewhat higher blubber concentrations of OC contaminants. In contrast, northern fur seals sampled from the Pribilof Islands had blubber concentrations of certain OC contaminants that were about an order of magnitude higher than those found in the other seal species. Differences in contaminant concentrations among the Alaska seals may be explained by differences in feeding habits and migratory patterns, age or gender did not appear to account for the differences observed. The highest concentrations of OCs were found in harbor seals stranded along the northwestern US mainland, which is consistent with higher concentrations of anthropogenic contaminants being found in urban coastal areas than in more remote Arctic environments. The integration of real-time contaminant monitoring with specimen banking provides important baseline data that can be used to plan and manage banking activities. This includes identifying appropriate specimens that are useful in assessing temporal trends and increasing the utility of the banked samples in assessing chemical contaminant accumulation and relationships to biological effects.

Krahn, M. M., D. G. Burrows, et al. (2000). "White whales (Delphinapterus leucas) from three Alaskan stocks: concentrations and patterns of persistent organochlorines contaminants in blubber." J Cetacean Res Manage **1**(3): 239-249.

White whale (Delphinapterus leucas) blubber samples from three of the five different Alaskan stocks, Cook Inlet (N=20), Eastern Chukchi Sea (n=19), and Eastern Beaufort Sea (n=2), were analyzed for levels and patterns of chemical contaminants. Blubber from these whales contained ŠPCBs, ŠDDTs, Šchlordanes, HCB, dieldrin, mirex, Štoxaphene and ŠHCH, generally in concentration ranges similar to those found in white whales from the Canadian Arctic and lower than those in white whales from the highly contaminated St. Lawrence River. Males from the Cook Inlet and Eastern Chukchi Sea stocks had higher mean concentrations of all contaminant groups than did the females of the same stock, a result attributable to the transfer of organochlorine contaminants (OCs) from the mother to the calf during pregnancy and during

lactation. Principal component analysis of patterns of contaminants present in blubber showed that the Cook Inlet stock appeared to have identifiable contaminant patterns that allowed the stock to be distinguished from the others. Our results also showed that blubber from the three Alaskan stocks was a source of contaminant exposure for human subsistence consumers, but the health risks from consumption are currently unknown.

Kuletz, K. (1996). Marbled murrelet abundance and breeding activity at Naked Island, Prince William Sound and Kachemak Bay, Alaska before and after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 770-784.

The marbled murrelet *Brachyramphus marmoratus* is the most abundant seabird in Prince William Sound, Alaska, and breeds throughout the area affected by the 1989 Exxon Valdez oil spill. I compared pre- and postspill abundance and breeding activity of murrelets near the Naked Island group in central Prince William Sound, and in Kachemak Bay in lower Cook Inlet. Murrelet numbers at Naked Island were lower in 1989 than in 1978-1980 but were not lower in 1990-1992. At Kachemak Bay, where oiling was minimal, murrelet densities did not change between 1988 and 1989. I observed a lower ratio of juvenile to adult murrelets at Naked Island in postspill years, but data were insufficient to determine if reproduction was disrupted. There was no change in juvenile ratios in Kachemak Bay. My results suggest that the murrelet population at Kachemak Bay, further removed from the spill epicenter, was not as affected as the Naked Island population. The majority of murrelets breeding in Prince William Sound did not arrive until after most of the surface oil had dispersed. Murrelets near Kodiak Island and the southern Kenai Peninsula during April, including those migrating north, may have died in higher numbers than in the sound. A minimum of 8,400 *Brachyramphus* murrelets (including the Kittlitz's murrelet B. brevirostris) were killed by oil, perhaps 7% of the population in the spill zone. A 66% decline in the Prince William Sound murrelet population since the 1970s complicated the identification of spill-related effects on murrelets.

Kuletz, K. (1997). Marbled Murrelet Abundance and Breeding Activity at Naked Island, Prince William Sound, and Kachemak Bay, Alaska, Before and After the EXXON VALDEZ Oil Spill. Bird Study Number 6. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Migratory Bird Management.: 66p.

The author compared pre- and post-spill abundance and breeding activity of murrelets near the Naked Island group in central Prince William Sound, and in Kachemak Bay in lower Cook Inlet. Murrelet numbers at Naked Island were lower in 1989 than in 1978-1980 but not in 1990-1992. At Kachemak Bay, where oiling was minimal, murrelet densities did not change between 1988 and 1989. The results suggest that the murrelet population at Kachemak Bay, further removed temporally and spatially from the spill epicenter, was not affected as the

Naked Island populations in 1989. Murrelet numbers were negatively correlated to numbers of boats at both study sites, and cleanup activities likely contributed to disruption in 1989.

Kuletz, K., D. Irons, et al. (1996). Long-term changes in diets and populations of piscivorous birds and mammals in Prince William Sound, Alaska. Int. Symp. on the Role of Forage Fishes in Marine Ecosystems, Anchorage, Alaska (USA), 13-16 Nov 1996, American Fisheries Society.

During the past two decades, significant population changes of marine birds, mammals, and fish have been observed in the Gulf of Alaska. In the late 1970s, there was a shift from a regime typified by high abundance of shrimp, capelin, and Pacific sandfish to one dominated by pollock, cod, and flatfish in the 1980s. Seabird diets indicated that capelin (Mallotus villosus), the dominant prey in the 1970s, was replaced by sand lance (Ammodytes hexapterus) and gadids (Gadidae) in the 1980s. Concurrent with changes in diet there were declines in seabird populations and productivity at many colonies. However, seabird colonies in Kachemak Bay, in lower Cook Inlet, did not exhibit these declines. We sought to determine whether Prince William Sound showed evidence of changes similar to those of the Gulf of Alaska. We reviewed studies of marine bird and mammal populations in Prince William Sound. The U.S. Fish and Wildlife Service conducted surveys of the sound in July 1972 to derive population estimates. Following the 1989 Exxon Valdez oil spill, similar surveys were conducted in 1989-1991 and 1993. Population estimates of species and species groups were examined for declines from the 1972 surveys. Detailed information on marine mammals came from separate studies.

Kuletz, K., D. Marks, et al. (1997). At-Sea Abundance and Distribution of Marbled Murrelets in the Naked Island Area, Prince William Sound, Alaska, in Summer,1991 and 1992. Restoration Study Number 15-1. EXXON VALDEZ Oil Spill State-Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Migratory Bird Management.: 39p.

We studied the abundance and distribution of marbled murrelets (Brachyramphus marmoratus) in the Naked Island area of Prince William Sound, Alaska, in the summers of 1991 and 1992, to supplement inland nesting habitat studies conducted there. We surveyed randomly selected transects by boat in the 'inner zone' (water <2 km from shore) and 'outer zone' (waters 2-5 km from shore) in early summer (late May or early June) and late summer (late July or early August).

Kvenvolden, K. and P. Carlson (1992). Non-Exxon Valdez-related tar on the shores of Prince William Sound, Alaska. 43rd Arctic Science Conference, Valdez, AK, University of Alaska Fairbanks Geophysical Institute.

Kvenvolden, K. and P. Carlson (1995). Oil spills in Prince William Sound Alaska. 10th McKelvy Symposium Energy and the Environment, USGS.

Kvenvolden, K. and P. Carlson (1997). The Good Friday Catastrophes in Prince William Sound, Alaska, USGS.

"Almost exactly 25 years apart, two catastrophes hit the Prince William Sound area, both coincidentally on Good Friday. In 1964, the Great Alaska Earthquake caused a spill of asphalt from storage tanks in the old town of Valdez.; in 1989, the supertanker Exxon Valdez spilled North Slope crude oil. Today, it seems easier for us to find asphalt residues from 1964 than oil residues from 1989 on the beach cobbles and bedrock surfaces around Prince William Sound."
- Dr. Keith A. Kvenvolden, U.S. Geological Survey

In 1989, the supertanker Exxon Valdez spilled a large amount of crude oil into Prince William Sound.

About 258,000 barrels (11 million gallons) of crude oil from the North Slope of Alaska spilled into Prince William Sound when the supertanker grounded on Bligh Reef. The oil quickly spread southwest through the Sound into the Gulf of Alaska. Approximately 16 percent of the sandy, gravelly, and rocky shorelines of the Sound was coated with oily residues. Cleanup operations and natural processes have now removed much of the oil from affected shorelines. Although this spill caused significant environmental damage, especially to the wildlife, and cost millions of dollars to clean up, recent evidence suggests that an earlier spill event in the Sound may be more easily detected today than is the oil from 1989.

Kvenvolden, K., P. Carlson, et al. (1993). "Possible connection between two Alaskan catastrophies occurring 25 yr apart (1964 and 1989)." Geology **21**: 813-816.

Kvenvolden, K., P. Carlson, et al. (1994). Carbon isotopic identification of two sources of oil residues in Prince William Sound, Alaska. 207th National Meeting of the American Chemical Society, San Diego, California, USA, March 13-17,1994, American Chemical Society.

Kvenvolden, K., F. Hostettler, et al. (1995). "Ubiquitous tar balls with a California-source signature on the shorelines of Prince William Sound, Alaska." Environmental Science and Technology **29**(10): 2684-2694.

Although the shorelines of Prince William Sound still bear traces of the 1989 Exxon Valdez oil spill, most of the flattened tar balls that can be found today on these shorelines are not residues of Exxon Valdez oil. Instead, the carbon-isotopic and hydrocarbonbiomarker signatures of 61 tar ball samples, collected from shorelines throughout the northern and western parts of the sound, are all remarkably similar and have characteristics consistent with those of oil products that originated from the Monterey Formation source rocks of California. The carbonisotopic compositions of the tar balls are all closely grouped (ð ^{13}C PDB = -23.7 | 0.2), within the range found in crude ails from those rocks, but are distinct from isotopic compositions of 28 samples of residues from the Exxon Valdezoil Spill ((ð ^{13}C PDB = -29.4 | 0.1). Likewise, values for selected biomarker ratios in the tar balls are all similar but distinct from values of residues from the 1989 oil spill. Carbon-isotopic and biomarker signatures generally relate the tar balls to

oil products used in Alaska beforeonstruction and pavements. How these tar balls with such similar geochemical characteristics became so widely dispersed throughout the northern and western parts of the sound is not known with certainty, but the great 1964 Alaska earthquake was undoubtedly an important trigger, causing spills from ruptured storage facilities of California-sourced asphalt and fuel oil into Prince William Sound.

Kvenvolden, K., F. Hostettler, et al. (1991). Short-term effects of oil spills on the molecular record in sediments of San Francisco Bay, California and Prince William Sound, Alaska. Organic Geochemistry, Advances and Applications in Energy and the Natural Environment. D. A. C. Manning. Manchester, U.K., Manchester University Press: 527-530.

Kvenvolden, K., F. Hostettler, et al. (1993). "Hydrocarbons in oil residues on beaches of Islands of Prince William Sound, Alaska." Marine Pollution Bulletin **26**(1): 24-29.

Aliphatic and aromatic hydrocarbons were measured on oil residues from beaches on six islands in Prince William Sound, Alaska. In addition to altered products from the Exxon Valdez oil spill of 1989, we also found, at two widely separated locations, residues that are similar to each other but chemically distinct from the spilled oil. Terpanes, steranes, monoaromatic steranes, and carbon isotopic compositions of total extracts were most useful in correlating the altered products of the spilled oil. These same parameters revealed tht the two non-Valdez samples are likely residues of oil originally produced in California. The results indicate that oil residues currently on the beaches of this estuary have at least two quite different origins.

Kvenvolden, K., F. Hostettler, et al. (1996). Terpane biomarkers and carbon isotopes in environmental geochemistry application of a case study from Prince William Sound, Alaska. 212th American Chemical Society National Meeting, Orlando, Florida, USA, August 25-29,1996.

Kvenvolden, K., J. Rapp, et al. (1991). Tracking hydrocarbons from the Exxon Valdez oil spill in beach, shallow-water, and deep-water sediment of Prince William Sound, Alaska. Anchorage, AK, U.S. Geological Survey: 69-98.

Kvenvolden, K., C. Threlkeld, et al. (1993). Forensic geochemistry--carbon isotope identification of two sources of oil residues in Prince William Sound. 16th International Organic Geochemistry Symposium, Stavenger, NOrway, Falch Hurtigtrykk Press, Oslo Norway.

Ladousse, A. (1990). "Alaska: Bacteria against oil spill (Original Title Alaska: potion magique pour bacteries anti-marees noires)." Oceanorama. Institut oceanographique

Paul Ricard. Marseille(14): 27-31.

The impact at the coast of an oil pollution is considered by its evolution at the sea. The main conclusions of the operations during oil spill have initiated and guided research programs on chemical products, the objectives of which is to ameliorated new operational methods of biological treatment, such as the "Inipol E.A.P. 22" used to clean the Alaska coasts after the Exxon Valdez oil spill.

Lanctot, R., B. Goatcher, et al. (1999). "Harlequin duck recovery from the Exxon Valdez oil spill: a population genetics perspective." Auk **116**(3): 781-791.

Concerns about Harlequin Duck (Histrionicus histrionicus) population recovery following the Exxon Valdez oil spill led biologists to ask whether birds located in different molting and wintering areas belong to genetically distinct and, thus, demographically independent populations. Owing to the lack of direct observations of movements among marine areas, three classes of genetic markers that differed in mode of inheritance were used to evaluate the degree of genetic differentiation among wintering areas within Prince William Sound (PWS) and the Alaska Peninsula and Kodiak Archipelago (APKA). We could not reject the null hypothesis that the wintering aggregations within each region are composed of a single genetically panmictic population. Differences in genotype frequencies among wintering locations within PWS and APKA were low and nonsignificant for all three classes of markers. Furthermore, we saw no evidence for deviations in Hardy-Weinberg equilibrium or gametic disequilibrium between loci within a winter collection site as would be expected if these locales were composed of individuals from reproductively isolated (and genetically distinct) breeding locales. Finally no evidence for significant structuring was noted between PWS and APKA. Lack of spatial genetic structuring could be due to the cumulative effects of low levels of gene flow over long time periods, low levels of gene flow by immature birds moving between marine habitats, or to episodic dispersal caused by habitat alteration (e.g. Volcanic eruptions). Harlequin Ducks are likely to recolonize or enhance populations in areas recovering from environmental damage via emigration of birds from non-affected areas. Demographic studies suggest, however, that levels of movements are low, and that population recovery by emigration is a long-term process.

Laur, D. and L. Haldorson (1996). Coastal habitat studies the effect of the Exxon Valdez oil spill on shallow subtidal fishes in Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 659-670.

Fish communities were monitored in shallow (<20 m) depths of paired oiled and non-oiled (control) study sites within Prince William Sound in 1990 using diving transect techniques. Habitats studied were defined by dominant macrophytes, including eelgrass Zostera marina and Laminatia-Agarum. In eelgrass, young-of-the-year Pacific cod Gadus macrocephalus were the most abundant fish in both oiled and control sites; they occurred at significantly higher densities at oiled sites. In Laminaria-Agarum habitats, the Arctic shanny Stichaeus punctatus and small sculpins were the most common fishes, and young-

of-the-year Arctic shannies were more abundant in shallow depths at oiled sites. In both eelgrass and Laminaria-Agarum habitats, oiled sites had overall higher abundances of fishes than did control sites mainly because of the higher numbers of young-of-the-year fishes. Young-of-the-year Pacific cod from oiled eelgrass sites tended to have higher volumes of stomach contents and had eaten proportionally more mollusk larvae than had fish from control sites, where crustaceans were more common in diets. Differences in diet appear related to the relative availability of prey in oiled versus control eelgrass study sites, suggesting that increased abundance of young-ofthe-year Pacific cod at oiled study sites is related to the increased diversity and abundance of epifaunal prey taxa. Increased numbers of young-of-the-year fishes at oiled sites could also be the result of enhanced supply of planktonic larvae or decreases in predation at oiled sites.

Lautenberger, C. and L. Pearson (1995). Development of a unified federal/state, coastal/inland oil and hazardous substance contingency plan for the state of Alaska. Prevention, Response and Oversight Five Years after the Exxon Valdez Oil Spill. Proceedings of an International Conference, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science.

The passage of the Oil Pollution Act of 1990 (OPA 90) expanded the existing federal planning and response framework in several ways. OPA 90 created a new requirement for facility and tank vessel response plans and an "area-level" planning and coordination structure to help supplement federal, regional, and local planning efforts. OPA 90 amended the existing Clean Water Act (CWA), section 311(j)(4) which establishes area committees and area contingency plans (ACPs), as primary components of this structure. In 1980, the Alaska State Legislature enacted legislation which defines the state's policies regarding oil spills. Following the T/V Exxon Valdez oil spill, in 1989 and 1990 the legislature passed further legislation to expand and strengthen the state's oil spill program. Specifically in 1989, Senate Bill 261 required the Alaska Department of Environmental Conservation (ADEC) to develop, annually review, and revise the State Oil and Hazardous Substance Contingency Plans, (State Master & Regional Plans). State regional plans serve as annexes to the State Master Plan. This paper presents the coordinated and cooperative efforts by government agencies and local entities toward creating a "unified" Federal/State, Coastal/Inland Oil and Hazardous Substance Preparedness and Response Plan and the development and progress of "unified" Sub-Area/Regional Contingency Plans for the State of Alaska.

Leatherwood, S., C. Matkin, et al. (1990). "Killer whales, Orcinus orca , photo-identified in Prince William Sound, Alaska, 1976 through 1987." Canadian field-naturalist **104**(3): 362-371.

Individual Killer Whales, Orcinus orca , were identified from photographs taken incidental to other research (1976-1983) or during intensive studies of the species (1984-1987) in Prince William Sound (PWS), Alaska. The 232 identified animals were grouped into pods, based on observed associations, and assigned to the following conservatively defined age/sex categories: adult males (52, 22.41%), adult females (22, 9.48%), calves born 1986 or 1987 (9, 3.9%) or

"immatures/others" of both sexes (149, 6

Lee, J. S., S. Tanabe, et al. (1996). "Persistent organochlorines in steller sea lion (Eumetopias jubatus) from the bulk of Alaska and the Bering Sea, 1976-1981." Marine Pollution Bulletin **32**(7): 535-544.

Organochlorine pesticides and polychlorinated biphenyls (PCBs) were determined in the blubber and liver of Steller sea lion (Eumetopias jubatus) collected from the bulk of Alaska and the Russian Bering Sea. PCBs were the predominant organochlorines in the blubber, ranging in concentration from 5.7 to 41 mu g/g (lipid weight) in males and from 0.57 to 16 mu g/g in females. Concentrations of DDTs (DDT and its metabolites) in the blubber ranged from 2.8 to 17 mu g/g in males and from 0.19 to 6.5 mu g/g in females. The levels of chlordane compounds (CHLs) and hexachlorocyclohexanes (HCHs) were one to three orders of magnitude lower than those of PCBs and DDTs. The residue levels of PCBs, DDTs and CHLs in males increased with age, whereas in females they decreased sharply after maturity, suggesting the transfer of organochlorines in large quantities during lactation. Transfer rate of organochlorines through lactation was estimated to be 80% for PCBs and 79% for DDTs of the total body of adult female. Concentrations of organochlorines in the liver of the Steller sea lion from Alaska, on a lipid weight basis, were similar to those in the blubber. In addition, liver showed age-dependent accumulation of PCBs, DDTs and CHLs, similar to that in the blubber. The concentrations of all the organochlorines detected in the liver were clearly correlated with those in the blubber, indicating the lipophilic nature of organochlorines in accumulation and movement in the animal body. Residue levels of PCBs and DDTs in the liver of male Steller sea lions from the Bering Sea were significantly lower than those from Alaska, suggesting that Bering Sea animals have different foraging areas from the animals of the bulk of Alaska.

Lees, D., J. Houghton, et al. (1996). Short-Term Effects of Several Types of Shoreline Treatment on Rocky Intertidal Biota in Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society: Bethesda, Maryland, USA. **18:** 329-348.

Studies conducted in Prince William Sound during 1989 assessed short-term biological effects of treatment methods being considered or employed to treat oil-contaminated beaches. Treatment alternatives evaluated included (1) low-pressure warmwater wash (LP-VVW), (2) highpressure hot-water wash (HP-HW), (3) the dispersant Corexit 7664, and (4) the beach cleaner Corexit 9580 M2. Effects on the biota were assessed on the basis of changes in abundance of dominant taxa and in magnitude of selected assemblage attributes (e.g., percent cover by algae or animals and number of taxa) and, in some cases, observed mortality of organisms in the treatment areas. Significant reductions in one or more assemblage or population attributes and increases in the percent of dead mussels were observed in response to all types of treatment. The strongest and most consistent effects were observed following HP-HW treatment. These included heavy mortality in

rockweed and mussels. Generally, the programs were not designed to allow discrimination among the potential causes of damage. However, temperature appeared to cause significant mortality in the dominant plants and in grazing and filter-feeding animals at HP-HW sites. In contrast, available data suggest that neither chemical nor LP-WW treatments caused significant thermal impacts in the intertidal biota. An intermediate level of changes, both increases and decreases, accompanied the chemical and LP-WW treatments, whereas the highest percentage of changes, nearly all decreases, accompanied HP-HWs. The severe and persistent effects observed in many areas subjected to HP-HW throughout the spill area were still conspicuous in our most recent survey in the sound (July 1995). The observed displacement and mortality of clams and mussels suggest that physical and possibly chemical effects may have been substantial in some cases. Although dispersant and beach cleaner treatments appeared to be accompanied by the smallest number of significant changes in abundance, this conclusion is weak because the LP-WW that accompanied chemical applications during the tests was less rigorous than when performed alone. Moreover, the surveys were not focused on enumerating abundance of the types of organisms that toxicity data indicate are more susceptible to the types of chemicals tested. In fact, probable dosages applied appear to substantially exceed published LC50s (median lethal concentrations) for Corexit 7664 and later formulations of Corexit for many types of crustaceans and molluscs relevant to intertidal assemblages in Prince William Sound.

Leschine, T., J. McGee, et al. (1993). T/V Exxon Valdez oil spill: Federal on scene coordinator's report. Volume 1. Final rept. 24 Mar 89-10 Jun 92, Department of Transportation, Washington, DC (USA).: 582.

Table of Contents: Cultural and Natural History of Prince William Sound and Western Alaska; Vessel Stabilization, Lightering, and Salvage; Floating Oil Operations; Evolution of the FOSC's Response Organization; Exxon Response Organization; Shoreline Cleanup in 1989; Shoreline Cleanup in 1990; Shoreline Cleanup in 1991 and 1992; Chemical Shoreline Cleaners; Bioremediation; Cultural Resource Constraints; Other Shoreline Cleanup Issues; Waste Management; Wildlife Rescue and Rehabilitation; Communications and Air Operations Support; Vessel Support; Worker Health and Safety; Community Concerns; Federal Intergovernmental Relations; Response Management Authority; Public Affairs and Protocol; Personnel; Finance and Accounting; Information Management; and Problems Encountered (and Lessons Learned).

Leschine, T., J. McGee, et al. (1993). T/V Exxon Valdez oil spill: Federal on scene coordinator's report. Volume 2. Final rept. 24 Mar 89-10 Jun 92, Department of Transportation, Washington, DC (USA).: 1028.

Table of Contents: Chronology of Events; Prince William Sound Pollution Reports; Western Alaska Pollution Reports; and Selected Overflight Maps.

Leschine, T., J. McGee, et al. (1994). T/V EXXON VALDEZ Oil Spill: Federal On Scene Coordinator's Report. Volume 2. Govt Reports Announcements & Index (GRA&I),

Department of Transportation, Washington, DC. Office of the Secretary.: 1028p. Table of Contents: Chronology of Events; Prince William Sound Pollution Reports; Western Alaska Pollution Reports; and Selected Overflight Maps. Final rept. 24 Mar 89-10 Jun 92. See also PB90-916405 and Volume 1, PB94-121845.

Lessard, R., J. Wilkinson, et al. (1995). Bioremediation application in the cleanup of the 1989 Alaska oil spill. Bioremediation of Pollutants in Soil and Water; Symposium on Bioremediation, Fort Worth, Texas, USA, October 14-15,1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

Lethcoe, N. (1995). Protecting ecotourism and recreation resources in the event of an oil spill. Prevention, Response and Oversight Five Years after the Exxon Valdez Oil Spill. Proceedings of an International Conference, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science.

Ecotourism businesses and recreational users dependent on natural resources were virtually excluded from the Exxon Valdez oil spill (EVOS) response, cleanup, and restoration process. Both were denied legal standing for their claims for loss of use of natural resource and economic losses resulting from loss of clients. Recreational users and the ecotourism industry learned a number of lessons through trying to cope with EVOS. The Oil Pollution Act of 1990 (OPA 90) made changes which may help to provide better recognition, protection, and restoration of tourism resources in the future. However, an examination of contingency plans for the Prince William Sound area written since EVOS reveal that many of the lessons learned have not been incorporated into the contingency planning process. Recreation and ecotourism sites remain unidentified and unprotected. The paper identifies and suggests some possible solutions to remaining problem areas. OPA 90 intended to overturn the Robins Dry Dock rule making it possible for businesses to recover damages. However, whether businesses will be able to meet the requirements for proving a claim will probably take years of court tests that may be beyond the means of small businesses.

Linden, O. (1990). "What can we learn from Exxon Valdez? [editorial]." Environmental Research **51**(2): 117-9.

Twelve months have passed now since the grounding of the "Exxon Valdez " in Prince William's Sound, Alaska, and this may be the right time to start assessing what actually took place, what went wrong, and what was done to correct the mistake. The first lesson to be learned from Exxon Valdez is that major accidents with oil tankers still occur. The second major lesson of Exxon Valdez is that we cannot afford to ignore the lessons of the past. Lessons were ignored in three areas: (1) the "cleanup" of the oil, (2) the prevention of damage to the environment, and (3) the assessment of the extent of this damage. The cleanup certainly looked impressive. But what did it accomplish? Did it in any way undo

the damage done to the environment? No, of course it did not.

Lindstrom, J., P. Catterall, et al. (1994). Soil microbiological assays and their use in monitoring environmental damage and recovery. Far East Branch-Russian Academy of Sciences and American Association for the Advancement of Science. Bridges of the Science between North America and the Russian Far East; 45th Arctic Science Conference, Anchorage, Alaska, USA, August 25-27,1994 and Vladivostok, Russia, August 29-September 2,1994, Dalnauka Publishing House: Vladivostok, Russia.

Lindstrom, J. E., R. C. Prince, et al. (1991). "Microbial populations and hydrocarbon biodegradation potentials in fertilized shoreline sediments affected by the T/V Exxon Valdez oil spill." Applied and Environmental Microbiology **57**(9): 2514-22.

The effort of clean up the T/V Exxon Valdez oil spill in Prince William Sound, Alaska, included the use of fertilizers to accelerate natural microbial degradation of stranded oil. A program to monitor various environmental parameters associated with this technique took place during the summer of 1990. Microbiological assays for numbers of heterotrophic and oil-degrading microbes and their hydrocarbon mineralization potentials were performed in support of this program. Fertilizer addition resulted in higher hexadecane and phenanthrene mineralization potentials on treated plots than on untreated reference plots. Microbial numbers in treated and reference surface sediments were not significantly different immediately after the first nutrient application in May 1990. However, subsurface sediments from treated plots had higher numbers of hydrocarbon degraders than did reference sediments shortly after treatment. The second application of fertilizer, later in summer, resulted in surface and subsurface increases in numbers of hydrocarbon degraders with respect to reference sediments at two of the three study sites. Elevated mineralization potentials, coupled with increased numbers of hydrocarbon degraders, indicated that natural hydrocarbon biodegradation was enhanced. However, these microbiological measurements alone are not sufficient to determine in situ rates of crude oil biodegradation.

Lindstrom, S., J. Houghton, et al. (1996). "Recovery of seaweed associations in southwest Prince William Sound after Exxon Valdez oil spill." Journal of Phycology **32**(3 SUPPL): 29.

Lipscomb, T., R. Harris, et al. (1993).'Histopathologic lesions in sea otters exposed to crude oil. Narragansett, RI (USA), NOAA Environmental Research Labs, Narragansett, RI (USA): 13.

On 24 March 1989, the oil tanker Exxon Valdez ran aground on Bligh Reef in Prince William Sound, Alaska. In the months following the spill, over 1,000 sea otters (Enhydra lutris) from oil spill-affected areas are known to have died. The purpose of the study is to identify and describe histopathologic lesions associated with crude oil exposure in sea otters and to discuss possible

pathogeneses of the lesions. Materials available included tissues from oil-contaminated and uncontaminated otters that died in rehabilitation centers following the oil spill and tissues from otters that were found dead in the oil spill-affected area with external oil present. Tissues from apparently normal sea otters from an area not contaminated by crude oil, were also examined.

Lipscomb, T., R. Harris, et al. (1996). Histopathologic Lesions Associated with Crude Oil Exposure in Sea Otters. Marine Mammal Study 6-10. EXXON VALDEZ Oil Spill State Federal Natural Resources Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage.
Armed Forces Inst. of Pathology, Washington, DC. Dept. of Veterinary Pathology. Environmental Protection Agency, Narragansett, RI. Ecosystems Branch.: 18p.

Following the Exxon Valdez oil spill in Prince William Sound, Alaska, sea otters (Enhydra lutris) that appeared oiled, were in danger of becoming oiled, or were behaving abnormally were captured and taken to rehabilitation centers. Oil exposure was assessed by visual examination on arrival at the centers. Tissues from 51 oiled sea otters and from 6 unoiled sea otters that died in rehabilitation centers were examined histologically. Histologic examinations were performed on tissues from 5 sea otters found dead with external oil present shortly after the spill. Necropsies were performed on 214 sea otters that had been collected and frozen in the period following the oil spill. Tissues from 6 apparently normal sea otters collected from an area not affected by the oil spill were examined histologically, and none of these lesions were found. We conclude that pulmonary interstitial emphysema, gastric erosion and hemorrhage, centrilobular hepatic necrosis, and hepatic and renal lipidosis were associated with exposure to crude oil in sea otters. See also PB93-194512. Prepared in cooperation with Armed Forces Inst. of Pathology, Washington, DC. Dept. of Veterinary Pathology. and Environmental Protection Agency, Narragansett, RI. Ecosystems Branch.

Lipscomb, T., R. Harris, et al. (1994). Pathology of sea otters. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 265-279.

In spite of significant limitations, these studies represent the largest and most detailed investigation of the pathological effects of an oils spill on a marine mammal species. The findings support some long-held assumptions and bring to light much new information.

Because they lack a thick layer of subcutaneous fat, sea otters rely on their pelage for protection from cold water. Thus, it was suspected that sea otters would be highly vulnerable to oils spills because contact with crude oil would dramatically decrease the insulating properties of their fur, resulting in hypothermia and death. Indeed, the oil spill had a devastating effect on the sea otters of Prince William Sound, and hypothermia was a major problem in sea otters presented to rehabilitation centers. Death caused by hypothermia can occur wihout distinctive gross or histologic lesions.

Clinical, hematologic/blood chemistry, and postmortem findings, combined with previous research, suggest the following scenario. Oil-contaminated sea otters rapidly became hypothermic. They devote themselves to a life-or-death struggle to remove the oil by grooming. Feeding is drastically curtailed, and energy stores are rapidly depleted. Grooming is marginally effective at best and results in ingestion of crude oil. By unknown mechanisms, exposure to the oil causes interstitial pulmonary emphysemea which compromises respiration. Their desperate situation causes a powerful stress reaction. Gastric erosions form as the physiologic effects of stress reach a critical level. Hemorrhage into the gut begins. The combined effects of these factors overwhelm the otters; shock ensues, followed by death. Some sea otters succumb to hypothermia rapidly, and no lesions form. Others live long enough to develop some or all of the morphological markers that characterize this syndrome: interstitial pulmonary emphysema, gastric erosion and hemorrhage, hepatic and renal lipidosis, and centrilobular hepatic necrosis. Otters that are captured and taken to rehabilitation centers are subjected to additional stressors but are given medical and supportive care.

Lipscomb, T., R. Harris, et al. (1996). Pathological Studies of Sea Otters. Marine Mammal Study 6-11. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage.
Environmental Protection Agency, Narragansett, RI.
Armed Forces Inst. of Pathology, Washington, DC. Dept. of Veterinary Pathology.
Purdue Univ., Lafayette, IN. School of Veterinary Medicine.: 24p.

Following the Exxon Valdez oil spill, sea otters were captured and taken to rehabilitaion centers. Oil exposure was assessed by visual examination on arrival at the centers. Records of 21 oiled otters that died within 10 days of arrival at the centers were reviewed to define the laboratory abnormalities and clinical syndromes associated with these deaths. Tissues from 51 oiled and 6 unoiled sea otters that died in the centers were examined histologically. Histologic examinations were performed on tissues from 5 oiled otters found dead shortly after the spill. Nucropsies were performed on 214 sea otters that were collected and frozen following the oil spill. Pulmonary interstitial emphysema and gastric erosion and hemorrhage were common in oiled animals, and were less frequent in unoiled animals. Tissues from 6 sea otters collected from a nonoiled area were examined, and none of these lesions were found. We conclude that pulmonary interstitial emphysema, gastric erosion and hemorrhage, centrilobular hepatic necrosis, and hepatic and renal lipidosis were associated with exposure to crude oil in sea otters. Prepared in cooperation with Environmental Protection Agency, Narragansett, RI., Armed Forces Inst. of Pathology, Washington, DC. Dept. of Veterinary Pathology. and Purdue Univ., Lafayette, IN. School of Veterinary Medicine.

Lipscomb, T. P., R. K. Harris, et al. (1993). "Histopathologic lesions in sea otters

exposed to crude oil." Veterinary Pathology **30**(17): 1-11.

Following the Exxon Valdez oil spill in Prince William Sound, Alaska, sea otters (Enhydra lutris) that appeared to be contaminated with oil, that were in danger of becoming contaminated, or that were behaving abnormally were captured and taken to rehabilitation centers. Exposure to oil was assessed by visual examination when otters arrived at the centers. Degree of oil exposure was graded according to the following criteria: oil covering greater than 60% of the body--heavily contaminated; oil covering 30-60% of the body--moderately contaminated; oil covering less than 30% of the body or light sheen on fur--lightly contaminated. If there was no oil visible, otters were considered uncontaminated. Tissues from 51 oil-contaminated sea otters (14 males, 37 females) and from six uncontaminated sea otters (three males, three females) that died in rehabilitation centers were examined histologically. Among oil-contaminated sea otters, 19/46 had interstitial pulmonary emphysema, 13/40 had gastric erosion and hemorrhage, 11/47 had centrilobular hepatic necrosis, 14/47 had periportal to diffuse hepatic lipidosis, and 10/42 had renal tubular lipidosis. Of the uncontaminated sea otters, 1/6 had gastric erosion and hemorrhage and 1/6 had diffuse hepatic lipidosis. Histologic examinations were performed on tissues from five sea otters (three males, two females) found dead with external oil present 15 to 16 days after the spill. Periportal hepatic lipidosis and renal tubular lipidosis were found in 3/5, and interstitial pulmonary emphysema was found in 1/5. Tissues from six apparently normal sea otters (four males, two females) collected from an area not affected by an oil spill were examined histologically, and none of these lesions were found. We conclude that interstitial pulmonary emphysema, centrilobular hepatic necrosis, and hepatic and renal lipidosis of sea otters were associated with exposure to crude oil. Gastric erosion and hemorrhage may have been associated with stress of captivity and/or oil exposure.

Loughlin, T. (1994). Marine Mammals and the Exxon Valdez. San Diego, California, USA; London, England, UK, Academic Press, Inc.

Preface: When the 300-m supertanker Exxon Valdez grounded on Bligh Reef in Prince William Sound, Alaska, on 24 March 1989, approximately 258,000 barrels (11 million gallons) of crude oil were spilled onto the water. Federal, state and nongovernment scientists were on the scene within 24 hours to determine the trajectory of the spilled oil and its possible impact on wildlife. The chapters included here represent the combined efforts of these scientists to assess the impacts of the spill on marine mammals within and adjacent to Prince William Sound.

Activity during the aftermath of the spill was divided into response and natural resource damage assessment (NRDA). The response activities included monitoring the spill, cleanup, mitigation measures (such as identifying priority areas for deployment of protection booms) and rehabilitation of oiled wildlife. The NRDA program assessed injury to wildlife from 1989 to 1992 and included studies on marine and terrestrial mammals, birds, fish and shellfish, and coastal habitat. Both response activities and the NRDA studies on marine mammals are included

in this book and represent multidisciplinary topics covering popultion biology, behavior, pathology, and toxicology.

The work presented here is unique because it was initiated as a result of an accident. Thus, many activities wre guided by the needs of legal council (sic), which did not always involve the rigors of scientific methodology (e.g., Baffin Island Oil Spill project, summarized in Arctic 40 [Suppl 1], 1987). All of these studies were conducted by dedicated individuals who frequently labored under difficult circumstances but never compromised the quality of their work during this time of environmental crisis.

In some cases the marine mammal studies show a clear cause-and-effect relationship between exposure to the spilled oil and the death of some marine mammals. However, in most situations the results were equivocal and a cause-and-effect relationship could not be demonstrated.

I proposed to Academic Press that these studies be consolidated into a single volume to facilitate access of results to the scientific community and to state and federal agencies charged with the responsibility of conserving and protecting marine mammals. It is my hope that this volume wil be useful to marine scientists when (not if) the next spill occurs and that our efforts to understand the effects of the Exxon Valdez spill on marine mammals will help those responding to similar events.

Loughlin, T. (1994). Tissue hydrocarbon levels and the number of cetaceans found dead after the spill. Marine Mammals and the Exxon Valdez. T. R. Loughlin. San Diego, California, USA; London, England, UK., Academic Press, Inc.: 359-370.

Thirty seven cetaceans were found dead on Alaskan beaches from Kayak Island (eastern Gulf of Alaska) to King Salmon (Bristol Bay) during march through Ocitober 1989. The carcasses included 26 gray whales, 5 harbor porpoise, 3 unidentifiable whales, 2 minke whales, and 1 fin whale. Tissue samples were obtained from 7 of the 37 carcasses for hydrocarbon analysis and hitological examination. Results of the analyses and on-site necropsies could not determine the cause of death for any of the seven. The large number of stranded gray whales (n=26) was attributed to the timing of the search effort coinciding with the northern migration of gray whales, augmented by increased survey effort in the study area associated with the oil spill.

Loughlin, T., B. Ballachey, et al. (1996). Overview of studies to determine injury caused by the Exxon Valdez oil spill to marine mammals. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 798-808.

Marine mammal damage assessment studies after the Exxon Valdez oil spill concentrated on sea otters *Enhydra lutris*, harbor seals *Phoca vitulina*, Steller sea lions *Eumetopias jubatus*, killer whales *Orcinus orca*, and humpback whales *Megaptera*

novaeangliae. Sea otters and harbor seals were the most affected marine mammal; it was estimated that several thousand otters and several hundred harbor seals died within months of the spill. Steller sea lion, harbor seal, and sea otter numbers were monitored using aerial surveys. Studies of humpback whales and killer whales used photoidentification techniques to determine changes in abundance, distribution, mortality, and natality. Tissues from animals found dead in spill and control areas were analyzed for hydrocarbon levels. Sea otters, sea lions and harbor seals had elevated hydrocarbon levels, but only sea otters and harbor seals showed population declines associated with the spill. Humpback whales were not severely affected by the Exxon Valdez oil spill. Killer whale numbers in the resident AB pod declined after the spill. Coincidental evidence supports the oil spill as the causative agent.

Loughlin, T. and E. Sinclair (1994). Sample collection, storage, and documentation. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 377-382.

Soon after the Exxon Valdex oil spill (EVOS) federal and state government scientists developed a marine and terrestrial mammal tissue and organ sampling protocol. The protocol was distributed to all individuals and organizations expected to collect samples. The Trustees also organized and Analytical Chemistry Group and a Histopathology Technical Group for Oil Spill Assessment Studies. The two grous provided additional technical advice on sample collection, preservation, and processing of sample for toxicological and histopathological analysis to al Natural Resource Damage Assessment (NRDA) scientists. The following is a summary of these sampling protocols and of advice provided by interested experts.

Lowry, L. (1990). Alaska's role in mitigating the effects of the T/V Exxon Valdez oil spill on sea otters. Symposium to Evaluate the Response Effort on Behalf of Sea Otters after the T Exxon Valdez Oil Spill into Prince William Sound, Anchorage, Alaska, USA, April 17-19, 1990.

Lowry, L., K. Frost, et al. (1994). Observation of oiling of harbor seals in Prince William Sound. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 209-225.

Oil that spilled from the Exxon Valdez impacted a considerable amount of harbor seal habitat in central and western PWS. Our observations showed that harbor seals continued to use oiled habitats after the EVOS. Thier pelage became oiled when they used oiled haulout sites or contacted oil in the water. It appeared that seals became cleaner with time if they were not repeatedly exposed to oil. Seals older than pups molted their pelage in August, and no evidence of external oiling was seen in 1990.

Seals gave birth to hand cared for pups on oiled haulout sites during May-July. Many pups became oiled, sometimes within a few days of their birth. Shoreline

treatment conducted prior to the start of pupping did not prevent the contamination of pups.

During April-june the behavior of oiled seals in oiled areas was sometimes very different from that of harbor seals in "normal" circumstamnces. The behavioral changes were most likely due to pathological damage to nerves of the brain caused by haydrocarbon toxicity.

It is not clear how oiled pelage and skin may have contributed to the overall damage to seals that resulted from the spill. The possible effects of external oiling require further study.

Because of the large area to be covered, limited personnel, and other response and research priorities, we were not able to watch undisturbed seals as they encountered oil. Also, we were not able to observe what happened when oil initially moved into and onto areas where seals were swimming or hauling out. Since we could not repeatedly identify and observe specific animals, it was not possible to follow how individuals became oiled and what thappened to them. If circumstances allow in the future, research on seals in oils spill areas should include detailed behavior studies on individuals that are marked visually or telemetrically.

Lung, W., J. Martin, et al. (1993). "Eutrophication Analysis of Embayments in Prince William Sound, Alaska." Journal of Environmental Engineering **119**(5): 811-824.

Fertilizers were used in the summer of 1989 to accelerate bacterial growth in a bioremediation effort to clean up the beaches following the EXXON Valdez oil spill. Mathematical models were used to quantify the eutrophication potential in two selected embayments in Prince William Sound: Passage Cove and Snug Harbor. First, mass transport in these two embayments was determined to. Next, eutrophication models were developed for these two embayments to simulate the seasonal algal concentrations prior to fertilizer application. Finally, a series of nutrient-loading-scenarios based on different fertilizer and other chemical application rates were developed to investigate the impact. Model results and the data available indicated that the rapid exchange between embayments and the open water limits algal growth and buildup of concentrations of other chemicals applied to beaches. The exception is the potential for some ammonia toxicity at high application rates. Despite the limited data available it is clear that no significant increased algal growth would be expected following fertilizer application. Prepared in cooperation with Virginia Univ., Charlottesville. Dept. of Civil Engineering. and ASci Corp., Athens, GA.

Luoma, J. (1999). "Spilling the truth. Ten years after the worst oil spill in American history, Alaska is still feeling the effects of the Exxon Valdez disaster and cleanup." Audubon **101**(2): 52-62.

It was the most strikingly beautiful and horrifyingly ugly sight imaginable. I had cajoled my way onto a fishing boat working the waters of Kenai Fjords National

Park in the Gulf of Alaska. The view was of snowcapped mountains lanced with fir and spruce, and of glimmering waterfalls--broad veils, thin ribbons. That, at least, was the view looking up. Looking down was a sight that left me with troubled dreams for weeks: To the horizon, the sea had become a brown soup of weathered oil known as mousse, and death was everywhere. Instead of fishing, the crew was netting hundreds of dead, oil-slimed birds and sea otters, as a pile of carcass-filled garbage bags grew into a mountain on the boat's deck. That was in 1989, a week after the Exxon Valdez had run aground on March 24, causing the largest oil spill in U.S. history. Now, a full decade later, the once-oil-smothered shores of Prince William Sound are again beautiful--at least to the eye. Exxon insists that within two years of the accident, ecological recovery of the sound and the coastline was near complete. But oil residues remain, often buried on beaches, and scientists continue to record damage as oil seeps into the ecosystem.

Mackey, E. A., P. R. Becker, et al. (1996). "Bioaccumulation of vanadium and other trace metals in livers of Alaskan cetaceans and pinnipeds." Arch Environ Contam Toxicol **30**(4): 503-12.

Concentrations for 38 elements are routinely measured in the marine mammal liver tissues archived in the National Biomonitoring Specimen Bank (NBSB). Results show that hepatic concentrations of vanadium, selenium, silver, cadmium, and mercury are positively correlated with age for beluga whales (Delphinapterus leucas) and of vanadium, selenium, cadmium, and mercury with length for ringed seals (Phoca hispada). Many researchers have reported linear correlations of hepatic selenium, cadmium, and mercury with marine mammal age; however, there is only one other report of a linear correlation of hepatic vanadium with marine mammal age. Vanadium levels are at or below detection limits (or = 0.01 micrograms/g) in liver tissues of U.S. east coast marine mammals from the NBSB but are present at levels ranging from 0.02 to 1.2 micrograms/g of wet weight in the tissues of Alaskan marine mammals. Although only three bearded seal (Eriganthus barbatus) and three bow-head whale (Balaena mysticetus) liver samples have been analyzed, hepatic vanadium levels also increased with animal size for these species. The presence of relatively high levels of vanadium in the livers of these Alaskan animals may reflect a unique dietary source of vanadium, a unique geochemical source of vanadium, or anthropogenic input to the Alaskan marine environment.

Maki, A. (1990). The Exxon Valdez wildlife rescue and rehabilitation program. North American Wildlife and Natural Resources Conference, Denver, Colorado, USA, March 16-21, 1990, Wildlife Management Institute; Washington, D.C., USA.

This paper summarizes the organization and operation of the avian and sea otter rescue and rehabilitation programs associated with the Exxon Valdez oil spill during the spring and summer of 1989. These programs were the largest and most comprehensive effort of their kind ever attempted. Included are a short chronology of the rescue programs of both Prince William Sound and Gulf of Alaska and a description of the rehabilitation program. Details of the relative success rates of the programs and evaluations of rehabilitated animals are included to document the lesson learned from the rescue programs.

Maki, A. (1991). "The Exxon Valdez oil spill: Initial environmental impact assessment." Environmental Science and Technology **25**(1): 24-29.

The March 24, 1989, grounding of the Exxon Valdez on Bligh Reef in Prince William Sound, Alaska, USA, was unprecedented in scale. So too was Exxon's response to the oil spill and the subsequent shoreline cleaning program, including the employment of more than 11,000 people, utilization of essentially the entire world supply of containment booms and skimmers, and an expenditure of more than two billion dollars. In the days immediately following the Valdez spill, Exxon mobilized a massive environmental assessment program. A large field and laboratory staff of experienced environmental professionals and internationally recognized experts was assembled that included intertidal ecologists, fishery biologists, marine and hydrocarbon chemists. This field program to measure spill impacts and recovery rates was initiated with the cooperation of state and federal agencies. Although the agencies subsequently foreclosed cooperation in most of these studies because of litigation concerns, this comprehensive assessment program continues today. Through the end of 1989, this program has resulted in well over 45,000 separate samples of water sediment, and biota used to assess spill impacts. It is the intent of this paper to provide initial observations and preliminary conclusions from several of the 1989 studies.

Maki, A., E. Brannon, et al. (1995). An assessment of oil-spill effects on pink salmon populations following the Exxon Valdez oil spill: Part 2. Adults and escapement. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

This paper presents results of a field program designed to monitor the status of wildstock pink salmon (Oncorhynchus gorbuscha) populations in Prince William Sound following the Exxon Valdez oil spill. Field counts of spawning salmon were conducted each year from 1989 through 1992 to test for spill effects on the distribution and abundance of pink salmon adults spawning in selected streams in the southwestern portion of Prince William Sound, including streams from the most heavily oiled areas. Counts of whole-stream and intertidal escapement density were statistically compared for 40 study streams in 1989 and for a subset of those streams in successive years. Measurements of residual hydrocarbons were made from stream-bed sediments to test for correlations with spawning behavior. Adult pink salmon in the postspill years of 1990 and 1991, progeny of the year classes considered most vulnerable to the oil spill, returned in high numbers, with the wildstock spawners exceeding their parent year returns. In 1989, adult returns reflected the relatively weak run for that year with a mean spawner density of 0.68 fish/m super(2) in reference streams and 0.69 fish/m super(2) in oiled streams. In 1990, mean escapement density for reference streams was 1.40 fish/m super(2) and 1.55 fish/m super(2) for oiled streams, indicating the strongest run of the four study years. Trends in polycyclic aromatic hydrocarbon (PAH) concentrations for the majority of oiled streams show a general decline from 1989 to background levels by 1990. The measured PAH concentrations indicate low-level exposure to residual hydrocarbons that have not produced detectable differences in spawning behavior or escapement between streams from oiled areas compared with unoiled streams. In Part 1 of this paper, elements of the early lifestage survival of potentially affected year classes of pink salmon were examined by Brannon et al. (this volume). Conclusions indicate measures of

early lifestages were largely indistinguishable between oiled and unoiled streams. The early lifestage data, in combination with observations of the strength of postspill returns and analyses of escapement reported herein, are the basis for the conclusion that changes in the wildstock pink salmon population in Prince William Sound could not be attributed to the oil spill.

Maniscalco, J. (1996). Seabirds at feeding flocks in Prince William Sound, Alaska. Juneau, AK, University of Alaska.

Thesis

Maniscalco, J. and W. Ostrand (1996). Seabird behaviors at forage fish schools in Prince William Sound, Alaska. Forage Fishes in Marine Ecosystems: Proceedings of the International Symposium on the Role of Forage Fish in Marine Ecosystems, Anchorage, Alaska (USA), 13-16 Nov 1996, American Fisheries Society.

We studied the feeding behaviors of seabirds at mixed-species flocks in Prince William Sound, Alaska, during the summer of 1995. The largest and most persistent flocks were associated with postspawning male capelin. The presence of marbled murrelets and black-legged kittiwakes at the feeding flocks was positively correlated as was the presence of alcids and larids suggesting complementary feeding habits. Kittiwakes preferentially plunge-dived for fish while glaucous-winged gulls usually sat on the water and hop-plunged, possibly limiting access by kittiwakes. While feeding in mixed-species flocks, kittiwakes lost 6.7% of their food catches to interspecific kleptoparasitism and another 4.8% was lost intraspecifically. Kleptoparasitism against kittiwakes was most intense in tightly aggregated flocks and against alcids in loosely aggregated flocks. Jaegers were common kleptoparasites of kittiwakes in the largest flocks.

Maniscalco, J., W. Ostrand, et al. (1998). "Selection of fish schools by flocking seabirds in Prince William Sound, Alaska." Colonial Waterbirds **21**(3): 314-322.

We examined locational and size characteristics of fish schools encountered along transects in Prince William Sound, Alaska, during July-August 1995. We made comparisons between schools that had seabird flocks associated with them and schools that had no flocks nearby. Feeding flocks chose fish schools that were close to shore and in shallow water, as well as those that were smaller than the general population of fish schools. However, fish schools found near shore were significantly smaller than offshore fish schools, suggesting that flocking birds chose feeding habitat rather than school size. Numbers of birds in feeding flocks were positively correlated with fish school chord length and negatively correlated with density and depth of the schools.

Marks, D., K. Kuletz, et al. (1995). "Use of boat-based surveys to determine coastal inland habitat associations of marbled murrelets in Prince William Sound, Alaska." Northwestern Naturalist **76**(1): 63-72.

To identify potential marbled murrelet (Brachyramphus marmoratus) nesting habitat we surveyed western Prince William Sound, Alaska, for murrelet activity

between 12 June and 3 August 1992. We evaluated methods specific to boat-based surveys (vessel and shoreline) by comparing the number of murrelet detections and subcanopy flights during dawn watches adjacent to inland stations. We conducted boat-based surveys from a 19-m vessel (N = 44) and from shoreline stations (N = 23), and concurrently from adjacent inland stations (N = 17). Murrelet activity level and seasonal variation of activity were not significantly different when conducted from the vessel or from shoreline and were similar to surveys at adjacent inland stations. Survey stations near bay heads had higher activity levels than those near exposed coastlines, with the exception of bays that were glaciated or recently deglaciated. We used a timber-type database on a geographic information system to analyze relationships between murrelet activity and habitat within a 1-km radius of each survey station. Forested habitat, particularly forests with trees > 28 cm diameter, showed the strongest correlation to murrelet activity. Boat-based surveys are useful for a preliminary identification of potential murrelet nesting areas in remote and otherwise inaccessible, coastal habitat.

Marks, D. and N. Naslund (1994). "Sharp-shinned hawk preys on a marbled murrelet nesting in old-growth forest." Wilson Bulletin **106**(3): 565-567.

Martin, D., C. Whitmus, et al. (1990). Effects of Petroleum Contaminated Waterways on Migratory Behavior of Adult Pink Salmon. Govt Reports Announcements & Index (GRA&I), Dames and Moore, Seattle, WA.
Pacific Environmental Technologies, Inc., Edmonds, WA.
Washington Univ., Seattle. Lab. of Radiation Ecology.: 258p.

The report describes the effect of oil-contaminated water on the migratory behavior of adult pink salmon. Salmon behavior with and without oil contamination was examined during migration through Jakalof Bay in Alaska. Behavioral responses were measured in horizontal and vertical movement patterns, swimming speed, and duration-of-return to the home stream. Three control and three treatment experiments were conducted. The treatment group was exposed to a solution of aromatic hydrocarbons, similar in composition to Prudhoe Bay crude oil, which was injected into Jakalof Bay midway between a salmon holding pen and Jakalof Creek, a migratory stream. The study found that (1) migrating salmon do not appear to avoid oil-contaminated water with hydrocarbon concentrations at levels of 1 to 10 ppb, but do experience disorientation; (2) disorientation behaviors include searching and negative rheotaxis (retreat); (3) disorientation temporarily disrupts migration, but salmon eventually return to the home stream. These findings suggest that, even at concentrations too low to cause tainting or mortality, salmon exposed to hydrocarbons during migration retreat to re-establish orientation. Final rept. 1987-89. Prepared in cooperation with Pacific Environmental Technologies, Inc., Edmonds, WA., and Washington Univ., Seattle. Lab. of Radiation Ecology. Sponsored by National Ocean Service, Anchorage, AK. Ocean Assessments Div., and Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.

Martin, P. (1997). Effects of the EXXON VALDEZ Oil Spill on Migrant Shorebirds Using Rocky Intertidal Habitats of Prince William Sound, Alaska, during Spring,1989. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Migratory Bird Management.: 81p.

A minimum of a few 10,000's of surfbirds (Aphriza virgata) and black turnstones (Arenaria melanocephala) used rocky intertidal habitats of southwestern Prince William sound in spring 1989. Virtually all the shorebirds were found using shorelines, primarily on northern Montague Island, subjectively classified in the field as lightly oiled or unoiled. Surfbirds and black turnstones preyed mainly on herring eggs, blue mussels, and barnacles. Samples of these prey items from oiled areas contained petroleum-derived hydrocarbons, as did at some of the samples from the relatively clean portions of Montague Island. The results of chemical analysis of a small sample of shorebird liver tissues provided only limited support for the hypothesis that shorebirds had ingested significant quantities of petroleum-derived hydrocarbons. Surfbirds and black turnstones probably escaped significant population impacts as a result of the EVOs because shorelines which received heavy use by these species were largely spared contamination.

Marty, G., R. Heintz, et al. (1997). "Histology and teratology of pink salmon larvae near the time of emergence from gravel substrate in the laboratory." Canadian Journal of Zoology **75**: 978-988.

During salmonid larval development, emergence from gravel substrate is a major event marked by final yolk absorption and transition to exogenous feeding. The gross and histological changes associated with this fundamental biological process were investigated in pink salmon (Oncorhynchus gorbuscha) 4 weeks before emergence (alevins), at emergence (swim-up fry), and 2 weeks after emergence with or without exogenous feeding. Larvae were derived from artificially spawned eggs reared in gravel-filled incubators in the laboratory. Less than 1% of emergent larvae had gross lesions. These included opercular hypoplasia or dysplasia (semioperculum), spinal anomalies (lordosis and kyphosis), conjoined twins, and ophthalmic dysplasia. Apoptosis, or programmed cell death, was a common cellular change, and several cell types were involved; (i) intragonadal supporting cells, (ii) gastric submucosal gland epithelial cells, and (iii) midventral skin cells. Semiquantitative scores for apoptosis were usually highest in pre-emergent larvae and lowest in postemergent larvae. Larvae that were not fed during the first 2 weeks after emergence had slightly higher scores for apoptosis and hepatocellular megalocytosis than did fed controls.

Marty, G., J. Hose, et al. (1997). "Histopathology and cytogenetic evaluation of Pacific herring larvae exposed to petroleum hydrocarbons in the laboratory or in Prince William Sound, Alaska, after the Exxon Valdez oil spill." Canadian Journal of Fisheries and Aquatic Sciences **54**(8): 1846-1857.

Following the 1989 Exxon Valdez oil spill in Prince William Sound(PWS), Alaska, USA, Pacific herring(Clupea pallasi) larvae sampled from oiled sites had ascites, pericardial edema, and genotoxic damage. Laboratory study confirmed that these lesions were consistent with oil exposure. Pacific herring larvae were trawled from two oiled and two unoiled sites in PWS in May 1989. Larvae from oiled sites were shorter, had ingested less food, had slower growth (oiled, 0.07-0.10 mm/day; unoiled, 0.15-0.18 mm/day), and had higher prevalence of cytogenetic damage(oiled, 56-84%; unoiled, 32-40%) and ascites,(oiled, 16%; unoiled, 1%) than from unoiled sites. In the laboratory experiment, Pacific herring eggs were exposed to an oil-water dispersion of Prudhoe Bay crude oil(initial concentrations of 0.0,0.10,0.48,and 2.41 mg/L) and sampled for histopathology <24 h after hatching. Effects were significant at the 0.48 m/L dose. Lesions including ascites; hepatocellular vacuolar change; and degeneration or necrosis of skeletal myocytes, retinal cells, and developing brain cells. Lesions in field-sampled larvae were consistent with higher mortality rates documented in larvae from oiled sites.

Marty, G., M. Okihiro, et al. (1999). "Histopathology of adult Pacific herring in Prince William Sound, Alaska, after the Exxon Valdez oil spill." Canadian Journal of Fisheries and Aquatic Sciences **56**(3): 419-426.

Pacific herring (Clupea pallasi) sampled from oiled sites in Prince William Sound, Alaska, U.S.A., 3 weeks after the 1989 Exxon Valdez oil spill had multifocal hepatic necrosis and significantly increased tissue concentrations of polynuclear aromatic hydrocarbons (PAH). By comparison, Pacific herring from reference sites in 1989 and from all sites in 1990 and 1991 did not have hepatic necrosis or increased PAH concentrations. Adult Pacific herring were sampled for histopathology of liver, spleen thalenes in samples from 1989 is consistent with recent laboratory study in which crude oil exposure resulted in dose-dependent expression of viral hemorrhagic septicemia virus (VHSV). We conclude that Pacific herring were exposed to Exxon Valdez oil in 1989 and that development of hepatic necrosis in exposed fish probably was a result of VHSV expression.

Marty, G., J. Short, et al. (1997). "Ascites, premature emergence, increased gonadal cell apoptosis, and cytochrome-P4501A induction in pink salmon larvae continuously exposed to oil-contaminated gravel during development." Canadian Journal of Zoology **75**: 989-1007.

Development of pink salmon (Oncorhynchus gorbuscha) incubating in gravel contaminated with weathered Prudhoe Bay crude oil was retarded at concentrations as low as 55.2 mu g oil/g gravel. Larvae exposed to various levels of oil contamination were sampled 4 weeks before emergence, at emergence, and 13 days after emergence for histopathology (quantitative and semiquantitative) and cytochrome P4501A (CYP1A) induction (using immunohistochemical staining). A subset of postemergent fish was not fed. Hydrocarbon analysis by gas chromatography and mass spectroscopy revealed that tissue uptake of polynuclear aromatic hydrocarbons (PAH) was mediated by oil's dissolution in water, with significant biological effects when the peak total

PAH concentration in water was as low as 4.4 mu g/L. Oil-related effects included induction of CYP1A, development of ascites, and increased mortality. Several oil-related changes were indicative of premature emergence. Compared with control fish, for example, exposed fish of the same age and emerging on the same day had greater amounts of yolk and hepatocellular glycogen, increased apoptosis of gonadal cells and midventral skin cells, and less food in the gastrointestinal tract. Histological features were similar within groups of larvae sampled 4 weeks before and 13 days after emergence, and oil-induced changes were not affected by feeding during the first 13 days after emergence. Increased gonadal cell apoptosis may be related to later reproductive impairment documented in field studies of pink salmon up to 4 years after the Exxon Valdez oil spill.

Marty, G. D., E. F. Freiberg, et al. (1998). "Viral hemorrhagic septicemia virus, Ichthyophonus hoferi, and other causes of morbidity in Pacific herring (Clupea pallasi) spawning in Prince William Sound, Alaska, USA." Diseases of Aquatic Organisms **32** (1): 15-40.

Pacific herring Clupea pallasi populations in Prince William Sound, Alaska, USA, declined from an estimated 9.8 x 10(7) kg in 1992 to 1.5 x 10(7) kg in 1994. To determine the role of disease in population decline, 233 Pacific herring from Prince William Sound were subjected to complete necropsy during April 1994. The North American strain of viral hemorrhagic septicemia virus (VHSV) was isolated from 11 of 233 fish (4.7%). VHSV was significantly related to myocardial mineralization, hepatocellular necrosis, submucosal gastritis, and meningoencephalitis. Ichthyophonus hoferi infected 62 of 212 (29%) fish. I. hoferi infections were associated with severe, disseminated, granulomatous inflammation and with increased levels of plasma creatine phosphokinase (CPK) and aspartate aminotransferase (AST). I. hoferi prevalence in 1994 was more than double that of most previous years (1989 to 1993). Plasma chemistry values significantly greater (p 0.01) in males than females included albumin, total protein, cholesterol, chloride, glucose, and potassium; only alkaline phosphatase was significantly greater in females. Hypoalbuminemia was relatively common in postspawning females; other risk factors included VHSV and moderate or severe focal skin reddening. Pacific herring had more than 10 species of parasites, but they were not associated with significant lesions. Two of the parasites have not previously been described: a renal intraductal myxosporean (11% prevalence) and an intestinal coccidian (91% prevalence). Transmission electron microscopy of a solitary mesenteric lesion revealed viral particles consistent with lymphocystis virus. No fish had viral erythrocytic necrosis (VEN). Prevalence of external gross lesions and major parasites was not related to fish age, and fish that were year-lings at the time of the 1989 'Exxon Valdez' oil spill (1988 year class) had no evidence of increased disease prevalence.

Mather, D. and D. Esler (1999). "Evaluation of bursal depth as an indicator of age class of harlequin ducks." Journal of Field Ornithology **70**(2): 200-205.

We contrasted the estimated age class of recaptured Harlequin Ducks

(Histrionicus histrionicus) (n = 255) based on bursal depth with expected age class based on bursal depth at first capture and time since first capture. Although neither estimated nor expected ages can be assumed to be correct, rates of discrepancies between the two for within-year recaptures indicate sampling error, while between-year recaptures test assumptions about rates of bursal involution. Within-year, between-year, and overall discrepancy rates were 10%, 24%, and 18%, respectively. Most (86%) between-year discrepancies occurred for birds expected to be after-third-year (ATY) but estimated to be third-year (TY). Of these ATY-TY discrepancies, 22 of 25 (88%) birds had bursal depths of 2 or 3 mm. Further, five of six between-year recaptures that were known to be ATY but estimated to be TY had 2 mm bursas. Reclassifying birds with 2 or 3 mm bursas as ATY resulted in reduction in between-year (24% to 10%) and overall (18% to 11%) discrepancy rates. We conclude that age determination of Harlequin Ducks based on bursal depth, particularly using our modified criteria, is a relatively consistent and reliable technique.

Matkin, C., G. Ellis, et al. (1994). Status of killer whales in Prince William Sound, 1985-1992. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 141-162.

All seven regularly encountered, resident killer whale pods used the oiled areas of PWS in the year following the EVOS. Killer whales did not avoid oiled areas and did not avoid surfacing in oil slicks. Thus, there was a potential for whales to contact oil or consume oiled prey in the spill area. There were substantial losses of individulals within the AB pod only in the two years following the EVOS (1989-1990), with the death of13 whales, primarily juveniles and reprductive females. Although there was was a previous history of the AB pod inteacting with the PWS sablefish fishery and a significant rise in mortality rates at that time (1985-1986), there was no evidence of fishery-related mortalities in 1988-1990. Ananlyses demonstrated significantly higher mortality rates for PWS resident killer whales in 1988-1990 than for any period except when whales were being shot during sablefish fishery interactions. In addition, it is possible that the nine whales missing for 3 years from the transient AT1 group are also dead, though it is not certain because of the variability of associations between transient whales. The factors potentially responsible for the loss of the 14 AB pod whales are discussed in Dahlheim and Matkin.

Matkin, C., G. Ellis, et al. (1999). "Association patterns and inferred genealogies of resident killer whales (Orcinus orea) in Prince William Sound, Alaska." Fishery Bulletin **97**: 900-919.

The social structure and genealogical relationships of resident killer whale pods in Prince William Sound, Alaska, are inferred from association analysis and direct observation. During 1984-95 a total of 2444 hours of observation were made and 36,009 photographs were taken of identifiable killer whales. Cole's association index and a point correlation coefficient index were used to test the statistical significance and strength of associations between individuals, and a clustering procedure was used to delineate group structure. A total of 202 whales

were grouped into 9 pods. Genealogical relationships were inferred from the strength of bonds among pod members. Genealogical trees suggested that intrapod groups were matrilineal in structure. Splitting of one pod (AN pod) was observed during the study; however, there was no splitting of matrilineal groups.

Matkin, C., D. Matkin, et al. (1997). "Movements of resident killer whales in southeastern Alaska and Prince William Sound, Alaska." Marine Mammal Science **13** (3): 469-475.

McCain, B. B., D. W. Brown, et al. (2000). National Status and Trends Program National Benthic Surveillance Project: Pacific Coast; Organic Chemical Contaminants Cycles I to VII (1984-90), Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, U.S. Department of Commerce: 121pp + xv.

As a component of National Oceanic and Atmospheric Administration's (NOAA) National Status and Trends (NS&T) Program, the National Benthic Surveillance Project (NBSP) monitored levels of contaminants in sediment and bottomfish and prevalences of pathological conditions in bottomfish at selected sites throughout the U.S. coastline. This memorandum summarizes and interprets the status and trends of the organic chemical contaminants for 50 sites in Alaska, Washington, Oregon, and California for the years 1984-1990 and includes results of 3213 chemical analyses of sediment, fish stomach contents, fish liver, and bile samples. Thirty-one of these sites were in or near urban centers and were selected to be as representative as possible of waste inputs from multiple sources, although the sites were not necessarily representative of entire embayments.

Uniform sampling protocols and state-of-the-art analytical methods have produced an extensive database, which includes detailed information on the distribution of selected polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and chlorinated hydrocarbon insecticides (CHs) in surficial sediments and stomach contents of selected species of bottom-feeding fish. Coprostanol (COP) was determined in sediment samples as a marker compound of sewage. The PAHs were divided into two classes of compounds: lower molecular weight PAHs (LAHs), having two to three aromatic rings; and higher molecular weight PAHs (HAHs), having four to six aromatic rings. Livers were not analyzed for PAHs because they are of limited value due to the extensive biotransformation of these compounds to more polar metabolic products, most of which are readily excreted into the bile. Therefore, exposure of fish to PAHs was estimated by measuring fluorescent aromatic compounds (FACs) in bile and to PAHs in stomach contents. Concentrations of biliary FACs are reported as benzo[a]pyrene equivalents (FACs-H), representing the HAHs; or naphthalene equivalents (FACs-L), representing LAHs. Liver tissues of fish were analyzed for CHs, PCBs (tri- through decachlorobiphenyls), and several CHs including 2,2-bis(p-chlorophenyl)-1,1,1-trichloroethane and its metabolites (DDTs); chlordanes (a-chlordane and trans-nonachlor), dieldrin, and hexachlorobenzene (HCB).

The overall findings from the NBSP for the period 1984-90 indicated that the highest concentrations of most sediment-associated organic contaminants were present in the most highly urbanized areas, and that many of the organic contaminants were bioaccumulated by indigenous
marine fish species. The highest levels of organic contaminants were found at sites in San Francisco Bay (Hunters Point, Oakland Estuary), Santa Monica Bay, San Pedro Bay (Los Angeles and Long Beach), San Diego Bay, and Puget Sound (Seattle and Tacoma).

McCutcheon, S., J. Haines, et al. (1993). Nutrient Movement through Beach Media: Problems and Field Results Application to Enhance Cleanup of Oil Contaminated Shoreline. Govt Reports Announcements & Index (GRA&I), Environmental Protection Agency, Cincinnati, OH. Risk Reduction Engineering Lab.: 16p.

On March 24,1989, the Exxon Valdez went aground in Prince William Sound, Alaska, releasing approximately 11 million gallons of Prudhoe Bay crude oil. After learning of the magnitude of the spill, the EPA office of Research and Development (ORD) convened a meeting of nationally and internationally recognized scientists in the field of oil biodegradation to evaluate the feasibility of using bioremediation to assist in cleanup operations. Recommendations from the meeting urge ORD to plan and conduct a field demonstration project to evaluate the use of fertilizers for accelerating natural biodegradation of the spilled oil. Symposium paper. See also PB93-191336.

McDonald, L., W. Erickson, et al. (1995). Survey design, statistical analysis and basis for statistical inferences in coastal habitat injury assessment: Exxon Valdez oil spill. Exxon Valdes Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdes Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

The objective of the Coastal habitat Injury Assessment study was to document and quantify injury to biota of the shallow subtidal, intertidal, and supratidal zones throughout the shoreline affected by oil or cleanup activity associated with the Exxon Valdez oil spill. The results of these studies were to be used to support the Trustee's Type B Natural Resource Damage Assessment under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). A probability based stratified random sample of shoreline segments was selected with probability proportional to size from each of 15 strata (5 habitat types crossed with 3 levels of potential oil impact) based on those data available in July, 1989. Three study regions were used: Prince William Sound, Cook Inlet/Kenai Peninsula, and Kodiak/Alaska Peninsula. A Geographic Information System was utilized to combine oiling and habitat data and to select the probability sample of study sites. Quasi-experiments were conducted where randomly selected oiled sites were compared to matched reference sites. Two levels of statistical inferences, philosophical bases, and limitations are discussed and illustrated with example data from the resulting

studies.

McGurk, M. and E. Brown (1996). "Egg-larval mortality of Pacific herring in Prince William Sound, Alaska, after the Exxon Valdez oil spill." Canadian Journal of Fisheries and Aquatic Sciences **53**(10): 2343-2354.

We tested the hypothesis that instantaneous daily rates of egg-larval mortality of Pacific herring, Clupea pallasi, were greater at two oil-exposed sites than at two nonexposed sites. Egg-larval mortality is defined as the ratio of larval density at hatch to mean egg density divided by the number of elapsed days between the dates of the two estimates. There were significant differences between sites in egg density, small differences between sites in mean larval length, and no oil-related differences between sites in the rates of larval growth and loss. However, mean egg-larval mortality in the two oiled areas was twice as great as in the two nonoiled areas, and larval growth rates were about half those measured in populations from other areas of the north Pacific Ocean. These findings support the hypothesis of oil injury to herring embryos and larvae.

McGurk, M., D. Warburton, et al. (1990). Early life history of Pacific herring: 1989 Prince William Sound herring larvae survey. Burnaby B.C. (Canada): 272 pp.

The study measured growth, mortality and dispersal of wild Pacific herring, Clupea harengus , larvae from two oiled sites and two non-oiled sites in Prince William Sound in order to determine the impact of the Exxon Valdez oil spill on larval population dynamics. Water temperatures and degree of stratification were highest in the two shallow control sites in the north of the Sound and lowest in the two oiled sites nearest Hinchinbrook Entrance. Concentration of prey of herring larvae increased over the May-June period and was not significantly different between sites. No evidence was found to support the hypothesis that oil reduced growth rates or increased mortality rates of the larvae.

McGurk, M., D. Warburton, et al. (1990). Early life history of Pacific herring: 1989 Prince William Sound herring egg incubation experiment. Burnaby B.C. (Canada): 412.

In March, 1989, oil spilled from the tanker Exxon Valdez washed onto Pacific herring, Clupea pallasi harengus , spawning beaches in Prince William Sound, Alaska. The purpose of the study was to measure the viable hatch of herring eggs spawned on oiled and non-oiled beaches of the Sound. Over 180 samples of live eggs were taken from five control transects outside of the contaminated area and 18 transects within the contaminated area and incubated to hatch. Only a weak relationship between oil exposure and effects on the biology of herring embryos was apparent.

McGurk, M., H. Warburton, et al. (1993). Effects of the Exxon Valdex oil spill on survival of Pacific herring eggs and viability of their larvae. Nineteenth Annual Aquatic Toxicity Workshop,, Edmonton, Alberta, Canada, October 4-7,1992.

On March 24, 1989, the oil tanker Exxon Valdez spilled 250,000 barrels of

Prudhoe Bay crude oil onto the surface of Prince William Sound, Alaska. The spill coincided with the spawning period of Pacific herring (Clupea pallasi) in the Sound. Adult herring were first observed near their spawning grounds about one week after. Previous research has shown that growth and mortality of free-swimming herring larvae were not significantly different between oiled and non-oiled areas of the Sound, suggesting that any effect of the oil spill on herring may have been restricted to the egg stage. We tested this hypothesis by measuring survival, hatching schedule and viability of herring eggs collected from oiled and non-oiled areas of the Sound and incubated in laboratory aquaria.

Meador, J., R. Clark, et al. (1994). National Status and Trends Program for National Benthic Surveillance Project: Pacific Coast. Analyses of Elements in Sediment and Tissue Cycles I-V (1984-88). NOAA Technical Memorandum NOAA-TM-NMFS-NWFSC-16, National Marine Fisheries Service, Seattle, WA. Northwest Fisheries Science Center.: 218p.

This technical memorandum summarizes and interprets the results for the metal and metalloid (elements) contaminants for the first 5 years (1984-88) of the Pacific coast portion of the National Benthic Surveillance Project (NBSP). The NBSP determines the levels of contaminant chemicals and prevalence of pathological lesions in bottom fish and relates them to contaminant levels in associated sediment. An extensive database has been developed, which includes detailed information on the distribution of selected elemental contaminants. These include the toxic elements antimony, arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, tin, and zinc as well as the major elements aluminum, iron, manganese, and silicon in surficial sediments, liver tissues, and in stomach contents of selected fish. Of the 51 sites sampled in Washington, Oregon, California (West Coast), and Alaska, 27 were located in or near urban centers. See also PB93-183911.

Mearns, A. (1996). Exxon Valdez shoreline treatment and operations implications for response assessment monitoring and research. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5,1993, American Fisheries Society; Bethesda, Maryland, USA. **18:** 309-328.

Existing operational and research information was examined to evaluate the effectiveness and effects of shoreline treatment and supporting operations during response to the March 1989 Exxon Valdez oil spill. The primary treatment methods were manual cleanup, aggressive shoreline washing with specially designed vessels, bioremediation, and, in 1990 and 1991, berm relocation. Other types of treatment (chemical cleaners, rock washing) were proposed, tested, and rejected. Treatment activity at some sites lasted for up to 2 months. Published data suggest that 1989 treatment removed between 4 and 9% of the stranded oil; additional data suggest that high-pressure hot-water washing was twice as effective as this average. About one-third of all shoreline segments in western Prince William Sound received high-pressure hot-water washing coupled in many areas with beach-face coldwater deluge. Calculations from shoreline

biological-monitoring data suggest that although half of the midintertidal shoreline seaweed and other marine life survived oiling, these were nearly completely destroyed by the cleanup at the aggressively treated sites. The effectiveness of bioremediation and berm relocation was studied. Only anecdotal information exists for evaluating the effectiveness and effects of other technologies. Review of photos also suggests that aggressive treatment in midsummer 1989 produced sediment plumes that may have redistributed oil offshore of treatment sites. Operations supporting shoreline treatment were extensive: more than 10,000 people expended 20.5 million hours using more than 1,600 vessels and thousands of aircraft sorties. The literature suggests noise, low-flying aircraft, vessel avoidance (deflection), and anchor chain could have affected marine and terrestrial biota. Despite these concerns, shoreline treatment was undertaken under constraints that presumably did minimize additional impacts. Continuing studies of this spill should include treatment and supporting operations as potential sources of injury.

Meldinger, J. (1999). Response Mobilization following the Exxon Valdez Oil Spill and its Effects on Subsistence Villages. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 105-114.

The problems, issues, situations and responses of the various parties following the spill are described. At the time of the spill, none of the parties-Exxon, the governments, or health agencies-was adequately prepared to address concerns of Natives, i.e., to implement testing programs or effectively communicate information regarding the effect of oil on subsistence resources. For example, food supplies at several villages were running low when the spill occurred, yet villagers were reluctanct to consume subsistence foods following the spill fearing their foods were contaminated. Furthermore, adequate official respone about food safety to allay their fears was slow to come to residents. Interests and responses of the concerned parties (e.g., villagers, Exxon, the Oil Spill Task Force, various government agencies) are explained. Several issues relative to this spill provide a basis for planning improved response to future spills.

Michel, J. and M. Hayes (1996). Evaluation of the Condition of Prince William Sound Shorelines Following the Exxon Valdez Oil Spill and Subsequent Shoreline Treatment. Volume 1. Summary of Results. Geomorphological Shoreline Monitoring Survey of the Exxon Valdez Spill Site, Prince William Sound, Alaska, September 1989-August 1992. NOAA Technical Memorandum NOAA-TM-NOS-ORCA-73-V1, National Ocean Service, Seattle, WA. Office of Ocean Resources Conservation and Assessment Research Planning Inst., Inc., Columbia, SC.: 130p.

The objective of this special study was to collect samples of the various types of residual oil, in close cooperation with the geomorphological studies, so that the interpretations would include an understanding of the physical setting and processes which have contributed to the weathering history. The report presents the results of the August 1992 survey and a summary of the persistence of oil in representative shoreline environments. Special emphasis has been placed on

presentation of summary of the subsurface oiling patterns and changes over time. Technical memo. Color illustrations reproduced in black and white. Also pub. as National Ocean Service, Seattle, WA. Office of Ocean Resources Conservation and Assessment rept. no. NOAA-TM-NOS-ORCA-73-V1. See also Volume 2, PB96-113295. Sponsored by National Ocean Service, Seattle, WA. Office of Ocean Resources Conservation and Assessment.

Michel, J. and M. Hayes (1999). "Weathering Patterns of Oil Residues Eight Years after the Exxon Valdez Oil Spill." Marine Pollution Bulletin **38**(10): 855-863.

Eight years after the Exxon Valdez spill, oil residues in Prince William Sound, Alaska ranged from moderately to extremely weathered. The least weathered residues were found in samples collected from gravel beaches with well-established armor. There had been little to no change in weathering stage for the oil from these sites since 1994. There was evidence of some physical erosion, but little chemical change for this deeply penetrated oil. In contrast, most other oil residues have increased in weathering, compared to 1994. Only one asphalt pavement was at a moderate weathering stage. All other samples contained hydrocarbons which were at advanced or extreme weathering stages.

Middaugh, D., P. Chapman, et al. (1996). "Responses of embryonic and larval inland silversides, Menidia beryllina, to a water-soluble fraction formed during biodegradation of artificially weathered Alaska North Slope crude oil." Archives of Environmental Contamination and Toxicology **31**(3): 410-419.

Weathered Alaska North Slope crude oil (ANS 521) was stirred for 2 and 14 days in 20ppt salinity sterile seawater or for 14 days in seawater with nutrients and a group of three (GO3) microorganisms from Prince William Sound, Alaska, that were capable of biodegrading hydrocarbons. A total of 0.65 and 0.69 mg/L water soluble fraction (WSF) of neutral fraction hydrocarbons was recovered from the 2- and 14-day stirred sterile systems, respectively. In comparison, a total of 7.5 mg/L WSF neutral fraction hydrocarbons was recovered from systems containing ANS 521 that were stirred and biodegraded by the GO3 microbes for 14 days. Toxicity/teratogenicity tests were conducted with neutral fraction hydrocarbons recovered from the sterile and biodegraded systems using embryonic inland silversides, Menidia beryllina. Hydrocarbons from the sterile systems did not cause statistically significant teratogenic responses at concentrations of 1%, 10%, and 100% (w/v) of recovered fractions (redissolved in 20ppt salinity sterile seawater). Counts of heart contraction rates were significantly lower (alpha less than or equal to 0.05) at the 100% WSF concentration of hydrocarbons on days 5 and 6 of embryogenesis. In contrast, recovered and redissolved neutral fraction hydrocarbons from ANS 521, that were biodegraded for 14 days, caused statistically significant (alpha less than or equal to 0.05) teratogenic responses at the 1, 10, and 100% WSF concentrations. Measurement of heart contraction rates showed statistically significant (alpha less than or equal to 0.05) reductions at the 100% WSF concentration on days 2 through 6 of embryogenesis, compared to controls.

Middaugh, J. and e. al. (2000). Assessment of exposure to POPs in 5 Aleutian and Pribilof villages. International Conference in Arctic Development, Pollution, and Biomarkers of of Human Health, Anchorage AK.

Miles, A., D. Calkins, et al. (1992). "Toxic elements and organochlorines in harbor seals (Phoca vitulina richardsi), Kodiak, Alaska, USA." Bulletin of Environmental Contamination and Toxicology **48**(5): 727-32.

Marine and estuarine habitats near urban or industrialized regions are vulnerable to contaminated runoff. Harbor seals (Phoca vitulina richardsi), which occur throughout much of the northern hemisphere, are useful mammalian biomonitors because they feed, reproduce, and rest near or on shore and are high-level trophic consumers. They have often been monitored for contaminants in Europe. To date, no studies have been reported on contaminants in harbor seals from industrialized areas of Alaska. In the vicinity of Anchorage, Alaska's largest urban and industrial city, harbor seals are sedentary and limited to coastal waters; some movements have been documented but there is no evidence of extensive migrations. Although some harbor seals in the Kodiak Archipelago move up to 100 km along the shore, strong fidelity to specific haulout sites is more common. These seals eat mainly non-migratory fishes and octopi. Harbor seal numbers have declined substantially from unknown causes in the southern part of the Kodiak Archipelago. The Alaska Department of Fish and Game (ADF&G) suggested that the decline is a trend for the entire Kodiak region and other Alaskan waters. Contaminants have been suggested as a possible reason for the precipitous decline of Steller sea lions (Eumetopias jubatus) in the region , and were suspected in the decline of harbor seals. In this study, harbor seals were sampled from throughout the Kodiak Archipelago to determine concentrations of certain metals, metalloids, polychlorinated biphenyls (PCBs), and organochlorine pesticides, and to determine if these concentrations varied by sex or accumulated with age. All seals were collected within 75 km of Cook Inlet, an estuary next to Anchorage. The targeted elements or compounds were known to be toxic to a wide spectrum of organisms.

Miller, G., J. Seeb, et al. (1994). "Saltwater exposure at fertilization induces ploidy alterations, including mosaicism, in salmonids." Canadian Journal of Fisheries and Aquatic Sciences **51**(Supplement 1): 42-49.

We found that salt water induces ploidy alterations in salmonid embryos. Flow cytometry analysis revealed significantly higher frequencies of haploids, triploids, heteroploid mosaics, and aneuploids in rainbow trout (Oncorhynchus mykiss) embryos experimentally exposed to salt water from fertilization to the two- and eight-cell stages of development. Heteroploid mosaics have been reported in diploid and triploid salmonid hybrids, although none were observed in the triploid coho salmon or diploid and triploid coho salmon (O. kisutch) x chinook salmon (O. tshawytscha) hybrids we examined. No mosaics were observed in intertidally spawned pink salmon (O. gorbuscha) embryos. Salt water could induce ploidy alterations by causing chromosome segregation errors during meiosis, mitosis, or both. Heteroploid embryos appeared morphologically normal although they

may possess physiological deficiencies not immediately apparent.

Miller, S., G. White, et al. (1997). "Brown and black bear density estimation in Alaska using radiotelemetry and replicated mark-resight techniques." Wildlife Monographs (133): 1-55.

Accurate density and population estimates are needed to manage bear populations but are difficult to obtain. Most such estimates reported for bears are largely subjective and lack estimates of precision. Fifteen brown bear (Ursus arctos) and 3 black bear (U. americahus) density estimates were obtained in Alaska during 1985 through 1992 using 2-9 replicates of capture-mark-resight (CMR) techniques in 17 different areas. Our studies used radiotelemetry to document movements of marked animals into ana from search areas. This procedure essentially eliminated the need to correct density estimates for edge or periphery effects caused by absence of geographic closure. To estimate population size, we used a maximum-likelihood estimator modified to accommodate temporary movements of marked animals into and from our search areas. Our approach permitted direct calculations of density from our population estimates. Our procedures provided density estimates that were repeatable, were comparable among areas, included estimates of precision, and were more objective than methods historically used to estimate bear abundance. Our density estimation procedures have widespread applicability for other wildlife studies using radiotelemetry.Our estimates were obtained within a wide spectrum of habitats and provided a range of Alaskan densities from 10.1 to 551 brown bears (all ages)/1,000 km(2) and from 89 to 289 black bears (all ages)/1,000 km (2). Our highest brown bear density is probably near the maximum for this species, but areas with lower densities (3.9/1,000 km(2)) have been reported in Alaska. Areas with black bear densities higher than in our study areas probably occur in Alaska. Brown bear densities were 6-80 times greater in coastal areas where abundant runs of multiple species of salmon (Oncorhynchus spp.) were available to bears than in interior areas. Our CMR technique provided useful data for bear population management and impact assessments and has potential for application to other species and areas.

Mitchell, K. (1990). Workshop to design baseline and monitoring studies for the OCS Mining Program, Norton Sound, Alaska. Workshop proceedings. Outer Continental Shelf Report U.S. Mineral Management. Service, U.S. Mineral Management. Service: 181.

The final report contains the workshop proceedings of the workshop held November 30 to December 1, 1989 in Anchorage, Alaska to Design Baseline and Monitoring Studies for the OCS Mining Program Norton Sound, Alaska. The following subjects were covered: Background; Workshop structure, products, and logistics; Recent results on trace metal content of environmental samples in vicinity of Nome, Alaska; Detecting contamination or trends in the concentration of trace metals on marine environments; Potential hazards of sediment interstitial waters to marine benthic organisms; Accumulation and toxicity of mercury, cadmium, and lead in vertebrates; Habitat alteration; WestGold's environmental

monitoring program; Monitoring of the Nome population; Human exposure as a monitor of environmental contamination: its possibilities and limitations as illustrated by the case of methylmercury in northern Quebec; General sampling considerations for baseline surveys of offshore mineral mining; Suggested baseline and monitoring program for Norton Sound gold dredging operation on Federal lands near Nome, Alaska. (See also PB91-135640. Sponsored by Minerals Management Service, Anchorage, AK. Alaska Outer Continental Shelf Office.)

Moles, A. (1998). "Sensitivity of ten aquatic species to long-term crude oil exposure." Bulletin of Environmental Contamination and Toxicology **61**(1): 102-107.

A few researchers have used long-term exposures to crude oil water-soluble fraction (WSF) to assess the effects of petroleum on such processes as bioenergetics, growth, reproduction, stamina, and feeding rate. This is the first paper, however, to compare long-term toxicity of oil to a wide variety of phyla, using the same stable oil generation and analytical methods for comparison. We compare the 4- and 28-d sensitivities of 10 marine animals to the WSF of Cook Inlet crude oil. We also compare out results to published 4-d static bioassay values for the same species. These data are intended to provide resource managers with information on the comparative vulnerability of different species in a variety of habitats.

Moles, A. (1999). "Parasitism, feeding rate, and hydrocarbon uptake of pink shrimp Pandalus borealis fed a crude oil contaminated diet." Bulletin of Environmental Contamination and Toxicology **62**(3): 259-65.

Pink shrimp, Pandalus borealis, are fished commercially in both the North Pacific and North Atlantic Oceans. In the northeast Pacific, commercial fisheries catches have fallen in half over the last two decades and the decline has been attributed to continuously expanding harvests coupled with environmental changes (Wolotira et al. 1990). Pandalid shrimp hatch as males and transform into females after 2-3 yrs. growth. Pink shrimp are opportunistic foragers closely associated with the soft bottom sediments all along the 550 square miles of Alaska's outer continental shelf This same area, which constitutes over half the United States' coastline, has been the subject of oil leasing, exploration and drilling. Juvenile pink shrimp (males) are found in shallow (<50 m) waters (Wolotira et al. 1990). As nearshore residents, juvenile shrimp are therefore more vulnerable to pollution than are other life stages that are present in deeper water. If hydrocarbons are released into the inshore nursery areas, juvenile shrimp would come in contact with oil contaminated water, sediment, or food. Shrimp larvae and adults are among the animals most sensitive to oil in water and show cumulative effects following long-term exposure (Stickle et al. 1987). However, epibenthic shrimp are unlikely to be exposed to water-borne oil for long periods because hydrocarbons rapidly evaporate in the water column following an oil spill. Little oil finds its way into the lower subtidal sediments as well (O'Clair et al. 1996). Although pink shrimp do not bury in the sediment, they feed on benthic detritis. Following an

oil spill, shrimp or their prey may be contaminated by direct ingestion of colloidal crude oil (Conover 1971). To determine if oiled food would be consumed and incorporated into tissues by shrimp, I determined feeding rates and hydrocarbon uptake of male pink shrimp exposed to oiled food.

Moles, A. and B. Norcross (1998). "Effects of oil-laden sediments on growth and health of juvenile flatfishes." Canadian Journal of Fisheries and Aquatic Sciences **55**(3): 605-610.

Juvenile yellowfin sole (Pleuronectes asper), rock sole (Pleuronectes bilineatus), and Pacific halibut (Hippoglossus stenolepis) had reduced growth following 30-90 days of exposure to sediments laden with Alaska North Slope crude oil. Changes in fish health bioindicators after 90 days, i.e., increases in fin erosion, liver lipidosis, gill hyperplasia, and gill parasites, coupled with decreases in macrophaae aggregates, occurred at hydrocarbon concentrations (1600 mug/g) that reduced growth 34-56% among the flatfishes. Chronic hydrocarbon pollution of nearshore nursery sediments could alter growth and health of juvenile flatfishes. Recruitment of juveniles to the fishery may decline because of increased susceptibility to predation and slower growth.

Moles, A., S. Rice, et al. (1994). "Non-avoidance of hydrocarbon laden sediments by juvenile flatfishes." Netherlands Journal of Sea Research **32**(3-4): 361-367.

Behavioural tests were used to determine whether juvenile flatfishes were capable of detecting and avoiding sediment containing various concentrations of petroleum hydrocarbons. Three species of juvenile Alaskan flatfishes: rock sole (Pleuronectes bilineatus), yellowfin sole (P. asper), and Pacific halibut (Hippoglossus stenolepis) were tested in laboratory chambers containing contaminated mud or sand offered in combination with clean mud, sand or granule. The flatfishes were able to detect and avoid heavily oiled (2%) sediment, but they did not avoid lower concentrations of oiled sediment (0.05%). Oiled sediment was favoured over unoiled sediment if the unoiled sediment was of the grain size not preferred by that species. Oiled sand or mud was always preferred over unoiled granule. The observed lack of avoidance at concentrations likely to occur in the environment may lead to long-term exposure to contaminated sediment following a spill. Recruitment of juveniles may be affected if the exposure to oil is long enough to affect growth and survival.

Moles, A., S. Rice, et al. (1993). Herring parasite and tissue alterations following the Exxon Valdez oil spill. Proceedings of the 1993 International Oil Spill Conference, Tampa, Florida, March 20 - April 1, 1993.

Monnett, C. and L. Rotterman (1996). Technical Report: Marine Mammals Study Number 6. Mortality and Reproduction of Sea Otters Oiled and Treated as a Result of the EXXON VALDEZ Oil Spill. Marine Mammal Study 6-14. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports

Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage.: 56p.

Radio-instrumented sea otters (N = 45) that were released into eastern Prince William Sound during summer,1989, following efforts to rehabilitate them at otter treatment centers, have been monitored regularly for approximately 2 years. Respective survival rates of male and female sea otters released from the treatment centers were: Year 1: males P = 0,401, females P = 0.401, females P = 0.445; Year 2: males P = 0.714, females P = 0.692. Only 2 of 11 (18%) mature females pupped during 1990. Sea otters released from treatment centers had lower survivorship and pupping rates than sea otters in other study populations. Technical rept. Sponsored by Exxon Valdez Oil Spill Trustee Council, AK.

Monnett, C., L. Rotterman, et al. (1990). Postrelease monitoring of radio-instrumented sea otters in Prince William Sound. Sea Otter Symposium: Proceedings of a Symposium to Evaluate the Response Effort on Behalf of Sea Otters After the T/V Exxon Valdez Oil Spill into Prince William Sound.

Monson, D. and B. Ballachey (1996). Age Distributions of Sea Otters Found Dead in Prince William Sound, Alaska, Following the EXXON VALDEZ Oil Spill. Marine Mammal Study 6-15. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage.: 23p.

Age distribution of sea otters (Enhydra lutris) found dead on beaches in western Prince William Sound Alaska, from 1976 to 1984, were compared to those of sea otters found dead from 1989 to 1993, following the Exxon Valdez oil spill. The age distribution of sea otters recovered in western Prince William Sound prior to the spill was bimodal and composed of primarily young and old animals. The high proportion of prime-age otters recovered immediately following the spill indicates significant losses occurred within a segment of the population which normally experiences very low mortality. The high proportion of prime-age otters recovered in 1990-1991 may be evidence of a prolonged, spill-related effect on the western Prince William Sound sea otter population.

Monson, D. H., D. Doak, et al. (2000). "Long-term impacts of the Exxon Valdez oil spill on sea otters, assessed through age-dependent mortality patterns." Proc. Natl. Acad. Sci. **10**: 1073-.

We use age distributions of sea otters (Enhydra lutris) found dead on beaches of western Prince William Sound, Alaska, between 1976 and 1998 in conjunction with time-varying demographic models to test for lingering effects from the 1989 Exxon Valdez oil spill. Our results show that sea otters in this area had decreased survival rates in the years following the spill and that the effects of the spill on annual survival increased rather than dissipated for older animals. Otters born after the 1989 spill were affected less than those alive in March 1989, but do show continuing negative effects through 1998. Population-wide effects of the spill appear

to have slowly dissipated through time, due largely to the loss of cohorts alive during the spill. Our results demonstrate that the difficult-to-detect long-term impacts of environmental disasters may still be highly significant and can be rigorously analyzed by using a combination of population data, modeling techniques, and statistical analyses.

Mooers, C. and J. Wang (1998). On the implementation of a three-dimensional circulation model for Prince William Sound, Alaska. Continental Shelf Research. **18:** 253-277.

The POM (Princeton Ocean Model), a three-dimensional, primitive equation ocean circulation model, is applied to prince William Sound, Alaska. A 3-D concentration equation for passive tracers is added to POM to explore transport pathways and rates, plus retention zones and residence times. The 3D structures of the current, density, and passive tracer concentration are examined for realistic bottom topography, idealized Alaskan coastal water inflow /outflow, and idealized wind-forcing. Based on observational evidence and ecological concerns, the 'lake/river hypothesis' (i.e. the effect of weak versus strong throughflow on the ecology of the Sound) is explored to determine its influence on the circulation and transport patterns of passive tracers. Strong inflow through Hinchinbrook Entrance (river-like case) is crucial to the vigorous cyclonic circulation in the Sound and strong coupling to offshore influences, while with a weak inflow (lake-like case), the circulation in the Sound is much weaker and weakly coupled to offshore influences. The strength of the inflow and the wind direction are particularly important for determining the nature of the secondary branches of the throughflow in the northwestern Sound and the position, strength, and number of cyclonic and anticyclonic gyres. Mesoscale eddies are induced in the deep basins that have not yet been studied observationally. The advection of buoyant (relatively fresh) coastal water into the Sound significantly influences the circulation pattern and upper-layer density stratification. Idealized winter and summer wind-forcing generate distinctive surface circulation patterns that are important to the transport pathways, residence times, and retention zones of passive tracers; for example, northward an westward winds increase the northernmost penetration of passive tracers entering the Sound from offshore and the residence time substantially.

Morado, J. and L. Mooney (1997). "Observations on the histopathology of bay mussels, Mytilus trossulus: Oil assessment studies in Prince William Sound, Alaska." Journal of Shellfish Research **16**(1): 350-351.

On 24 March, 1989, the supertanker Exxon Valdez ran aground Bligh Reef in Prince William Sound (PWS), Alaska spilling approximately 258,000 barrels (11 million gallons) of crude Alaska North Slope oil. In the days that followed, oil from the spill was directed southwest past Knight Island, PWS and into the Gulf of Alaska by the prevailing wind and surface water current. Once in the Gulf of Alaska, the oil continued southwest, contaminating beaches along the Alaskan Peninsula, Kenai Peninsula and the Kodiak Archepeligo. Overall, more than 1100

km of coastline was contaminated by the oil. This study was initiated to contrast, on a very limited scale, the overall condition of Prince William Sound reference mussels, Mytilus trossulus, to those chronically exposed to residual oil from the Exxon Valdez oil spill. The mussel collections were from a single, focal sampling period which limits the ability to draw clear causal relationships. Recognition of this problem necessitated an evaluation of the overall fitness of collected mussels, therefore, both normal and pathological observations were recorded so that the general condition of mussels from oiled and unoiled sites could be determined and compared. In general, non-specific hemocytic infiltrates, brown cell aggregates and digestive gland metaplasia were more prevalent in mussels from heavily oiled sites than from control specimens. In contrast, nutrient storage cells were less prevalent in heavily oiled mussels than in mussels collected from control sites. These results suggest that mussels are still affected by residual oil, four years after the spill. (DBO)

Morris, B. and T. Loughlin (1994). Overview of the Exxon Valdez oil spill 1989-1992. Marine Mammals and the Exxon Valdez. T. R. Loughlin. San Diego, California, USA; London England, UK., Acadmeic Press, Inc.: 1-22.

Mortensen, D. and M. Carls (1994). Effects of crude oil ingestion on growth and microstructure of juvenile pink salmon, Oncorhynchus gorbuscha, otoliths. Proceedings of the 16th Northeast Pacific Pink and Chum Salmon Workshop, Juneauu, Alaska, USA, February 24-26, 1993, University of Alaska, Alaska Sea Grant College Program; Fairbanks, Alaska, USA.

Juvenile pink salmon (Oncorhynchus gorbuscha) were fed a commercially prepared food contaminated with three levels of crude oil: 0.37 x 0.03 mg oil per g food (low-oil treatment), 2.8 x 0.2 mg/g (mid-oil treatment) and 35 x 4 mg/g (high-oil treatment). Over 8 weeks, growth of sagittal otoliths and number of growth rings (increment number) in these groups were compared to untreated controls. Significant differences (P less than or equal to 0.05) in otolith growth among all oil levels and the controls were evident after one week. Significant differences in increment number among mid- and high-oil treatments and the controls were produced by the second week of the experiment. By week 6, growth of otoliths in all oil treatments was significantly less than in controls, and increment number was significantly less in mid- and high-oil treatments than in controls. All fish were fed clean food after week 6, but otoliths remained smaller and increment number less in treated groups through the remainder of the experiment. Reduced otolith growth and increment formation with increasing oil concentration followed a pattern similar to that of somatic growth. Because check marks can be used as references to index the history of a fish, otolith deposits in wild fish conceivably could be used to estimate the impacts of a major environmental disturbance, such as the Exxon Valdez oil spill. In our experiment, changes in otolith structure did not disappear when fry were returned to clean food; the otolith had faithfully recorded the event in its microstructure.

Mortenson, D. and M. Carls (1995). Effects of crude oil ingestion on growth and microstructure of juvenile pink salmon (Oncorhynchus gorbuscha) otoliths. Recent Developments in Fish Otolith Research. D. Secor, J. Dean and S. Campana, University of South Carolina Press: 197-209.

Mossner, S. and K. Ballschmiter (1997). "Marine mammals as global pollution indicators for organochlorines." Chemosphere **34**(5-7): 1285-96.

Blubber tissues of the following marine mammals differing in their geographic distribution (North Atlantic, North Pacific, Bering Sea/Arctic Ocean), trophic level, and feeding habits were analyzed for their organochlorine contents: two seal species (harbor seals--Phoca vitulina, northern fur seals--Callorhinus ursinus), three toothed whale species (belukha whales--Delphinapterus leucas, one common dolphin-- Delphinus delphis, one pilot whale--Globicephala melaena), and one baleen whale species (a bowhead whale--Balaena mysticetus). As xenobiotics were quantified the seven indicator congeners of the polychlorinated biphenyls (PCB 28, 52, 101, 118, 138, 153, and 180), three isomers of the hexachlorocyclohexanes (alpha-, beta- and gamma- HCH) as well as six components of the DDT-group (4,4'-DDT, 4,4'-DDD, 4,4'-DDE, 2,4'-DDT, 2,4'-DDD, and 2,4'-DDE). When comparing the xenobiotic levels of these marine mammals, it showed that the animals from the western North Atlantic were contaminated about 15 times more with organochlorines than the animals from the eastern North Pacific and the Bering Sea/Arctic Ocean. The total organochlorine burden, the 4,4'-DDE-percentage as well as the metabolic PCB patterns correlate with the trophic levels of the marine mammals studied. The quantitative analyses were done by high-resolution capillary gas chromatography with electron capture detection (HRGC/ECD) whereas the analyses of the metabolic PCB patterns were done by high-resolution capillary gas chromatography and mass selective detection (HRGC/MSD).

Mueller, J., S. Resnick, et al. (1992). "Effect of Inoculation on the Biodegradation of Weathered Prudhoe Bay Crude Oil." Journal of Industrial Microbiology **10**(2): 95-102.

The grounding of the Exxon Valdez on March 24,1989, resulted in the release of approx. 42 million liters of Prudhoe Bay crude oil into the waters of Prince William Sound, Alaska. Enrichment cultures from oil-contaminated beach material from Prince William Sound, Alaska, generated both a mixed bacterial community of indigenous, oil-degrading marine microorganisms and a pure culture oil-degrader, strain E12V. The mixed and axenic cultures were used in comparative shake flask studies of inoculation on biodegradation of Prudhoe Bay crude oil. Within 12 h following inoculation of homogenized, oiled beach material with the mixed culture, total CO2 production was increased 2-fold relative to a noninoculated control. Moreover, measurements of phenanthrene degradation (as determined by the release of 14CO2 from (9-14C)phenanthrene) showed a 2- or 3-fold greater degradation when inoculated with either strain E12V or with the mixed culture, respectively. However, as medium was replaced by a

simulated tidal cycle, the observed stimulation of CO2 production decreased, and the addition of strain E12V had no greater effect on total CO2 production than the addition of inorganic nutrients alone. Chemical analysis of oil recovered after 7 days incubation also suggested that, while these cultures are capable of efficient biodegradation of Prudhoe Bay crude in liquid culture, inoculation of beach material with high numbers of these microorganisms had little effect on the rate and extent of biodegradation of weathered crude oil. Overall, the sustained stimulatory effect was no greater than that observed with the addition of inorganic nutrients alone. Prepared in cooperation with Technical Resources, Inc., Gulf Breeze, FL., and SBP Technologies, Inc., Atlanta, GA.

Mulcahy, D. and B. Ballachey (1994). Hydrocarbon residues in sea otter tissues. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 313-330.

All the sea otters examined in this study were early victims of the EVOS, all were moderately to heavily covered with oil, and all had gross lesions consistent with exposure to crude oil. Aliphatic and aromatic hydrocarbons were detected in all tissues examined. The patterns of hydrocarbon incidences and concentrations allowed us to divide the animals into three groups, perhaps related to the route of exposure and the duration of life following exposure. Principal components analysis separated the hydrocarbon concentrations in kidney, liver, and muscle samples taken from the ten oiled sea otters from PWS from samples taken from unoiled sea otters from southeastern Alaska. Concentrations of aliphatic and aromatic hydrocarbons were two to eight times higher in tissues from the oiled sea otters compared to tissue from the unoiled sea otters. There was an upper limit of 1 microgram per gram of individual hydrocarbons in the tissues sampled. This low concentration in oiled sea otters probably resulted from the limited time for mobilization of hydrocarbons in sea otters that died quickly after exposure and metabolism by inducible enzyme systems of the original hydrocarbons into compounds that were not included as part of the laboratory analysis of the tissues.

Our study showed that measurements of the hydrocarbons found in crude oil did not give an optimum assessment of exposure of each animal to crude oil. Measurement of oil metabolites may provide a superior approach. Necropsies of affected carcasses by experienced veterinarians or veterinary pathologists should be considered an essential part of damage assessment following an oil spill.

Mulcahy, D., E. D, et al. (1999). "Loss of abdominally-implanted radio transmitters equipped with percutaneous antennas from harlequin ducks." Journal of Field Ornithology **70**(2): 244-250.

We documented extrusion and loss of abdominally implanted radio transmitters with percutaneous antennas from adult female Harlequin Ducks (Histrionicus histrionicus). Birds were captured during wing molt (late August to mid-September) in 1995-1997. Of 44 Harlequin Ducks implanted with radios and

recaptured, 7 (16%) had lost their transmitters and 5 (11%) had radios in the process of extruding. Most (11 of 12) extrusions and losses occurred in birds implanted with radios in 1996 and recaptured in 1997. We suggest that transmitter extrusions and losses were due largely to changes in transmitter design made between 1995 and 1996. Transmitters implanted in 1996 were cylindrical rather than spherical, had a flat end with an abrupt edge, and the lower portion of the antenna was reinforced. Radio losses occurred after the 7-mo monitoring period and caused no apparent harm to the birds. Investigators using implanted radios with percutaneous antennas for long-term projects should be aware of the potential for radio extrusion and should minimize the problem by using transmitters that have no sharp edges and that are wide, rather than narrow.

Mulcahy, D. and D. Esler (1999). "Surgical and immediate postrelease mortality of harlequin ducks (Histrionicus Histrionicus) implanted with abdominal radio transmitters with percutaneous antennae." Journal of Zoo and Wildlife Medicine **30**(3): 397-401.

Radiotelemetry is an essential tool in the study of free-ranging bird populations, and a variety of transmitter-attachment methods have been developed. A promising new method is abdominal implantation of a transmitter with a percutaneous antenna. Researchers using this technique should be concerned about and aware of mortality during surgery and during the immediate postrelease period (the 14-day period following surgery). Of 307 radio-implant surgeries performed between 1995 and 1997 in harlequin ducks (Histrionicus histrionicus), 7 (2.3%) deaths were documented during surgery or anesthetic recovery. Of 295 birds released with implanted radios, 10 (3.4%) died during the immediate postrelease period. Modifications to anesthetic procedures used in the 204 surgeries performed in 1996 and 1997 reduced mortality to 1.5% during surgery and 1.5% during the immediate postrelease period. Anesthetic modifications included intubation of all birds, placement of birds on all elevated platform that allowed the head to rest at a level lower than the body during surgery, placement of a heated water blanket under the birds during surgery, monitoring of body temperature, and use of electrocardiogram and Doppler ultrasound to monitor heart rates and arrhythmias. Low levels of mortality associated with abdominal implantation of radio transmitters may be unavoidable, but mortality can be minimized with adjustments to anesthetic technique.

Munson, D. (1998). Shoreline Assessment and Oil Removal; ADEC in Prince William Sound, Alaska. EXXON VALDEZ Oil Spill Restoration Project Final Report Restoration Project 94266b. Govt Reports Announcements & Index (GRA&I), Alaska State Dept. of Environmental Conservation, Anchorage. Office of Restoration and Research.: 76p.

During the summer of 1994, a five person crew from the village of Chenega under the direction of an on site manager from the Alaska Department of Environmental Conservation conducted manual treatment, debris and rebar removal and ground surveys at 11 subdivisions in Prince William Sound. Fourteen sites within 4 different shoreline subdivisions with persistent surface

asphalt were manually treated to accelerate natural degradation. Removal of flagging and other miscellaneous shoreline debris left by cleanup and damage assessment crews was undertaken as possible. Six additional shoreline subdivisions near the village of Chenega were assessed because of the ongoing concern for subsistence and recreational resources within close proximity to the village. A comparison of the sites from 1993 to 1994 showed that little to no improvement had occurred at these sites.

Murphy, M., R. Heintz, et al. (1999). "Recovery of pink salmon spawning areas after the Exxon Valdez oil spill." Transactions of the American Fisheries Society **128**: 909-918.

Murphy, S., R. Day, et al. (1997). "Effects of the Exxon Valdez oil spill on birds: Comparisons of pre- and post-spill surveys in Prince William Sound, Alaska." Condor **99**(2): 299-313.

We used data from pre- and post-spill surveys to assess the effects of the Exxon Valdez oil spill on the abundance and distribution of birds in Prince William Sound, Alaska. We conducted post-spill surveys during mid-summer (1989-1991) in 10 bays that had been surveyed prior to the spill (1984-1985) and that had experienced different levels of initial oiling from the spill (unoiled to heavily oiled). We evaluated whether there were changes in overall abundance across all bays between the pre-spill and post-spill sampling periods, and changes in abundance in unoiled/lightly oiled bays versus moderately/heavily oiled bays that would suggest oiling impacts. Of 12 taxa examined for changes in overall abundance, 7 showed no significant change, 2 (Bald Eagle and Glaucous-winged Gull) increased in abundance, and 3 (Red-necked Grebe, Pelagic Cormorant, and Pigeon Guillemot) decreased in abundance during all three post-spill years. Of the 11 taxa examined for differences in use of oiled versus unoiled habitats, 7 showed no significant response, 1 (Black-legged Kittiwake) exhibited a positive response to oiling, and 3 (Pelagic Cormorant, Black Oystercatcher, and Pigeon Guillemot) exhibited negative responses to initial oiling. We conclude that the impacts of this oil spill on abundance and distribution of birds were most evident in 1989, the year of the spill, and were most pronounced for Pigeon Guillemots. By 1991, signs of recovery were evident for all taxa that showed initial oiling impacts.

Myers, M., C. Stehr, et al. (1993). National Benthic Surveillance Project: Pacific Coast. Fish Histopathology and Relationships between Toxicopathic Lesions and Exposure to Chemical Contaminants for Cycles 1 to 5 (1984-88). Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Seattle, WA. Northwest Fisheries Science Center.: 177p.

The report presents and interprets the results of histopathology studies conducted on 17 species of bottomfish captured at 45 sites between 1984 and 1988 as part of the Pacific Coast portion of the National Benthic Surveillance Program (NBSP) in conjunction with NOAA's National Status and Trends Program (NS&T). The location of sampling sites ranged from Prudhoe Bay in

Alaska to San Diego Bay in California, and incorporated sites. Twenty-three were located in or near urban embayments, and the 22 remaining sites were in nonurban embayments, five of which served as comparison or reference sites on the basis of minimal levels of sediment contaminants detected (Kamishak Bay, AK; Nisqually Reach, WA; and Bodega Bay, Dana Point, and outer Mission Bay, CA). These comparison sites were selected so that the same fish species could be collected from minimally contaminated environments as opposed to those obtained at urban or more contaminated sites. Six primary target species were identified for statistical analyses that examined the relationships between occurrence of particular toxicopathic diseases or lesions in the liver and kidney and levels of potential or actual exposure to contaminants. These species were selected because they were broadly distributed geographically and were abundant among the sampling sites, they had previously documented significant prevalences of contaminant-associated diseases, or the geographic distribution of similar diseases among the sites suggested an association with contaminant exposure. These primary target species were flathead sole, English sole, starry flounder, hornyhead turbot, white croaker, and black croaker. All specimens were examined for the presence of necrotic, sclerotic and proliferative lesions in the kidney, as well as lesions. Technical memo. See also PB89-180632 and PB91-172346.

Myers, M. S., C. M. Stehr, et al. (1994). "Relationships between toxicopathic hepatic lesions and exposure to chemical contaminants in English sole (Pleuronectes vetulus), starry flounder (Platichthys stellatus), and white croaker (Genyonemus lineatus) from selected marine sites on the Pacific Coast, USA." Environ Health Perspect **102**(2): 200-15.

Relationships between hepatic lesions and chemical contaminant concentrations in sediments, stomach contents, liver tissue, and bile were statistically evaluated in three species of bottomfish, English sole (Pleuronectes vetulus), starry flounder (Platichthys stellatus), and white croaker (Genyonemus lineatus), captured from 27 urban and nonurban sites on the Pacific Coast from Alaska to southern California. Lesions detected were neoplasms, preneoplastic foci of cellular alteration, nonneoplastic proliferative lesions, unique or specific degenerative/necrotic lesions, nonspecific degenerative/necrotic lesions, and hydropic vacuolation of biliary epithelial cells and hepatocytes. In general, lesion prevalences were significantly higher in all three species captured at chemically contaminated urban sites, and certain lesions had significantly higher relative risks of occurrence at urban sites in Puget Sound, San Francisco Bay, the vicinity of Los Angeles, and San Diego Bay. Concentrations of polycyclic aromatic hydrocarbons, polychlorinated biphenyls, DDT and its derivatives, and chlordanes and dieldrin in sediment, stomach contents, liver, and fluorescent aromatic compounds in bile were significant risk factors for the occurrence of neoplastic, preneoplastic, nonneoplastic proliferative, and specific degenerative/necrotic lesions, as well as hydropic vacuolation. Fish age also had a significant influence on occurrence of several hepatic lesions, but gender was rarely a significant risk factor. These relationships provide strong evidence for the involvement of environmental contaminants in the etiology of hepatic lesions

in several marine bottomfish species and clearly indicate the utility of these lesions as biomarkers of contaminant-induced effects in wild fish.

Nakatani, R. and A. Nevissi (1991). "Effect of Prudhoe Bay (Alaska, USA) crude oil on the homing of coho salmon in marine waters." North American Journal of Fish Management **11**(2): 160-166.

Resource managers and the fishing industry have expressed concern that a crude-oil spill occurring in the pathway of a salmon run may destroy the ability of the maturing salmon to reach the home stream. To address this concern, groups of mature 3-year-old and precocious 2-year-old coho salmon Oncorhynchus kisutch were tagged and exposed in seawater for 1 h to sublethal concentrations of Prudhoe Bay crude oil, dispersed oil, or seawater oil dispersant alone, and then were released in seawater about 5 km from their home stream. The results show that the coho salmon's homing success and speed of return to the home stream were not affected by any of the treatments. The longevity of holding tests, in which coho salmon were held in saltwater net-pens after experimental treatments, showed that the larger 3-year-old coho salmon were more sensitive to the stress of confinement than in the smaller 2-year-old fish.

Naslund, N., K. Kuletz, et al. (1995). "Tree and habitat characteristics and reproductive success at marbled murrelet tree nests in Alaska." Northwestern Naturalist **76**(1): 12-25.

Neff, J. and W. Burns (1996). "Estimation of polycyclic aromatic hydrocarbon concentrations in the water column based on tissue residues in mussels and salmon: An equilibrium partitioning approach." Environmental Toxicology and Chemistry **15**(12): 2240-2253.

Equilibrium partitioning was used to estimate concentrations of dissolved polycyclic aromatic hydrocarbons (PAHs) in the water column from PAH residues in tissues of mussels and juvenile pink salmon collected from coastal marine waters affected by the Exxon Valdez oil spill. Estimated concentrations were within factors of 2 to 5 for fish and 5 to 10 for mussels of average total dissolved and particulate PAHs measured in concurrent water samples. Temporal trends of estimated and measured water-column PAH concentrations were comparable. Water-column PAH concentrations estimated from residues in tissues of mussels (Mytilus trossulus) were higher than estimates based on residues in tissues of juvenile pink salmon (Oncorhynchus gorbuscha). Possible reasons for this difference include seasonal variations in mussel lipid content, differences in PAH uptake and depuration rates between fish and mussels, differences in how fish and mussels interact with particulate oil, and possible short exposure times for juvenile pink salmon. All of these factors may play a role. In any event, estimates of dissolved PAHs in the water column, based on PAH residues in either fish or mussel tissue, confirm that PAH concentrations generally did not exceed water quality standards for protection of marine life.

Neff, J., E. Owens, et al. (1995). Shoreline oiling conditions in Prince William Sound following the Exxon Valdez oil spill. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

Following the Exxon Valdez oil spill of March 24, 1989, in Prince William Sound, Alaska, Exxon conducted comprehensive, systematic shoreline surveys in cooperation with federal and state authorities to obtain information on the distribution and magnitude of shoreline oiling and to identify natural and cultural resources requiring special protection. Similar joint surveys were performed during the springs of 1990, 1991, and 1992 on all Prince William Sound and Gulf of Alaska shorelines that were suspected of having remnants of weathered oil and that would benefit from further cleanup. The extent of oiling declined substantially between 1989 and 1992: in 1989, survey teams found oil on about 16% (783 km) of the approximately 5 000 km of shoreline in Prince William Sound; in the spring of 1991, they found oil on about 96 km; and, in May 1992, on only about 10 km of shoreline in the sound. During this period, most of the oil was located in the biologically least productive upper intertidal and supratidal zones. In the springs of 1990, 1991, and 1992, isolated pockets of subsurface oil were found, chiefly in small scattered zones in coarse cobble/boulder sediments in the upper intertidal or supratidal zones. In 1991, about one-third of the subdivisions in Prince William Sound with surface oil also contained some subsurface oil. The areal extent of this subsurface oil declined by nearly 70% between 1991 and 1992, from about 37 000m super(2) to about 12 000m super (2). Moreover, where subsurface oil remained in 1992, it was present in lesser amounts. Rates of oil removal were greatest on coastal sections treated early in the spring and summer of 1989. Where shoreline treatment was delayed, the subsequent rate of removal of oil from the shore by natural processes was slower.

Neff, J. and W. Stubblefield (1995). Chemical and toxicological evaluation of water quality following the Exxon Valdez oil spill. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

As part of a comprehensive water-quality assessment program performed in Prince William Sound and the western Gulf of Alaska following the Exxon Valdez oil spill of March 24, 1989, water samples were collected from 417 locations, most of them in areas through which the oil drifted, to assess the distribution and concentrations of petroleum hydrocarbons in the water column. Over 5 000 water samples were analyzed for individual and total petroleum alkanes and for aromatic hydrocarbons by very sensitive gas chromatographic techniques. A total of 2 461 of these samples were analyzed for polycyclic aromatic hydrocarbons (PAHs). Concurrent with some of these samples, an additional 123 water samples were collected in April 1989 (a week to a month after the spill) at 32 offshore locations and in June 1989 at 7 nearshore sites in Prince William Sound to determine the toxicity of the water to representative species of marine

organisms. The toxicity of Prince William Sound water was assessed with standard Environmental Protection Agency (EPA) and American Society for Testing and Materials (ASTM) marine toxicity tests with representative species of three taxonomic groups: (1) Skeletonema costatum (a marine diatom), (2) Mysidopsis bahia (a crustacean), and (3) larval/juvenile Cyprinodon variegatus (a fish, the sheepshead minnow). Highest concentrations of total PAHs, the best indicator of the potential toxicity of the spilled oil to water-column organisms, were observed in the water column of Prince William Sound in the first two months after the spill. Measured PAH levels were below the state of Alaska's water quality standard of 10 ppb total aromatic hydrocarbons. This finding is consistent with National Oceanic and Atmospheric Administration (NOAA) water samples collected during the same time period. PAH concentrations in the water column of the sound declined rapidly with time after the spill to essentially background concentrations of 0.01 to 0.1 ppb by mid to late summer of 1989. No water samples from spill path areas of the western Gulf of Alaska contained more than 1.0 ppb total PAHs. These concentrations are well below concentrations reported in the scientific literature to be toxic to marine plants and animals. Eight of 329 samples (2.4%) of the water surface contained between 10 and 29.3 ppb total PAHs; these samples probably contained oil sheen material. Toxicity tests with full strength Prince William Sound water showed no acute or chronic toxicity to three representative species of marine organisms. There was no dose-response relationship for any species or seawater sample, and there was no relationship between the concentration of total PAHs in the undiluted seawater samples and percentage of survival or relative growth rates in the test organisms. These studies show that the traces of petroleum hydrocarbons present in the water column of Prince William Sound and the western Gulf of Alaska shortly after the spill were well below concentrations capable of producing harmful effects in populations of sensitive species and life stages of marine organisms.

Newman, S., J. Piatt, et al. (1997). "Hematological and plasma biochemical reference ranges of Alaskan seabirds: Their ecological significance and clinical importance." Colonial Waterbirds **20**(3): 492-504.

Blood was analyzed from 151 pelagic marine birds to establish reference ranges for hematological and plasmic biochemical parameters from healthy, wild populations of Pacific seabirds. Of the 13 species examined, 9 were from the Family Alcidae (N = 122 individuals) and the remainder (N = 29) from the Families Phalacrocoracidae, Laridae, and Procellariidae. Three of 8 hematological parameters (total white blood cell count, lymphocyte count and eosinophil count) differed significantly among species, as did 9 of 13 plasma biochemical parameters (alkaline phosphatase, aspartate aminotransferase, creatine kinase, cholesterol, glucose, lactate dehydrogenase, total bilirubin, total protein and field total protein). There were no differences among species for packed cell volume, buffy coat, cell counts of heterophils, monocytes and basophils, or for concentrations of alanine aminotransferase, triglycerides, uric acid and calcium. Plasma calcium concentration, triglyceride levels and field total protein varied significantly between sexes, with females having higher mean

concentrations of all 3 parameters. However, no significant relationships between measures of breeding condition (brood patch size, subcutaneous and mesenteric fat deposits, or ovarian follicle size and ovary weight) and calcium or alkaline phosphatase concentrations in female birds could be identified. Alanine aminotransferase and uric acid were the only analytes which did not differ significantly between species or sexes.

Nighswander, T. S. (1999). The Role of the Alaska Oil Spill Health Task Force following the Exxon Valdez Oil Spill. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 33-50.

The Alaska Oil Spill Task Force (OSHTF) was organized shortly after the oil spill to address the health issues related to the spill and the cleanup activities. The potential and perceived serious situations involving subsistence foods was quickly raised, e.g., many residents feared they would be poisoned by consuming their susbsistence foods. Major problems encountered by the OSHTF included a lack of food-safety information from past oil spills as well as effective modes to communicate information to the residents. The OSHTF worked to establish credibility with the villagers as many seemed skeptical of "outsiders". It appeared that the analytical testing done in a nationally respected laboratory, under rigorous protocols by knowledgeable scientists, and presented to the villagers through written word, videos, and in face-to-face conversations simply could not completely convince all villagers of the safety of their food. Perhaps most importantly, the scientific conclusions simply were not consistent with the villagers' perceptions about the health of their environment. Identification of such perceptions and activities to resolve them are included herein.

Nighswander, T. S. and N. Peacock (1999). The Communication of Health Risk from Subsistence Food in a Cross Cultural Setting: Lessons Learned from the Exxon Valdez Oil Spill. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 206-236.

Communicating risk following a mega-disaster such as the Exxon Valdez oil spill is a major challenge for those organizations responsible for advising the public about the safety of using potentially contaminated natural resources as subsistence foods. The difficulties worsen the longer they go unaddressed as responding organizations struggle to define the problem, collect and analyze data, and develop a credible message. The degree of difficulty increases if there is a perception that the risk is being ignored or is not taken seriously and if the risk communication takes place in a cross-cultural setting. As shown in this chapter, the formation of the Oil Spill Health Task Force (OSHTF) and the evolution of its risk communication efforts illustrate one case of institutional changes in the context of disaster response. Federal and state agencies, Alaska Native groups, and Exxon conducted the subsistence study and developed and

communicated health advice within the framework of the OSHTF as a response to changing perceptions of the nature of the problem.

The OSHTF used many different approaches to communicate the results of the scientific studies and the conclusions of the risk assessment, but it continued to recognize the need to better "take into account the knowledge and experience of the people" (Scott and Receveur 1995) and develop new ways to incorporate traditional knowledge. As the activities of the OSHTF came to a close, the Subsistence Restoration Projects funded by the Trustee Council built on our experiences to improve community involvement and collaborative study design. Community involvement and the application of traditional knowledge became key goals of the Trustee Council's oil spill restoration program.

Nishimoto, M. and G. Byrd (1997). Effects of the EXXON VALDEZ Oil Spill on Fork-Tailed Storm-Petrels Breeding in the Barren Islands, Alaska. Bird Study Number 7. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Homer, AK.: 25p.

We evaluated fork-tailed storm-petrels (Oceanodroma furcata) at East Amatuli Island, Barren Islands, the largest storm-petrel breeding colony within the trajectory of the oil slick, to determine whether there was evidence of adverse effects, following the 1989 Exxon Valdex oil spill. Although we were unable to measure all possible indicators, we found insufficient evidence to conclude that there were significant adverse impacts to breeding storm-petrels in 1989.

Norcross, B. (1992). "Responding to an oil spill: Reflections of a fisheries scientist." Fisheries **17**(6): 4-.

When the Exxon Valdez hit Bligh Reef on 24 March 1989, it spilled 10.6 million gallons of Prudhoe Bay crude oil into Prince William Sound, Alaska. It was necessary for scientists to respond immediately. Ideally, environmental studies would be designed prior to an oil spill and be ready for implementation, but no contingency plan was in place for fisheries scientists to respond to an oil spill in Alaska. Norway has yearly drills which include oil companies, clean-up crews, and government agentcies, as well as university scientists. The author's study was very iterative. The null hypothesis for the study of larval fish in Prince William Sound had to be that the oil did not change species composition, abundance, and condition. The alternative hypothesis was that it did change them. The objectives evolved daily. They were formulated after the first cruise in April, refined after the second cruise in early May 1989, and continually reanalyzed throughout the summer of 1989. Designing an oil spill study is very difficult. One problem is the inherent non-repeatability. A second problem is the unavailability of baseline data. Baseline data often are inadequate to generate hypotheses. The author suggests having a generic sampling plan in place. Details of the plan can be adapted to specific spill areas as needed.

Norcross, B. and M. Frandsen (1996). Distribution and abundance of larval fishes in

Prince William Sound, Alaska during 1989 after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 463-486.

Field studies were conducted in 1989 to determine spatial and temporal variation of finfish larvae in Prince William Sound in the months following the Exxon Valdez oil spill. This study contributes basic larval fish occurrence information for Prince William Sound. Unfortunately, it is biased as a baseline because it represents the ecosystem following an oil spill. The patterns of distribution are interpreted in the context of oceanographic patterns affecting transport of oil and larvae. Temporal and spatial distribution and abundance patterns are shown for the six most dominant taxa of larval fishes captured: walleye pollock *Theragra chalcogramma*, northern smoothtongue *Leuroglossus schmidti*, Pacific herring *Clupea pallasi*, capelin *Mallotus villosus*, rockfishes *Sebastes* spp., and flathead sole *Hippoglossoides elassodon*. Most larval fishes were in the upper 50 m of the water column and either concentrated in the oiled western portions of Prince William Sound or were transported through those areas by the same processes that moved the oil.

Norcross, B., M. Frandsen, et al. (1995). "Larval herring distribution abundance and sublethal assessment in Prince William Sound, Alaska during 1989 following the Exxon Valdez oil spill." Canadian Technical Report of Fisheries and Aquatic Sciences(2060): 61.

Norcross, B., J. Hose, et al. (1996). "Distribution, abundance, morphological condition, and cytogenetic abnormalities of larval herring in Prince William Sound, Alaska, following the Exxon Valdez oil spill." Canadian Journal of Fisheries and Aquatic Sciences **53**(10): 2376-2387.

Pacific herring (Clupea pallasi) larvae were collected throughout Prince William Sound in May, June, and July following the Exxon Valdez oil spill of March 1989. Movement of herring larvae is related to current patterns within the sound, and deformed larvae were found both inside and outside of areas considered to be oiled. Herring may have been exposed to oil as embryos in contaminated spawning areas and as larvae encountering the oil trajectory. Although it was impossible to estimate the effects of exposure to Exxon Valdez oil, many larvae exhibited symptoms associated with oil exposure in laboratory experiments and other oil spills. These included morphological malformations, genetic damage, and small size. Growth between May and June 1989 was the lowest ever reported for field-caught larval herring. Jaw malformations and genetic damage were highest in May and were elevated through the western area of Prince William Sound, which overlapped the oil trajectory. In June 1989, jaw development was normal, but genetic damage persisted. In contrast, in May 1995, jaw and cytogenetic development were normal and significantly different from those in larvae in 1989.

Nysewander, D., C. Dippel, et al. (1997). Effects of the EXXON VALDEZ Oil Spill on

Murres: A Perspective from Observations at Breeding Colonies. Bird Study Number 3. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Homer, AK. Alaska Maritime National Wildlife Refuge.: 84p.

The authors surveyed murres (Uria spp.) annually from 1989 through 1991 at breeding colonies within the trajectory of the oil to determine whether numbers had declined and to evaluate the effects of oil on nesting phenology and reproductive success, following the 1989 Exxon Valdez oil spill. The colonies the authors surveyed contained the majority of the estimated 200,000 murres attending colonies in the affected area, and they found reduced numbers at all study colonies following the spill. In addition, nesting was delayed and productivity rates were far below normal following the spill. In contrast, numbers of murres did not decline and reproductive parameters were normal at 2 colonies the authors surveyed outside the trajectory.

O'Clair, C., J. Short, et al. (1996). Contamination of intertidal and subtidal sediments by oil from the Exxon Valdez in Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 61-93.

In the 3 years after the Exxon Valdez oil spill, we sampled subtidal sediments at 45 sites in Prince William Sound to determine the geographical, bathymetric, and temporal distribution of oil in benthic sediments. We sampled sediments at mean lower low water (0 m) and at subtidal depths of 3, 6, 20, 40, and 100 m. Triplicate composite sediment samples were collected at each station in spring, summer, and fall each year (1989-1991). Our results are based on 1,278 sediment samples analyzed by gas chromatography-mass spectrometry. At locations with oiled shorelines, sediments from 0 m, several meters below the zone where the oil initially stranded, had the greatest concentrations of total polynuclear aromatic hydrocarbons excluding perylene (TPAH) found in benthic sediments in 1989. The highest average TPAH concentration was 12,700 ng/g at 0 m at Disk Island in July 1989. Shallow subtidal sediments (3-20 m) had a PAH composition pattern characteristic of weathered Exxon Valdez oil (EVO-PAH pattern) at 80% of the oiled locations in Prince William Sound in 1989. Contamination of subtidal sediments by Exxon Valdez oil reached a depth of at least 20 m at five of those locations sampled in 1989. The greatest concentration of oil was at shallow depths. We found little evidence of Exxon Valdez oil in sediments from great depths (greater than or equal to 40 m); the TPAH concentration in these sediments was similar at oiled and reference locations. The EVO-PAH pattern was rarely present consistently in replicate samples from these depths. The TPAH concentration in sediments from greater than or equal to 100 m usually exceeded that observed at 40 m. At heavily oiled locations, the total n-alkane (TNA) concentration was greatest where the TPAH concentration was greatest and the EVO-PAH pattern was observed. The highest TNA concentration was 31,100 ng/g in intertidal sediments from Northwest Bay (July 1989). The TNA concentration varied widely among reference and assessment stations where the EVO-PAH pattern was absent. After 1989, hydrocarbons matched the EVO-PAH pattern less often, Exxon Valdez oil hydrocarbons were more patchily distributed, and concentrations of these hydrocarbons

decreased in benthic sediments. By 1990, the mean TPAH concentration in sediments from 0 m at many oiled sites had declined to 100-200 ng /g, comparable to that of the prespill background. In 1990 in shallow subtidal sediments, the EVO-PAH pattern was consistently present only at Block Island and Northwest Bay. No consistent trend in TPAH concentration was apparent with depth. In 1991 a further decrease in the TPAH concentration was observed at oiled sites; the EVO-PAH pattern was consistently present only at Northwest Bay. In contrast to the intertidal region where Exxon Valdez oil caused major biological impacts, subtidal sediments probably did not have oil concentrations that were acutely toxic to benthic or demersal macrobiota; however, the oil in shallow subtidal sediments may have induced subtle changes in biotic communities in heavily oiled bays. At greater depths (greater than or equal to 40 m) contamination by Exxon Valdez oil was negligible. The changes, if any, that occurred in deep benthic communities as a result of this oil spill were probably obscured by natural variability.

O'Clair, C., J. Short, et al. (1998). Subtidal Monitoring: Recovery of Sediments in the Northern Gulf of Alaska. Restoration Project 95285. EXXON VALDEZ Oil Spillestoration Project Final Report. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Juneau, AK. Auke Bay Lab.: 33p.

The authors sampled subtidal and low intertidal sediments at eight locations in the northern Gulf of Alaska in July 1994 to determine the geographical and bathymetric distribution of oil from the Exxon Valdez oil spill in the subtidal region and compare oil concentrations with those in the low intertidal zone. Sediments were sampled near mean low water and at three subtidal depths in the 3-20 m range. The sediments were analyzed for hydrocarbons using gas chromatography/mass spectroscopy. No Exxon Valdez oil was found in sediments from 0 m at assessment sites where the greatest mean intertidal concentration of total polynuclear aromatic hydrocarbons excluding perlyene was observed at Hallo Bay. The greatest mean concentration of total polynuclear aromatic hydrocarbons excluding perylene in benthic sediments occurred at 6 m at Windy Bay. Petroleum hydrocarbons at the 20 m depth were chiefly (47% of all 20-m assessment samples) from the 'Katalla' source. See also PB96-196944.

Oakley, K. and K. Kuletz (1996). Population reproduction and foraging of pigeon guillemots at Naked Island, Alaska, before and after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 759-769.

After the 1989 Exxon Valdez oil spill in Prince William Sound, Alaska, we studied pigeon guillemots *Cepphus columba* breeding just 30 km from the grounding site. The postspill population was 43% smaller than the prespill population, but we could not attribute the entire decline to the spill because a decline in this guillemot population may have predated the spill. However, relative declines in the population were greater along oiled shorelines, suggesting that the spill was responsible for some of the decline. Reproduction appeared largely unaffected, but the cryptic nature of guillemot nests

undoubtedly reduced our ability to detect failed nests. Nesting success was lower, but the apparent cause - greater losses of chicks to predators - was not obviously related to the spill. Fledging weight and growth rates of chicks and the rate at which adults delivered food to their chicks were not lower after the spill. The most likely explanation for the few effects observed is that oil was present on the surface waters of the study area for a relatively short period before the guillemots returned to begin their annual reproductive activities.

Oakley, K. and K. Kuletz (1996). Population, Reproduction and Foraging of Pigeon Guillemots at Naked Island, Alaska, Before and After the EXXON VALDEZ Oil Spill. Bird Study Number 9. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Migratory Bird Management.: 57p.

Following the 1989 Exxon Valdez oil spill in Prince William Sound (PWS), Alaska, we studied pigeon guillemots (Cepphus columba) breeding just 30 km from the grounding site. The post-spill population was 43% less than the pre-spill population, but we could not attribute the entire decline to the spill because a decline in the PWS guillemot population may have predated the spill. However, relative declines in the population were greater along oiled shorelines, suggesting that the spill was responsible for some of the decline. The most likely explanation for the few effects observed is that oil was present on the surface waters of the study area for a relatively short period before the guillemots returned to begin their annual reproductive activities.

Oakley, K., T. Wade, et al. (1999). Aliphatic and Polycyclic Aromatic Hydrocarbons in Eggs, Livers and Stomach Contents of Black-Legged Kittiwakes in Prince William Sound, Alaska, after the EXXON VALDEZ Oil Spill. Bird Study 8. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Texas A and M Univ., College Station. Geochemical and Environmental Research Group.: 90p.

Aliphatic and polycyclic aromatic hydrocarbon (PAHs) concentrations were determined in eggs (n=5), livers (n=24), and stomach contents (n=14) of black-legged kittiwakes (Rissa tridactyla) in Prince William Sound, Alaska, following the March 1989 Exxon Valdez oil spill. The single egg collected in 1989 from an oiled colony was contaminated with diesel oil, and the four eggs collected in 1990 from an unoiled colony were not contaminated. Kittiwake livers did not contain PAH concentrations above the method detection limit, but concentrations of phytane and unresolved complex mixture (UCM) in the livers suggested that kittiwakes ingested oil in 1989. Stomach contents of kittiwakes, presumably schooling fish, did not contain an aliphatic signal, but did contain PAH residues, almost exclusively napthalenes. 'Fingerprinting' of the oil ingested by kittiwakes was not possible, and the significance of oil ingestion to the kittiwakes could not be determined. See also PB97-112676 and PB96-204276. Prepared in cooperation with Texas A and M Univ., College Station. Geochemical and Environmental Research Group.

OASIS Environmental, I. (2000). Focused Aquatic Biota Sampling - King Salmon Airport, Alaska, United States Air Force, 611th Air Support Group, 611th Civil Engineer Section.

Executive Summary:

Sampling and analysis of environmental media including fish, sediment, and surface water was conducted at King Salmon Airport (KSA), Alaska during 1999. The purpose of the investigation was to evaluate potential contamination of aquatic biota and wetlands resulting from migration of chemicals of potential concern (COPCs) from suspected source areas, to validate previous results that indicated COPCs in fish, to assess the aerial extent of affected fish, to identify source areas and to evaluate concentrations in surface water.

Samples of fish were collected from water bodies and wetlands within or adjacent to three sites at KSA: Eskimo Creek (SS11), King Salmon Creek (LF05) and King Salmon Creek and wetlands (LF14). A total of 19 samples, consisting of resident and nonresident fish, were collected under permit from the Alaska Department of Fish and Game. The results of chemical analysis indicate that certain COPCs detected at some of the sites are also present in fish samples collected at or near those sites. These include some pesticides (i.e. DDT, chlordane, hexachlorobenzene, ect.); benzene, toluene, ethylbenzene, and xylenes (BTEX); and polychlorinated biphenyls (PCBs). The concentrations of these chemicals in fish are below screening values with a few exceptions.

Samples of sediment and surface water were collected from three sites at KSA in 1999: Eskimo Creek (SS11), King Salmon Creek (LF05) and King Salmon Creek and wetlands (LF14). In addition, semi-permeable membrane devices (SPMDs) were deployed at locations in King Salmon Creek for a one-month period. A total of 38 sediment and water samples for a variety of chemical analyses were collected from discrete sample locations. The results indicate that certain COPCs are present at low concentrations in the creek water and sediment located downgradient of potential source areas. Low levels of COPCs were detected in sediment and surface water samples, including background samples.

Chemicals detected in sediment and surface water that were also detected in fish include: BTEX; DDT; chlordane and its constituents; hexachlorobenzene; and dieldrin.

BTEX was detected in Eskimo Creek surface water and sediment downgradient of Seep 1 and 2 above background concentrations. Gasoline range organics (GRO) were detected at elevated concentrations in the sediment of Eskimo Creek at the two sampling locations, one upstream and one downstream of the downtown seep.

Trichloroethylene (TCE) was detected in Eskimo Creek surface water and sediments. TCE concentrations were greatest below a suspected TCE source area at KSA.

Comparison of the concentrations of chemicals in sediment and water to screening criteria indicates a small proportion of samples exceed these. Generally, the frequency of detections and concentrations at locations immediately downgradient of suspected source areas are higher than that observed at distant downgradient locations, which supports the concept of natural attenuation of chemicals migrating from source areas.

The 1997 and 1999 aquatic biota evaluations suggest that additional monitoring of fish at KSA is not warranted because these have been adequately characterized. However,

additional monitoring of surface water and sediments is recommended to provide evidence of long-term trends.

Okey, T. and P. D (1999). A mass-balanced model of trophic flows in Prince William Sound: decompartmentalizing ecosystem knowledge. Proceedings of the 16th Lowell-Wakefield Symposium September 30 - October 3, 1998, Anchorage, AK.

Olla, B., V. Estelle, et al. (1988). "Responses of Polychaetes to Cadmium-Contaminated Sediment: Comparison of Uptake and Behavior." Environmental Toxicology and Chemistry **7**: 1-6.

The burrowing behavior of three polychaete species (Nereis virens and Nephtys caeca) was examined after variable exposure periods (7, 14, 21 and 28 d) to sediment contaminated with a cadmium concentration of about 40 mg/kg (dry weight). Most comparisons of burrowing times and rates between exposed and unexposed worms were not statistically significant. Those that were significant were relatively minor, e.g., a maximum reduction in burrowing time of 6.3 s, and probably would have little ecological relevance. The feeding behavior of G. dibranchiata on the polychaete Euzonus mucronata was not affected by a 28-d exposure to cadmium-contaminated sediment. Prepared in cooperation with National Marine Fisheries Service, Kodiak, AK. Northwest and Alaska Fisheries Center.

Olsen, J., J. Wenburg, et al. (1996). "Semiautomated multilocus genotyping of Pacific salmon (Oncorhnychus spp.) using microsatellites." Molecular Marine Biology and Biotechnology **54**(4): 259-272.

Ostrand, W. (1999). "Marbled murrelets as initiators of feeding flocks in Prince William Sound, Alaska." Waterbirds **22**(2): 314-318.

I sought to determine which seabird species initiated small, ephemeral, multispecies feeding flocks in Prince William Sound, AK (PWS). I observed 47 feeding flocks at fire sites during June 1996 and determined the initiating species at 34. All of the latter flocks were initiated by pursuit divers, of which 76.5% were Marbled Murrelets (Brachyramphus marmoratus), the most abundant seabird in PWS. Formation of feeding flocks followed either of two scenarios: 1) larids were attracted to a feeding location by the presence or activity of Marbled Murrelets (26.9%), or 2) both larids and murrelets were present anti flock feeding began after the murrelets dove from the surface (50.0%). Other principal participants were Black-legged Kittiwakes (Rissa tridactyla) and Glaucous-winged Gulls (Larus glaucescens).

Ostrand, W., K. Coyle, et al. (1996). Selection of forage-fish schools by murrelets and tufted puffins in Prince William Sound, Alaska. Forage Fishes in Marine Ecosystems: Proceedings of the International Symposium on the Role of Forage Fish in Marine

Ecosystems, Anchorage, Alaska (USA), 13-16 Nov 1996, American Fisheries Society.

Studies examining the distribution of seabirds and their prey have determined that seabird and forage abundances are correlated, but that the strength of this relationship generally weakens as the spatial scale decreases (for review see Hunt 1988). The poor correlation between seabirds and their prey abundances at finer scales suggests that seabirds do not have sufficient knowledge of the distribution of prey to consistently select the best prey patches (Hunt 1988). Hence, seabirds may be more effective if they supplement their searches for food by exploiting the efforts of other seabirds by joining foraging flocks (Hunt 1988). Mehlum et al. (1996) correlated Bruennich's guillemot (Uria lomvia) abundance to forage density at a fine scale by including a prey density threshold that excluded nonpreferred food items from their correlation analysis. In examining fine-scale relationships between common tern (Sterna hirundo) and forage fish, Safina and Burger (1985) did not find a relationship between predator and prey abundance, but did find a significant relationship between the number of birds, depth to prey, and the presence of predatory fish. These fine-scale studies suggest that birds may select patches by prey characteristics as well as abundance. We sought to explore the relationship between seabirds and forage-fish schools at fine scales within Prince William Sound, Alaska. To explicitly test for fine-scale selection of forage fish by tufted puffins (Fratercula cirrhata) and brachyramphine murrelets (Brachyramphus spp.), we analyzed our data using fish schools as the sampling unit.

Ostrand, W., K. Coyle, et al. (1998). "Selection of forage-fish schools by murrelets and tufted puffins in Prince William Sound, Alaska." Condor **100**: 286-297.

We collected hydroacoustic and bird-observation data simultaneously along transects in three areas in Prince William Sound, Alaska, 21 July-11 August 1995. The probability of the association of fish schools with Marbled Murrelets (Brachyramphus marmoratus) and Tufted Puffins (Fratercula cirrhata) was determined through the use of resource selection functions based on logistic regression. Mean (plus or minus SD) group sizes were small for both species, 1.7 plus or minus 1.1 and 1.2 plus or minus 0.7 for Marbled Murrelets and Tufted Puffins, respectively. Oceanographically, all study areas were stratified with synchronous thermo- and pycnoclines (a water layer of increasing temperature and density, respectively, with increasing depth). Our analysis indicated that Tufted Puffins selected fish schools near their colony, whereas Marbled Murrelets selected smaller, denser fish schools in shallower habitats. We suggest that murrelets selected shallower habitats in response to lower maximum diving depths than puffins. Small feeding-groups size is discussed in terms of foraging theory and as a consequence of dispersed, low density food resources.

Ostrand, W., G. Drew, et al. (1998). "Evaluation of radio-tracking and strip transect methods for determining foraging ranges of black-legged kittiwakes." Condor **100**(4): 709-718.

We compared strip transect and radio-tracking methods of determining foraging

range of Black-legged Kittiwakes (Rissa tridactyla). The mean distance birds were observed from their colony determined by radio-tracking was significantly greater than the mean value calculated from strip transects. We determined that this difference was due to two sources of bias: (1) as distance from the colony increased, the area of available habitat also increased resulting in decreasing bird densities (bird spreading). Consequently, the probability of detecting birds during transect surveys also would decrease as distance from the colony increased, and (2) the maximum distance birds were observed from the colony during radio-tracking exceeded the extent of the strip transect survey. We compared the observed number of birds seen on the strip transect survey to the predictions of a model of the decreasing probability of detection due to bird spreading. Strip transect data were significantly different from modeled data; however, the field data were consistently equal to or below the model predictions, indicating a general conformity to the concept of declining detection at increasing distance. We conclude that radio-tracking data gave a more representative indication of foraging distances than did strip transect sampling. Previous studies of seabirds that have used strip transect sampling without accounting for bird spreading or the effects of study-area limitations probably underestimated foraging range.

Page, D., P. Boehm, et al. (1995). Identification of hydrocarbon sources in the benthic sediments of Prince William Sound and the Gulf of Alaska following the Exxon Valdez oil spill. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

Advanced hydrocarbon fingerprinting methods and improved analytical methods make possible the quantitative discrimination of the multiple sources of hydrocarbons in the benthic sediments of Prince William Sound (PWS) and the Gulf of Alaska. These methods measure an extensive range of polycyclic aromatic hydrocarbons (PAH) at detection levels that are as much as two orders of magnitude lower than those obtained by standard Environmental Protection Agency methods. Nineteen hundred thirty six (1936) subtidal sediment samples collected in the sound and the eastern Gulf of Alaska in 1989, 1990, and 1991 were analyzed. Fingerprint analyses of gas chromatography-mass spectrometry data reveal a natural background of petrogenic and biogenic PAH. The petrogenic background is derived largely from oil seeps in the eastern Gulf of Alaska. Age-dated (super(210)Pb) sediment cores indicate that significant input of seep hydrocarbons into Prince William Sound has been going on for at least 160 years and probably for thousands of years. Superimposed on this natural background are locally elevated concentrations of anthropogenic hydrocarbons from sources such as diesel fuel and pyrogenic PAH that are found primarily adjacent to active or historical sites of human use. Exxon Valdez crude, its weathering products, and diesel fuel refined from Alaska North Slope crude are readily distinguished from the natural seep petroleum background and from each other because of their distinctive PAH distributions. Mixing models were developed to calculate the PAH contributions from each source to each sediment

sample. These calculations show that most of the seafloor in PWS contains no detectable hydrocarbons from the Exxon Valdez spill, although elevated concentrations of PAH from seep sources are widespread. In those areas where they were detected, spill hydrocarbons were generally a small increment to the natural petroleum hydrocarbon background. Low levels of Exxon Valdez crude residue were present in 1989 and again in 1990 in nearshore subtidal sediments off some shorelines that had been heavily oiled. By 1991 these crude residues were heavily degraded even more sporadically distributed.

Page, D., P. Boehm, et al. (1996). "The natural petroleum hydrocarbon background in subtidal sediments of Prince William Sound, Alaska, USA." Environmental Tocicology and Chemistry **15**(8): 1266-1281.

A natural regional petroleum hydrocarbon background has been identified in the subtidal sediments of Prince William Sound that is readily distinguished from Exxon Valdez spill oil by chemical fingerprinting methods. This hydrocarbon background is derived from natural petroleum seeps in the eastern Gulf of Alaska. The Alaska Coastal Current carries fine-grained sediments and associated hydrocarbons from seep areas to the east into Prince William Sound, where they are deposited on the seafloor. The analysis of age-dated sediment cores indicates that this process has been going on for the past 160 years, and probably for many thousands of years. In addition, results of a stratified random study of nearshore subtidal sediments conducted in 1990 show that this is a general phenomenon throughout the sound and is significant even in shallow water (3 to 30 m). For example, oleanane, a saturate petroleum biomarker found in Prince William Sound prespill background petroleum and seep sources but not in Exxon Valdez petroleum, is present in subtidal sediment samples from locations throughout the sound. This supports the conclusion that seep areas to the east are major sediment sources for the sound. Moreover, polycyclic aromatic hydrocarbon mixing model calculations show that, although Exxon Valdez spill-oil residues are present in nearshore subtidal sediments, they generally form a small increment on the natural background. The recognition of preexisting natural and anthropogenic hydrocarbon sources in a spill area is a fundamentally important component of any natural resource damage assessment.

Page, D., P. Boehm, et al. (1997). "An estimate of the annual input of natural petroleum hydrocarbons to seafloor sediments in Prince William Sound, Alaska." Marine Pollution Bulletin **34**(9): 744-749.

Natural seepage is an important contributor to the petroleum baseline of the marine environment at many locations. For areas known to be influenced by natural petroleum seepage, this source of hydrocarbons can be an important part of the baseline. The actual annual input of petroleum from natural seepage is uncertain, with estimates of total worldwide annual seep inputs ranging from 0.025 x 10 super(6) to 6 x 10 super(6) t yr super(-1). One reason for this uncertainty is that observations of seeps often lack sufficient geographic sampling density over an adequate period of time to allow accurate estimates of

inputs to a given geographical area to be made. Further complicating the estimation of oil seepage rates is the fact that, for a given location, the rate of seepage can vary considerably over time. For example, variable seepage rates of 7-10 t day super(-1) have been estimated for the Coal Oil Point (California) offshore seeps by slick area/thickness measurements and by direct collection of oil from submarine seeps made at different times. Where conditions permitted the actual visualization of surface oil slicks by remote sensing, estimates of regional seepage rates of ca. 17 100 t yr super(-1) were made for a seep area in the Gulf of Mexico offshore of Louisiana. There are also reports of flow estimates for individual seeps based on direct observation.

Page, D., P. Boehm, et al. (1998). "Petroleum sources in the western Gulf of Alaska/Shelikoff Strait area." Marine Pollution Bulletin **36**(12): 1004-1012.

Petroleum hydrocarbons form an important part of the hydrocarbon baseline of the western Gulf of Alaska/Shelikoff Strait region. The sources that contribute to this baseline include terrestrial and marine natural oil seeps, oil production-related discharges, oil spills from vessels and petroleum product releases from various commercial activities. The purpose of this paper is to define some of the natural petroleum sources present in an area of Alaska that is also part of the spill zone of the Exxon Valdez oil spill (EVOS) and to compare these sources with hydrocarbons in sediment samples from the region. The major impacts of the EVOS occurred within Prince William Sound. However, after 7 days, EVOS oil was transported out of Prince William Sound into the western Gulf of Alaska region. Any EVOS oil entering the Gulf of Alaska region had been at sea for at least 7 days and generally much longer and had lost, through weathering, a major portion of its toxic fraction. Because the initial impact was most severe within Prince William Sound, most of the scientific effort was devoted to studies in that region. However, there were a number of scientific studies that included sampling stations in the western Gulf of Alaska/Shelikoff Strait region. Data from these studies also provide some information on the petroleum hydrocarbon baseline of this area and these are considered in the present paper along with previously unpublished chemistry data for samples collected by the authors from petroleum seeps in the Alaska Penninsula in 1993 and 1994. The area considered in this paper is bounded by the northeast part of the Kodiak Island group to the east, Kalgin Island in Cook Inlet to the North and Perryville/Ivanoff Bay on the Alaska Peninsula to the west and south.

Page, D., P. Boehm, et al. (1999). "Pyrogenic polycyclic aromatic hydrocarbons in sediments record past human activity: A case study in Prince William Sound, Alaska." Marine Pollution Bulletin **38**(4): 247-260.

Polycyclic aromatic hydrocarbons (PAH) are sensitive recorders of past human activities in Prince William Sound, Alaska. In the nearshore subtidal sediments of bays, the fingerprints of the pyrogenic (combustion-derived) PAH record numerous sites of both present and historical human activities including active

settlements, fish hatcheries, fish camps and recreational campsites, in addition to abandoned settlements, canneries, sawmills, and mining camps. In instances, there are high levels of PAH attributable to past human activities even though there is little remaining visual evidence of these activities on the shorelines. Forest fires are also an important source of pyrogenic PAH in subtidal sediments at certain time periods and locations and pyrogenic PAH from atmospheric fallout forms part of the regional PAH background. These pyrogenic PAH fingerprints are superimposed on a regional background of natural petroleum hydrocarbons derived from seeps in the eastern Gulf of Alaska. In isolated locations, weathered traces of the Exxon Valdez oil spill were detected as a minor part of the total PAH present from all sources.

Page, D., E. Gilfillan, et al. (1995). Shoreline ecology program for Prince William Sound, Alaska following the Exxon Valdez oil spill: Part 1. Study design and methods. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

The objective of the Coastal habitat Injury Assessment study was to document and quantify injury to biota of the shallow subtidal, intertidal, and supratidal zones throughout the shoreline affected by oil or cleanup activity associated with the Exxon Valdez oil spill. The results of these studies were to be used to support the Trustee's Type B Natural Resource Damage Assessment under the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). A probability based stratified random sample of shoreline segments was selected with probability proportional to size from each of 15 strata (5 habitat types crossed with 3 levels of potential oil impact) based on those data available in July, 1989. Three study regions were used: Prince William Sound, Cook Inlet/Kenai Peninsula, and Kodiak/Alaska Peninsula. A Geographic Information System was utilized to combine oiling and habitat data and to select the probability sample of study sites. Quasi-experiments were conducted where randomly selected oiled sites were compared to matched reference sites. Two levels of statistical inferences, philosophical bases, and limitations are discussed and illustrated with example data from the resulting studies.

Papa, R. and P. Becker (1999). Alaska Harbor Seal (Phoca vitulina) Contaminants: A Review with Annotated Bibliography. Govt Reports Announcements & Index (GRA&I), National Inst. of Standards and Technology (CSTL), Gaithersburg, MD. Analytical Chemistry Div.: 262p.

The numbers of harbor seals (Phoca vitulina) have declined steadily and substantially over the last two decades in the Central and Western Gulf of Alaska, including Prince William Sound. Although the reasons for this decline have not been identified, hyptheses have included fishery interactions, changes in availability of food resources, human harvests, disease, increase in predation, increase in disturbance, and pollution. Although the presence of contaminants has been suggested as one possible causative factor in the decline of both the harbor seal and Steller sea lion, very little information is readily available on contaminant concentrations in these animals. As an initial step in the development of a database that can be used to define the types of studies needed to address the possible role of anthropogenic contaminants in the decline of this species, existing data and information on levels of contaminants in

the harbor seals of Alaska, the contiguous U.S., and other areas of the world were reviewed. This report provides references and current scientific literature, as well as 'gray' literature and unpublished databases. This report is divided into three sections: (1) a synthesis of information based on the review, (2) tables that summarize the published data, and (3) an annotated bibliography.

Parker, W. (1995). A research program to ensure that best available technology is used in preventing and responding to oil spills in Alaska and the North Pacific. Prevention, Response and Oversight Five Years after the Exxon Valdez Oil Spill. Proceedings of an International Conference, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science.

This paper will identify the gaps in present oil spill prevention and response programs in Alaska as identified by the Alaska Hazardous Substances Spill Technology Review Council (HSSTRC). It will then discuss the research program being set up to fill these gaps and to ensure that best available technology is available to Alaskan shippers and responders. This plan will describe research goals in several areas including prevention, response, remediation, damage assessment, and restoration. The HSSTRC is coordinating this plan in cooperation with the Interagency Federal Oil Spill Coordinating Committee. Funding for research will be discussed, in particular the utilization of $5 million from the Exxon Valdez criminal settlement appropriated for oil spill research and development (R&D) in the 1993 Alaska Legislature for use until December 1, 1997.

Parson, T. A. S. (In preparation). A Contaminant Assessment for Kenai National Wildlife Refuge, Alaska. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office.

Paul, A. (1997). "Use of bioenergetic measurements to estimate prey consumption, nutritional status and thermal habitat requirements for marine organisms reared in the sea." Bulletin of the National Research Institute of Aquaculture **Supplement 3**: 59-68.

Paul, A. and J. Paul (1998). "Comparisons of whole body energy content of captive fasting age zero Alaskan Pacific herring (Clupea pallasi Valenciennes) and cohorts over-wintering in nature." Journal of Experimental Marine Biology and Ecology **226**: 75-86.

Changes in whole body energy content (WBEC) of captive age-0 Pacific herring (Clupea pullasi Valenciennes) forced to fast during winter was measured and compared to cohorts collected in the field. Somatic energy content (kJ times g super(-1) wet wt) of fasting captives declined at a rate of 23 J times g super(-1) wet wt per day from 1 December 1995 to 25 January 1996 (56 days) at a mean temperature of 6.6 degree C. In another observation, fish captured on 1 December 1995 and held without feeding until 1 April 1996 (122 days) had an average WBEC that changed from 5.2 to 3.2 kJ times g super(-1) wet wt during

captivity at about 5.2 degree C. Fish that died during fasts had WBEC values ranging from 2.8 to 3.6 kJ times g super(-1) wet wt. During March 1996 the WBEC of field collected age-0 herring averaged 3.8 kJ times g super(-1), with approximately 40% having WBEC less than or equal to 3.6 kJ times g super(-1) wet wt. Thus, by March the average recruit had used most of its stored energy. These observations confirm that in the northern Gulf of Alaska region age-0 herring rely heavily on stored energy to survive their first winter.

Paul, A. and J. Paul (1998). "Spring and summer whole body energy content of Alaskan juvenile Pacific herring." Alaska Fishery Research Bulletin **5**(2): 131-136.

During the spring and summer of 1996 and 1997, we examined the whole-body energy content (WBEC) of Pacific herring Clupea pallasi less than or equal to 165 mm standard length (SL) from Prince William Sound, Alaska. From May to October, somatic energy (kJ times g super(-1) wet weight) exhibited a wide range of values relative to length. Young-of-year recruits, which appeared in July of both years, typically had WBEC of 2-3 kJ times g super(-1) wet weight after metamorphosis, and older fish had WBEC of 4-6 kJ times g super(-1) wet weight. By October the WBEC of juvenile herring was typically 4-6 kJ times g super(-1) wet weight. The consequences of the large seasonal and size-related variability in WBEC in juvenile herring is discussed relative to the transfer of energy to predators.

Paul, A. and J. Paul (1999). First year energy storage patterns of Pacific herring and walleye pollock: insight into competitor strategies. International Symposium on Ecosystem Considerations in Fisheries Management, Fairbanks, AK.

Paul, A. and J. Paul (1999). "Interannual and regional variations in body length, weight, and energy content of age 0 Pacific herring from Prince William Sound, Alaska." Journal of Fish Biology **54**: 996-1001.

Age-0 Pacific herring were surveyed in October of 4 years in a large northern Gulf of Alaska estuary, to determine the range of variations in length, weight and whole body energy content (WBEC). These parameters reflect their preparedness for surviving their first winter's fast. During the surveys there were distinct regional and interannual variations in all three parameters for individual groups of herring in Prince William Sound. Likewise, with each collection there was typically a large range of size and WBEC values. The average standard length was (plus or minus) 80 plus or minus 13 mm (range=40-118), the mean whole body wet weight was 5 times 7 plus or minus 3 times 0 g (range=0 times 7-29 times 2) and the average WBEC of all age-0 herring captured, regardless of year or site (n=1471), was 5 times 4 plus or minus 1 times 0 kJ g super(-1)wet weight (range=2 times 4-9 times 4). The large range of WBEC and size indicates that age-0 herring at different capture sites were not all equally prepared for surviving their first winter.

Paul, A. and J. Paul (1999). "Energy contents of whole body, ovaries and ova from pre-

spawning Pacific herring." Alaska Fishery Research Bulletin **6**(1): 29-34.

The energy content of whole bodies (WBEC), ovaries (OEC), and ova taken from ripe Pacific herring Clupea pallasi collected from one site in Prince William Sound, Alaska was measured to determine how female nutritional status influenced ova energy content and OEC. The average female WBEC was 23.86 kJ per gram dry weight (SD = ± 1.19), and the average energy content of one ovum was 8.1 J (SD = ± 0.9). The WBEC of spawning females varied considerably. No clear relationship was found between either female body weight or WBEC and the mean energy content of ova or OEC per gram. Well-fed females, those identified by high WBEC, did not have a higher average energy content in their ova. Apparently Pacific herring allocate energy to somatic growth rather than enriching OEC per gram. This strategy would improved their chances to successfully propagate because bigger females spawn more eggs.

Paul, A., J. Paul, et al. (1996). "Ovarian energy content of Pacific herring from Prince William Sound, Alaska." Alaska Fishery Research Bulletin **3**(2): 103-111.

Ovarian energy content (OEC; measured in kilojoules) of ripe whole ovaries and per gram of ovary wet weight (OEC g super(-1)) were examined for Pacific herring Clupea pallasi from Prince William Sound, Alaska. Specimens were collected in 1995 and 1996. The OEC of whole ovaries was related linearly to whole body weight, but OEC g super(-1) of ovary was not. Just prior to spawning OEC was typically between 5 and 7 kJ g super(-1) of ovary. There were no significant differences in OEC g super(-1) of ovary between groups of females from different capture sites in the 1995 collections, but in 1996 there were small but significant differences in OEC values related to capture site. When the OEC values from all fish collected in 1995 were pooled and compared to all those collected in 1996, there was no significant difference in OEC g super(-1) of ovary between years. The number of ova present just prior to spawning exhibited no clear relationship to OEC g super(-1) of ovary. About 97% of OEC was expended during spawning. The OEC of whole ovaries was used to estimate the energy from herring spawn added to Prince William Sound beaches from 1988 to 1995. Since 1989, when there was a massive oil spill, the annual amount of energy added to the Prince William Sound ecosystem by herring eggs has decreased from 68 x 10 super(9) kJ to 10 x 10 super(9) kJ in 1995, which in addition to being a concern for recruitment, could also be important to species relying on herring spawn as an energy source.

Paul, A., J. Paul, et al. (1998). "Fall and spring somatic energy content for Alaskan Pacific herring (Clupea pallasi Valenciennes 1847) relative to age, size and sex." Journal of Experimental Marine Biology and Ecology **223**: 133-142.

During the fall of 1995 and spring of 1996, the whole body energy content (WBEC) of Pacific herring (Clupea pallasi Valenciennes 1847) from Prince William Sound, Alaska, was examined. Somatic energy (kJ g super(-1) wet wt.) exhibited a wide range of values relative to fish length. In the fall young of the year (YOY) recruits had an average of 5.7 kJ g super(-1) wet wt. for whole body samples vs. 8.0 for age 1 and 9.4-10.2 kJ g super(-1) for fish of ages 2 to 7. The

following spring the 1995 year class which had just survived their first winter averaged 4.4 kJ g super(-1) wet wt. for somatic samples, and age 1 fish had similar values, while herring ages 2 to 7 had WBEC > 5 kJ g super(-1). The difference in somatic energy content between adult male and female fish captured in fall and again in the spring just prior to spawning, was about 4 kJ g super(-1) wet wt., or about a 40% change. The difference in mean values for somatic energy content for YOY herring was only about 1.4 kJ g super(-1) suggesting either the recruits ate more food during the winter than the adults, had lower energetic needs, or only those with higher than average energy stores survived the winter. The fall measures of WBEC showed the YOY and age 1 fish stored markedly less energy to over-winter than older herring. Thus, energetically the recruiting year class, and those entering their second winter, are the most at risk of over-winter mortality.

Paul, A., J. Paul, et al. (1998). "Seasonal changes in whole-body energy content and estimated consumption rates of age 0 walleye pollock from Prince William Sound Alaska." Estuarine, Coastal and Shelf Science **47**: 251-259.

This study examined the somatic energy content and prey consumption needs of recruiting walleye pollock Theragra chalcogramma in one of Alaska's large estuaries to begin to evaluate the role of this species in the food-web. Age 0 pollock were collected from Prince William Sound in the fall and spring during 2 years. In the fall of 1995, few recruits <70 mm standard length (SL) were present and the mean whole-body energy content (WBEC) was 3.6 (plus or minus 0.2) kJ g super(-1) wet wt. In the following spring the 1995 year class survivors were greater than or equal to 80 mm SL and the mean WBEC was 4.0 kJ g super(-1) (plus or minus 0.5). In the fall of 1996 the age 0 pollock had an average WBEC of 3.6 kJ g super(-1) (plus or minus 0.2), identical to 1995, but smaller 60-70 mm fish were common. In the spring of 1997 few fish <70 mm were captured and WBEC averaged 3.4 kJ g super(-1) (plus or minus 0.4). In both years, recruits were generally able to maintain or improve their WBEC over the winter. There was marked variation in WBEC for fish from different collection sites. Changes in WBEC of the 1996 year class was monitored during their first year.

Paul, A. and M. Willette (1997). Geographical variation in somatic energy content of migrating pink salmon fry from Prince William Sound: a tool to measure nutritional status. Forage Fishes in Marine Ecosystems: Proceedings of the International Symposium on the Role of Forage Fish in Marine Ecosystems.

The nutritional condition of nearshore migrating pink salmon fry (Oncorhynchus gorbuscha) from three different locations in Prince William Sound was measured during the spring of 1995. Two sample sites were on the west side of the sound where hatcheries release large numbers of fry, and one on the east where hatchery fry are rare. Whole body energy (kJ/g) wet weight was a good indicator of nutritional status while both wet and dry weight condition factors were less reliable measures of it. The whole body energy content of the fry averaged 3.2, 3.6, and 4.4 kJ/g wet weight at the three study sites where fry were most abundant, moderately abundant, and least abundant, respectively. The energy

content of the fish from the three regions was statistically different. Fry in the best nutritional state had a somatic energy content greater than or equal to 4 kJ/g wet weight. Only 2% of the 89 fry sampled from the two west side sites on 31 May and 2 June 1995 had somatic energy contents greater than or equal to 4 kJ/g wet weight, versus 76% of 42 fry collected from the single east side site on 27 May. These results in conjunction with zooplankton and stomach contents data from the three sites suggest that competition for food may have limited the growth of fry at the west side sampling sites where hatcheries were releasing large numbers of fish.

Peacock, N. and L. J. Field (1999). The March 1989 Exxon Valdez Oil Spill: A Case Study in Responding to Subsistence Seafood Safety Issues. Evaluating and Communicating Subsistence Seafood Safety in a Cross-Cultural Context: Lessons Learned from the Exxon Valdez Oil Spill. L. J. Field, J. A. Fall, T. S. Nighswander, N. Peacock and U. Varanasi. Pensacola, FL, USA, Society of Environmental Toxicology and Chemistry (SETAC): 1-20.

The Exxon Valdez oil spill (approximately 10.8 million gallons) in Prince William Sound, Alaska stands out in the minds of most Americans as a major environmental diseaster. The spilled oil spread southwestward accross Prince William Sound into the Gulf of Alaska and past Kodiak Island, effecting areas used for subsistence by residents of 15 predominantly Alaska Native villages. A general overview of the spill, the areas effected by the spilled oil, and the concerns, planning, and activities that took place relative to the safety of the Natives subsistence foods are included. Also, a syllabus of the book describes the organiztion of the book and some of the issues addressed.

Pearson, L. (1995). Development of technology protocols for oil and hazardous substance spill response appropriate for the state of Alaska. Prevention, Response and Oversight Five Years after the Exxon Valdez Oil Spill. Proceedings of an International Conference, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science.

On March 24, 1989, as the oil spread from the T/V Exxon Valdez throughout Prince William Sound, the floodgate swung open and entrepreneurs raced out to promote the use of their concepts, inventions, or products designed for spill response. Thousands of product packets were submitted to the U.S. Coast Guard, Environmental Protection Agency, Exxon, and the state. At that time, there were no standard tests and methodologies adopted by the federal and state government to review and screen the products.

Pearson, W., R. Elston, et al. (1999). "Why did the Prince William Sound, Alaska, Pacific herring (Clupea pallasi) fisheries collapse in 1993 and 1994? Review of hypotheses." Can. J. Fish. Aquat. Sci. **56**(4): 711-737.

Following record harvests of Pacific herring (Clupea pallasi) in Prince William Sound, Alaska, in the 3 years after thee Exxon Valdez oil spill, the fishery failed in 1993. The hypotheses advanced to explain this dramatic 1993 decline occur in

3 categories: 1) effects associated with the 1989 oil spill, 2) harvesting effects, and 3) natural phenomena. Based on a review, the authors are convinced that a combination of increasing Prince William Sound herring biomass and decreasing food supply led to a poor condition of Prince Willima Sound herring, which resulted in the 1993 decline. Other natural causes could have contributed to the decline, including disease, cold water temperatures, increased predation, and other natural stochistic processes. No evidenc supports hypotheses that the decline resulted solely from overharvesting or underharvesting. The record high population levels and harvest of Prince William Sound herring in the years after the 1989 oil spill, the lack of change from the expected age-class distribution, and the low level of oil exposure documented for herring in 1989 and the following years all indicate that the 1989 oil spill did not contribute to the 1993 decline. Poor nutritional status, either alone or in combination with disease or other natural factors, was most likely responsible for the 1993 collapse.

Pearson, W., E. Moksness, et al. (1995). A field and laboratory assessment of oil spill effects on survival and reproduction of Pacific herring following the Exxon Valdez spill. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

Pacific herring, Clupea pallasi, spawn along hundreds of kilometres of shoreline in Prince William Sound. Herring eggs incubate in intertidal and shallow subtidal areas attached to kelp and eelgrass. In April 1989, following the Exxon Valdez oil spill, there was potential in Prince William Sound for localized effects on spawning herring, their eggs, and the hatching larvae. Field and laboratory investigations in 1989 and 1990 were designed to assess potential injury to Prince William Sound herring by testing for differences between oiled regions and unoiled reference areas and by relating biological response variables to the concentrations of polycyclic aromatic hydrocarbons (PAH) in eggs-on-kelp samples. Hydrocarbon analyses and laboratory incubation were conducted on eggs-on-kelp samples from Prince William Sound and Sitka Sound. The eggs and hatching larvae were examined to evaluate several response variables: egg development, hatch, larval survival, abnormal development of larvae, larval length, and larval yolk-sac volume. Analysis of 1989 shoreline surveys indicate that about 96% of the total spawn length (158 km) in Prince William Sound occurred along shorelines with no oiling, and less than 1% of the 1989 total spawn length occurred along shorelines with moderate to heavy oiling.

Perrollaz, D. and J. Rash (1990). Analysis of sea otter fur for crude oil contamination. Symposium to Evaluate the Response Effort on Behalf of Sea Otters after the T/V Exxon Valdez Oil Spill into Prince William Sound, Anchorage, Alaska, USA, April 17-19, 1990, U S Fish and Wildlife Service.

Piatt, J. and P. Anderson (1996). Response of common murres to the Exxon Valdez oil

spill and long-term changes in the Gulf of Alaska marine ecosystem. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 720-737.

Short-term effects of the 1989 TV Exxon Valdez oil spill on seabirds were dramatic and well documented. Seabird populations at sea in the spill zone were immediately depressed, and more than 30,000 dead, oiled seabirds were recovered from beaches within months of the spill. It is estimated that 250,000 seabirds were killed by oil, of which 74% were murres *Uria* spp. Based on comparisons of prespill (1970s) and postspill (1989-1994) data, long-term effects on murres attributed to oil pollution included population declines, reduced breeding success, and delayed breeding phenology. Populations remained depressed, but breeding success and phenology gradually returned to normal levels by 1993. An alternative hypothesis to explain these long-term effects is that murres were responding to natural events in their marine environment. Reduced flow of the Alaska Coastal Current (ACC) in 1989 may have reduced and delayed biological productivity in the ACC. On a broader time scale, marked changes in marine fish communities have occurred during the past 20 years. Coincident with cyclical fluctuations in seawater temperatures, the abundance of small forage species (e.g., northern pink shrimp *Pandalus borealis*, capelin *Mallotus villosus*, and Pacific sandfish *Trichodon trichodon*) declined precipitously in the late 1970s while populations of large predatory fish (e.g., walleye pollock *Theragra chalcogramma*, Pacific cod *Gadus macrocephalus*, and flatfish) increased dramatically. Correspondingly, seabird diets shifted from mostly capelin in the 1970s to mostly Pacific sand lance *Ammodytes hexapterus* and juvenile pollock in the late 1980s. Furthermore, a variety of seabirds and marine mammals both inside and outside of the oil spill zone exhibited signs of food stress (population declines, reduced productivity, die-offs) throughout the 1980s and early 1990s. We conclude that available data are inadequate to distinguish between long-term effects of the Exxon Valdez oil spill on murres and a natural response of murres to long-term changes in their marine environment.

Piatt, J., G. Drew, et al. (1999). Biological effects of the 1997-1998 ENSO event in lower Cook Inlet, Alaska. Proceedings of the 1998 Science Board Symposium on the Impacts of the 1997/1998 El Nino Event on the North Pacific Ocean and its Marginal Seas.

Anomalously warm sea surface temperatures (SSTs) were observed in the Gulf of Alaska (GOA) beginning in June of 1997, but not in Cook Inlet until September, 1997. Warm temperature anomalies at the surface and at depth persisted until May of 1998, when temperatures returned to average in the GOA and Cook Inlet. Thus, temperature anomalies occurred outside the core window of productivity (June-August) for forage fish and seabirds in both 1997 and 1998. Abundance or production of phytoplankton, zooplankton, fish, and seabirds in lower Cook Inlet varied among years, and overall appeared to be depressed in 1998. A few biological anomalies that might be attributed to ENSO effects were observed: seabird die-offs, reduced productivity and delayed phenology were linked to a reduction or delay in food availability, but the mechanism by which anomalously warm water temperatures in winter reduce forage fish availaility

during the summer breeding seasosn for seabirds is not known.

Piatt, J. and R. Ford (1996). How many seabirds were killed by the Exxon Valdez oil spill? Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 712-719.

After the Exxon Valdez oil spill of 24 March 1989, 36,115 dead seabirds were recovered from beaches and processed at morgues. Most or all of 1,888 live oiled seabirds brought to rehabilitation centers also died and about 3,260 oiled carcasses were never delivered to morgues. Of these 41,263 carcasses accounted for, we estimated conservatively that only 30,000 were killed by oil pollution. Carcass drift and recovery experiments conducted in the affected area during the spill and 1 year later, along with historical experiments conducted in other oceanographic regions, suggest that only a fraction (range = 4-30%) of birds killed were likely to have been recovered from beaches. Regression analysis of these drift-recovery data predicts a 15% recovery rate (r super(2) = 0.38, P = 0.015). We recognize uncertainties in the assumptions and parameter values used to extrapolate total mortality from drift-recovery data, but we have confidence that mortality fell within the extreme range of estimates (100,000-690,000 birds killed) because these reflect a very wide range of observed and experimentally determined parameter values. Total mortality can also be estimated by comparing pre- and postspill colony population estimates. Uncertainties about these census data are greater than those associated with drift-recovery data, but nonetheless provide an independent mortality estimate of similar magnitude. Taken together, all evidence suggests that about 250,000 seabirds were killed by Exxon Valdez oil.

Piatt, J. and C. Lensink (1989). "Exxon Valdez bird toll." Nature **342**: 865-866.

On March 24, 1989, the oil tanker Exxon Valdez spilled 260,000 barrels of Alaska North Slope crude oil into Prince William Sound. Oil drifted in a southwesterly direction into the Gulf of Alaska and eventually covered 25,000 square km of coastal and offshore waters occupied by more than a million marine birds. As predicted, we have witnessed an unprecedented toll of marine birds from oil pollution, which is summarized here.

Piatt, J., C. Lensink, et al. (1990). "Immediate impact of the "Exxon Valdez" oil spill on marine birds." Auk **107**(2): 387-397.

On 24 March 1989, the oil tanker 'Exxon Valdez' spilled 260,000 barrels of crude oil in Prince William Sound, Alaska (USA). Oil eventually drifted over 30,000 km2 of costal and offshore waters occupied by approximately one million marine birds. More than 30,000 dead birds of 90 species were retrieved from polluted areas by 1 August 1989. Of those identified, murres (74%), other alcids (7.0%), and sea ducks (5.3%) suffered the highest mortality from oil, and most (88%) birds were killed outside of Prince William Sound. A colony of 129,000 murres at the Barren Islands was probably devastated. Another 7,000 birds were retrieved between 1 August and 13 October, but most of those birds appeared to have

died from natural causes. This later die-off was composed largely of shearwaters and other procellariids (51%), gulls (22%), and puffins (14%). Based on aerial and ship-based surveys for populations at risk, and extrapolating from the number of dead birds recovered, we estimate that the total kill from oil pollution was from 100,000 to 300,000 birds.

Piatt, J., N. Nasland, et al. (In press 1999). "Nesting habitat selection and nest-site fidelity in the Kittlitz' Murrelet (Brachyramphus brevirostris)." Northwestern Naturalist.

Piatt, J. and N. Naslund (1995). Abundance, distribution, and population status of marbled murrelets in Alaska. ECOLOGY AND CONSERVATION OF THE MARBLED MURRELET. C. Ralph, G. J. Hunt, M. Raphael and J. Piatt. Anchorage, AK. **No. 152:** 285-294.

Ship-based surveys conducted throughout Alaska during the 1970's and 1980's, and more recent small boat surveys conducted in the northern Gulf of Alaska, suggest that about 280,000 murrelets reside in Alaska during summer. Most Marbled Murrelets are concentrated offshore of large tracts of coastal coniferous forests in southeast Alaska, Prince William Sound, and the Kodiak Archipelago. About 1-3 percent of murrelets breed wholly outside of forested areas in Alaska, and these presumably all nest on the ground. At sea, murrelets tend to occupy sheltered waters of bays, fiords, and island straits, and often aggregate near large river outflows or tide rips. Small boat surveys of Prince William Sound and Christmas Bird Count trends suggest that Marbled Murrelet populations in Alaska declined by about 50 percent between 1972 and 1992. Population declines may have resulted from cumulative effects of oil pollution, gill netting, logging of old-growth breeding habitat, and natural changes in the marine environment. The Exxon Valdez oil spill killed an estimated 8,400 murrelets in 1989, or about 3 percent of the Alaska population. The toll from chronic pollution is unknown. About 3300 murrelets (89 percent adult) die annually in fishing nets in Alaska - a sustained adult mortality rate of 1.5 percent per annum. The extent or effect on murrelets of logging in Alaska are unknown. While only 7 percent of the old-growth has been harvested in the Tongass National Forest, about 40 percent of the highly productive old-growth in the forest has already been logged. A decline in forage fish populations in the Gulf of Alaska during the last 20 years may account for reduced breeding success and population size of several seabird species, including murrelets. Murrelet populations should be sensitive to small increases in adult mortality from the above factors because production by murrelets is low and must therefore be balanced by a low annual adult mortality rate.

Piatt, J., D. Roby, et al. "Habitat use, diet, and breeding biology of Tufted Puffins in Prince William Sound, Alaska." Northwestern Naturalist **78**: 102-109.

Piatt, J., D. Roby, et al. (1999). Tufted Puffins as Samplers of Forage Fish. Restoration

Project (APEX) 95163D. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Biological Sciences Center, Anchorage. Biological Resources Div.
Oregon State Univ., Corvallis. Oregon Cooperative Wildlife Research Unit.: 30p.

Restoration Project 95163D was initiated as part of the Alaska Predator Ecosystem Experiment (APEX) project to study seabird and forage fish interactions in Prince William Sound. Puffins have been used historically as samplers of marine fish communities in the Gulf of Alaska because they typically catch and deliver whole, fresh samples of forage fish to their offspring. These samples are relatively simple to collect at colonies. In addition, parameters of breeding, such as meal delivery rates, chick growth rates, and reproductive success, can be used to infer information about the abundance and availability of local prey stocks. In summer 1995, Tufted Puffins were used as 'samplers' to assess prey availability to other seabirds in Prince William Sound that were affected by the spill, but whose populations have not recovered from losses incurred during the spill. Prepared in cooperation with Oregon State Univ., Corvallis. Oregon Cooperative Wildlife Research Unit.

Piatt, J. and T. van Pelt (1997). "Mass-mortality of guillemots (Uria aalge) in the Gulf of Alaska in 1993." Marine Pollution Bulletin **34**(8): 656-662.

During the first six months of 1993, about 3500 dead and moribund guillemots (Uria aalge) were observed throughout the northern Gulf of Alaska coast (ca 1800 km range). Mortality peaked during March. Highest numbers were observed in western Prince William Sound and along the south coast of the Kenai Peninsula. Large flocks of live gullemots gathered in nearshore waters, in contrast to most winters when guillemots reside offshore. Most guillemots recovered were extremely emaciated (ca 60% of normal weight) and sub-adult (80%). Based on carcass deposition and persistence experiments, we calculate that about 10 900 birds eventually came ashore on beaches that were surveyed. Even if most birds killed made it to shore, only a fraction of beaches in the Gulf of Alaska were surveyed and we estimate that a minimum total of 120 000 guillemots died. Results of other investigations on potential causes of mortality (biotoxins, pathogens, parasites, metals, etc.) were either negative or inconclusive, and necropsies lead us to believe that starvation was the proximate cause of death. Reduced food availability could have been related to anomalous sea conditions found during the prolonged 1990-1995 El Nino-Southern Oscillation event.

Picou, J., D. Gill, et al. (1994). Environmental crisis and adaptive responses in sub-arctic communities coping with the Exxon Valdez oil spill. Far East Branch-Russian Academy of Sciences and American Association for the Advancement of Science. Bridges of the Science between North America and the Russian Far East; 45th Arctic Science Conference, Anchorage, Alaska, USA, August 25-27,1994 and Vladivostok, Russia, August 29-September 2,1994, Dalnauka Publishing House; Vladivostok, Russia.

Ponce, R. A., G. M. Egeland, et al. (1998). "Twenty years of trace metal analyses of marine mammals in Alaska: evaluation and summation." Int J Circumpolar Health **57** (Suppl 1): 576-81.

The compilation of existing data on contaminants in the marine food chain is essential in addressing concerns regarding the magnitude of potential human exposures and in the evaluation of subsistence food safety. This paper presents a summary of studies on trace metals in tissues of Alaska marine mammals from the 1970s to the present, along with derived mean tissue trace metal concentrations. The derived mean can serve as a norm against which future monitoring results may be compared, and may be used to estimate human exposure to trace metals through the consumption of marine mammals. Additionally, the variation among studies in the reported mean tissue concentrations has been described through a derived standard deviation. Sufficient analytical and methodological details were available to derive means and standard deviations for tissues in bearded seal, bowhead whale, beluga whale, fur seal, harbor seal, Pacific walrus, and ringed seal. A high concordance between trace metal values reported in tissues (i.e., liver, kidney, muscle) was observed despite significant differences in reported sampling and analytical methodologies. Consistent with other reviews of trace metal concentrations in marine species, the standard deviation of tissue metal concentrations was generally or = 100% of the reported mean. Significant gaps in available information remain, particularly for muscle tissues and for methylmercury, despite the considerable efforts to monitor marine mammal species in Alaska.

Prichard, A. (1997). Evaluation of pigeon guillemots as bioindicators of nearshore ecosystem health. Fairbanks, AK, University of Alaska.

Thesis

Prichard, A., D. Roby, et al. (1997). "Pigeon guillemots as a sentinel species: A dose-response experiment with weathered oil in the field." Chemosphere **35**(7): 1531-1548.

Nests of pigeon guillemots (Cephus columba) were located along the south shore of Kachemak Bay, Alaska, and monitored during the breeding seasons of 1994 and 1995. Rates of nestling growth were measured and blood samples were collected for measurements of serum biomarkers. Haptoglobin, total protein, alanine aminotransferase, aspartate aminotransferase, and sodium in sera were measured as potential biomarkers of oil ingestion. Differences in mean levels of biomarkers were observed between years, and between nestlings and adults, as well as among locations within Kachemak Bay. During summer 1995, a controlled dose-response experiment was conducted with weathered Prudhoe Bay Crude Oil. Fifty-one nestlings were divided into three groups: controls, nestlings fed 0.05 ml of oil, and nestlings fed 0.20 ml of oil. Each experimental nestling was fed the dose of weathered oil twice: once at approximately day 20, and again 5 days later at approximately day 25 post-hatching. Blood samples were collected immediately before dosing on days 20, 25, and again on day 30 post-hatching. Site-specific differences in some blood variables were observed among treatments. These results suggest that the

doses of weathered oil administered to guillemot nestlings were not sufficient to induce a persistent inflammatory response.

Prince, R. (1992). Bioremediation of oil spills with particular reference to the spill from the Exxon Valdez. Symposia of the Society for General Microbiology. Microbial Control of Pollution, Cardiff, Wales, UK, March 1992, Cambridge University Press; Cambridge, England, UK; New York, New York, USA.

Bioremediation played an important role in the cleanup following the oil spill from the Exxon Valdez in Prince William Sound, Alaska. The initial spill response included washing the beaches and collecting the oil with skimmers, but while this was in progress a joint program between Exxon and the United States Environmental Protection Agency investigated the feasibility of using bioremediation to remove residual oil. Early experiments demonstrated that oil biodegradation on affected shorelines was nutrient-limited, and several fertilizer application strategies were tested to overcome this limitation. Two fertilizers, the liquid oleophilic Inipol EAP22 and the solid slow-release Customblen super(TM), were chosen for wide-scale application. Field monitoring convincingly demonstrated that the fertilizer strategy effectively stimulated oil biodegradation severalfold, with no adverse environmental impacts.

Pritchard, P. (1990). Bioremediation of oil contaminated beach material in Prince William Sound, Alaska, USA. 199th ACS (American Chemical Society) National Meeting, Boston, Massachusetts, USA, April 22-27, 1990, American Chemical Society.

Pritchard, P. (1991). Bioremediation as a technology: Experiences with the Exxon Valdez Oil Spill. Ecological Research Series; U.S. Environmental Protection Agency: 18.

The results from the oil spill bioremediation project have demonstrated convincingly that fertilizers can be applied to oiled beaches to overcome nutrient limitations, thereby enhancing biodegradation of the oil. In Prince William Sound, the natural biodegradation rate of oil on the beaches was found to be quite high, primarily because of small concentrations of ammonia and phosphate in seawater that are introduced into the beach material with each tide. However, the addition of fertilizers was capable of increasing this biodegradation as much as two to three fold above background activity. In addition, the extent of enhanced degradation was such that beaches became visually cleaner and aesthetically improved.

Pritchard, P. (1991). "Bioremediation as a technology: Experiences with the Exxon Valdez oil spill." Journal of Hazardous Materials **28**(1-2): 115-130.

The results from our spill bioremediation project have demonstrated convincingly that fertilizers can be applied to oiled beaches to overcome nutrient limitations, thereby enhancing biodegradation of the oil. In Prince William Sound, the natural biodegradation rate of oil on the beaches was found to be quite high, primarily

because of small concentrations of ammonia and phosphate in seawater that are introduced into the beach material with each tide. However, the addition of fertilizers was capable of increasing this biodegradation as much as two to three fold above background activity. In addition, the extent of enhanced degradation was such that beaches became visually cleaner and aesthetically improved.

Pritchard, P. and C. Costa (1991). "EPA's Alaska USA oil spill bioremediation project." Environmental Science & Technology **25**(3): 372-379.

The bioremediation of hazardous wastes, although not a new concept, has recently taken on new significance as an increasingly effective and potentially inexpensive cleanup technology. A contributory factor has been a more comprehensive understanding of the natural biodegradation potential of microbial communities in many different types of habitats. Several field demonstrations have now convincingly utilized laboratory test information to develop effective treatment strategies for bioremediation. For similar reasons, the significance and feasibility of the bioremediation of oil-contaminated environmental materials has also increased. In addition, major oil spills like that of the Exxon Valdez have galvanized public attention to alternative cleanup technologies. Oil biodegradation in aquatic (marine and freshwater), terrestrial, and groundwater environments has been extensively studied in laboratory systems over the past 20-30 years, but it is only recently that this information has been considered for large-scale bioremediation efforts. Definitive success in the restoration of gasoline-contaminated aquifers and oil-contaminated soils has occurred because of the application of this basic research data base.

Pritchard, P., J. Mueller, et al. (1992). "Oil spill bioremediation: Experiences, lessons and results from the Exxon Valdez oil spill in Alaska ." Biodegradation **3** (2-3): 315-335.

The use of bioremediation as a supplemental cleanup technology in the Exxon Valdez oil spill, in Prince William Sound, Alaska, has proven to be a good example of the problems and successes associated with the practical application of this technology. Field studies conducted by scientists from the U.S. Environmental Protection Agency have demonstrated that oil degradation by indigenous microflora on the beaches of Prince William Sound was accelerated by adding fertilizer directly to the surfaces of oil-contaminated beaches. Although several types of fertilizers were used in the studies, only the results from the application of an oleophilic fertilizer are presented. The fertilizer enhanced biodegradation of the oil, as measured by changes in hydrocarbon composition and bulk oil weight per unit of beach material, by approximately two-fold relative to untreated controls. Laboratory studies verified the usefulness of the oleophilic fertilizer as a nutrient source, but the contribution of its oleophilic components towards enhancing biodegradation is still unclear. These studies supported bioremediation as a useful cleanup strategy that was subsequently used by Exxon on a large scale. The Exxon Valdez experience has also provided a number of informative lessons that have significant relevance to future oil bioremediation efforts. This paper discusses these lessons and the difficulties in

assessing the effectiveness of bioremediation in the field.

Purcell, J., E. Brown, et al. (2000). "Aggregations of the jellyfish Aurelia labiata: abundance, distribution, association with age-0 walleye pollock, and behaviors promoting aggregation in Prince William Sound, Alaska, USA." Marine Ecology Progress Series **195**: 145-158.

Aurelia labiata medusae occured in aggregations with hundreds to millions of jellyfish. The aggregations were widely distributed in inlets of Prince William Sound (PWS) Alaska. Aerial surveys of OWS in May to August of 1995, 1996 and 1997 showed marked interannual variation in the numbers of aggregations observed, from a minimum of 38 in 1997 to a maximum of 557 in 1996. Acoustic surveys showed that the aggregations extended from near-surface (0 to 5 m) to 15 m depth. Schools of young-of-the-year walleye pollock Theragra chalcogramma were associated with A. labiata, both within and below the aggregations. All seine catches that contained juvenile pollock also contained jellyfish. Medusa swimming was also analyzed from underwater videotapes in order to elucidate how aggregations might be formed and maintained. Medusae did not swim in circles in the aggregations. Medusae all swam vertically in the same direction, either up or down, in crowded parts of the aggregations, suggesting that they had become concentrated in flow features, like convergences, in the water column. Reduced swimming, due primarily to frequent collisions among medusae in the aggregations, also may have caused the medusae to become concentrated. The potential adventages of congregation include increased fertilization success, retention near shore where planula settlement sites and zooplankton prey may be more abumdant, retention in convergences where zooplankton are concentrated, and reduced predation.

Purcell, J. and M. Sturdevant (2000 In press). "Prey selection and dietary overlap among zooplanktivorous jellyfish and juvenile fishes in Prince William Sound, Alaska." Mar. Ecol. Prog. Ser.

Quakenbush, L. T. and E. Snyder-Conn (1993). Pathology and Contaminant Case Report on Three Steller's Eiders from Alaska. Anchorage, AK, U.S. Fish and Wildlife Service, Northern Alaska Ecological Services: 32 pp.

Quinn, T. and R. Gates (1997). "Estimation of salmon escapement: models with entry, mortality and stochasticity." Natural Resource Modeling **10**(3): 217-250.

Rall, D. P. (1989). "Oil spill health effects [letter; comment]." Science **246**(4930): 564.

Marcia Barinaga's article "Alaskan oil spill: Health risks uncovered" (News & Comment, 4 Aug., p. 463) captured the flavor fo the Conference on the Alaskan Crude Oil Spill and Human Health very well.

A matter that could cause some misunderstanding, however, is the misstatement in the middle of the artcil labeled "the good news", that the highly toxic polycyclic aromatic compounds "Evaporated from the spilled oil within several days". The lightest fractions of the oil, the single ring compounds that are of most concern for inhalation exposures, did evaporate rapidly. The polycyclic aromatic hydrocarbons, on the other hand, tend to concentrate in the weathered oil and may be of significant long-term concern for health, since we know that some of these compounds are hazardous and some are associated with cancer.

Rapp, J., F. Hostettler, et al. (1990). Comparison of Exxon Valdez oil with extractable material from deep-water bottom sediment in Prince William Sound and the Gulf of Alaska. Anchorage, AK, U.S. Geological Survey: 36pp.

Raucher, S. (1992). "Raising the stakes for environmental polluters: The Exxon Valdez criminal prosecution." Ecology Law Quarterly **19**(1): 147-185.

Contents include: the case against Exxon; the Clean Water Act; strict criminal liability; the felony provisions; and fines and deterrence.

Rebar, A., B. Ballachey, et al. (1996). Hematology and Clinical Chemistry of Sea Otters Captured in Prince William Sound, Alaska Following the EXXON VALDEZ Oil Spill. Marine Mammal Study 6-17. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Fish and Wildlife Research Center, Anchorage.
Veterinary Clinical Pathologist, West Lafayette, IN.: 14p.

Hematologic and serum chemical analyses were performed on sea otter blood samples collected from 31 adult males, 63 adult females, and 42 pups captured in western Prince William Sound (oiled area), and 12 adult males, 40 adult females, and 15 pups captured in eastern Prince William Sound (unoiled area) in 1989 and 1990. Hemotologic differences between eastern and western adult males were minimal. There were no differences in hematologic parameters between eastern and western female otters. As a group, western pup hematocrits, hemoglobins, and red cell counts were significantly lower than those of eastern pups. From a biological perspective, these reductions were minimal but supported by individual animal data. Prepared in cooperation with Veterinary Clinical Pathologist, West Lafayette, IN.

Rebar, A., T. Lipscomb, et al. (1995). "Clinical and clinical laboratory correlates in sea otters dying unexpectedly in rehabilitation centers following the Exxon Valdez oil spill." Veterinary Clinical Pathology **32**(4): 346-350.

Following the Exxon Valdez oil spill, 347 oiled sea otters (Enhydra lutris) were treated in rehabilitation centers. Of these, 116 died, 94 within 10 days of presentation. Clinical records of 21 otters dying during the first 10 days of rehabilitation were reviewed to define the laboratory abnormalities and clinical syndromes associated with these unexpected deaths. The most common

terminal syndrome was shock characterized by hypothermia, lethargy, and often hemorrhagic diarrhea. In heavily and moderately oiled otters, shock developed within 48 hours of initial presentation, whereas in lightly oiled otter shock generally occurred during the second week of captivity. Accompanying laboratory abnormalities included leukopenia with increased numbers of immature neutrophils (degenerative left shift), lymphopenia, anemia, azotemia (primarily prerenal), hyperkalemia, hypoproteinemia/hypoalbuminemia, elevations of serum transaminases, and hypoglycemia. Shock associated with hemorrhagic diarrhea probably occurred either as a direct primary effect of oiling or as an indirect effect secondary to confinement and handling in the rehabilitation centers. Lightly oiled otters were less likely to die from shock than were heavily oiled otters (22% vs. 72%, respectively). Heavily oiled otters developed shock more rapidly and had greater numbers of laboratory abnormalities, suggesting that exposure to oil was an important contributing factor.

Reese, L. (1998). Levels of organoclorine contamination in blue mussels, Mytilus trossulus, from the Aleutian Archipelago. Santa Cruz, University of California, Santa Cruz.

Thesis

Resnick, S. and E. Brown (1991). Mineralization of n-hexadecane: A measure of hydrocarbon-degrading ability of bacteria from oiled beaches in Prince William Sound, Alaska, USA. 91st General Meeting of the American Society for Microbiology, Dallas, Texas, USA, May 5-9,1991, American Society for Microbiology.

Rice, S., M. Babcock, et al. (1994). Persistence of high concentrations of Exxon Valdez crude oil in mussels and underlying sediments three years after the oil spill. Bridges of the Science between North America and the Russian Far East; 45th Arctic Science Conference,, Anchorage, Alaska, USA, August 25-27, 1994 and Vladivostok, Russia, August 29-September 2, 1994, Dalnauka Publishing House C Vladivostok, Russia.

Rice, S. and A. Moles (1991). Humpies and hydrocarbons: relating laboratory effects studies to potential effects from the Exxon Valdez oil spill. Proceedings of the 15th Northeast Pacific Pink and Chum Salmon Workshop, Parksville, B.C., February 27 - March 1, 1991.

Rice, S., J. Short, et al. (1989). "Uptake and catabolism of tributyltin by blue crabs fed TBT contaminated prey." Marine Environmental Research **27**(2): 137-146.

Accumulation and catabolism of tributyltin (TBT) was measured in blue crabs (Callinectes sapidus) after 16-day exposures to TBT-contaminated prey. TBT and the metabolites, DBT and MBT, were separated by gas chromatography and measured by atomic absorption (GCAA) in prey and in crab tissues during the 16-day test. Crabs were fed grass shrimp Palaemonetes pugio contaminated

with 1.8 mug TBT, 0.09 mug DBT and 0.03 mug MBT per gram wet weight tissue. Feeding rates for exposed and non-exposed crabs were equal during the 16-day test. In 16 days, exposed crabs consumed about 2.02 mug of TBT. TBT was sequentially debutylated in a significant manner by blue crabs, but not by the grass shrimp. TBT concentrations peaked in crabs after 4 days of feeding, at 0.12 mug g-1. DBT peaked at 8 days at 0.39 mug g-1, and MBT peaked at 12 days at 0.35 mug g-1. Total butyllins reached equilibrium by 8 days, but the relative toxic burden declined from 8-16 days because the proportion of TBT continued to decline. Growth, molting success and feeding rates were not affected in the juvenile crabs during the 16-day test. Catabolism of TBT reduces tissue concentrations of TBT, thereby increasing the tolerance of blue crabs to TBT.

Rice, S., R. Spies, et al. (1996). Proceedings of the Exxon Valdez Oil Spill Symposium. American Fisheries Society Symposium 18. Anchorage, Alaska, USA February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA.

The Exxon Valdez oil spill on 24 March 1989 was one of those singular events in history that changes peoples lives. Like other rare events of such momentous nature, almost all of those people who were affected by this tragedy - the largest tanker oil spill in United States history - can tell you where they were and what they were doing when the news of the oil spill in Prince William Sound, Alaska, hit them. For many of these people, the changes wreaked by the oil spill still affect their lives and livelihoods over 6 years later. The authors of this volume of papers are among those whose lives were jolted and changed by the oil spill. Largely government workers for state or federal natural resource agencies, or university scientists, they put their regular jobs and preoccupations in abeyance as the enormous effort was mounted - on hours or days notice - to determine, document, and attempt to understand the impacts of this oil spill on the abundant and valuable natural resources of Prince William Sound and the Gulf of Alaska. The wide variety of information the authors report in this volume was obtained through long and arduous efforts that began urgently but were painstakingly extended, in most cases, for several years.

Rice, S. and R. Thomas (1989). "Effect of pre-treatment exposures of toluene or naphthalene on the tolerance of pink salmon (Oncorhynchus gorbuscha) and kelp shrimp (Eualis suckleyi)." Comparative Biochemistry and Physiology, C **94C**(1): 289-293.

Toluene pre-treatment exposures did not affect survival of kelp shrimp (Eualis suckleyi) or pink salmon (Oncorhynchus gorbuscha) fry in subsequent bioassays. Naphthalene pre-treatment exposure to kelp shrimp caused increased sensitivity in subsequent bioassays. Naphthalene pre-treatment exposures to pink salmon caused increase in tolerance in subsequent bioassays. Tolerance increase was proportional to concentration and duration of pre-treatment exposures, and decreased with periods of depuration.

Richter, Z. and J. Braddock (1995). Bioavailability of phenanthrene in marine intertidal

sediments. Landscapes: Human Ecology, Landscape Ecology, Earth System Science; 46th AAAS Arctic Division Science Conference, Fairbanks, Alaska, USA, September 19-22, 1995, AAAS Arctic Division; Fairbanks, Alaska, USA.

Ritchie, R. J. and S. Ambrose (1996). "Distribution and population status of bald eagles (Haliaeetus leucocephalus) in interior Alaska." Arctic **49**(2): 120-128.

We summarize information available on natural history, numbers, distribution, and status of bald eagles (Haliaeetus leucocephalus) in six regions of interior Alaska: Upper Yukon, Lower Yukon, Tanana, Kuskokwim, Susitna, and Upper Copper. We identified 347 nesting territories using information from local researchers, a raptor nest atlas, unpublished raptor survey reports, and our own surveys. Nearly 85% of these territories were from the Copper, Susitna, and Tanana drainages. Extrapolating from the number of known nests and approximate survey coverage per drainage, we estimate that 525 to 725 pairs of bald eagles nest in interior Alaska. Observations also suggest that this population has increased substantially since the middle of this century and that numbers in some areas continue to increase. Reasons for these increases may include (1) improving health of individuals in this population; (2) reduced persecution in Alaska and in wintering areas outside the state; (3) immigration into interior Alaska from rebounding or expanding populations elsewhere; and (4) changing environmental conditions (e.g., warmer temperatures). Banding and migration data suggest that part of the population that nests north of the Alaska Range may winter in areas different from those used by populations that nest south of the Alaska Range. No environmental contaminants measured in eggs occurred at concentrations known to result in sublethal or lethal effects, and most organochlorine pesticide and mercury concentrations were an order of magnitude lower than concentrations in bald eagle eggs elsewhere in the United States.

Robards, J., J. Anthony, et al. (1999). "Changes in proximate composition and somatic energy content for Pacific sand lance (Ammodytes Hexapterus) relative to maturity and season in Kachemak Bay, Alaska." Journal of Experimental Marine Biology and Ecology.

Mean dry-weight energy values of adult Pacific sand lance (Ammodytes hexapterus) peaked in spring and early summer (20.91 kJg super(-1) for males, 21.08 kJg super(-1) for females), then declined by about 25% during late summer and fall (15.91 kJg super(-1) for males, 15.74 kJg super(-1) for females). Late summer declines in energy density paralleled gonadal development. Gender differences in energy density (males < females) were only apparent from August to October. Adult sand lance spawn in October, entering the winter with close to their minimum whole body energy content. Juvenile sand lance exhibited a relatively constant protein to lipid ratio until they reached 80 mm fork length. Thereafter, relative proportions of protein remained constant while lipid proportions increased significantly. Dry weight energy densities of juveniles increased from a minimum 16.67 kJg super(-1) to a maximum of 19.68 kJg super(-1), and (per g) are higher than adults in late summer. The seasonal

food value of adult sand lance to predators varies markedly, but maximum energetic value coincides with important feeding periods for marine mammals, fish, and seabirds.

Robards, M. and J. Piatt (1999). Sand lance: a review of biology and predator relations and annotated bibliography. U.S. Forest Service Technical Report Series, USDA, FOREST SERVICE PACIFIC NORTHWEST RESEARCH STATION RESEARCH PAPER.: 521 pp.

Six species of sand lance (Ammodytes) in temperate and boreal regions are currently recognized. Sand lance can occupy a wide range of environmental conditions, but all appear to be dormant predominantly in winter, and one species is in summer also. They lack a swim bladder and spend much of their time buried in specific substrates. Copepods are the primary food. Spawning usually occurs in fall or winter (although some species also spawn in spring), eggs are demersal, and larvae may hatch at times of low food abundance. Sand lance usually occur in schools and are regarded as a relatively high-quality forage fish.Sand lance constitute a major prey for at least some populations of over 100 species of consumer, including 40 species of birds, 12 species of marine mammals, 45 species of fishes, and some invertebrates. Variation in the availability of sand lance (and other forage fishes) can have major effects on the breeding success and survival of their predators. Commercial fishing and other pressures on sand lance populations potentially have ramifying effects on many species of wildlife.The bibliography contains over 1,700 references on the family Ammodytidae, with an emphasis on the genus Ammodytes. Keywords are provided for each reference and have been further organized into taxonomic, geographic, subject, and predator indexes.

Robards, M., J. Piatt, et al. (1999). "Temporal and geographic variation in fish populations in nearshore and shelf areas of lower Cook Inlet, Alaska." Fishery Bulletin **97**(4): 962-977.

Nearshore and shelf fish communities were studied in three areas of lower Cook Inlet, Alaska: the Barren Islands (oceanic and well-mixed waters), Kachemak Bay (mixed oceanic waters with significant freshwater runoff), and Chisik Island (estuarine waters). Fish were sampled with beach seines (n = 413 sets) and midwater trawls (n = 39 sets). We found that lower Cook Inlet supported a diverse nearshore fish community of at least 52 species. Fifty of these species were caught in Kachemak Bay, 24 at Chisik Island, and 12 at the Barren Islands. Pacific sand lance dominated Barren Islands and Kachemak Bay nearshore habitats, comprising 99% and 71% of total individuals, respectively. The nearshore Chisik Island fish community was not dominated by any one species; instead it exhibited higher diversity. These spatial differences appeared linked to local oceanographic regimes and sediment influx. Analysis of historical data revealed that the nearshore Kachemak Bay fish community changed significantly between 1976 and 1996, showing increased diversity and abundance in several taxa, notably gadids, salmonids, pleuronectids, and sculpins. Decadal differences appeared to be related to large-scale climate changes in the North

Pacific. Catches of most taxa peaked in May-August, and were low during other months of the year. Several species were present for only part of the summer. Species composition of seine catches differed significantly between consecutive high and low tides, but not between consecutive sets or years. Midwater trawls took 26 species, 14 of which were present in Kachemak Bay, 19 near Chisik Island, and 7 at the Barren Islands. Community structures in shelf and nearshore waters were similar: diversity was high and abundance low at Chisik Island, whereas a few abundant species dominated at both Kachemak Bay and the Barren Islands. In addition, the low fish abundance near Chisik Island appeared to be related to declining seabird numbers at this colony.

Robards, M., J. Piatt, et al. (1999). "Maturation, fecundity, and intertidal spawning of Pacific sand lance (Ammodytes hexapterus) in the Northern Gulf of Alaska." Journal of Fish Biology **54**(5): 1050-1068.

Pacific sand lance Ammodytes hexapterus in Kachemak Bay, Alaska, showed no sexual dimorphism in length-to-weight (gonad-free) ratio or length-at-age relationship. Most matured in their second year, males earlier in the season than females, but females (31%) attained a higher gonadosomatic index than males (21%). Sand lance spawned intertidally once each year in late September and October on fine gravel or sandy beaches soon after the seasonal peak in water temperatures. Sand lance in Cook Inlet and Prince William Sound displayed similar maturation schedules. Schools were dominated 2 : 1 by males as they approached the intertidal zone at a site where spawning has taken place for decades. Sand lance spawned vigorously in dense formations, leaving scoured pits in beach sediments. Fecundity of females (93-199 mm) was proportional to length, ranging from 1468 to 16 081 ova per female. About half of the overall spawning school fecundity was derived from age group 1 females (55% of the school by number). Spawned eggs were 1 times 02 mm in diameter, demersal, slightly adhesive, and deposited in the intertidal just below the waterline. Sand lance embryos developed over 67 days through periods of intertidal exposure and sub-freezing air temperatures.

Rock, K., E. Rock, et al. (1994). "Degree of association and use of a helper by coastal river otters, Lutra canadensis, in Prince William Sound, Alaska." Canadian Field Naturalist **108**: 367-369.

Nine (6 males and 3 females) River Otters, Lutra canadensis, from the Esther Passage area in Prince William Sound. Alaska, were implanted with radio transmitters during the summers of 1990 and 1991. Two females frequently occurred in association with one another (8 of 20 radio locations in 1991; 40 of 72 radio locations in 1990) and had degrees of association of 0.80 and 0.71 for each year, respectively. The average degree of association was only 0.36 for male otters in this same population. In August of both years, these two female otters were observed with pups, and both females fed, carried, and played with the pups, despite one female being a subadult in 1990. Helping with the care of young by subadults is known to exist in only a few species of mammals, but our observations suggest that this behavior exists in marine populations of river

otters.

Rogers, J., R. Araujo, et al. (1990). Role of microorganisms in the bioremediation of the oil spill in Prince William Sound, Alaska., Ecology Research Service, Environmental Protection Agency (U.S.): 15.

The U.S. Environmental Protection Agency's Alaskan Bioremediation Project was initiated in the aftermath of the March 24, 1989, Exxon Valdez oil spill. The objective of the project was to demonstrate an alternative cleanup method for oil-contaminated shorelines based on enhancing natural biodegradation of the oil through the addition of nitrogen and phosphorus nutrients. The enhancement process is a well-recognized and scientifically sound approach to bioremediation but had never been tested on a large scale in marine environments. The project was managed by EPA's Office of Research and Development with financial, scientific, and logistical support from the Exxon Company USA.

Rooper, C. (1996). Physical and biological factors affecting Pacific herring egg loss in Prince William Sound, Alaska. Fairbanks, AK, University of Alaska.

Thesis

Roseneau, D. and G. Byrd (1997). Using Pacific halibut to sample the availability of forage fishes to seabirds. Forage Fishes in Marine Ecosystems: Proceedings of the International Symposium on the Role of Forage Fish in Marine Ecosystems.

Evaluating the influence of fluctuating prey populations (e.g., forage fishes) is critical to understanding the recovery of seabirds injured by the T/V Exxon Valdez oil spill; however, it is expensive to conduct hydroacoustic and trawl surveys to assess forage fish stocks over broad regions. As part of the 1995 Exxon Valdez Oil Spill Trustee Council-sponsored Alaska Predator Ecosystem Experiment, we tested the feasibility of using sport-caught Pacific halibut (Hippoglossus stenolepis) to obtain spatial and temporal information on capelin (Mallotus villosus) and Pacific sand lance (Ammodytes hexapterus), two forage fishes important to piscivorous seabirds. We examined 586 halibut stomachs collected from vessels in a 100-150 vessel charter boat fleet fishing throughout Cook Inlet waters during late May-early September. Catch locations and dates provided information on geographic and seasonal variation in the incidence of capelin and sand lance in seven eastern inlet subunits between Ninilchik and Shuyak Island. We also obtained data on prey brought to chicks of black-legged kittiwake (Rissa tridactyla), common murre (Uria aalge), and tufted puffin (Fratercula cirrhata) at the Barren Islands to help evaluate the sampling technique. At the Barren Islands, capelin were the most numerous fish in halibut stomachs, and they were the most common prey fed to murre and kittiwake chicks by number and weight, respectively. They were also the largest prey group by weight in puffin chick diets. In the Point Adam area, where samples were collected during June through early August, we detected seasonal changes in the relative abundance of sand lance and capelin. Sand lance were most common in June, and capelin increased after early July. Based on our results,

we concluded that this relatively simple cost-effective method can supply useful information on forage fish stocks in areas where seabird feeding and charter boat fishing activities overlap.

Rotterman, L. and C. Monnett (1996). Technical Report: Marine Mammals Study Number 6. Mortality of Sea Otter Weanlings in Eastern and Western Prince William Sound, Alaska during the Winter of 1990-91. Marine Mammal Study 6-18. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Cordova.
Prince William Sound Science Center, Cordova, AK.: 22p.

Sixty-four dependent sea otters Eastern Prince William Sound (EPWS): n = 24; Western Prince William Sound (WPWS), the oil spill area: n = 401 were captured, examined, instrumented with radio-transmitters, and monitored in Prince William Sound between September 1990 and July 15, 1991. While the absolute timing of instrumentation was similar for pups in EPWS and the oil spill area, pups in the oil spill area weighed significantly less at the time of capture than their counterparts in EPWS. Most pups in EPWS became independent of their mothers in October, whereas mother-pup separation typically occurred in November and December in the oil spill area. Most mortality in EPWS occurred during November and December of 1990, whereas most mortality in the oil spill area occurred during January 1991. Survival rates of weanlings over their first winter (analyses consider data until May 1,1991) were significantly higher in EPWS (the control) than in the oil spill region. Prepared in cooperation with Prince William Sound Science Center, Cordova, AK. Sponsored by Alaska Fish and Wildlife Research Center, Anchorage.

Roy, N., J. Stabile, et al. (1999). "High frequency of K-ras mutations in pink salmon embryos experimentally exposed to Exxon Valdez oil." Environmental Tocicology and Chemistry **18**(7): 1521-1528.

Previous studies demonstrated reduced survivorship of pink salmon embryos from populations in Prince William Sound, Alaska, USA, that were exposed to Exxon Valdez-released oil compared with populations from matched nonoiled streams. Survivorship was also significantly decreased in embyros from lineages that were oiled in Prince William Sound and reared in clean water under controlled hatchery conditions compared with the descendants of nonoiled lineages. This suggests that the effect of oiling o ions to weathered Prudhoe Bay crude oil. Polymerase chain reaction and direct DNA sequence analyseswere used to identify mutational hotspots within exons 1 and 2 of K-ras, and 3' primer mismatch analysis was used to determine the frequency of mutations in the 40 offspring of two families of pink salmon that were experimentally exposed to oiled or clean gravel. Mutations were only observed at codons 12, 13, and 61 of K-ras, sites that are frequently mutated in animal and human tumors. All mutatio atings. These results indicate that exposure of pink salmon embryos to weathered Prudhoe Bay crude oil under controlled laboratory conditions can elicit somatic cell mutations in high frequency at mutational hotspots in genes such as K-ras.

However, the frequency of these events in oiled natural populations of pink salmon and other vulnerable species in Prince William Sound and the heritability of these mutations within oiled lineages have yet to be evaluated.

Roy, N., J. Stabile, et al. (In press). "An evaluation of molecular genetic damage to pink salmon embryos experimentally exposed to Prudhoe Bay crude oil." Environmental Toxicology and Chemistry.

Royer, T., J. Vermersch, et al. (1990). "Ocean circulation influencing the Exxon Valdez oil spill ." Oceanography **3** (2): 3-10.

In March 1989, North America's largest marine oil spill occurred in one of its largest estuaries: Alaska's Prince William Sound. Observations of the spill trajectory serve to delineate the circulation within the sound and along the southern coast of Alaska. This region has very high rates of freshwater discharge and intense wind stresses: the average annual amount of fresh water entering the Northeast Pacific drainage system is at least 20% larger than the Mississippi River system, and the seasonal signals of wind stress and wind stress curl here are the largest in the North Pacific. Even as the oil was being released in the sound, it came under the influence of this coastal circulation. The spilled oil and subsequently released surface drifters have served as tracers that can be used to examine our knowledge of the processes affecting regional coastal flow. This knowledge might be applied to coastal processes elsewhere.

Rudd, L., J. Perry, et al. (1996). "Changes in mutagenicity during crude oil degradation by fungi." Biodegradation **7**(4): 335-343.

Two fungal strains, Cunninghamella elegans and Penicillium zonatum, that grow with crude oil as a sole carbon source were exposed to three crude oils that exhibit a range of mutagenic activity. At regular time intervals following fungal incubation with the various crude oils, extracts were tested for the presence of mutagenic activity using the spiral Salmonella assay. When the most mutagenic of the oils, Pennsylvania crude oil, was degraded by C. elegans or by P. zonatum, its mutagenicity was significantly reduced; corresponding uninoculated (weathered) controls of Pennsylvania crude remained mutagenic. West Texas Sour crude oil, a moderately mutagenic oil, exhibited little change in mutagenicity when incubated with either C. elegans or P. zonatum. Swanson River Field crude oil from Cook Inlet, Alaska is a slightly mutagenic oil that became more mutagenic when incubated with C. elegans; weathered controls of this oil showed little change in mutagenicity. Mycelial mat weights measured during growth on crude oils increased corresponding to the biodegradation of about 25% of the crude oil.

Rudis, D., C. Henny, et al. (1994). Metals contamination in Alaskan scoters. Bridges of the Science between North America and the Russian Far East; 45th Arctic Science Conference, Anchorage, Alaska, USA, August 25-27, 1994 and Vladivostok, Russia,

August 29-September 2, 1994, Dalnauka Publishing House, Vladivostok, Russia.

Saeki, K., M. Nakajima, et al. (1999). "Vanadium accumulation in pinnipeds." Arch Environ Contam Toxicol **36**(1): 81-6.

Vanadium in four species of pinnipeds (northern fur seals [Callorhinus ursinus], Steller sea lions [Eumetopias jubatus], harbor seals [Phoca vitulina], and ribbon seals [Phoca fasciata]) caught in the Northern Pacific was analyzed using ICP-MS to understand its accumulation and distribution. In northern fur seals, relatively high concentrations of vanadium were observed in the liver, hair, and bone. Ninety percent of the vanadium burden in the body was concentrated in these three tissues, which comprise 20% of total body weight. Hepatic vanadium concentrations in the four pinniped species were significantly correlated to age, although the levels varied with species. An increase in vanadium accumulation in the liver of northern fur seals was caused by an increase of retention in nuclei and mitochondria fraction in the cells. Vanadium concentrations in liver were significantly correlated with mercury, silver, and selenium concentrations in northern fur seals, Steller sea lions, and harbor seals.

Salazar, M. and S. Salazar (1997). "Preliminary results of a caged bivalve study at 70 meters in Port Valdez, Alaska." Canadian Technical Report of Fisheries and Aquatic Sciences(2192): 95.

Mytilus-trossulus

Sale, D., J. Gibeaut, et al. (1996). Nearshore Transport of Hydrocarbons and Sediments Following the EXXON VALDEZ Oil Spill. Subtidal Study Number 3B. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska State Dept. of Environmental Conservation, Juneau.
SnowOtter Environmental Consulting, Seattle, WA.
Texas Univ. at Austin. Bureau of Economic Geology.
National Marine Fisheries Service, Juneau, AK. Auke Bay Lab.: 105p.

Following the Exxon Valdez oil spill, sediment traps were deployed in nearshore subtidal areas of Prince William Sound, Alaska (PWS) to monitor particulate chemistry and mineralogy. Complemented by benthic sediment chemistry and core sample stratigraphy at the study sites, results were compared to historical trends and data from other Exxon Valdez studies. These results clearly indicate the transport of oil-laden sediments from oiled shorelines to adjacent subtidal sediments. The composition of hydrocarbons adsorbed to settling particulates at sites adjacent to oiled shorelines matched the PAH pattern of weathered Exxon Valdez crude oil. Prepared in cooperation with SnowOtter Environmental Consulting, Seattle, WA., Texas Univ. at Austin. Bureau of Economic Geology. and National Marine Fisheries Service, Juneau, AK. Auke Bay Lab.

Sanger, G. and M. Cody (1996). Survey of Pigeon Guillemot Colonies in Prince William

Sound, Alaska. Restoration Project 93034. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), Fish and Wildlife Service, Anchorage, AK. Migratory Bird Management.: 70p.

During a survey of 98% of Prince William Sound's (the Sound) shoreline in May and June 1993 the authors found 184 pigeon guillemot colonies, most of which were previously unknown. There were no guillemots at 14 former colony sites, but the authors found new colonies within a few km of eight of these sites. The authors counted a total of 3028 pigeon guillemots, including 1012 that were unassociated with colonies. The authors' count is within the range of a Sound-wide estimate of 3000 to 4900 guillemots from pelagic and shoreline surveys by another project in July 1993. These figures reflect a continuing depressed population compared with a 1970's high of about 15,000.

Sasaki, S., T. Ota, et al. (1993). "Hydrocarbon composition of salmon in the Gulf of Alaska." Nippon Suisan Gakkaishi **59**(5): 801-806.

The hydrocarbon composition in the flesh and liver of salmon, Oncorhynchus nerka, O. keta, O. mykiss, and O. kisutch, caught in the Gulf of Alaska were analyzed with open-tubular gas-liquid chromatography. The hydrocarbon contents of total lipids were 0.04-0.12% in the flesh and 0.22-0.67% in the liver, respectively. The salmon had normal hydrocarbons ranging in chain length from C13 to C28 with an odd-chain predominance. The major hydrocarbons in present samples were pristance and squalene. The sums of these two components exceeded half of the total hydrocarbons in both tissues of the salmon. C10, C20, and C25 isoprenoid hydrocarbons were also detected in this study. While the results in this study suggested that there were relatively small differences in the hydrocarbon composition depending on the species, hardly an difference in the hydrocarbon composition was observed depending on the year of catch and locality in the Gulf of Alaska.

Sasaki, S., T. Ota, et al. (1991). "Hydrocarbon components of salmons in the Gulf of Alaska." Nippon Suisan Gakkaishi **57**(1): 111-117.

The hydrocarbon components in some tissues of sockeye salmon Oncorhynchus nerka and chum salmon O. keta caught in the Gulf of Alaska were investigated with open-tubular gas-liquid chromatography. At least 60 peaks were detected, of which 26 components were identified. The salmons had normal hydrocarbons ranging in chain length from C_{13} to C_{28} with an odd-chain predominance. The major hydrocarbons of the present samples were pristane and squalene. The total contents of these components in all samples exceeded 60% of the total hydrocarbons. In particular, pristane accounted for 85-90% of total hydrocarbons in the viscera and stomach contents of both salmons.

Saulitis, E., C. Matkin, et al. (2000). "Foraging strategies of sympatric killer whale (Orcinus orca) populations in Prince William Sound, Alaska." Marine Mammal Science **16**(1): 94-109.

Sawyer, D. C. and T. D. Williams (1996). "Chemical restraint and anesthesia of sea otters affected by the oil spill in Prince William Sound, Alaska." J Am Vet Med Assoc **208**(11): 1831-4.

Saxton, W., R. Newton, et al. (1993). "Polycyclic aromatic hydrocarbons in seafood from the Gulf of Alaska following a major crude oil spill." Bulletin of Environmental Contamination and Toxicology **51**(4): 515-522.

More than ten million gallons of Prudhoe Bay crude oil spilled into Prince William Sound, Alaska, when the supertanker Exxon Valdez ran aground on Bligh Reef March 24, 1989. The oil spread over thousands of square miles of prime commercial fish waters, causing State and Federal agencies to initiate immediate controls to ensure that seafood contaminated with this crude oil did not enter commercial channels. As a consequence, the 1989 herring fishery was closed for the season, and other fisheries, including the salmon fishery, were closely monitored.

Schantz, M. M., B. J. Koster, et al. (1993). "Determination of PCBs and chlorinated hydrocarbons in marine mammal tissues." Science of the Total Environment **139-140**: 323-45.

Selected tissues (blubber, liver, kidney and muscle) from marine mammals, which were collected as part of the Alaska Marine Mammal Tissue Archival Project (AMMTAP), were analyzed for polychlorinated biphenyl (PCB) congeners and chlorinated pesticides. Concentrations of these compounds in the different tissues were compared and blubber was selected as the primary tissue for organic contaminant analyses for the AMMTAP based on higher levels (1-2 orders of magnitude) in this tissue compared to liver, kidney and muscle. Concentrations for 15 PCB congeners and 12 chlorinated pesticides are reported for 10 different animals of three species (northern fur seal, ringed seal and belukha whale) from five different sites.

Scheel, D. and K. Hough (1997). "Salmon fry predation by seabirds near an Alaskan hatchery." Marine Ecology Progress Series **150**: 35-48.

We estimated the mortality of hatchery-raised pink Oncorhynchus gorbuscha and chum O. keta salmon fry from seabird predation near a salmon hatchery in Lake Bay, Prince William Sound, Alaska, USA. Field counts of seabirds and observations of feeding rates for plunge-diving seabirds were obtained during salmon fry releases between April and June 1995. Several hundred birds of 7 piscivorous species aggregated in front of the hatchery. Consumption rates were determined from focal-animal sampling and energetic models. For most species, per capita consumption rates based on behavioral data were lower than those calculated from energetic considerations. From energetic models and fry movement rates, we estimated that 2.7 to 5.9 million juvenile salmon (1.1 to 2.4% of released fry) were consumed during the study period. Differences between the energetics models accounted for 64% of this range; assumptions about fry movement rates accounted for the remainder. Gulls recorded during

aerial surveys throughout Prince William Sound were significantly associated with spawning herring and hatchery sites, but not with miles of coast with herring spawn present. The correlation of bird aggregations with the presence of these small fish indicates that concentrations of prey fish have an important influence on the distribution of birds at sea during this time of the year. Bird numbers in both boat counts and aerial surveys declined from early May to early June. Taken together, these results indicate that salmon fry just entering the marine environment were not especially susceptible to avian predation. Their vulnerability to predation was apparently buffered by the presence of other attractive food patches within seabird foraging range early in our study period, and by declines in the numbers of seabirds foraging along the shoreline later in the study.

Schell, D., B. Barnett, et al. (1998). "Carbon and nitrogen isotope ratios in zooplankton of the Bering, Chukchi and Beaufort seas." Marine Ecology Progress Series **162**: 11-23.

Zooplankton from the Bering, Chukchi, and Beaufort seas and a transect across the Arctic Ocean were collected from 369 stations on 18 cruises in the years 1985-1990 and 1993-1995. Carbon and nitrogen isotope ratio analyses were performed on the major taxonomic groups present--calanoid copepods, euphausiids and chaetognaths. The sampled waters around Alaska were divided into 11 subregions based on water mass characteristics and the zooplankton statistically tested for significant differences in the isotope ratios. Within all regions, copepods were significantly more depleted in super(13)C than euphausiids (average delta super(13)C difference for copepods = -1.1 ppt than euphausiids), but showed no significant differences from euphausiids in delta super(15)N except in the eastern Alaskan Beaufort Sea where copepods were relatively enriched in super(15)N.

Schmidt, D., J. Koenigs, et al. (1994). Predator-induced changes in copepod vertical migration: explanations for decreased overwinter survival of sockeye salmon. Theory and Application in Fish Feeding Ecology. D. Stouder, K. Fresh and R. Feller: 187-209.

In recent years, catastrophic reductions in the sockeye salmon (Oncorhynchus nerka) smolt outmigrations from the turbid Kenai River system in Alaska have occurred despite high brood-year escapements. These observed decreases did not correspond with changes in the physical environment or major reductions of zooplankton biomass in the major rearing lake (Skilak). Diaptomus and Cyclops, the dominant zooplankton taxa of this glacial lake (turbidity = 5 NTU), display strong diel vertical migration (DVM). Ovigerous individuals (primarily Cyclops) in Skilak Lake displayed a highly accentuated DVM. We hypothesize that the major decrease in production of sockeye salmon smolts from Skilak Lake resulted from effects of large escapements on the rearing sockeye food base. Specifically, we theorize that the increased density of juvenile sockeye salmon increased the predation pressure on zooplankton, which induced a strong DVM of ovigerous copepods. Thus, by migrating deeper the copepods presumably reduced their vulnerability as prey. In contrast, in nearby Tustumena Lake (turbidity = 40 NTU), which had no large escapements, and in other glacial lakes within the Kenai

River system that lack significant planktivores, copepods were observed to have minimal DVM. The lack of correlation of the observed wintering mortality of juvenile sockeye with other limnological parameters supports the proposed hypothesis.

Schmidt, D., K. Tarbox, et al. (1993). Kenai River sockeye salmon: An assessment of overescapements as a cause of the decline. THE EXXON VALDEZ OIL SPILL SYMPOSIUM, BETHESDA, MD (USA), American Fisheries Society.

In the Kenai River, the estimated number of smolts of sockeye salmon Oncorhynchus nerka decreased from 30 million in 1989 to less than 500,000 in 1992, while parent-year escapements were high. In 1989, an estimated 1.4 million sockeye salmon entered the Kenai River as a result of curtailed fishing because of oil on the fishing grounds from the Exxon Valdez oil spill. We examined the causes for declining smolt production and identified decreased winter survival of age-0 juvenile sockeye salmon rearing in Skilak and Kenai lakes as the major contributor to this decline. We compared smolt production in the Kenai system with that from Tustumena Lake, a nearby system that had an average escapement in 1989 that did not exhibit major changes in smolt production. Adult returns from years with extremely low smolt production in the Kenai system are needed to verify smolt estimation methods. Preliminary examination of limnological data (chemical, physical, and zooplankton forage base) from Skilak and Kenai lakes provided no obvious explanation for the major decline in winter survival of juvenile sockeye salmon. Because diel vertical migration of zooplankton differed among Kenai Peninsula glacial lakes with different densities of planktivores, we hypothesize that behavioral changes in the zooplankton induced by predation was a major contributor to the decreased production of juvenile sockeye salmon in the Kenai River lakes.

Schneider, D. (1993). "Oil spill has long-term effects." Water Environment and Technology **5**(9): 30-32.

Scientists at a meeting earlier this year concluded that Alaska's Prince William Sound still has not recovered from the 1989 Exxon Valdez oil spill. The scientists say that the 40.9 x 10^6-L (10.8 x 10^6-gal) spill's lingering effects can be measured in the sound's populations of marine mammals, birds, fish, and shellfish. More than 100 federal, state, and university scientists presented findings at the Exxon Valdez Oil Spill Symposium, held in Anchorage, Alaska. The meeting was sponsored by the Exxon Valdez Oil Spill Trustee Council, the Alaska Sea Grant College Program, and the Alaska Chapter of the American Fisheries Society. According to the Exxon Valdez Oil Spill Trustee Council, about 257,000 bbl of Alaska North Slope crude oil spilled from the tanker Exxon Valdez into Prince William Sound. Cleanup efforts recovered 18,000 to 22,000 bbl, while 51,000 to 103,000 bbl evaporated, and 350 bbl were burned in a short-lived attempt to ignite parts of the slick. Approximately 131,650 to 188,000 bbl were not recovered. Although remediation has been ongoing for the past 3 years, oil persists on 36.7 km (22.8 mi) of beach in the sound. According to the meeting's attendants, the spill's effects after 4 years are widespread: Harbor seals, whose

population was declining before the spill, continue to disappear. About 80% of adult harbor seals in the path of the slick became oiled, as did many of the pups born in the months immediately after the spill. Approximately 345 seals died immediately after the spill. Wild pink salmon, harlequin ducks, herring, and common murres are not reproducing normally. Scientists say that this problem is caused by oiled intertidal areas where the fish spawn, causing functional sterility and genetic defects. Herring, an important food source for seals and the basis of a multi-million dollar commercial fishery, are still impacted by oil-contaminated spawning grounds. Most herring eggs laid shortly after the spill on kelp beds near shore never hatched. Last year, when 4-year-old herring attempted to spawn, less than half the eggs hatched. Scientists are concerned that genetic changes could slow the recovery of the sound's herring population. As many as 500,000 common murres, small penguin-like seabirds that nest on Alaska's cliffs, were killed in the spill.

Schnoor, J. (1991). "The Alaska oil spill: Its effects and lessons." Environmental Science & Technology **25**(1): 14.

On March 24, 1989, a serious environmental accidend occurred. It was not a human tragedy of the magnitude of the methylisocyanate leak at Bhopal, India, or of the Chernobyl nuclear disaster in the Soviet Union. However, the oil spill in Prince William Sound, Alaska, soaked and killed plants and animals over 2,000 miles of shoreline and 500 miles away. Some 30,000 dead birds of 90 species were retrieved within the first four months following the spill. Scientists continue to to research the long-term effects on bird hatching success, fish spawning, and mammal bioaccumulation of hydrophobic organics. Reasonable people differ in their interpretation of these results, the magnitude of the long-term damage, and estimates of recovery time. In the series of articles beginnign with this issue, the leading authorities who were involved with the cleanup effort and scientific studies will report their results for the first time.

Scofield, E., R. T. Bowyer, et al. (1999). "Baseline levels of Hsp 70, a stress protein and biomarker, in halibut from the Cook Inlet region of Alaska." Sci Total Environ **226**(1): 85-8.

The levels of Hsp 70, a heat shock protein, was quantitatively determined in Pacific halibut, Hippoglossus stenolepis, from the Cook Inlet region in south central Alaska. A dot blot analysis using a monoclonal antibody for Hsp 70 was combined with a standard protein analysis to determine Hsp 70 levels in 26 samples from gills. The average Hsp 70 concentration was 4.6 micrograms/mg, with levels ranging from 2.2 to 14.5 micrograms/mg total protein. Mercury in gill tissue also was measured and, in the 26 samples, only three samples had concentrations of mercury (X = 0.10 mg/kg, range = 0.09-0.11) above the minimum detection level.

Scribner, K., J. Bodkin, et al. (In press 1994). Population genetic studies of the sea otter (Enhydra lutris): a review and interpretation of available data. Proceedings of the

Marine Mammal Genetics Symposium, La Jolla, CA.

Scrudato, R. (2000). Potential for long term sources of contaminants to Alaskan environments resulting from military site remediation of hazardous waste and petroleum sites. International Conference on Arctic Development, Pollution, and Biomarkers fo Human Health, Anchorage AK.

A consequence of the military buildup during WWII and ensuing Cold War era was the creation of highly contaminated sites throughout the arctic region of the U.S., Greenland and Canada. During WWII military installations were created in response to the Japanese invasion of the Aleutian Islands as well as subsequent military concerns about potential strategic military threats posed by the former Soviet Union. Military installations were constructed along the Aleutian Island chain as well as at other remote Island and mainland locations to guard against the threatening Japanese invasion of the Alaskan islands and mainland. In addition, during the Cold War, more than 60 DEW Line facilities were established along the 66th parallel to monitor and track Soviet military activity.

This paper discusses ongoing remedial activities being conducted by the Department of Defense at two remote, Alaska island locations. Groundwater at Adak, a Navy facility created shortly after the Japanese attack and invasion of the Aleutian Islands, is primarily impacted by petroleum fuels. In addition, PCBs and other chlorinated hydrocarbons and trace metals used by the military over the years, impact the area groundwater and nearshore, coastal sediments and biota. Unexploded ordnance also pose threats to the local inhabitants, visitors, and natural resources.

Seagars, D. J. and J. Garlich-Miller (In review). "Organochlorine compounds and aliphatic hydrocarbons in Pacific walrus blubber." Marine Pollution Bulletin.

Seeb, J., C. Habicht, et al. (1998). "Allozyme, mtDNA, and microsatellite variants describe structure of populations of pink and sockeye salmon in Alaska." North Pacific Anadromous Fish Commission 1998 Bulletin(1): 300-318.

Seeb, J., C. Habicht, et al. (1999). "Allozyme and mitochondrial DNA variation describe ecologically important genetic structure of even-year pink salmon inhabiting Prince William Sound, Alaska." Ecology of Freshwater Fish **8**: 122-140.

Allozyme and mitochondrial DNA (mtDNA) data were obtained from pink salmon throughout Prince William Sound, Alaska, from two hatchery, five upstream, and 20 tidal locations distributed among five management regions collected during 1994. Screening for allozymes included 66 loci for 92 to 100 fish per sample. Thirty-four loci had variant allele frequencies >0.01 in one or more collections and were used for population analyses. Eight haplotypes were detected after screening 40 fish per collection for variation at the ND5/ND6 region of mtDNA using six restriction enzymes. Significant and apparently stable differences

detected by both data sets permit rejecting a null hypothesis of panmixia and support managing native populations in Prince William Sound at the regional level. Distinctions between upstream and tidal collections were detected within Lagoon Creek (allozymes) and Koppen Creek (mtDNA). Significant regional heterogeneity was detected within upstream (allozymes and mtDNA) and tidal (allozymes) collections; however, upstream collections were more divergent from each other than were tidal collections. The absence of distinction of Armin F. Koernig Hatchery from almost all regions was consistent with multiple origins of this stock. Conversely, Solomon Gulch Hatchery in the East Region was distinct from all regions but East, consistent with a more restricted origin and influence.

Seeb, L., W. Templin, et al. (1997). Kenai River Sockeye Salmon Restoration. Restoration Project 96255-2. EXXON VALDEZ Oil Spill Restoration Project Final Report. Anchorage, AK, Alaska Dept. of Fish and Game, Anchorage. Div. of Commercial Fisheries Management and Development.: 94.

Genetic data from sockeye salmon (Oncorhynchus nerka) were collected from the Kenai River, a major salmon-producing system impacted by the Exxon Valdez Oil Spill, as well as all other significant spawning populations contributing to mixed-stock harvests in Cook Inlet, Alaska. A total of 68 allozyme loci were resolved from 47 putative populations. Allozyme data reveal a substantial amount of genetic diversity among populations. Mixed-stock analyses using maximum likelihood methods with 27 loci were evaluated to estimate the proportion of Kenai River populations in Cook Inlet gillnet fisheries. Simulations indicate that Kenai River populations can be identified in mixtures at a level of precision and accuracy useful for restoration and fishery management. Fishery samples were analyzed both inseason (within 48 h) and postseason. Samples from fish wheels from the Kenai, Kasilof, Yentna, and Susitna River systems were also analyzed. Microsatellite DNA data were also collected from four populations to assess the ability of this technique to discriminate among populations. Results from this study are currently being used in the management and restoration of Kenai River sockeye salmon injured in the 1989 Exxon Valdez oil spill.

Seiser, P. E., L. Duffy, et al. (2000). "Comparison of Pigeon Guillemot, Cepphus columba, blood parameters from oiled and unoiled areas of Alaska eight years after the Exxon Valdez oil spill." Marine Pollution Bulletin **40**(2): 152-164.

In 1997, we compared the hematological and plasma biochemical profiles among populations of pigeon guillemots, Cepphus columba, in areas oiled and not oiled by the 1989 Exxon Valdex oil spill (EVOS) that occured in Prince William Sound (PWS), Alaska. Pigeon guillemot populations in PWS were injured by EVOS and have not returned to pre-spill levels. If oil contamination is limiting recovery of pigeon guillemots in PWS, then we expected that blood parameters of pigeon guillemots between oiled and unoiled areas and that these differences would be consistent with either toxic responses or lower fitness. We collected blood samples from chicks at approximately 20 and 30 days after hatching. Physiological changes associated with chick growth were noted in

several blood parameters. We found that only calcium and mean cell volume were significantly different between the chicks in oiled and unoiled areas. Despite these differences, blood biomarkers provided little evidence of continuing oil injury to peigoen guillemot chicks, eight years after the EVOS. Preliminary data from adults indicated elevated aspartate aminotransferase activity in the adults from the oiled area, which is consistent with hepatocellular injury. Because adults have greater opportunities for exposure to residual oil than nestlings, we recommend studies that fully evaluate the healthof adults residing in oiled areas.

Senner, S. (1997). "Exxon Valdez oil spill: fate and effects in Alaskan waters." Wilson Bulletin **109**: 3.

Sharp, B., M. Cody, et al. (1996). Effects of the Exxon Valdez oil spill on the black oystercatcher. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 748-758.

Oil spilled from the Exxon Valdez in March 1989 affected an estimated 4,013 km of intertidal shoreline in Prince William Sound, the Kenai and Kodiak coasts, and the Alaska Peninsula. Intertidal habitats were still extensively oiled in 1990. The black oystercatcher *Haematopus bachmani*, a shorebird that forages in the intertidal zone, was studied in Prince William Sound at oiled sites (Green, Little Green, and Channel islands) in 1989 and 1990 and at a non-oiled control site (Montague Island) in 1989 to determine oil spill effects on reproduction and behavior. Oil cover on meter-square quadrats in oystercatcher-foraging areas on Green Island averaged 23 and 17% in 1989 and 1990, respectively. Relative to the control site, the proportion of nonbreeding oystercatcher pairs was higher on oiled sites in 1989, and eggs laid were smaller. Success of clutches to hatching was unexpectedly higher on oiled sites, and predators destroyed a smaller proportion of nests. In 1989, chick mortality was higher on oiled sites than on the non-oiled one and was positively correlated with amount of oil present in foraging territories. In 1990, chick production remained lower on oiled territories and failed completely on bioremediated shorelines.

Sharp, D., S. Sharr, et al. (1993). Homing and straying patterns of coded wire tagged pink salmon in Prince William Sound. 16th Northeast Pacific Pink and Chum Salmon Workshop, Juneau, AK (USA), 24-26 Feb 1993, Alaska Univ., Fairbanks (USA). Alaska Sea Grant Program.

Homing and straying patterns of coded-wire tagged pink salmon (Oncorhynchus gorbuscha) originating from four hatcheries and six streams in Prince William Sound (PWS) were assessed for the 1991 return year. PWS hatcheries released 615 million pink salmon fry in 1990. Of these, 1,032,000 fry were tagged with coded-wire tags using 32 unique tag codes. Outmigrations from six study streams yielded 2,120,000 wild stock pink salmon fry of which 258,000 were tagged. Coded tags identified a fish's release location, its release or outmigration

date and, for hatchery-bred salmon, the rearing strategy employed prior to release. Initially, tagged juvenile salmon were recovered during their early marine life and were used to compare growth and survival for salmon from oiled and unoiled areas of PWS. Tagged adults returning in 1991 were recovered in commercial fisheries allowing managers to assess the contribution of an individual hatchery's or stream's production to the overall commercial catch and to compare the ocean survival of salmon stocks of known oil exposure history.

Sharr, S., B. Bue, et al. (1996). Injury to Salmon Eggs and Preemergent Fry in Prince William Sound. Fishhellfish Study Number 2. EXXON VALDEZ Oil Spill, State/Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Anchorage. Div. of Commercial Fisheries Management and Development.: 206p.

Pink salmon embryo mortality was elevated in oil contaminated streams during the falls of 1989, 1990, and 1991. Increased embryo mortality was detected in the lower intertidal zones in 1989 while elevated mortalities were observed at the highest intertidal zone in 1990. These findings were consistent with how stream oiling was expected to take place: all intertidal zones were contaminated in 1989 with the remaining oil being deposited in the highest intertidal zone in 1990. Embryo mortality was significantly higher in all zones for the oil contaminated streams in 1991. No difference in embryo to preemergent fry survival was detected for the 1989, 1990, or 1991 brood years. See also PB95-966003 and PB96-966006.

Shaw, D. (1992). "The Exxon Valdez oil-spill: Ecological and social consequences." Environmental Conservation **19**(3): 253-258.

Major oil-spills, such as occurred following the grounding of the tanker Exxon Valdez in March 1989 in Prince William Sound, Alaska, account for only a small fraction of the total anthropogenic input of petroleum to the marine environment. Yet major spills can result in significant and even acute impacts, trigger ecological changes requiring decades for recovery, and command considerable public attention. Thus catastrophic oil-spills in general, and the Exxon Valdez spill in particular, differ from other chronic human alterations of coastal marine systems. Estimates of the fate of the 38,000 metric tons of crude oil lost by the Exxon Valdez are imprecise, but perhaps 30-40% evaporated, 10-25% was recovered, and the rest remains in the marine environment. Roughly 1,500 km of coastline were oiled in varying degrees. Much of this coastline consists of gravel beaches into which oil penetrated to depths as great as 1 m.

Shigenaka, G. (1990). Chlordane in the marine environment of the United States: Review and results from the National Status and Trends Program. Rockville, MD (USA), National Ocean Serv., Rockville, MD (USA). Off. of Oceanography and Marine Assessment: 260.

The report serves two broad purposes. First, recent results for marine environmental concentrations of chlordane from NOAA's National Status and

Trends (NS&T) Program are summarized and interpreted. Second, research and monitoring results for chlordane from other sources are summarized for reference. The report is organized into several discrete sections which are intended to facilitate ease of use and reference. The first sections provide general information on chlordane chemistry, use, and production. These are followed by discussions of known toxic effects, primarily in traditional laboratory test animals used to generate results applicable to human health studies. Summaries and discussions of environmental residues comprise the remaining portions of the report. In the following section, other chlordane investigations that have been undertaken in other parts of the world and in other environmental media are summarized in order to provide a broader context and a degree of perspective for the U.S. coastal and estuarine results. The final section discusses general aspects of the results reviewed, such as any consistencies or inconsistencies suggested by the studies.

Shigenaka, G. and C. J. Henry (1995). Use of mussels and semipermeable membrane devices to assess bioavailability of residual polynuclear aromatic hydrocarbons three years after the Exxon Valdez oil spill. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

Mussels (Mytilus cf. trossulus) were transplanted to a heavily oiled and extensively treated site on Smith Island, Prince William Sound, Alaska, in 1992. A new monitoring and assessment tool, the semipermeable membrane device, was also deployed to compare hydrocarbon uptake with mussels and to evaluate the route of exposure to mussels. Both mussels and semipermeable membrane devices accumulated polynuclear aromatic hydrocarbons during 14- and 52-day deployments, particularly at the oiled site. Accumulation levels were similar between mussels and the semipermeable membrane devices, but the distribution of individual hydrocarbons differed. The results permit some inference about route of exposure to mussels. Sheens leaching from subsurface deposits of residual oil, and particulate material with adsorbed hydrocarbons were apparently more important exposure pathways than dissolved hydrocarbons in water. Semipermeable membrane devices show promise as monitoring tools and to provide insights into exposure pathways for biota.

Short, J. and M. Babcock (1996). Prespill and postspill concentrations of hydrocarbons in mussels and sediments in Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 149-166.

Hydrocarbon concentrations in intertidal mussels (*Mytilus trossulus*) and sediments were compared before and after crude oil from the TV Exxon Valdez contaminated beaches in Prince William Sound. Comparison of hydrocarbon concentrations in these samples at stations inside and outside the path of the oil and before and after landfall of the spilled oil were used to (1) evaluate the significance of petroleum hydrocarbon contaminants

found after the spill, (2) establish restoration criteria for affected beaches, and (3) determine natural recovery rates for these beaches. Concentrations of polynuclear aromatic hydrocarbons (PAHs) near or below detection limits in mussels outside the path of the spilled oil, or collected before oil became beached, indicate that other sources of PAHs were negligible and that seawater in the spill area generally was free of anthropogenic hydrocarbon pollution. Contamination of mussels by PAHs derived from natural sources, such as marine oil seeps, was not detected. Contamination of mussels was highest during the first few weeks after the spill, followed by a consistent decline. Concentrations of hydrocarbons derived from Exxon Valdez oil were highest and most persistent in mussels near or on heavily oiled beaches. Contamination of lower intertidal sediments by PAHs derived from Exxon Valdez oil was less than 1,000 ng/g (dry weight basis), even when concentrations in adjacent upper intertidal sediments were higher by factors exceeding 10. Concentrations of spill-derived PAHs in lower intertidal sediments consistently declined during the years after the spill. At stations unaffected by the spilled oil, total PAH (TPAH) concentrations in lower intertidal sediments were usually less than 100 ng/g, except near Hinchinbrook Entrance. Analytical data on mussels and sediments for stations sampled before the spill and for unaffected stations can be used to establish restoration criteria for oiled beaches.

Short, J. and P. Harris (1996). Chemical sampling and analysis of petroleum hydrocarbons in near-surface seawater of Prince William Sound after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 17-28.

To assess contamination from spilled oil after the grounding of the Exxon Valdez on 24 March 1989, we sampled 32 locations in Prince William Sound, Alaska, for petroleum hydrocarbons in seawater at depths of 1 and 5 m. Most locations were sampled in each of three periods between 31 March and 8 May 1989. Triplicate seawater samples were taken at each location and depth and were extracted into dichloromethane. Of 501 samples taken, 243 were analyzed for 22 alkane and 43 polynuclear aromatic hydrocarbon (PAH) analytes. Results show that PAHs from Exxon Valdez crude oil contaminated seawater to a depth of at least 5 m and at concentrations up to 6.24 plus or minus 0.63 mu g/L at nine contiguously located stations in the region encompassing northwest Montague Strait-northern Knight Island-Smith Island, 1-2 weeks after the grounding. Highest PAH concentrations were near heavily oiled beaches, which apparently were a reservoir of spilled oil that continued to contaminate adjacent seawater at PAH concentrations up to 1.59 mu g/L after 5 weeks. Polynuclear aromatic hydrocarbons from Exxon Valdez crude oil were available to marine fauna during the first few weeks after the grounding, especially in nearshore waters. Measured PAH concentrations, however, were well below levels that are acutely toxic to marine fauna.

Short, J. and P. Harris (1996). Petroleum hydrocarbons in caged mussels deployed in Prince William Sound after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:**

29-39.

Mussels *Mytilus trossulus*, initially free of hydrocarbons, were deployed in nearshore waters along the path of oil spilled from the Exxon Valdez to determine the biological availability and persistence of petroleum-derived hydrocarbons. Mussels were deployed at 22 locations inside Prince William Sound and 16 locations outside the sound at depths of 1, 5, and 25 m for 2-8 weeks. We conducted four successive deployments in 1989 after the spill and two in 1990 and 1991. Mussels were analyzed for 23 alkane and 43 polynuclear aromatic hydrocarbon (PAH) analytes. Concentrations of PAHs in mussels deployed along the oil's path decreased with depth, time, and distance from heavily oiled beaches. The highest concentration of total PAHs was 45,200 ng/g dry tissue weight at Herring Bay, 1-m depth, 1-2 months after the spill. Concentrations were nearly that high at north Smith Island and Snug Harbor. Lower concentrations with PAH composition similar to Exxon Valdez crude oil were detected at other locations inside Prince William Sound, except at the control site, Olsen Bay. Concentrations of PAHs in mussels deployed inside Prince William Sound declined by late summer 1989. In 1990 and 1991, PAHs could only be detected near heavily oiled beaches at concentrations that were usually below 500 ng/g. Alternative sources of petroleum hydrocarbons in the mussels were negligible compared with Exxon Valdez crude oil. Petroleum hydrocarbons similar to those of Exxon Valdez crude oil were detected only sporadically outside the sound in 1989 and were generally below detection limits in 1990 and 1991. Accumulation of hydrocarbons derived from Exxon Valdez crude oil by deployed mussels indicates that these hydrocarbons were available to subsurface marine fauna, such as fish and invertebrates during the summer after the spill, especially in shallow waters near oiled beaches. Oil accumulated from seawater at these trophic levels would serve as a route of oil exposure through ingestion by fauna at higher trophic levels.

Short, J. and P. Harris (1996). Petroleum Hydrocarbons in Near-Surface Seawater of Prince William Sound, Alaska, Following the EXXON VALDEZ Oil Spill I: Chemical Sampling and Analysis. Airater Study Number 3. EXXON VALDEZ Oil Spill State/Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Juneau, AK. Auke Bay Lab.: 72p.

We sampled 32 locations during each of three sampling periods between 31 March through 8 May 1989 in Prince William Sound, Alaska, for hydrocarbons in seawater at depths of 1-m and 5-m following the grounding of the T Exxon Valdez on 24 March 1989. Samples were analyzed for 22 alkane and 43 polynuclear aromatic hydrocarbon (PAH) analytes. The results show that Exxon Valdez crude oil PAHs were available to subsurface marine fauna the first few weeks following grounding of the T/V Exxon Valdez, especially in near-shore, near-surface waters that are biologically productive. Measured PAH concentrations, however, were well below those acutely toxic to marine fauna. See also PB96-196969.

Short, J. and P. Harris (1996). Petroleum Hydrocarbons in Near-Surface Seawater of Prince William Sound, Alaska, Following the EXXON VALDEZ Oil Spill II: Analysis of

Caged Mussels. Airater Study Number 3. Subtidal Study Number 3A. EXXON VALDEZ Oil Spill State/Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Juneau, AK. Auke Bay Lab.: 135p.

Mussels (Mytilus trossulus) were deployed at 22 locations inside Prince William Sound and 16 locations outside the Sound at depths of 1, 5 and 25 m for 2 to 8 weeks to determine the biological availability and persistence of petroleum-derived hydrocarbons from the Exxon Valdez Oil (EVO) spill. Four successive deployments were made in 1989, and two each in 1990 and 1991. Mussels were analyzed for 27 alkane and 43 polynuclear aromatic hydrocarbon (PAH) analytes. PAH concentrations derived from EVO in mussels decreased with depth, time, and distance from heavily oiled beaches. Hydrocarbon accumulation derived from EVO by deployed mussels indicates petroleum hydrocarbons were available to subsurface marine fauna the summer following the spill, which may be a route of oil ingestion exposure by fauna at high trophic levels. See also PB96-196951.

Short, J. and R. Heintz (1997). "Identification of Exxon Valdez oil in sediments and tissues from Prince William Sound and the Northwestern Gulf of Alaska based on a PAH weathering model." Environmental Science and Technology **31**(8): 2375-2384.

We used a first-order loss-rate kinetic model of polynuclear aromatic hydrocarbon (PAH) weathering to evaluate 7767 environmental samples collected for the Exxon Valdez oil spill (EVOS) for the presence of spilled oil. The model was developed from experiments with gravel coated with crude oil and washed for 6 months. The modeled PAH included the 14 most persistent compounds of 31 analyzed by GC. Parameters include loss-rate constants related to the energy required for PAH to escape from petroleum and a quantitative index of weathering. The model accounts for 91% of the temporal variability of modeled PAH concentrations. We compared the discrepancies between measured and model-predicted PAH concentrations of EVOS samples with a probability distribution of these discrepancies derived from the experimental weathering results. Only 1541 field samples contained sufficient PAH for valid application of the model; three-fourths fit the model at alpha \ 0.01 type I error, 9% fit an alternate model characterized by the absence of weathering, 17% fit neither model, and a few fit both models. The 1164 total samples that fit the weathering model account for 86% of the summed PAH concentrations detected in all 7767 samples. We conclude that first-order loss-rate kinetics account for the dominant PAH weathering processes in the EVOS and that the rate of weathering is determined mainly by the ratio of surface area to volume of petroleum in the environment.

Short, J. and R. Heintz (1998). "Source of polynuclear aromatic hydrocarbons in Prince William Sound, Alaska, USA, subtidal sediments." ENVIRONMENTAL TOXICOLOGY AND CHEMISTRY **17**(9): 1651-1651.

Short, J., T. Jackson, et al. (1996). Analytical methods used for the analysis of

hydrocarbons in crude oil, tissues, sediments, and seawater collected for the Natural Resources Damage Assessment of the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 140-148.

This paper describes the analytical methods used for quantitative determination of hydrocarbons in samples of crude oil, biological tissues, marine sediments, and seawater that were collected for the Natural Resources Damage Assessment of the *Exxon Valdez* oil spill.

Short, J., K. Kvenvolden, et al. (1998). "Natural hydrocarbon background in benthic sediments of Prince William Sound, Alaska: Oil vs coal." Environmental Science & Technology **33**(1): 34-42.

The source of the background hydrocarbons in benthic sediments of Prince William Sound (PWS), AK, where the 1989 Exxon Valdez oil spill (EVOS) occurred, has been ascribed to oil seeps in coastal areas of the Gulf of Alaska (GOA). We present evidence that coal is a more plausible source, including (i) high concentrations of total PAH (TPAH), between 1670 and 3070 ng/g, in continental shelf sediments adjacent to the coastal region containing extensive coal deposits; (ii) PAH composition patterns of sediments along with predictive models that are consistent with coal but not oil; (iii) low ratios (<0.2) of triaromatic steranes to methylchrysenes found in sediments and coals, contrasting with the high ratios (11 and 13) found in seep oil; and (iv) bioaccumulation of PAH in salmon collected within 100 m of the Katalla oil seeps but not in filter-feeding mussels collected near oil field drainages 9 km from the seeps, indicating negligible transport of bioavailable PAH from Katalla seeps t o the GOA. In contrast with oil, PAH in coal are not bioavailable, so the presence of coal in these benthic sediments confers no adaptive benefit to biota of the marine ecosystem with respect to PAH insults from anthropogenic sources.

Short, J., C. O'Clair, et al. (1994). Distribution and persistence of polynuclear aromatic hydrocarbons, PAH's, in marine sediments of Prince William Sound after the Exxon Valdez oil spill. Bridges of the Science between North America and the Russian Far East; 45th Arctic Science Conference, Anchorage, Alaska, USA, August 25-27, 1994 and Vladivostok, Russia, August 29-September 2, 1994, Dalnauka Publishing House; Vladivostok, Russia.

Short, J., S. Rice, et al. (1989). "Occurrence of tri-n-butyltin-caused imposex in the North Pacific marine snail Nucella lima in Auke Bay, Alaska." Marine biology **102**(3): 291-297.

Like female dog whelks (Nucella lapillus) in the Atlantic Ocean, females of the Pacific gastropod N. lima respond to low concentrations of tri-n-butyltin (TBT) by growing a penis and vas deferens. This condition, termed imposex, was found to occur in N. lima collected from August 1987 to May 1988 along a TBT pollution gradient associated with a marina in Auke Bay, Alaska. Imposex, as measured

by relative penis size (RPS) of females to males, increased from 0.0 to 34.27 along this gradient and as measured by vas deferens sequence-index (VDS) increased similarly from 0.0 to 4.29. Concentrations of TBT in N. lima increased from below detection limits (about 0.010 mu g Sn g super(-1) dry tissue wt) to 0.065 mu g Sn g super(-1) dry tissue wt along the gradient. The gradient was determined by measuring TBT in whole-body tissues of bay mussels (Mytilus edulis). Concentrations of TBT in mussels increased from below detection limits of 0.833 mu g Sn g super(-1) dry tissue wt in mussels from within the marina that was the major local source of TBT. Imposex, tissue TBT burden, and position along a TBT pollution gradient are significantly correlated ($P < 0.01$) in N. lima .

Short, J., D. Sale, et al. (1996). Nearshore transport of hydrocarbons and sediments after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 40-60.

Sediment traps were deployed in seawater depths of 10 m to 20 m to evaluate the transport of oil-laden sediments from oiled beaches to adjacent shallow subtidal sediments after the Exxon Valdez oil spill of 24 March 1989 in Prince William Sound, Alaska. Sediments collected by these traps between November 1989 and March 1991 were analyzed for petroleum hydrocarbons and for sedimentological and mineralogical characteristics. Benthic surface and core sediment samples were also collected and analyzed for hydrocarbons and for sedimentological characteristics, which are compared with similar results for trapped sediments. Results of the hydrocarbon analyses of the trapped sediments indicate that Exxon Valdez oil was transported from oiled beaches to adjacent shallow subtidal sediments. Total polynuclear aromatic hydrocarbon (PAH) concentrations of trapped sediments were highest at the East Arm of Northwest Bay during the first trap deployment period, when concentrations exceeded 75,000 ng/g (dry weight basis). Total PAH concentrations of sediments trapped at the other three oiled locations ranged from 8,660 to 28,400 ng/g. Total PAH concentrations generally declined with time to 700-6,280 ng/g for sediments trapped during the March 1991-June 1991 deployment interval. Total PAH concentrations of sediments trapped at other stations were generally lower (<3,500 ng/g) and were usually compositionally distinct from Exxon Valdez oil. These oil-laden suspended sediments were only slightly incorporated into adjacent benthic surface sediments. Total PAH concentrations derived from Exxon Valdez oil were less than 2,500 ng/g in shallow (10-20 m) benthic surface sediments at oiled locations and approached this value only in the East Arm of Northwest Bay. Elsewhere, total PAH concentrations derived from any source were generally well below 500 ng/g. Contributions to shallow subtidal benthic sediments of PAHs derived from other sources, including anthropogenic sources and PAH-laden sediments carried into Prince William Sound through Hinchinbrook Entrance, are generally well below 400 ng/g at locations within or near the path of the spill through the sound. Sedimentological results indicate (1) mobilization of fine, oil-contaminated sediments from heavily oiled upper intertidal beaches by winter wave action and beach treatment activities and (2) residence times of oil in shallow epibenthic sediments on the order of months. The residence time increases with proximity to heavily oiled beaches where waves or treatment cause erosion but where adjacent subtidal areas are protected

from wave and tidal energy. The conditions favorable for prolonged accumulations of elevated oil concentrations in shallow epibenthic sediments are restrictive, so that substantial and prolonged shallow subtidal sediment contamination is probably limited to relatively few locations. However, higher levels of contamination probably occur in deeper, lower energy, fine-grained sedimentation sites within oiled embayments.

Short, J. and J. Sharp (1989). "Tributyltin in bay mussels (Mytilus edulis) of the Pacific Coast of the United States." Environmental Science & Technology **23**(6): 740-743.

Tissue concentrations of tributyltin (TBT) were measured by graphite furnace and atomic absorption spectrometry (GFAA) and by gas chromatography coupled with and atomic absorption spectrophotometer as the detector (GCAA) in bay mussels (Mytilus edulis) collected from Sand Diego Bay (CA), Monterey Bay (CA), Puget Sound (WA), Auke Bay (AK) and Kodiak Harbor (AK) in 1986 and 1987; results from both methods were not significantly different ($P < 0.871$). Concentrations of TBT in mussels ranged from less than 0.005 micrograms of TBT per gram of wet tissue weight to 1.08 micrograms per gram of wet tissue weight. Concentrations of TBT in mussels sampled from Puget Sound were significantly lower ($P < 0.033$) in March 1987 than in June 1986, possibly due to the influence of boats freshly painted with marine antifoulants during the spring. Our results may be useful as a benchmark to guage the efficacy of recently endacted legislation restricting the use of marine antifoulants containing TBT on the Pacific coast of the United States.

Short, J., B. Wright, et al. (1998). A fingerprinting misinterprestation: Previous claims for the natural "petroleum" hydrocarbon background in subtidal sediments of Prince William Sound, Alaska. 19th Annual Society of Environmental Toxicology and Chemistry Meeeting.

Claims have been made repeatedly in the literature that subtidal sediments in Prince William Sound (PWS), Alaska were contaminated by crude oil produced from natural seeps prior to the 1989 Exxon Valdez oil spill. This hydrocarbon background was identified with natural oil seeps at Katalla and elsewhere along coastal areas of the Gulf of Alaska (GOA) based on the presence of oleanane and the ratio of C2-dibenzotiophenes to C2-phenanthrenes. A more thorough assessment of all available hydrocarbon data combined with an evaluation of other plausible hydrocarbon sources reveals that the actual source is most likely coal. This evidence includes (1) high concentrations of total PAH in continental shelf sediments co-extensive with upland coal deposits; (2) low ratios (<0.2) of triaromatic steranes to methylchrysenes in sediments and coals, but high ratios (11 and 13) in Katalla oil; (3) presence of bisnorhopane in sediments and coal, but its absence in Katalla oil; (4) the bioaccumulation of PAH in biota collected within 100 m of the Katalla oil seeps, but the absence of most PAH in mussels collected near coalfield drainages 9 km from the oil seeps; and (5) absence of PAH losses from experimentally weathered coal. PAH in these coals are not bioavailable, so the presence of coal in the benthic sediments of this region confers no adaptive benefit to biota of the aquatic ecosystem with respect to PAH insults from anthropogenic sources.

Sienkiewicz, A. and K. O'Shea (1992). Response and management strategies utilized during the Kenai pipeline crude oil spill, Nikiski, Alaska. Proceedings of the Fifteenth Arctic and Marine Oil Spill Program Technical Seminar, Edmonton, AB (Canada), 10-12 Jun 1992.

This paper discusses and describes the response and management strategies utilized for the Kenai spill. These strategies include the formulation of an oil spill response cooperative in Cook Inlet through the pooling of the resources of many oil industries. Extensive pre-planning through the joint development and review of enhanced oil discharge contingency plans, training, spill drills, and continuous evaluations provides the base for the development and further refinement of the strategies. Much of the infrastructure necessary to manage the spill had been developed prior to the discharge because of this pre-planning. The rapid development of a structured management system and previously developed working relationships between the responding personnel also assisted in the spill. An improved communications system which consisted of radio, visual, and direct personnel interactions led to a cohesive understanding between the actual operation and the command structure.

Smith, R., R. Khan, et al. (1994). Tumors, lesions, and an eye parasite in flatfish from Resurrection Bay, Alaska. Proceedings of the International Symposium on North Pacific Flatfish, Anchorage, AK (USA), 26-28 Oct 1994, Alaska Sea Grant Coll. Program, Fairbanks, AK (USA).

Five species of flatfish from depths of 5-40 m in Resurrection Bay, Alaska, were examined to determine frequency and intensity of external lesions and parasites. Skin tumors were observed in 20% of the yellowfin sole, Pleuronectes asper, 67% of the flathead sole, Hippoglossoides elassodon, and 20% of the Dover sole, Microstomus pacificus. No skin lesions were observed on either English sole, Pleuronectes vetulus or arrowtooth flounder, Atheresthes stomias. Fin necrosis was seen in 4% of the yellowfin sole.

Sol, S., L. Johnson, et al. (1994). Contaminant effects on reproductive output in North Pacific flatfish. Proceedings of the International Symposium on North Pacific Flatfish; Twelfth Lowell Wakefield Symposium, Anchorage, Alaska, USA, October 26-28,1994, Alaska Sea Grant College Program; Fairbanks, Alaska, USA.

In a series of laboratory and field studies conducted in Puget Sound, Washington, we have investigated the impact of chemical contaminants on reproductive function in several common pleuronectid species, including English sole (Pleuronectes vetulus) and rock sole (Lepidopsetta bilineata). We have found that exposure to and uptake of chemical contaminants such as aromatic and chlorinated hydrocarbons is associated with several types of reproductive dysfunction. Inhibited gonadal development, depressed plasma concentrations of reproductive steroids, reduced spawning success, reduced egg size, and reduced egg and larval viability, appear to be most closely correlated with exposure to aromatic hydrocarbons (AHs), although poly-chlorinated biphenyls

(PCBs) and other chlorinated hydrocarbons may also be involved, particularly in altered egg development and reduced egg viability. Although the long-term impact that reproductive impairment might have on the survival and abundance of affected fish is not known, preliminary results of a population modeling study with English sole from polluted sites in Puget Sound suggest that contaminant-related declines in reproductive output may have the potential to reduce the growth rate of English sole subpopulations in urban areas.

Sotsky, J. B., C. W. Greer, et al. (1994). "Frequency of genes in aromatic and aliphatic hydrocarbon biodegradation pathways within bacterial populations from Alaskan sediments." Canadian Journal of Microbiology **40**(11): 981-5.

A significant proportion of the naturally occurring hydrocarbon- degrading populations within Alaskan sediments affected by the Exxon Valdez oil spill had both the xylE and alkB genes and could convert hexadecane and naphthalene to carbon dioxide; a greater proportion of the population had xylE than had alkB, reflecting the composition of the residual oil at the time of sampling; nearly equal populations with xylE alone, alkB alone, and xylE + alkB genes together were found after exposure to fresh crude oil; populations with xylE lacking alkB increased after enrichment on naphthalene. Thus, the genotypes of hydrocarbon-degrading populations reflected the composition of the hydrocarbons to which they were exposed.

Spies, R., S. Rice, et al. (1996). The effects of the Exxon Valdez oil spill on the Alaskan coastal environment. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 1-16.

The 1989 Exxon Valdez oil spill had an immediate acute effect on seabirds, bald eagles *Haliaeetus leucocephalus*, marine mammals, and intertidal communities in Prince William Sound and portions of the northern Gulf of Alaska. Longer-term impacts, some lasting several years or more, were found on Pacific herring *Clupea pallasi*, pink salmon *Oncorhynchus gorbuscha*, Dolly Varden *Salvelinus malma*, cutthroat trout *O. clarki*, and the intertidal and subtidal environments in Prince William Sound. The spill and the subsequent cleanup activity also had impacts on important coastal archaeological sites, the use of marine resources by subsistence communities, and the social structure of spill-area communities. The oil was distributed over hundreds of kilometers from Bligh Reef in Prince William Sound well into the Gulf of Alaska. Beached oil penetrated deeply into cobbled beaches and still persists in some areas beneath the surface layer of rocks and under mussel beds 5 years after the surface cleanup. Dispersion, recovery, transformation, evaporation, photodegradation, and especially bacterial degradation have been the main processes removing the oil from the ecosystem. The determination of injury and recovery and the restoration program were undertaken by the United States and Alaska governments through the Exxon Valdez Oil Spill Trustee Council. Several sources of uncertainty, particularly the lack of prespill data on marine resources, have hampered a full determination of the spill's effects, leading to a variety of interpretations. However, numerous species sustained significant damage, especially sea surface dwellers

such as seabirds and marine mammals. The intertidal communities were severely impacted, and early life history stages of intertidally spawning fish were affected. Recovery is occurring at different rates for different species. Constraints on recovery and the underlying causes of declines apparent in some species before the spill are the subject of several ecosystem-based studies. The practical legacy from the scientific studies of resource damage assessment and restoration are a greater understanding of how a rich subarctic marine ecosystem can be affected by a large petroleum spill, provision of new and improved tools for management of natural resources, and a better understanding of the marine ecosystem of Prince William Sound and the northern Gulf of Alaska.

Spraker, T. (1990). Hazards of releasing rehabilitated animals with emphasis on sea otters and the T/V Exxon Valdez oil spill. Sea Otter Symposium: Proceedings of a Symposium to Evaluate the Response Effort on Behalf of Sea Otters After the T/V Exxon Valdez Oil Spill into Prince William Sound.

Spraker, T., L. Lowry, et al. (1994). Gross necropsy and histopathological lesions found in harbor seals. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 281-312.

This study documented pathological conditions observed in harbor seals collected after the EVOS. Nineteen seals were examined that were found dead in Prince William Sound and the Gulf of Alaska, or that died in captivity. Fifteeen of the 19 were oiled, but because of carcass conditions and the lengthy time between death and sampling, it was difficult to ascertain any causes of death. Thirteen of the 19 were pups, and stress or toxic effects of oil may have contributed to their deaths. Two older seals likely died due to blunt trauma. Twenty seven additional seals, both oiled and unoiled, were collected, examined, and sampled within minutes after death. Gross examination and detailed hisopathology of these 27 documented several types of lesions that were probably caused by crude oil. Skin irritation, conjuctivitis, and liver lesions occured more frequently in oiled seals. This damage was relatively mild, and probably reversible, in most cases. Four types of lesions characteristic of hydrocarbon toxicity were found in the brain of oiled seals. These lesions occurred principally in the thalamus and probably explain disorientation and lethargy observed in seals immediately following the spill. The lesions were most acute in a seal collected 35 days after the spill and milder in seals collected later. It is likely that severely affected seals died prior to our sampling, and the animals that we collected were those that survived the short-term effects of the spill.

Spruell, P., B. Greene, et al. (1999). "Inheritance of nuclear DNA markers in gynogenetic haploid pink salmon (Oncorhynchus gorbuscha)." Journal of Heredity **90** (2): 289-296.

We describe the inheritance of 460 PCR-based loci in the polyploid-derived pink salmon (Oncorhynchus gorbuscha) genome using gynogenetic haploid embryos. We detected a length polymorphism in a growth hormone gene (GH-2) intron that is caused by an 81 bp insertion homologous to the 3 theta end of the

salmonid short interspersed repetitive element (SINE) Smal. Such insertion polymorphisms within species bring into question the use of SINEs as phylogenetic markers. We confirmed that a microsatellite locus encodes a PCR-null allele that is responsible for an apparent deficit of heterozygotes in a population sample from Prince William Sound. Another set of microsatellite primers amplified alleles of the same molecular weight from both loci of a duplicated pair. In our analysis of several PCR-based multilocus techniques, we failed to detect evidence of comigrating fragments produced by duplicated loci. Segregation analysis of PCR-based markers using gynogenetic haploid embryos ensures that the interpretation of molecular variation is not complicated by heterozygosity, diploidy, or gene duplication. We urge investigators to test the inheritance of polymorphisms in salmonids prior to using them to measure genetic variation.

St. Aubin, D. and J. Geraci (1994). Summary and conclusions (Marine Mammmals and the Exxon Valdez). Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 371-376.

The grounding of the Exxon Valdez in Prince William Sound (PWS) unleashed a flurry of activity to contain and clean up the crude oil, rescue and rehabilitate affected animals, and determine the impact of the spill on the evnironment. Marine mammals drew special attention, with $18 million invested in rehabilitation and $5 million for damage assessment and research during 1989-1991. Driven largely by the need to answer questions of legal liability, the priority of much of this effort was to quantify the losses.

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It is apparent from the studies presented in this volume that good baseline data yield better answers sooner - a reminder of the value of ongoing studies into fundamental biological questions. The EVOS investigation also showed that some questions can be answered in rehabilitation centers, which will invariably form a major part of future responses. Researchers, while working with care-givers at these centers, can use information on recovery, residual effects, and mechanisms of toxicity to supplement field data for a more comprehensive understanding of how oil affects wild marine mammal populations.

Stanley, H. (1995). Citizen oversight under OPA 90: Report card from Prince William Sound. International Conference Prevention, Response, and Oversight Five Years After the Exxon Valdez Oil Spill, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science.

This paper will provide an overview of the experience and work of the Regional Citizens' Advisory Council of Prince William Sound (RCAC) in terms of whether it has met implicit and explicit expectations of its founding members, residents of the affected region, Alyeska Pipeline Service Company, and the Oil Pollution Act of 1990 (OPA 90).

Stekoll, M. and L. Deysher (1996). "Recolonization and restoration of upper intertidal

Fucus gardneri (Fucales, Phaeophyta) following the Exxon Valdez oil spill." Hydrobiologia **326-327**: 311-316.

The Exxon Valdez oil spill in March 1989 and subsequent cleanup caused injury to intertidal Fucus gardneri populations especially in the upper intertidal. A survey in 1994 in Prince William Sound, Alaska showed that the upper boundary of Fucus populations at oiled sites was still an average of 0.4 m lower than the upper boundary at unoiled sites. Restoration of severely damaged Fucus populations was started on a small-scale at a heavily oiled rocky site in Herring Bay, Prince William Sound. Experiments employed mats of biodegradable erosion control fabric to act as a substratum for Fucus germlings and to protect germlings from heat and desiccation stress. A series of plots was covered with mats made from a resilient coconut-fiber fabric in June 1993. Half of the mats were inoculated with Fucus zygotes. A series of uncovered control plots was also monitored. There was no enhancement of Fucus recruitment on the rock surfaces under the mats. Dense populations of Fucus developed on the surface of all of the mats by the summer of 1994. The natural rock surfaces in the control plots, both inoculated and not, were barren of macroscopic algal cover. By September 1994, the juvenile thalli on the mats were approximately 2 cm in length. Inoculating the mats had an effect only in the upper region of the intertidal. It is expected that the thalli will become fertile during the 1995 season. These thalli may serve as a source of embryos to enhance the recovery of new Fucus populations in this high intertidal area.

Stekoll, M., L. Deysher, et al. (1993). Seaweeds and the Exxon Valdez oil spill. Proceedings of the 1993 International Oil Spill Conference: Prevention, Preparedness, Response, Washington, D.C., American Petroleum Institute Publication.

Stekoll, M., L. Deysher, et al. (1996). Coastal habitat injury assessment intertidal communities and the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 177-192.

This paper summarizes results of intertidal community studies from the Natural Resource Damage Assessment, Coastal Habitat Injury Assessment (CHIA) Project carried out from spring 1990 through summer 1991. Injuries to the intertidal plant and invertebrate populations by the Exxon Valdez oil spill and subsequent cleanup treatment activities were documented over the entire area of the spill, from Prince William Sound to the Alaska Peninsula. A stratified random sample of oiled sites was selected and populations on matching reference (control) sites were compared. Statistically significant differences between oiled-treated and reference sites are interpreted as injury resulting from the oil spill. These differences are summarized for algal and invertebrate variables, such as percent cover, biomass, and abundance. Results indicate that the oil spill and subsequent cleanup treatment had serious effects that were evident throughout the entire region, at least until 1991, when the study ended. The organisms most often showing differences between oiled-treated and reference sites included Fucus, limpets, mussels, barnacles,

littorine gastropods, and oligochaetes. However, the responses of the intertidal biota to the oil spill and treatment varied depending on the tidal elevation, habitat, and region. As of 1991 recovery of the intertidal biota showed varying patterns for the oiled-treated sites depending on the tide level, habitat, and region. Additional monitoring is needed to determine complete recovery of these affected areas.

Stephens, S. (1994). Then & Now: Changes since the Exxon Valdez oil spill. International Conference Prevention, Response, and Oversight Five Years After the Exxon Valdez Oil Spill, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science.

This paper provides an overview of how factors that led to the nation's worst oil spill have been addressed since 1989. The Exxon Valdez oil spill was not simply a freak accident. While Exxon was responsible, myriad other factors allowed it to happen. It could have been prevented by stronger prevention practices and vigilant government oversight. Once the spill occurred, better response planning could have lessened the impacts. Prince William Sound and communities in the path of tanker traffic are better protected from major spills. Industry, government agencies, and the communities are better prepared to respond should a spill occur. Important steps have been taken to prevent oil spills from occurring. Crews are better trained and monitored. Masters are held to more stringent requirements. Measures have been instituted to increase chances of safe passage and reduce the possibility of accidents. Yet gaps remain.

Stock, G. (1995). Oil spill prevention measures undertaken in the wake of the Exxon Valdez oil spill. International Conference on Prevention, Response, and Oversight Five Years After the Exxon Valdez Oil Spill, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science.

This paper discusses oil spill prevention measures undertaken in the wake of the Exxon Valdez oil spill. The purpose is to give you some update and insight into where we are, relative to where we were in March of 1989, regarding preventing a major oil spill such as we saw with the grounding of the Exxon Valdez. I think you will see that we are much better off now than we were prior to March 1989. Are we where we need to be? We all have our own opinion on this issue.

Stokesbury, K., R. Foy, et al. (1999). "Spatial and temporal variability in juvenile Pacific herring, Clupea pallasi, growth in Prince William Sound Alaska." ENVIRONMENTAL BIOLOGY OF FISHES **56**(4): 409-418.

We examined the spatial and temporal variability of juvenile Pacific herring, Clupea pallasi, growth within Prince William Sound, Alaska. Pacific herring, ranging from post-larval to mature fish, were collected from four spatially segregated bays between October 1995 and March 1998. Linear growth equations from each bay were similar. However, growth rates and wet weight-at-length, reflecting condition, of juvenile Pacific herring cohorts varied seasonally and annually. The short term spatial variability in juvenile Pacific herring growth suggested that each bay was a unique nursery area. The physical and biological

conditions within each bay appeared to dictate Pacific herring growth rate.

Stokesbury, K., K. J, et al. (2000). "Spatial distributions of Pacific herring, Clupea pallasi, and walleye pollock, Theragra chalcogramma, in Prince William Sound, Alaska." FISHERY BULLETIN **98**(2): 400-409.

Nursery areas of Pacific herring, Clupea pallasi, and walleye pollock, Theragra chalcogramma, were identified by using acoustic surveys in October 1995, and in March and July 1996 in Prince William Sound, Alaska. Pacific herring and walleye pollock were aggregated in the east-northeast and west-southwest areas. Juvenile Pacific herring spent the first two years of their lives isolated within bays. Water temperatures within bays were cooler in the summer and warmer in the winter compared with temperatures measured along coastal passages and the open coast. Although these temperature differences were small and based on point observations their accumulative effect over the season may be considerable. The school structure of juvenile Pacific herring varied seasonally. Newly recruited age-0 Pacific herring were tightly aggregated, forming a few, dense schools within a single-size cohort, in shallow water at the heads of bays in July. Age-0 Pacific herring were still aggregated within bays in shallow water in October, but the school structure was less cohesive and size cohorts began to mix. School structure and distribution completely changed in March as age-0 Pacific herring moved away from the shores into deeper water and spread out forming sparse shoals of mixed-size cohorts. Juvenile Pacific herring joined the adult schools after their second winter, leaving as new recruits entered the bays. Juvenile walleye pollock also aggregated within bays and were spatially segregated from adults. However, there appeared to be little overlap between Pacific herring and walleye pollock juveniles because they occupied different portions of the water column within these bays.

Stokesbury, K., G. Thomas, et al. (1997). Spatial distribution of Pacific herring, Clupea pallasi, in Prince William Sound, Alaska. Arctic Science and Resource Management: Exploring the Issues; 48th American Association for the Advancement of Science: Arctic Division Science Conference, Valdez, Alaska, USA, September 24-27, 1997, Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, Alaska, USA.

Stone, R. and S. Johnson (1998). "Prolonged exposure to mine tailings and survival and reproductive success of ovigerous tanner crabs, Chionoecetes bairdi." Bulletin of Environmental Contamination and Toxicology **61**(4): 548-556.

Recently, plans to reopen the Alaska-Juneau gold mine near Juneau, Alaska included submarine tailings disposal (STD) as an option for disposal of the finely crushed rock that remains after milling and mineral separation. Because information is scarce on the effects of STD on marine life, numerous studies were initiated to assess the potential biological consequences of STD (Johnson et al. 1998, US EPA 1996). In addition to smothering the sea floor, STD may introduce elevated metal concentrations to the benthic environment and pose a

toxicological hazard to marine life becase non-target metals would remain as part of the tailings. Tanner crabs (Chionoecetes bairdi), a commercially important resource in Alaska, are intimately assoicated with benthic sediment; females completely or partially bury their eggs in sediment while brooding eggs up to one year and may need to oviposit in a soft substratum to allow for complete cementation of the eggs to the setae. Sublethal effects of exposure to heavy metals on crustacena embryos include inhibition of egg sac development, prolonged larval development, inhibition of larval molting, and reduced growth. Tanner crabs may initially avoid areas affected by STD, but later recolonie the altered sea floor and incorporated harmful levels of contaminants into their tissues.

Stout, J. H. (1998). Spectacled eider (Somateria fischeri) contaminants survey report. Anchorage, AK, U.S. Department of the Interior
Fish and Wildlife Service
Ecological Services Anchorage Field Office
605 West 4th Avenue, Room G-62, Anchorage AK 99501: 19pp.

The contaminant studies outlined by the Spectacled Eider Recovery Plan included broad inquiries into the identification, concentrations, distribution, effects and sources of environmental contaminats affecting spectacled eider (Someateria fischeri) populations and their prey. This report summarizes the current state of contaminants knowledge in spectacled eiders, current/ongoing studies and future study objectives based on discussions with researchers and rseource managers.

The studies reviewed for this report fell into the three general categories of (a) petroleum-related hydrocarbons (b) organochlorine compounds and (c) elements. With petroleum-related compounds, eider embryos appear to be particularly susceptible to theri toxic effects, while adults appear more susceptible to their adverse thermoregulatory effects. The risk of exposure of spectacled eiders to petroleum-realted hydrocarbons is currently unknown, but may be low relative to other contaminants. Organochlorine compounds have been found in spectacled eiders at or near the lower limits of analytical detection (< 0.05 ppm) and well below the toxic thresholds found in other birds; thus, organochlorines appear to pose minimal risk to spectacled eiders. In contrast, however, select elements (cadmium, copper, lead, selenium and zinc) have been found in spectacled eiders at high concentrations relative to other species. Some of these elements are known or suspected to be toxic to waterfowl. Current and future eider contaminant studies should focus on elements, their distribution, sources, availability, and associated effects on waterfowl.

Stout, J. H. (1999). Baseline Hydrocarbon Sampling for the Valdez Duck Flats, Valdez, Alaska. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services: 18 pp.

Stout, J. H. and K. A. Trust (1997). Contaminant Residues in Bald Eagles (Heliaeetus

leucocephalus) from Adak Island, Alaska. Anchorage, AK, U.S. Fish and Wildlife Service, Anchorage Field Office, Ecological Services: 46 pp.

Strand, J., S. Senner, et al. (1993). Process to identify and evaluate restoration options. Proceedings of the 1993 International Oil Spill Conference: Prevention, Preparedness, Response, Washington, D.C., American Petroleum Institute Publication.

Stringer, W., K. Dean, et al. (1992). "Detection of petroleum spilled from the MV Exxon Valdez." International Journal of Remote Sensing **13**(5): 799-824.

An analysis of remotely sensed imagery of the Exxon Valdex oil spill is described and the usefulness of the various wavelengths and platforms available (Landsat, AVHRR, SPOT) is discussed. The spill was sufficiently large that the main body could be detected by the low resolution (1 km) AV RR system. However the higher resolution of Landsat TM and SPOT (30 m and 10 m) was required to identify individual features such as windrows, etc. The utility and uniqueness of a multispectral TM signature developed to identify spilled oil is discussed in detail with reference to direct terrestrial meaurements of oil reflectance and the possibility of other sources of the signature such as ocean vegetation and direct reflectance from some beach materials. Other directly observable ocean parameters such as sea surface temperature and suspended sediment were noted and incorporated into the analysis of terms of ocean circulation and the creation of weathered spill products such as 'tar balls'. The 'mid-infrared' (TM band 5) provided the strongest component of the oil signature. However, the spill was observable in other wavelengths as well, including the thermal infrared where at various times and locations it appeared either warmer or cooler than the surrounding waters. These observations are discussed in terms of oil emissivity and reflected solar radiation.

Stubblefield, W., G. Hancock, et al. (1995). Evaluation of the toxic properties of naturally weathered Exxon Valdez crude oil to surrogate wildlife species. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill. P. Wells, J. Butler and J. Hughes. Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA. **1219:** 665-692.

The toxic properties of naturally weathered Exxon Valdez crude oil (WEVC) to avian and mammalian wildlife species were evaluated using the surrogate species, mallard duck, Anas platyrhynchos, and European ferret, Mustela putorius. This study was conducted to evaluate the potential for toxic (rather than physical) injury to wildlife species that may have been exposed to WEVC, either through external contact or through dietary uptake. Previous studies have assessed the toxicity of unweathered crude oils, including Alaskan North Slope Crude, but little information exists regarding the toxicity of a naturally weathered crude oil, typical of that encountered following a spill. A battery of laboratory toxicity tests was conducted, in compliance with standard and published test procedures, to evaluate acute and subchronic toxicity of WEVC. These included

tests of food avoidance, reproductive effects, and direct eggshell application toxicity. Naturally weathered EVC, recovered postspill from Prince William Sound, was used as the test material. No treatment-related mortalities or gross signs of toxicity were noted in ducks at oral doses of 5 000 mg/kg body weight or at dietary concentrations up to 100 000 ppm (mg WEVC/kg diet), or in ferrets at oral doses up to 5 000 mg/kg body weight. Test animals did not avoid oil-contaminated food. No significant adverse effects were noted in birds fed diets containing up to 2 000 mg WEVC/kg diet in the reproductive toxicity test. However, significant reductions in mean eggshell thickness and strength were observed in birds fed 20 000 mg WEVC/kg diets. Applications of up to 92 mg/egg of WEVC to developing eggs produced no toxic effects. Feeding weathered EVC to ducks and ferrets at oral doses or dietary concentrations exceeding those representing maximum likely field exposures from heavily affected spill areas did not significantly affect survival, growth, or reproduction. These results suggest that naturally weathered EVC posed little toxic risk to wildlife consuming oil or oiled food items following the Exxon Valdez spill, particularly considering the environmental exposure conditions that existed in the spill-affected area after 1989.

Sturdevant, M. (1999). Forage Fish Diet Overlap, 1994-1996. APEX Project: Alaska Predator Ecosystem Experiment in Prince William Sound and the Gulf of Alaska. Exxon Valdez Oil Spill Restoration Project Final Report (Restoration Project 98163C), Auke Bay Laboratory, National Marine Fisheries Service, Juneau, Alaska.

Sturdevant, M. (2000 In press). "Summer zooplankton density and composition estimates from 20-m vertical hauls using three net meshes." Alaska Fish. Res. Bull.

Sturdevant, M., A. Brase, et al. (2000). "Feeding, prey fields and potential competition of young-of-the-year walleye pollock (Theragra chalcogramma) and Pacific herring (Clupea pallasi) in Prince William Sound, Alaska, 1994-95." Fish. Bull.

Sturdevant, M., A. Celewycz, et al. (1991). Distribution, size, and feeding habits of juvenile pink salmon in nearshore habitats of northwestern Prince William Sound. Proceedings of the 15th Northeast Pacific Pink and Chum Salmon Workshop, Parksville, British Columbia, November, 1991, Pacific Salmon Commission, Vancouver, British Columbia.

Sturdevant, M. and L. Hulbert (2000). "Diet overlap, prey fields, prey selection, and potential food competition among allopatric and sympatric forage fish species in Prince William Sound: juvenile Pacific herring, Pacific sandlance and pink salmon." Mar. Ecol. Prog. Ser.

Sturdevant, M., A. Wertheimer, et al. (1994). Diet of juvenile pink and chum salmon in

oiled and non-oiled nearshore habitats in Prince William Sound 1989 and 1990. 16th Northeast Pacific Pink and Chum Salmon Workshop, Juneau, Alaska, USA, February 24-26, 1993, University of Alaska, Fairbanks, Alaska, USA.

The diets of juvenile pink salmon *Oncorhynchusgorbuscha* and chum salmon *keta* were studied in nearshore habitats in oiled and non-oiled areas of Prince William Sound after the March *1989 Exxon Valdez oil spill.* Food consumption by pink and chum salmon did not decrease in the presence of oil. Stomach fullness and food quantity were similar in oiled and non-oiled areas in both *1989* and *1990. Oil* globules or sheen were observed, however, in the stomachs of pink and chum salmon from oiled sites in *1989.* Because no oil was observed in fish stomachs from non-oiled sites in *1989* or from any site in *1990,* these observations suggest that ingested oil could be a route of hydrocarbon contamination. Zooplankton averaged *69%* of pink and *56% of* chum salmon diet biomass in the 2 years. Small and large calanoid copepods were the primary zooplankters consumed by pink and chum salmon, respectively. Diets in oiled and non-oiled areas changed from *1989* to *1990.* Pink salmon fed more on zooplankton in oiled areas than in non-oiled areas in *1989.* Both pink and chum salmon fed less on zooplankton in oiled areas than in non-oiled areas in *1990.* Conversely, both species ate epibenthic prey less in oiled areas in *1989,* and more in oiled areas in *1990.* These interannual. changes in diet between oiled and non-oiled areas could have been caused by differences in distribution of fish, by interannual variation in prey availability, or by effects of oil.

Sugai, S., I. Lindstrom, et al. (1997). "Environmental influences on the microbial degradation of Exxon Valdez oil on the shorelines of Prince William Sound, Alaska." Environmental Science and Technology **31**(5): 1564-1572.

Biodegradation was a major mechanism for removing oil resulting from the Exxon Valdez oil spill in Prince William Sound, Alaska. For three field seasons, we examined the hexadecane, phenanthrene, and naphthalene mineralization potentials of hydrocarbon-degrading microorganisms and the accompanying hydrocarbon concentrations from intertidal and shallow subtidal sediments. We found that mineralization potentials were not directly dependent on sediment substrate concentrations, but environmental factors influenced the ability of microbial populations to mineralize polycyclic aromatic and aliphatic compounds. These factors included the intensity of physical mixing experienced, the treatments received, and the availability of alternative carbon sources. In 1989, when the Exxon Valdez oil was relatively unweathered and before shoreline treatment was begun, the mineralization potentials of aromatic hydrocarbons were high at many sites even in the presence of alkanes at higher concentrations. However, by 1990, mineralization potentials for alkanes were greater than those for aromatics at oiled sites exposed to terrestrial biowaxes or fatty acids from the bioremediation process. Therefore, our study shows that sediment chemistry data alone cannot predict the persistence of hydrocarbons following the Exxon Valdez oil spill and demonstrates the need for systematic ecosystem-level studies of the abiotic and biotic factors influencing biodegradation.

Sundberg, K., L. Deysher, et al. (1996). Intertidal and Supratidal Site Selection Using a Geographical Information System. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society: Bethesda, Maryland, USA. **18:** 167-176.

A geographical information system (GIS) was employed in the selection of sampling sites for the intertidal and supratidal injury assessment of the *Exxon Valdez oil* spill. The use of GIS was suggested by (1) the large amounts of shoreline (potentially 2,003 kilometers) contaminated by this oil spill, (2) the extreme heterogeneity of shoreline types and degrees of oiling in the *Exxon Valdez oil spill* area, (3) the need to embody the various shoreline habitats and degrees of oiling in the assessment, and (4) the need to make statistical inferences regarding intertidal and supratidal injury to the universe of all oiled shorelines in this oil spill area. The shoreline affected by the *Exxon Valdez oil* spill was stratified into 15 classes based on habitat type and degree of oiling. Potential sampling sites were randomly drawn from the database with probability proportional to size. Field surveys conducted in 1989 to verify shoreline classifications, verify degree of oiling, and locate and mark shoreline segments for subsampling found many misclassified sites. Moderately to heavily oiled sites selected in the stratified random sample were retained and subjectively paired with reference (non-oiled or very lightly oiled) sites. The final quasi-experimental study design for intertidal and supratidal injury assessment consisted of 50 oiled sites paired with 47 reference sites. Randomly selected oiled sites maintained their probability-based selection status for inferences to the entire *Exxon Valdez oil spill* area. Recommendations are made concerning the future use of GIS for intertidal and supratidal injury assessments.

Swan, M. (1991). "Ground water quality at Kenai Peninsula, Alaska. ." GeoTimes **36** (12): 18-20.

An unusual coalition of industries, private citizens, environmentalists, and government agencies is studying ground water on the Kenai Peninsula in south-central Alaska. In February 1990, public concern about groundwater contamination associated with more than 30 years of oil-development activities, led to forming the Kenai Peninsula Ground-Water Task Force. The task force consists of representatives of seven government agencies, six companies, two environmental groups, and six local citizens. The six companies are all associated with petrochemicals, refining, and oil production, and are members of the Alaska Oil and Gas Association. The U.S. Geological Survey, Alaska Department of Natural Resources, Alaska Oil and Gas Association, Kenai Peninsula Borough, and Kenai Soil and Water Conservation District have funded the 1990-91 studies.

Tabak, H., S. Desai, et al. (1990). Biodegradation of the Alaskan USA weathered crude oil constituents. 90th Annual Meeting of the American Society for Microbiology 1990, Anaheim, California, USA, May 13-17, 1990, American Society for Microbiology.

Tabak, H., J. Haines, et al. (1991). Enhancement of Biodegradation of Alaskan

Weathered Crude Oil Components by Indigenous Microbiota with the Use of Fertilizers and Nutrients. International Oil Spill Conference, San Diego, California, March 4-7, 1991.

Bench-scale biodegradability studies of the Alaskan weathered crude oil were undertaken as part of the bioremediation project for the shorelines of Prince William Sound, Alaska, contaminated by the Exxon Valdez oil spill. The purpose of the studies was to evaluate the capability of the indigenous microbial consortium of the sea water and island beach areas, to biodegrade the weathered crude oil's alkane hydrocarbon and polynuclear aromatic (PAH) constituents in batch-type respirometric reactors and shaker flask systems. See also PB93-236545 and PB90-264011. Prepared in cooperation with Cincinnati Univ., OH. Dept. of Chemical and Nuclear Engineering.

Taft, D., D. Egging, et al. (1995). Sheen surveillance: An environmental monitoring program subsequent to the 1989 Exxon Valdez shoreline cleanup. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

In the fall of 1989, an aerial surveillance program was implemented to locate oil sheens (or slicks) originating from shorelines affected by the Exxon Valdez spill. The objectives of the program were to identify any oil on the water that warranted response and to identify those sections of shoreline that would be priority candidates for further cleanup in 1990. The program initially surveyed the entire affected area, but, because proportionally fewer sheens were spotted in the Gulf of Alaska, the program was refocused on Prince William Sound in early 1990. The surveillance program consisted of frequent low-altitude flights with trained observers in a deHavilland Twin Otter outfitted with observation ports and communication equipment. The primary surveillance technique used was direct visual observation. Other techniques, including photography, were tested but proved less effective. The flights targeted all shorelines of concern, particularly those near fishing, subsistence, and recreational areas. The observers attempted to locate all sheens, estimate their size and color, and identify the source of the oil found in the sheen. Size and color were used to estimate the volume of oil in each sheen. Samples were collected whenever possible during the summer of 1990 using a floating Teflon super(TM) sampling device that was developed for easy deployment from a boat or the pontoon of a float plane. Forty four samples were analyzed by UV-fluorescence spectroscopy. Eleven of these samples were also analyzed by GC/MS. In general, the analyses confirmed the observers' judgement of source. The flights from late September 1989 through early September 1990 identified 827 petroleum hydrocarbon sheens. About two-thirds of the sheens were related to the Exxon Valdez or were of indeterminate source. For the purposes of analyses these were combined and treated as if their origins were all from the Exxon Valdez. The numbers and volumes of these sheens decreased dramatically with time after the onset of winter storms. The Exxon Valdez related sheens sighted during the spring and summer of 1990 contained volumes averaging less than two litres of oil each. By the summer of

1990, the number and size of Exxon Valdez sheens were smaller than those associated with normal vessel activity in Prince William Sound. There was no disruption of commercial fishing activities because of Exxon Valdez related sheens in 1990. The program was discontinued in September 1990 because the number and volume of spill-related sheens had declined to low levels.

Tanabe, S., K. P., et al. (1996). "Enantiomeric ratios of a-hexachlorocyclohexane in blubber of small cetaceans." Mar Poll Bull **32**(1): 27-31.

The enantomeric ratio of alpha-hexachlorocyclohexane (a-HCH) in blubber of 10 species of adult male small cetatcens has been determined by means of capillary gas chromatography using beta-cyclodextrin as a chiral stationary phase. The enantiomeric ratios of (+)-a-HCH to (-)-a-HCH ranged from 1.6 to 2.8, showing diverse values. Moreover, even in the same species, the ratios varied between animals collected from different localities. Dall's porpoise (Phocoenoides dalli) collected from the Bering Sea had enantiomeric ratios of 2.0-2.1 and others, from the North Pacific and Japan Sea, exhibited ratios of 1.6-1.9. The ratios of beta-HCH (b-HCH) concentration to total HCH concentration (b-HCH/Sum HCH) was linearly related to the enantiomeric ratios of a-HCH ($r = -0.46$, $p<0.005$). This may indicate that the metabolic capacity to degrade HCH isomers among cetaceans can be evaluated in terms of degradation of the (+)-a-HCH enantiomer. Present enantiomeric ratios were compared with earlier observationon various environmental samples and unbablanced degradation of (+)- and (-)-a-HCH enantiomers was suggested in small cetaceans.

Taylor, S. (1992). The 0.45- to 1.1-micrometers Spectra of Prudhoe Crude Oil and of Beach Materials in Prince William Sound, Alaska. Govt Reports Announcements & Index (GRA&I), U.S. Army Cold Regions Research and Engineering Lab, Hanover, NH: 19p.

The spectral response in the visible and near-infrared (wavelengths of 0.45 to 1. 10 micon) of different amounts of Prudhoe crude oil on water was measured. Spectral reflectance measurements were made of selected beaches and beach materials in Prince William Sound to provide ground truth data for the MEIS 11 imagery collected during the Exxon Valdez spill. A spectral mixing model was used to predict how different amounts of oil would change the spectra of beach materials in Prince William Sound. Beaches Pollution Detectability Spectral reflectance Oil Visible, near IR wavelengths. Special rept.

Teas, H. I., H. Cumberland, et al. (1993). "Responses of eelgrass Zostera marina to weathered crude oil in Prince William Sound Alaska." American Zoologist **33**(5): 111A.

Templin, W. (1995). Reconstruction of wild pink salmon (Oncorhynchus gorbuscha) runs in Prince William Sound, Alaska. Fairbanks, AK, University of Alaska.

Thesis

Templin, W., J. Collie, et al. (1993). Run reconstruction of the wild pink salmon fishery in Prince William Sound, 1990-1991. Exxon Valdez Oil Spill Symp., Anchorage, AK (USA), 2-5 Feb 1993, Anchorage, AK (USA), American Fisheries Society.

We reconstruct the abundances of the 1990 and 1991 runs of pink salmon Oncorhynchus gorbuscha in Prince William Sound for use in damage assessment. The basic problem is to allocate the catch in mixed-stock fisheries to the component stocks. With no information to directly identify stocks, the run reconstruction uses available information on migration and the timing of escapement and harvest. A migration model moves the salmon backward in time from the spawning streams, through the districts in Prince William Sound to the Gulf of Alaska, adding the catch as the salmon pass through each fishery encountered. Two major assumptions in the model are (1) migration is governed by a transition matrix that is constant over time and (2) stocks are equally vulnerable to exploitation in a district. The run reconstruction suggests that the pink salmon stocks experienced different harvest rates and that the exploitation pattern differed in 1990 and 1991. The Coghill stock had high estimated harvest rates because it migrates through several districts where it encounters intense harvest pressure. The Montague and Southeastern stocks had low estimated harvest rates because very little fishing occurred in these districts, and they do not migrate through any other districts. Testing the sensitivity of the results to assumptions about migratory rates and timing revealed that errors in these assumptions have little effect on final estimates. The migration pathways are the largest source of uncertainty in the run reconstruction results. Because harvest rates differ among stocks, it is important to consider the total run of a stock, and not just its escapement, when assessing oil spill damage. However, uncertainty in the reconstructed run sizes may exceed the magnitude of the estimated damages.

Templin, W., T. I. Quinn, et al. (1993). 16th Northeast Pacific Pink and Chum Salmon Workshop, Juneau, AK (USA), 24-26 Feb 1993. 16th Northeast Pacific Pink and Chum Salmon Workshop, Juneau, AK (USA), 24-26 Feb 1993.

The manager of a salmon fishery must balance present economic opportunity against future wild salmon production. The ratio of harvested fish to the total run is referred to as the harvest rate. The number of salmon required for spawning depends on the population's productivity; target harvest rates for wild salmon are typically below 50%. Given the manager's vicarious control of fishing effort, the target harvest proportion is difficult to achieve even with a single population of salmon. Mixed-stock fisheries are even more difficult to manage, because of the inability to attain the target harvest rate for each stock. One may have to balance the underharvesting of productive stocks with possible overharvesting of less productive stocks. The situation is simplified if the stocks may be temporally or spatially separated or if they are similarly productive. The realized seasonal stock-specific harvest rate depends on interacting patterns of fishing effort and salmon abundance. The Prince William Sound pink salmon (Oncorhynchus gorbuscha) fishery has harvested roughly 22 million fish per year since 1979. The hatchery fish to wild fish composition of the catch is roughly 4:1, making the

hatcheries the major contributors to the catch. Because hatcheries require fewer spawners to produce a return of mature fish, these stocks can sustain harvest rates above 90%. Domination of the fishery by hatchery produced pink salmon makes it more difficult to conserve the wild stock.

Testa, J., D. Holleman, et al. (1994). "Estimating populations of marine river otters in Prince William Sound, Alaska using radiotracer implants." Journal of Mammalogy **75**(4): 1021-1032.

Thomas, R., M. Carls, et al. (1997). "Mixed function oxidase induction in pre- and post-spawn herring (Clupea pallasi) by petroleum hydrocarbons." Comparative Biochemistry and Physiology **116C**(2): 141-147.

We compared the uptake of water-accommodated fractions of Alaska North Slope crude oil in pre- and post-spawn herring (Clupea pallasi) and the resulting induction of mixed function oxygenase activity. Both groups of herring accumulated significant quantities of polycyclic aromatic hydrocarbons in muscle tissue. Pre-spawn herring accumulated higher concentrations of hydrocarbons and retained them longer. Induction of mixed function oxygenase activity in pre-spawn fish was one-third to one-half that in post-spawn fish. Inability of pre-spawn herring to induce mixed function oxygenases at as high a level as post-spawn fish may explain higher tissue concentrations and retention of hydrocarbons in the pre-spawn animals.

Thomas, R., P. Harris, et al. (1999). "Survival in air of Mytilus trossulus following long-term exposure to spilled Exxon Valdez crude oil in Prince William Sound." Comparative Biochemistry and Physiology **122C**(1): 147- 52.

Mussels, Mytilus trossulus, were sampled in 1996 from beaches in Prince William Sound (PWS) which contained residual oil resulting from the Exxon Valdez oil spill of March 1989, and from one beach which had been lightly oiled in 1989, but contained no residual oil in 1996. The latter mussels served as un-oiled references. Mussels were also collected from Tee Harbor, Southeast Alaska, to be used as an additional reference group. Where the size of the individuals in the resident population would permit, two size groups were sampled, 32-35 and 18-20 mm in length. Polynuclear aromatic hydrocarbon (PAH) concentrations in mussel tissue, and air survival time were determined for each group of mussels. Total PAH concentrations were significantly greater in tissue of mussels from oiled beds (0.6-2.0 micrograms g^{-1}) than from references (0.01-0.12 microgram g^{-1}) ($P < 0.01$). Oil-exposed mussels had significantly lower LT^{50} values ($P < 0.05$) for air survival than reference groups. Tolerance of small mussels to air exposure was significantly greater ($P < 0.01$) than large mussels in both the unoiled reference and oil exposed groups.

Thomas, R., E. Patrick, et al. (1997). Development of an ecosystem model for managing the fisheries resources of Prince William Sound. Developing and Sustaining

World Fisheries Resources - The State of Science and Management. Second World Fisheries Congress. D. Hancock, D. Smith, A. Grant and J. Beumer. Collingwood, VIC, Australia, CSIRO: 606-613.

Thomas, R., S. Rice, et al. (1988). "Differences in hydrocarbon uptake and mixed function oxidase activity between juvenile and spawning adult coho salmon exposed to Cook Inlet, Alaska, USA, crude oil." American Zoology **28**(4): 104A.

Coho salmon smolts accumulated up to 30 times more hydrocarbon in selected tissues than did coho salmon jacks when exposed to water-soluble fraction of Cook Inlet crude oil. Aryl hydrocarbon hydroxylase (AHH) activity continued to increase during 12 days of exposure in coho smolts, in contrast to jacks in which AHH activity peaked at 2 days and remained elevated during 20 days of exposure. Cytochrome P-450 concentrations peaked in 48 hr and returned to control levels in exposed smolts. In exposed and control jacks, cytochrome P-450 decreased during the 20 day experimental period. Concentrations of P-450 were significantly greater, however, in exposed jacks than in control jacks. Aryl hydrocarbon hydroxylase (AHH) activity and cytochrome P-450 concentrations were greater in non-exposed coho smolts and jacks than in non-exposed pre-spawning adults.

Thomas, R. E., C. Brodersen, et al. (1999). "Lack of physiological responses to hydrocarbon accumulation by Mytilus trossulus after 3-4 year chronic exposure to spilled Exxon Valdez crude oil in Prince William Sound." Comparative Biochemistry and Physiology **122C**(1): 153- 63.

Mussels, Mytilus trossulus, were sampled in 1992 and 1993 from beaches in Prince William Sound that had been oiled by the Exxon Valdez spill of March, 1989. At some of the oiled beaches, mussels were collected from beds overlying oiled sediments, and from bedrock adjacent to these beds. Mussels were also collected from beaches within the Sound that had not been impacted by the spill. Polynuclear aromatic hydrocarbon (PAH) concentrations in mussel tissue, physiological responses (byssal thread production, condition index, clearance rate, and glycogen content), were determined for each group of mussels. Total PAH concentrations in mussel tissue ranged from 0 to 6 micrograms g-1, and were significantly greater in mussels from oiled beds than those from reference beds. No significant differences were noted in byssal thread production, condition index, clearance rate, or glycogen content between oiled sample sites and reference sites. The lack of physiological response was surprising because mussels in this study were chronically exposed to PAH for 3-4 years, and none of the physiological responses measured appeared to be affected by that exposure. The lack of a physiological response suggests that chronically exposed mussels may develop a physiological tolerance to PAH, but we recognize that these measures may not have been sensitive enough to discriminate response from background noise.

Thorsteinson, L., T. Rowles, et al. (1997). The Alaska Marine Mammal Tissue Archival

Project, AMMTAP: An Arctic environmental monitoring resource. Arctic Science and Resource Management: Exploring the Issues; 48th American Association for the Advancement of Science: Arctic Division Science Conference, Valdez, Alaska, USA, September 24-27, 1997, Alaska Sea Grant College Program, University of Alaska Fairbanks, Fairbanks, Alaska, USA.

Travis, M. (1990). Bioremediation of petroleum spills in Arctic and subarctic environments: A feasibility study. Updated report., U.S. Army Cold Regions Research and Engineering Lab: 28.

Bioremediation is the process of enhancing indigenous microbes in soil and groundwater to metabolize organic contaminates into harmless by-products. Oil-degrading microorganisms are widely distributed in Alaska's soils. Researchers have biodegraded Prudhoe Bay crude oil in test plots from Barrow to Palmer, Alaska, USA. Bioremediation methods increase soil oxygen and nutrient levels by aeration and fertilization. Soil microbes respond by increasing their activity and population. The larger and more active microbial population utilizes the crude oil as a carbon source and accelerate the degradation of the oil. Polyethylene coverings significantly raise summer soil temperatures. However, special attention must be given to oxygen transport. Hydrogen peroxide injected into soil and groundwater at 100 ppm significantly elevates oxygen levels without detrimental effects to microbes. Fertilizers that utilize inorganic sources of nitrogen and contain N:P:K ratios of 10:1:1 stimulate microbial growth.

Trust, K., D. Esler, et al. (2000 In press). "Cytochrome P450 1A Induction in Sea Ducks Inhabiting Nearshore Areas of Prince William Sound, Alaska." Marine Pollution Bulletin **40**(5): 397-403.

Trust, K. A., J. F. Cochrane, et al. (1997). Environmental Contaminants in three eider species from Alaska and Arctic Russia, US Fish and Wildlife Service, Ecologocial Services, Anchorage Field Office.

This study provides baseline data on contaminant concentrations in three eider species from coastal areas of western and northern Alaska and arctic Russia. Substantial declines in Alaskan-breeding populations of the spectacled (Somateria fisheri) and Steller's eiders (Polysticta stelleri), have gone largely unexplained and have raised concerns about contaminant exposures on breeding grounds and in the Bering Sea and Arctic Ocean. Of the 78 eider carcasses we acquired, 51 were common eiders (Somateria mollissima), 18 were spectacled eiders and 7 were Steller's eiders.

Given that many arctic and subarctic marine organisms have been found with notable concentrations of organochlorines in their tissues, we were surprised to find minimal concentrations in these eiders from Alaska and arctic russia. As for the elemental residues, aluminum, barium, beryllium, boron, iron, magnesium, manganese, molybdenum, nickel, strontium, vanadium and zinc residues were found at levels that were biologically essential or were far below concentrations

believed to cause harmful effects in birds and thus are not discussed. The remaining analytes (arsenic, cadmium, chromium, copper, lead, mercury, and selenium) are discussed either because they are known to be toxic at relatively low concentrations or because they were found at concentrations warranting further review.

The data suggest that cadmium was elevated in some spectacled eiders, copper was elevated in common and spectacled eiders, lead was elevated in a few eiders believed to have ingested lead shot and selenium was highly elevated in spectacled eiders. It is not clear, however, why concentrations were elevated in these birds or how widespread the contamination in the population is in their populations. Furthermore, we do not know whether these elevated concentrations represent an increase in risk to eider populations. Results from this report, however, will help to focus future studies involving contaminants and routes of exposure.

Trust, K. A., K. Rummel, et al. (2000). "Contaminant exposure and biomarker responses in Spectacled eiders (Somateria fischeri) from St. Lawrence Island." Archives of Environmental Contamination and Toxicology **38**: 107-113.

Effects of chemical contaminant exposure may be contributing to the decline of spectacled eiders (Somateria fischeri) nesting in coastal areas of western Alaska. We evaluated chemical exposure and potential effects in 20 male eiders collected near St. Lawrence Island, Alaska. Analytes included metals, trace elements, chlorinated organics, and super(137)Cesium (137Cs). Effects of contaminant exposure were evaluated using histopathology adn biochemical measures of porphyrin profiles, cytochrome P450 activities, and metallothionein (MT) concentrations. Copper, cadmium, and selenium concentrations were elevated in spectacled eiders when compared to literature values for other marine birds. Only a few samples had trace concentrations of chlorinated organic compounds. Muscle 137Cs levels were all below the average minimum quantifiable concentration of 0.079 Bq per gram. No histopathological lesions were associated with elevated contaminant concentrations in liver, kidney, or testes. Protoporphyrin was found in highest concentration in both the liver and kidneys, followed by coproporphyrin and ruoporphyrin, respectively. Hepatic uroporphyrin concentrations correlated significantly to hepatic arsenic concentrations. mean activities of hepatic EROD, MROD, BROD, and PROD wer consistent with other avian species. Comparisons of cadmium/MT ratios from this study to published literature ratios in seven marine avain species suggest that, although adult male spectacled eiders have elevated liver concentrations of certain MT-inducing metals, their MT concntrations are not as strongly induced as would be predicted based on literature values. Despite elevated metal concentrations, the apparent good health of the St. Lawrence birds suggests that should these contaminants be a factor in population declines, they likely act by decreasing fecundity or survival fo young rather than via direct health impacts on adult male spectacled eiders.

Tubb, M. (1991). "Response to Exxon's $1-billion spill settlement. ." Ocean Industry **26**

(3): 15.

A compilation of reactions to the Exxon Valdez oil spill settlement is presented. Comments are extracted from numerous news sources reviewed by Ocean Industry . Exxon still faces more litigation. Some 200-300 lawsuits have been filed as a result of the spill, including claims from environmental groups, Alaskan villagers and others.

Tumeo, M., J. Braddock, et al. (1994). "Effectiveness of a biosurfactant in removing weathered crude oil from subsurface beach material." Spill Science & Technology Bulletin **1**(1): 53-59.

The University of Alaska Fairbanks Environmental Technology Laboratory is conducting ongoing research into the effectiveness of a biosurfactant, PES-51 registered , in removing weathered crude oil from beach material. A field test was conducted from 1 to 7 July 1993 in Sleepy Bay on La Touche Island in Prince William Sound. The results of chemical analysis of the beach material before and after treatment show that diesel range petroleum hydrocarbons are completely removed to levels below the detection limit of 0.5 mg/kg. Semivolatile petroleum hydrocarbons were reduced an average of 70%. The microbial data collected indicate that no inhibition of microbial activity in sediments is caused by treatment. The numbers and activity of hydrocarbon-degrading organisms were enhanced immediately following treatment and for about a month afterwards. There was no evidence of dissolved hydrocarbons or increased microbiological activity in seawater samples, providing evidence that oil was not transported offshore during the treatment process.

Udevitz, M. and B. Ballachey (1998). "Estimating survival rates with age-structure data." Journal of Wildlife Management **62**: 779-792.

Udevitz, M., B. Ballachey, et al. (1996). Population Model for Sea Otters in Western Prince William Sound. Restoration Project 93043-3. Sea Otter Demographics. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), National Biological Service, Anchorage, AK. Alaska Science Center.: 39p.

A large portion of the western Prince William Sound (PWS) sea otter population was killed by the Exxon Valdez oil spill in March 1989, but little is known about the dynamics of the population before the spill in March 1989, or the rate at which the population can be expected to recover. We estimated age-specific reproductive and survival rates for the western PWS population before the spill based on examinations or reproductive tracts and the age structure of carcasses collected in 1989. We developed a new technique for estimating survival rates that uses age-structure and age-at-death data, and does not require the assumption of a stable age structure. Because of the lack of data for estimating juvenile survival rates, were considered a series of 4 potential scenarios. The population was projected to decrease slightly during the first year under all of the scenarios and then begin increasing, achieving maximum rates of increase

ranging from 10% to 14% per year and recovering to its estimated 1985 population size in 10 to 23 years. Projected population sizes during the first few years after the spill are in broad agreement with estimates based on boat surveys in 1990, 1991, and 1993.

Udevitz, M., J. Bodkin, et al. (1995). "Sea otter detectability in boat-based surveys of Prince William Sound, Alaska." Marine Mammal Science **11**(1): 59-71.

Udevitz, M., J. Bodkin, et al. (1995). "Detection of sea otters in boat-based surveys of Prince William Sound, Alaska." Marine Mammal Science **11**(1): 59-71.

Boat-based surveys have been commonly used to monitor sea otter (Enhydra lutris) populations, but there has been little quantitative work to evaluate detection biases that may affect these surveys. We used ground-based observers to investigate sea otter detection probabilities in a boat-based survey of Prince William Sound, Alaska. We estimated that 30% of the otters present on surveyed transects were not detected by boat crews. Approximately half (53%) of the undetected otters were missed because the otters left the transects, apparently in response to the approaching boat. Unbiased estimates of detection probabilities will be required for obtaining unbiased population estimates from boat-based surveys of sea otters. Therefore, boat-based surveys should include methods to estimate sea otter detection probabilities under the conditions specific to each survey. Unbiased estimation of detection probabilities with ground-based observers requires either that the ground crews detect all of the otters in observed subunits, or that there are no errors in determining which crews saw each detected otter. Ground-based observer methods may be appropriate in areas where nearly all of the sea otter habitat is potentially visible from ground-based vantage points.

Ulvestad, D. (1995). Prince William Sound Community College and fishing vessel oil spill response training. Prevention, Response and Oversight Five Years after the Exxon Valdez Oil Spill. Proceedings of an International Conference, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant Coll. Program Rep. Alaska Univ. Inst. Mar. Sci.

During the Exxon Valdez oil spill cleanup, it became obvious that fishing vessels were a valuable asset. They have become an integral part of Alaska's oil spill response capability. The Prince William Sound Response Plan and the Nearshore Response Plan both require a trained group of oil spill technicians to operate a fleet of small boats. Fishing vessels are in an ideal position to fulfill this function. Fishing vessels are already located in Prince William Sound and can be quickly and easily converted into oil spill response vessels. Their captains and crews have the local knowledge and small boat operating skills necessary for maximum effectiveness. Prince William Sound Community College (PWSCC) is in the second year of a fishing vessel crew training program. The three major goals of this training are: (1) to teach vessel crews to safely operate the equipment they will employ to contain and cleanup a spill, (2) to provide general health and safety training, and (3) to give participants an insight into their

responsibilities during an oil spill response. The training is modular in nature. The first year provides basic instruction. Each subsequent year reviews the first year and presents new material. The classes are structured to include both classroom and on-the-water training utilizing the fishing vessels. This paper will describe the development of the training curriculum and the training program in its current form.

United States. Congress. House. Committee on Interior and Insular Affairs. Subcommittee on Water Power and Offshore Energy Resources. (1989). Investigation of the Exxon Valdez oil spill, Prince William Sound, Alaska : oversight hearings before the Subcommittee on Water, Power, and Offshore Energy Resources of the Committee on Interior and Insular Affairs, House of Representatives, One Hundred First Congress, first session. Washington, U.S. G.P.O. : For sale by the Supt. of Docs. Congressional Sales Office U.S. G.P.O.

United States. Congress. House. Committee on Merchant Marine and Fisheries. (1993). Prince William Sound after Exxon Valdez oil spill : hearing before the Committee on Merchant Marine and Fisheries, House of Representatives, One Hundred Third Congress, first session, on the ecological changes in Prince William Sound after the Exxon Valdez oil spill and the use of fines imposed, March 24, 1993. Washington, U.S. G.P.O. : For sale by the U.S. G.P.O. Supt. of Docs. Congressional Sales Office.

United States. Congress. House. Committee on Merchant Marine and Fisheries. Subcommittee on Coast Guard and Navigation. (1989). Exxon Valdez oil spill : hearing before the Subcommittee on Coast Guard and Navigation of the Committee on Merchant Marine and Fisheries, House of Representatives, One Hundred First Congress, first session, on topics concerning the Exxon Valdez oil spill into the Prince William Sound of Alaska, April 6, 1989. Washington, U.S. G.P.O. : For sale by the Supt. of Docs. Congressional Sales Office U.S. G.P.O.

Urho, L. (1991). Impact of an oil spill on herring stock. Lowell Wakefield Fisheries Symposium. Proceedings of the International Herring Symposium, Anchorage, Alaska, USA, October 23-25, 1990, Alaska Sea Grant College Program; Fairbanks, Alaska, USA.

Van Pelt, T., J. Piatt, et al. (1997). "Proximate composition and energy density of some North Pacific forage fishes." Comparative Biochemistry and Physiology **118A**(4): 1393-1398.

Mature pelagic forage fish species (capelin, sand lance, squid) had greater lipid concentrations than juvenile age-classes of large demersal and pelagic fish species (walleye pollock, Pacific cod, Atka mackerel, greenling, prowfish, rockfish, sablefish). Myctophids preyed on by puffins have at least twice as much lipid per gram compared to mature capelin, sand lance and squid, and an order

of magnitude greater lipid concentrations than juvenile forage fish. Energy density of forage fishes was positively correlated with lipid content, and negatively correlated with water, ash-free lean dry mass (mostly protein), and ash contents.

Van Pelt, T., J. Piatt, et al. (1999). "Vocalizations of the Kittlitz's Murrelet." Condor **101** (2): 395-398.

We present the first documentation of Kittlitz's Murrelet (Brachyramphus brevirostris) vocalizations, based on recordings made in Glacier Bay, Alaska, in 1994. We identified two apparently related types of calls: groan and quack. The Kittlitz's Murrelet calls were markedly different from the most common calls of the congeneric Marbled Murrelet (Brachyramphus marmoratus), but shared characteristics with the Marbled Murrelet's less common "groan" call. Phylogeny, breeding biology, and habitat characteristics may explain relationships between the congeneric vocalizations. More complete knowledge of the Kittlitz's Murrelet vocal repertoire is needed before vocalizations can be either used or discarded in the design of effective programs to monitor this rare and poorly-known species.

van Tamelen, P. and M. Stekoll (1995). Recovery mechanisms of the brown alga, Fucus gardneri, following catastrophic disturbance: lessons from the Exxon Valdez oil spill. Proceedings of the Third Glacier Bay Science Symposium, Anchorage, AK, National Park Service.

van Tamelen, P. and M. Stekoll (1996). Population response of the brown alga *Fucus gardneri* and other algae in Herring Bay, Prince William Sound, to the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 193-211.

Disturbance of populations of the brown alga *Fucus gardneri* and other intertidal algae by the Exxon Valdez oil spill and subsequent cleanup efforts was examined with an after-event, control-impact paired design study in Herring Bay, Prince William Sound. At oiled sites, both on rocky and coarse-textured shorelines, the larger size-classes of *Fucus* occurred in depressed numbers in 1990, but recovered to control levels by 1992. Populations in the upper intertidal zones recovered more slowly. In some areas a transient increase in ephemeral algae preceded *Fucus* repopulation. *Fucus* reproductive potential was significantly lower in plants from oiled areas in the upper intertidal zone. Reproductive capacity of the Herring Bay *Fucus* population had not recovered by the end of the field season in 1993. Populations in oiled areas that were cleaned with hot water and water under high pressure showed more damage and slower recovery.

van Tamelen, P. and M. Stekoll (1996). "The role of barnacles in recruitment and subsequent survival of the brown alga, Fucus gardneri (Silva)." Journal of Experimental

Marine Biology and Ecology **208**: 227-238 K.

Barnacles enhance recruitment of fucoid algae by reducing either herbivore pressure or desiccation stress, but no study has evaluated subsequent survival of algae recruiting onto barnacles. This study examined the substratum use patterns of small (<2 cm), medium (2-10 cm), and large (>10 cm) Fucus gardneri (Silva) plants in Prince William Sound, Alaska. Germlings were found growing on barnacles in either equal or greater proportions than the abundance of barnacles suggests. Plants large enough to be reproductive, however, were found almost exclusively in crevices or on smooth rock substrata. The effects of tidal level and wave exposure on the habitat use by Fucus were relatively minor compared to the effect of plant size. Fucus plants recruiting onto barnacles suffer higher mortality compared to those on rock. Marked young plants on barnacles had about 20% lower survival compared to similar sized plants growing on rock surfaces over one summer. In addition, the breaking strength of plants growing on rocks was about three times greater compared to plants growing on barnacles. Despite the initial positive effects of barnacles on fucoid recruitment, germlings growing on barnacles have a high probability of dislodgement before reaching reproductive age.

van Tamelen, P., M. Stekoll, et al. (1997). "Recovery processes of the brown alga Fucus gardneri following the 'Exxon Valdez' oil spill: Settlement and recruitment." Marine Ecology Progress Series **160**: 265-277.

The 1989 'Exxon Valdez' oil spill and subsequent cleanup efforts left many shorelines in Prince William Sound (Alaska, USA), especially in the higher tidal zones, mostly devoid of the dominant intertidal alga Fucus gardneri. Settlement and recruitment processes of F. gardneri were studied to determine the factors that can limit F. gardneri recolonization. Zygote settlement rates were initially lower at oiled sites relative to unoiled sites, but increased to values similar to those for unoiled sites in the lower intertidal zones after 3 yr. In the upper intertidal, settlement rates after 3 yr had not yet converged with those at unoiled sites. The low settlement rates of F. gardneri at oiled sites were probably due to low densities of reproductive plants and limited egg dispersal. Settlement was also negatively correlated to net flow of water. The effect of substrate rugosity on settlement was investigated by using grooved ceramic tiles. We found that grooves enhance survival and recruitment of germlings in the high intertidal zone. Germlings survived best initially in deep, narrow grooves. After 2 yr there were more recruits in medium width, deep grooves. Manipulation of F. gardneri canopy over tiles revealed that F. gardneri canopy ameliorated heat and desiccation stress, but a whiplash effect dislodged small plants. Overall the positive effects of canopy were stronger than the negative effects. There were no significant herbivore effects on germling survival, but both recruitment and average thallus size were increased in the absence of herbivores.

Varanasi, U., D. Brown, et al. (1993). Volume II: Supplemental Information Concerning a Survey of Alaskan Subsistence Fish, Marine Mammal, and Invertebrate Samples Collected 1989-91 for Exposure to Oil Spilled from the Exxon Valdez. NOAA Technical

Memorandum NMFS-NWFSC-13. Seattle, Washington, USA, National Marine Fisheries Service, Seattle, WA. Northwest Fisheries Science Center.: 184p.

The Exxon Valdez ran aground on Bligh Reef, Prince William Sound, Alaska on March 24, 1989, spilling millions of gallons of Prudhoe Bay crude oil (PBCO). During the weeks following the spill, large amounts of oil flowed towards southwestern Prince William Sound, and as a result, many shorelines were oiled. The spreading of spilled oil raised concerns of native Alaskans that their subsistence seafoods (fish, marine mammals, and invertebrate organisms) were contaminated by the spilled petroleum. In the study, edible flesh of fish, marine mammals, and shellfish from 22 native subsistence food collection areas and from two reference areas (Angoon and Yakutat) were analyzed for aromatic compounds (ACs). Technical memo. See also PB94-131935.

Varanasi, U., D. W. Brown, et al. (1993). Volume I: Survey of Alaskan Subsistence Fish, Marine Mammal, and Invertebrate Samples Collected 1989-91 for Exposure to Oil Spilled from the *Exxon Valdez*. Seattle, WA, USA, U. S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center
2725 Montlake Blvd. E.
Seattle, WA USA 98112: 110.

The Exxon Valdez ran aground on Bligh Reef, Prince William Sound, Alaska on March 24, 1989, spilling millions of gallons of Prudhoe Bay crude oil (PBCO). During the weeks following the spill, large amounts of oil flowed towards southwestern Prince William Sound, and as a result, many shorelines were oiled. In the study, edible flesh of fish, marine mammals, and shellfish from 22 native subsistence food collection areas and from two reference areas (Angoon and Yakutat) were analyzed for aromatic compounds (ACs). Vertebrates can readily biotransform ACs to metabolites that are concentrated in bile for excretion. This process greatly limits the accumulation of ACs in tissues such as edible flesh. Thus, for fish and marine mammals, bile was first analyzed for the presence of fluorescent aromatic compounds (FACs) as an indication of exposure to petroleum. Technical memo. See also PB91-152132.

Varanasi, U., S. Chan, et al. (1991). Survey of Subsistence Fish and Shellfish for Exposure to Oil Spilled from the Exxon Valdez. First Year, 1989. NOAA Technical Memorandum NMFS F/NWC-191, National Marine Fisheries Service, Seattle, WA. Northwest and Alaska Fisheries Center.: 159p.

More than 500 fish and shellfish samples collected from native Alaskan fishing grounds were analyzed for aromatic contaminants (ACs) from petroleum (alkylated and unsubstituted aromatic hydrocarbons with 2-7 benzenoid rings and dibenzothiophenes). Intertidal molluscs (mussels, clams, chitons, and snails) from Windy Bay, Kodiak (City), Chenega Bay, and Old Harbor consistently had more than 100 parts-per-billion (ppb) ACs, with levels in mussels from Windy Bay and Kodiak as high as 12,000 to 18,000 ppb. Levels of ACs in molluscs, crabs, and sea urchins from other villages were less than 10 ppb, a level

comparable to that measured in shellfish from the designated reference area in Southeast Alaska near Angoon. Nonparametric statistics on 147 samples of molluscs showed that levels of ACs in molluscs from Windy Bay, Kodiak, and Chenega Bay were significantly higher (p □ 0.05) than those in the Angoon molluscs sampled. In an unofficial advisory opinion, the Food and Drug Administration has indicated that little risk is involved in the consumption of the nonsmoked subsistence foods studied. Technical memo.

Varanasi, U., S. Chan, et al. (1991). National Benthic Surveillance Project: Pacific Coast. Part 2. Technical Presentation of the Results for Cycles 1 to 3 (1984-86). Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Seattle, WA. Northwest and Alaska Fisheries Center.: 215p.

The National Benthic Surveillance Project (NBSP) is designed to provide information on levels of chemical contaminants in surface sediments in coastal and estuarine areas, and the levels of these same contaminants (or their metabolites) in selected marine organisms. Information is also gathered on the prevalence of pollution-associated pathological conditions in representative bottomfish. The presence of selected chemical contaminants and certain pathological conditions in fish have become useful indicators of environmental degradation. Part II covers technical aspects of the Pacific Coast portion of the NBSP for the years 1984-86. Included are descriptions of sampling strategies and analytical methods, as well as a detailed presentation of the data. The Results and Discussion Section addresses the principal findings and compares them with those previously reported. Some information presented here may overlap with the Summary and Overview Section of Part I (Varanasi et al. 1988); however, the voluminous data produced in the study requires that information be presented in ways which allow for both a quick perusal in the Overview and a more detailed examination here. Technical memo. See also PB89-180632.

Varanasi, U., S. Chan, et al. (1989). National Benthic Surveillance Project: Pacific Coast, Part 1, Summary and Overview of the Results for Cycles 1 to 3 (1984-86). Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Seattle, WA. Northwest and Alaska Fisheries Center.: 74p.

The report summarizes and interprets the results of the first 3 years of the Pacific Coast phase of the National Benthic Surveillance Project (NBSP), a component of NOAA's National Status and Trends Program. A comprehensive database has been developed, which includes detailed information on the distribution of a variety of chemical contaminants. These contaminants include selected aromatic hydrocarbons, PCBs, organochlorine insecticides and metals in surficial sediments and in liver tissue, bile, and stomach contents of selected bottom-feeding fish. The overall finding from the NBSP for the years 1984-86 indicated that the highest concentrations of most sediment-associated contaminants were present in the highly urbanized areas, and that contaminants were bioavailable to indigenous marine species. Technical memo.

Varanasi, U., T. Collier, et al. (1996). Assessment of Oil Spill Impacts on Fishery

Resources: Measurement of Hydrocarbons and Their Metabolites, and Their Effects, in Important Species. NRDA Project Subtidal 7. EXXON VALDEZ Oil Spill State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Seattle, WA. Northwest Fisheries Science Center.: 314p.

Studies were conducted from 1989 to 1991 to assess injury to fisheries resources related to the Exxon Valdz oil spill. These studies were designed to determine exposure of fish to petroleum-derived compounds, specifically aromatic hydrocarbons, and assess possible effects. Over 4000 fish were collected from >50 sites in Prince William Sound, Lower Cook Inlet, and embayments along the Kenai and Alaska Peininsulas. Biliary fluorescent aromatic compounds (FACs) and hepatic aryl hydrocarbon hydroxylase (AHH) activities were measured, and used to determine degree of exposure of fish to aromatic compounds. The results showed continuing exposure through 1991 of several benthic fish species, which suggested persistent petroleum contamination of subtidal sediments. While major histopathological and reproductive effects were not documented, the potential impact on fishery resources of long-term exposure to petroleum, albeit at moderate to low levels, could not be determined from these studies.

Varanasi, U., J. Stein, et al. (1994). Chemical contaminants in gray whales (Eschichtius robustus) stranded in Alaska, Washington, and California, U.S.A. Govt Reports Announcements & Index (GRA&I), National Marine Fisheries Service, Seattle, WA. Northwest Fisheries Science Center.
Cascadia Research Collective, Olympia, WA.: 114p.

The concentrations of chlorinated hydrocarbons (CHs) such as polychlorinated biphenyls (PCBs), 1,1,1-trichloro-2,2-bis(p-chlorophenyl) ethanes (DDTs), 1,1-dichloro-2,2-bis(p- chlorophenyl) ethenes (DDEs), and chlordanes, and essential (e.g., zinc, selenium, copper) and toxic (e.g., mercury, lead) elements were measured in tissues and stomach contents from 22 gray whales (Eschrichtius robustus) stranded between 1988 and 1991. The stranding sites ranged from the relatively pristine areas of Kodiak Island, Alaska, to more urbanized areas in Puget Sound, Washington, and San Francisco Bay, California, with the majority of the sites on the Washington outer coast and in Puget Sound. Similar to concentrations in tissues, no significant differences were observed in concentrations of elements in stomach contents between whales stranded in Puget Sound and whales stranded at the more pristine sites. The lack of data from apparently healthy gray whales limits the assessment of whether the levels of anthropogenic contaminants found in tissues may have deleterious effects on the health of gray whales. Technical memo. Prepared in cooperation with Cascadia Research Collective, Olympia, WA.

Varanasi, U., J. E. Stein, et al. (1994). "Chemical contaminants in gray whales (Eschrichtius robustus) stranded along the west coast of North America." Sci Total Environ **145**(1-2): 29-53.

The concentrations of selected chlorinated hydrocarbons (e.g. PCBs, DDTs,

DDEs, chlordanes) and essential (e.g. zinc, selenium, copper) and toxic (e.g. mercury, lead, arsenic) elements were measured in tissues and stomach contents from 22 gray whales (Eschrichtius robustus) stranded between 1988 and 1991 at sites from the relatively pristine areas of Kodiak Island, AK, to more urbanized areas in Puget Sound, WA, and San Francisco Bay, CA. The majority of animals were stranded at sites on the Washington outer coast and in Puget Sound. The gray whale has the unique feeding strategy among Mysticeti of filtering sediments to feed on benthic (bottom dwelling) invertebrates. Thus, the wide geographical distribution of the stranded whales allowed (1) an initial assessment of whether concentrations of chemical contaminants in these whales exhibited region specific differences and (2) whether toxic chemicals that accumulate in sediments may have contributed to the mortality and stranding of gray whales near the more polluted urban areas. Analyses for chlorinated hydrocarbons in blubber from 22 animals showed no apparent significant differences among stranding sites. The concentrations of sigma PCBs and sigma DDEs in blubber, for example, ranged from 120 to 10,000 and 9 to 2100 p.p.b. (ng/g) wet weight, respectively. Additionally, analyses of chlorinated hydrocarbons and selected elements in liver (n = 10) also showed no apparent significant differences between whales stranded in Puget Sound and whales stranded at more pristine sites (Alaska, Washington outer coast and Strait of Juan de Fuca and Strait of Georgia). For example, the concentrations of sigma PCBs and sigma DDEs in liver ranged from 79 to 1600 and 7 to 280 p.p.b., respectively, and the concentrations of the toxic elements, mercury and lead ranged from 9 to 120 and 20 to 270 p.p.b., respectively. Analyses of stomach contents revealed low concentrations of chlorinated hydrocarbons, but high concentrations (wet weight) of aluminum (1,700,000 ± 450,000 p.p.b.), iron (320,000 ± 250,000 p.p.b.), manganese (23,000 ± 15,000 p.p.b.), and chromium (3400 ± 1300 p.p.b.), but no significant differences were observed between whales stranded in Puget Sound compared to whales stranded at the more pristine sites. The relative proportions of these elements in stomach contents of stranded whales were similar to the relative proportions in sediments, which is consistent with a geological source of these elements from the ingestion of sediment during feeding. Thus, overall, the concentrations of anthropogenic chemicals in stranded gray whales showed little relation to the levels of chemical contaminants at the stranding sites.(ABSTRACT TRUNCATED AT 400 WORDS)

Venkatesh, S. (1990). "Model simulations of the drift and spread of the Exxon Valdez oil spill." Atmosphere-Ocean **28**(1): 90-105.

In this paper the drift and spread of the Exxon Valdez oil spill that occurred on 24 March 1989 are simulated using a modified version of the Canadian Atmospheric Environment Service oil spill behaviour model. The net drift of the oil with wind and ocean currents taken into account is three to four times that with either wind or ocean currents alone. Although a 12-d drift of the spill containing the higher concentrations of oil parcels is in very good agreement with observations, model simulations show the presence of oil farther to the south, albeit in lower concentrations. The lateral spread of the oil is also very well simulated by the model.

Venosa, A., J. Haines, et al. (1991). Enhancement of oil biodegradation on a Prince William Sound beach with commercial inocula. Program and Abstracts. Second International Marine Biotechnology Conference (IMBC '91), Baltimore, MD (USA), 13-16 Oct 1991.

In a separate laboratory study evaluating the effectiveness of 10 commercial products in stimulating enhanced biodegradation of Alaska North Slope crude oil, two bacterial products provided greater alkane degradation in closed flasks than controls supplied only with excess nutrients. A randomized complete block experiment was designed in which four small plots consisting of a no-nutrient control, a mineral nutrient plot, and two plots receiving mineral nutrients plus the two products were laid out in random order on a beach in Prince William Sound that had been contaminated 16 months earlier from the Exxon Valdez spill. Results indicated no significant differences among the four treatments in the 27-day time period of the experiment.

Venosa, A., J. Haines, et al. (1992). "Efficacy of Commercial Inocula in Enhancing Biodegradation of Weathered Crude Oil Contaminating a Prince William Sound Beach." Journal of Industrial Microbiology **10**(1): 1-11.

In a laboratory study evaluating the effectiveness of 10 commercial products in stimulating enhanced biodegradation of Alaska North Slope crude oil, two of the products provided significantly greater alkane degradation in closed flasks than indigenous Alaskan bacterial populations suppied only with excess nutrients. These two products, which were microbial in nature, were then taken to a Prince William Sound beach to determine if similar enhancements were achieveable in the field. A randomized complete block experiment was designed in which four small plots consisting of a no-nutrient control, a mineral nutrient plot, and two plots receiving mineral nutrients plus the two products were laid out in random order on a beach in Prince William Sound that had been contaminated 16 months earlier from the Exxon Valdez spill. These four plots comprised a 'block' of treatments, each block being replicated four times on the same beach. Triplicate samples of beach sediment were collected at four time intervals and analyzed for oil residue weight and alkane hydrocarbon profile changes. The results indicated no significant differences ($P < 0.05$) among the four treatments in the 27-day time period of the experiment. A statistical power analysis, however, revealed that the variability in the data prevented a firm conclusion in this regard. Failure to detect significant differences was attributed not only to variability in the data but also to the highly weathered nature of the oil and the lack of sufficient time for biodegradation to take place.

Venosa, A., J. Haines, et al. (1990). Protocol for testing bioremediation products against weathered Alaskan crude oil. Cincinnati, OH (USA), Ecology Research Service, U.S. Environmental Protection Agency, Cincinnati, OH (USA): 26.

In the summer of 1989, EPA and Exxon Corp. conducted a joint field study to determine if natural biodegradation of the Prudoe Bay crude oil spilled from the

Exxon Valdez could be accelerated by application of oleophilic and water soluble fertilizers. Numerous private firms have since submitted proposals to have their microbial products tested for bioremediation enhancement. EPA commissioned the National Environmental Technology Applications Corporation (NETAC) to coordinate an effect to select and test commercial products for efficacy against Alaskan crude oil. The paper presents the protocol, the test results, and conclusions derived from the study. (Prepared in cooperation with Engineering and Economics Research, Inc., Reston, VA, and Cincinnati Univ., OH.)

Venosa, A., J. Haines, et al. (1991). "Screening of commercial inocula for efficacy in stimulating oil biodegradation in closed laboratory system." Journal of Hazardous Materials **28**(1-2): 131-144.

On February, 1990, the U.S. Environmental Protection Agency issued a public solicitation for proposals to the bioremediation industry on testing the efficacy of commercial microbial products for enhancing degradation of weathered Alaskan crude oil. The Agency commissioned the National Environmental Technology Applications Corporation (NETAC), a non-profit corporation dedicated to the commercialization of environmental technologies, to convene a panel of experts to review the proposals and choose those that offered the most promise for success in the field. Forty proposals were submitted, and 11 were selected for the first phase of a two-tiered testing protocol (only 10 were tested because one company did not participate). The laboratory testing consisted of electrolytic respirometers set up to measure oxygen uptake over time and shake flasks to measure oil degradation and microbial growth.

ver Hoef, J. (1996). "Parametric empirical Bayes methods for ecological applications." Ecological Application **6**(4): 1047-1055.

Vincent, T., D. Scheel, et al. (1998). "Some aspects of diet and foraging behavior of Octopus dofleini (Wulker 1910) in its northernmost range." Pubblicazioni della Stazione zoologica di Napoli 1 Marine Ecology **19**(1): 13-29.

von Ziegesar, O., E. Miller, et al. (1994). Impacts on humpback whales in Prince William Sound. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 173-191.

The largest number of humbpack whales reported in PWS occurred in 1989-1990 coinciding with the highest survey effort associated with the EVOS. However, the number of whales per kilometer surveyed was lower in 1989-1990 than in 1988. This may be the result of surveying a larger portion of PWS in 1989 and 1990, including areas where humpback whales occurred in low density. The reduction in the number of whales seen in lower Knight Island Passage in 1989 was temporary and may have been related to increases in vessel and aircraft traffic associated directly with oil contamination, with clean-up activities, or it may have been caused by natural fluctuations in prey. Whales

were seen in lower Knight Island Passage in 1990, as in prespill years. Movements of whales into PWS from Hinchinbrook Entrance were also more common in 1990, 1 year after the spill. The reproductive rate was low in 1989 but in 1990 it was above hisotrical levels. When compared to previous years, no significant differences could be detected in CCR. There were no humpback whale deaths or strandings observed during 1989-1990 in PWS.

The results of this study do not indicate a change in abundance, calving rates, seasonal residency time of femaile-calf pairs, or mortality. Temporary displacement from certain area of PWS was observed. During the 2-year study it was difficult to determine whether the EVOS had any measurable impact on the number of humpback whales occurring in PWS. Long-term physiological impacts to the whales or cumulative impacts to the ecosystem affecting humpback whale prey would not have been detected in this time period. However, because of the wide distribution of the North Pacific humpback whaleand the unequal survey effort in PWS between prespill and postspill years, effects, if any, of the EVOS may never be known.

Wade, T. L., L. Chambers, et al. (1997). "Toxaphene, PCB, DDT, and Chlordane Analyses of Beluga whale blubber." Chemosphere **34**(5-7): 1351-7.

Beluga whales bioaccumulate organochlorines from their environment. Blubber samples of Beluga Whales from Alaska's north coast contain organochlorines, including Toxaphene (polychlorinated camphenes) PCBs, DDTs and chlordane. Toxaphene was the organochlorine pesticide found in the highest concentration in all samples with the exception of the 6 year old male where PCBs were highest. The source of these organochlorines is likely global distillation from lower latitudes. Males had higher concentrations than females and the oldest male had higher concentration than the younger male. Females exhibit a decrease in concentrations with age. The fetus had about 10% higher concentrations for all organochlorines compared to the mother. Transplacental transfer of organochlorines and lactation lower the contaminant concentration in females. Older females have lower contaminate concentrations likely due to continual reproductive success. Consumption of older males will expose humans to higher levels of organochlorines.

Wall, L., J. Lash, et al. (1993). The Exxon-Valdez oil spill -- Woodward-Clyde Consultants' contributions to bioremediation. Workshop on the Use of Bioremediation for Oil Spill Response in the Great Barrier Reef Region, Townsville, Qld (Australia), 25 Feb 1991, Great Barrier Reef Marine Park Authority, Townsville, QLD (Australia).

About eleven million gallons of crude oil were spilled into Prince William Sound, Alaska, when the Exxon Valdez supertanker ran aground in 1989. Physical methods of removal were not very effective and damaged the local environment. Microbial activity on the polluted beaches was found to be inhibited by lack of nitrogen and phosphorus. A proposed treatment advocates the use of an emulsifier, a soil activator, and slow-release nutrients applied sequentially by helicopter.

Wang, J. (1998). "A two-channel laterally averaged estuarine circulation model (LAECIM)." Journal of Geophysical Research **103**(C9): 18381-18391.

Wang, J. and M. Ikeda (1997). "Inertial stability and phase error of time integration schemes in ocean general circulation models." Monthly Weather Review **125**(9): 2316-2327.

Numerical finite-difference schemes of time integration in widely used ocean general circulation models are systematically examined to ensure the correct and accurate discretization of the Coriolis terms. Two groups of numerical schemes are categorized. One group is suitable for simulating an inertial wave system and geostrophic adjustment processes in the ocean with the necessary condition for stability being 3F3 = 3f3 Delta t < 1 (where f is the Coriolis parameter and Delta t is the integration time step in the model), such as the predictor-corrector scheme (as shown in this study), the most commonly used leapfrog scheme (as used in MICOM, POM, SPEM, and many others), Euler-centered scheme (as used in SOMS), and leapfrog scheme plus Euler-centered Coriolis terms [as used in the Geophysical Fluid Dynamics Laboratory (GFDL) model]. The other group is able to serve as a long-term climate study using a large integration time step that may violate 3F3 = 3f3 Delta t < 1 by damping out inertial waves, such as the GFDL scheme plus Euler-backward Coriolis terms and the Euler predictor-corrector scheme plus an implicit treatment of the Coriolis terms used in OPYC model. Caution is made regarding the use of the Euler-forward and other schemes that produce unstable inertial waves; this problem could be serious for a calculation longer than one week. The predictor-corrector scheme is recommended as a replacement for the simple Euler-forward scheme. The explicit leapfrog and predictor-corrector schemes tend to overestimate the phase frequency, whereas the Euler schemes and implicit schemes underestimate it. To better simulate the correct phase frequency, F < 0.1 is recommended. Furthermore, an alternate use of an explicit scheme (e.g., leapfrog) and an implicit scheme (e.g., Euler backward or Masuno scheme, etc.) is strongly recommended to preserve the correct phase frequency.

Wang, J., M. Jin, et al. (1999). "Numerical simulation of the seasonal ocean circulation patterns and thermohaline structure of Prince William Sound." Fisheries Oceanography.

Wang, J. and C. Mooers (1996). Modeling Prince William Sound ocean circulation. Conference on Coastal Oceanic and Atmospheric Prediction January 28 - February 2, 1996, Atlanta, GA, American Meteorological Society, Boston.

Wang, J., C. Mooers, et al. (1997). A three-dimensional tidal model for Prince William Sound, Alaska. Computer Modelling of Seas and Coastal Region III. J. Acinas and C. Brebbia. Southampton, Computational Mechanics Publications: 95-104.

Wang, J., V. Patrick, et al. (1999). Modeling seasonal ocean circulation of Prince William Sound, Alaska using freshwater of a line source. Fourth International Conference on Computer Modelling of Seas and Coastal Regions Coastal Engineering 99 Incorporating the International Seminar on Marina Planning Design and Operation Marina 99. C. Brebbia and P. Anagnostopoulos, Coastal Engineering and Marina Developments: 57-66.

Wang, S., J. Lum, et al. (1994). "Relationship between growth and total nucleic acids in juvenile pink salmon *Oncorhynchus gorbuscha* fed crude oil contaminated food." Canadian Journal of Fisheries and Aquatic Sciences **50**(5): 996-1001.

Total nucleic acids of juvenile pink salmon, (Oncorhynchus gorbuscha) fed crude oil contaminated food were analyzed to determine if nucleic acid measurements can be used to evaluate growth of fish collected at oil spill sites. In general, the nucleic acid concentration (micrograms per milligram dry weight) of salmon fry fed food contaminated with either 0.37 or 2.78 mg crude oil/g food was not significantly affected. However, RNA concentration of fry fed food contaminated with 34.83 mg/g was reduced whereas DNA concentration increased. Results over 8 wk indicate decreased protein synthesis and cell content but maintenance of cell integrity in these fish. Growth was inversely related to the level of crude oil contamination in the food. The significant correlations between measured growth and RNA/DNA ratios and RNA contents (micrograms RNA per millimetre fork length) suggest that nucleic acid measurements can be used to compare growth of fish collected from the field.

Ward, A. (1997). A temporal study of the phytoplankton spring bloom in Prince William Sound, Alaska. Fairbanks, AK, University of Alaska.

Thesis

Warheit, K., C. Harrison, et al. (1998). EXXON VALDEZ Oil Spill Seabird Restoration Workshop. Held in Victoria, British Columbia in February 1990. Restoration Project 95038. EXXON VALDEZ Oil Spill Restoration Project Final Report. Govt Reports Announcements & Index (GRA&I), Oregon Inst. of Marine Biology, Charleston. Pacific Seabird Group.
Washington Dept. of Fish and Wildlife, Olympia. Habitat Management.
Harrison (Craig S.), Washington, DC.
Alaska Univ., Fairbanks. Inst. of Arctic Biology and Museum.: 198p.

The Pacific Seabird Group implemented a workshop designed to provide recommendations on restoration options for seabirds injured by EVOS (Exxon Valdez Oil Spill). The workshop produced criteria to be used to determine if the population effects resulting from a spill are a concern, and to establish a priority list for restoration activities. We set down specific operational goals for restoration activities. Pacific Seabird Group technical pub. 1. Prepared in cooperation with Washington Dept. of Fish and Wildlife, Olympia. Habitat

Management., Harrison (Craig S.), Washington, DC. and Alaska Univ., Fairbanks. Inst. of Arctic Biology and Museum. Sponsored by Oregon Inst. of Marine Biology, Charleston. Pacific Seabird Group.

Weiner, A. (1998). "Kenai River restoration and management." Fisheries **23**(1): 6-10.
A comprehensive program of restoration, land acquisition, recreation enhancement, and land management is underway on the Kenai River in southcentral Alaska. With 34 species of fish, including 5 species of salmon, Dolly Varden, and rainbow trout, the Kenai is the most productive river in this area. The river supports a multimillion-dollar commercial fishery for sockeye and king salmon and a world-class sport fishery for rainbow trout and king, sockeye, and silver salmon. This sport fishery supports more than 300 seasonal sportfishing guides and 340,000-plus angler days a year. The program is attempting to restore degraded fish habitat in the riparian zone of the mainstem, to acquire lands to protect fish habitat, to provide recreational access for anglers, and to manage lands in the watershed to prevent development-related harm. Funding for this program, currently in excess of $21 million, is provided by the state of Alaska, Exxon Valdez oil spill civil settlement and criminal restitution funds, National Marine Fisheries Service, Federal Aid for Sport Fish Restoration Fund, Dingell-Johnson Sport Fish Fund, Land and Water Conservation Fund, and Federal Highway Administration (Intermodal Surface Transportation Enhancement Act.

Weiner, A., C. Berg, et al. (1997). "The Exxon Valdez oil spill: habitat protection as a restoration strategy." Restoration Ecology **5**(1): 45-55.

Wells, P., J. Butler, et al., Eds. (1995). Exxon Valdez oil spill: Fate and effects in Alaskan waters. Third Symposium on Environmental Toxicology and Risk Assessment - Exxon Valdez Oil Spill. Atlanta, GA (USA), 26-28 Apr 1993, ASTM, Philadelphia, PA (USA).

Wertheimer, A., N. Bax, et al. (1996). Harpacticoid copepod abundance and population structure in Prince William Sound, one year after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 551-563.
Density and population structure of epibenthic harpacticoid copepods were compared between lightly oiled and heavily oiled beaches in two bays, Herring Bay and Bay of Isles, in Prince William Sound in 1990, 1 year after the Exxon Valdez oil spill. Level of oiling was categorized according to shoreline surveys in fall 1989. Mean densities of total epibenthic harpacticoid copepods in both bays and of *Harpacticus* spp. in Herring Bay were higher on heavily oiled beaches than on lightly oiled beaches. Proportions of copepodites and egg-bearing female copepods were similar at lightly and heavily oiled beaches. Level of oiling in 1989 explained more of the variance in copepod densities in

1990 than did substrate composition, macrophyte coverage, total organic carbon in the sediments, or polycyclic aromatic hydrocarbons in the sediments. Amount of oil in sediments was not significantly correlated with the 1989 oiling level; however, interpretation of the hydrocarbon data was complicated by cleanup activity and possible secondary contamination at the sites. The results of this study suggest that epibenthic harpacticoids, which are common prey for salmon fry, maintained or increased their abundance in response to direct and indirect impacts of the Exxon Valdez oil spill on their intertidal habitats during the year after the spill.

Wertheimer, A. and A. Celewycz (1996). Abundance and growth of juvenile pink salmon in oiled and non-oiled locations of western Prince William Sound after the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 518-532.

Juvenile pink salmon *Oncorhynchus gorbuscha* were sampled in oiled and non-oiled locations during their initial residency in the nearshore waters of Prince William Sound in 1989 and 1990. Pink salmon moved rapidly from sheltered bays to more exposed and steep beaches in migration corridors. Pink salmon were less abundant in oiled than in non-oiled locations in both 1989 and 1990; only 18% (1989) and 14% (1990) of pink salmon captured in systematic sampling were from oiled locations. Because the pattern of abundance did not change between years as oil contamination diminished, we attribute these differences to geographic variation in local production of pink salmon fry and in their migration pathways to the Gulf of Alaska, other than to exposure to oil. Juvenile pink salmon were significantly smaller and had significantly lower apparent growth in oiled than in non-oiled locations in 1989, but not in 1990. In 1989, when growth was lower in oiled locations, hydrocarbon contamination of the environment was greatest, and direct contamination of juvenile pink salmon was observed. In 1990, when growth was similar between oiled and non-oiled locations, hydrocarbon contamination of the environment was greatly diminished, and no direct contamination of juvenile pink salmon was observed. For these reasons, we attribute the lower growth in oiled locations in 1989 to exposure to Exxon Valdez crude oil.

Wertheimer, A., A. Celewycz, et al. (1994). The impact of the Exxon Valdez oil spill on juvenile pink and chum salmon and their prey in nearshore marine habitats. Proceedings of the 16th Northeast Pacific Pink and Chum Salmon Workshop, Juneau, Alaska, USA, February 24-26, 1993, University of Alaska, Fairbanks, Alaska, USA.

The objectives of this study were to determine the impact of the oil spill on juvenile pink and chum salmon during their initial period of marine residency in nearshore habitats. Field studies in 1989 and 1990 compared: (1) exposure to and contamination by hydrocarbons, (2) distribution, abundance, size and nominal growth rates, (3) feeding habits, and (4) prey abundance for these fish between pairs of oiled and non-oiled locations in western Prince William Sound.

Wertheimer, A., R. Heintz, et al. (in press). "Straying of adult pink salmon from their

natal stream following exposure as embryos to weathered Exxon Valdez crude oil." Transactions of the American Fisheries Society.

White, C., R. Ritchie, et al. (1995). Density and productivity of bald eagles in Prince William Sound, Alaska after the Exxon Valdez oil spill. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

Whitney, J., C. Lautenberger, et al. (1994). Alaska regional response team in-situ burn guidelines and pre-approvals. Arctic and Marine Oil Spill Program Technical Seminar, Vancouver, BC (Canada), 8-10 Jun 1994, Environment Canada, Ottawa, ON (Canada), 1994.

Use of burning as an available oil spill response method is an important issue in both the coastal and inland zones of Alaska. The capability to adequately respond to an oil spill in Alaska can be hampered by a number of critical factors, which combined with the potential to experience large spills, require tools," other than mechanical response such as in-situ burning (ISB), be preplanned and immediately available to responders and government officials to ensure an adequate response to spill events. Because of this, the Alaska Regional Response Team (ARRT) has been working over the past 2 to 3 years to develop procedures and guidelines, scientifically based, to facilitate the decision process regarding ISB. The first major hurdle was developing a consensus that, outside the immediate region of the fire, the potentially most damaging effects of the smoke plume were those on the health and safety of the general population. The natural resource agencies were unable to document any adverse effects of the smoke plume on biological populations and/or habitats. The second hurdle occurred with the determination that particulates in the smoke plume less than 10 microns in diameter were the major culprit causing potential adverse effects to the general population. As a result, the Alaska Hazardous Substances Spill Technology Review Council funded the National Institute of Standards and Technology (NIST) to model downwind particulate concentrations for the burning of North Slope and Cook Inlet crude oils under typical winter and summer conditions in southern and northern Alaska. Based on a very conservative interpretation of the National Ambient Air Quality Standards (NAAQS), a particulate level of 150 micrograms per cubic meter ($\mu g/m^3$) - real time, one hour average - was selected as the acceptable exposure level to the general population. Using these parameters, the Alaska ISB guidelines now allow the Unified Command (FOSC and SOSC) to authorize ISB without RRT consultation. Provisions have been developed to conduct a trial burn, conduct controlled and uncontrolled burns, extinguish a burn, monitor a burn, and notify the public of a burn.

Wiedmer, M., M. Fink, et al. (1996). Cytochrome P-450 induction and histopathology in preemergent pink salmon from oiled spawning sites in Prince William Sound.

Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 509-517.

The March 1989 Exxon Valdez oil spill contaminated intertidal pink salmon *Oncorhynchus gorbuscha* spawning areas in Prince William Sound and the Gulf of Alaska. To determine if 8- to 26-month old oil remaining in some spawning areas produced physiological responses in developing pink salmon eggs and alevins, we conducted an initial assessment of cytochrome P-4501A induction and histopathologic lesion occurrence in preemergent pink salmon collected from oiled spawning substrates. Egg and alevin samples were collected from four oiled and five reference sites in Prince William Sound, Alaska, between December 1989 and May 1991. Immunohistochemical staining for cytochrome P-4501A was increased in alevins from 13 of 16 samples from oiled sites, but was not increased in any of the 7 samples from the reference sites. Cytochrome P-4501A induction was not detected in egg samples from either oiled or control sites. Persistent P-4501A staining through the end of the study was evidence for chronic exposure of two year-classes of pink salmon to hydrocarbon contamination. Histopathologic lesions were more frequent in alevins from oiled sites, but differences were not statistically significant, and lesion occurrence seemed dependent on developmental stage. These results provide evidence that pink salmon alevins developing in heavily oiled sites were exposed to hydrocarbons more than 2 years after the initial spill and that the hydrocarbons induced detectable physiological changes. Results of this study were used to develop appropriate treatments for oiled anadromous fish streams.

Wiens, J. (1993). "Recovery of seabirds following the Exxon Valdex oil spill: An overview." Bulletin of the Ecological Society of America **74**(2 SUPPL): 486.

Wiens, J. (1995). Recovery of seabirds following the Exxon Valdez oil spill: An overview. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters; Third Symposium on Environmental Toxicology and Risk Assessment-Exxon Valdez Oil Spill, Atlanta, Georgia, USA, April 26-28, 1993, ASTM (American Society for Testing and Materials); Philadelphia, Pennsylvania, USA.

Assessing oil-spill effects requires rigorous definitions of "impact" and "recovery." Impact is defined as a statistically significant difference between samples exposed to oil and reference samples. Recovery is then the disappearance through time of such a statistical difference. Both impact and recovery must be assessed in relation to the background of natural variation that characterizes marine environments. There are three primary avenues of potential spill impacts on seabirds: on population size and structure, on reproduction, and on habitat occupancy and use. Detecting oil-spill effect involves comparisons of (1) observations taken following the spill with prespill data; (2) data gathered following the spill from oiled areas ("treatments") and unoiled areas ("controls") surveyed at the same time; or (3) measurements taken from sites along a gradient of oiling magnitude. The strengths and weaknesses of these approaches are discussed. In may situations, the third approach may be most useful. Following the Exxon Valdez oil spill in March 1989, over 35 000 dead

birds were retrieved. Model analyses suggested that actual seabird mortality could have been in the hundreds of thousands, prompting concerns about severe and persistent impacts on populations of several species, especially murres (Uria spp.). Recovery for some populations was projected to take decades. The findings of several studies conducted following the oil spill, however, indicate that these concerns may not be justified. These studies examined colony attendance and reproduction of murres as well as habitat utilization for the prevalent species in Prince William Sound and along the Kenai Peninsula. Surveys of attendance by birds at murre breeding colonies in 1991 indicated no overall differences from prespill attendance levels when colonies were grouped by the degree of oiling in the vicinity. At a large colony in the Barren Islands, where damage was described as especially severe, counts of murres were generally similar to historical estimates made in the late 1970s.

Wiens, J. (1996). "Oil, seabirds, and science. The effects of the Exxon Valdez oil spill." Bioscience **46**(8): 587-597.

When the supertanker Exxon Valdez ran aground on Bligh Reef in Prince William Sound, Alaska, on the morning of 24 March 1989, it aroused widespread concern about possible environmental devastation. Within hours, some 41 million liters of crude oil were released into the marine ecosystem, making this spill the largest in US history. Eventually, oil was found more than 900 km from the spill site, and roughly 2100 km of shoreline were contaminated with oil. Reports of mortality of marine birds were immediate, and images of oiled seabirds figured prominently in media coverage of the spill. Within a few months, more than 30,000 oiled carcasses had been retrieved from the water and beaches in the spill area, and estimates of overall mortality were substantially greater. Studies of the effects of the Exxon Valdez oil spill on seabirds were initiated shortly following the spill by researchers working for the State of Alaska and several federal agencies (the "Trustees") or supported by Exxon. By mid-summer 1989, however, litigation became a priority, and as a result the two groups conducted their studies separately, each with little knowledge of what the other group was doing. Reports of many of these studies have now been made public, and enough information is available to develop a general assessment of how the spill affected seabirds and whether the initial concerns were justified. The studies also provide some insights into how the scientific process itself may be affected by such well-publicized environmental accidents and into the relationships among preconceptions, advocacy, and science.

Wiens, J., T. Crist, et al. (1996). "Effects of the Exxon Valdez oil spill on marine bird communities in Prince William Sound, Alaska." Ecological Applications **6**(3): 828-841.

The supertanker Exxon Valdez ran aground on 24 March 1989, spilling 41e William Sound, Alaska. To examine effects of this oil spill on the marine bird community. we analyzed data from 11 survey cruises between June 1989 and August 1991. Cruises were conducted in 10 study bays differing in the magnitude of initial oiling. We gauged bird responses to the spill in terms of habitat use, measured by frequency of bay occupancy and species abundances

as functions of initial bay oiling. We focused on community-level measures to obtain a broader perspective than can be obtained from studies directed toward individual species of concern. Effects of the oil spill on community measures were most apparent shortly after the spill but diminished rapidly. Species richness was significantly lower in 1989 than at the same season 1-2 yr later, especially in heavily oiled bays. Species diversity (log-series alpha) was also significantly reduced in more heavily oiled bays in ear summer 1989 and 1990, but impacts evident in midsummer and fall 1989 were absent 1 yr later, and there were no significant relationships between diversity and bay oiling after midsummer 1990. Species occurrence in bays was more restricted immediately following the spill than 1-2 yr later, and widespread species were less abundant in early summer and fall 1989 than at the same seasons 1 yr later. This latter pattern was reversed in the midsummer surveys. perhaps because spill clean-up activities attracted large numbers of nonbreeding gulls. We used cluster analysis to define six avian guilds based on ecological characteristics of the species. Species richness of several guilds of birds feeding on or close to the shoreline was negatively related to initial oiling level until early or midsummer 1990. but not thereafter. Of these guilds, the richness of a guild of winter visitant and resident species showed the greatest negative association with initial oiling. However, the richness of guilds of solitary or colonial species that dive and/or feed on fish showed no significant relationships with oiling at any time. Correspondence analysis based on bird community composition indicated clear differences between heavily oiled and unoiled bays in 1989, but overall community composition converged between these sets of bays in subsequent years. Our analyses indicated that the Exxon Valdez oil spill had significant initial impacts on marine bird community structure, although they were not evenly distributed among ecological guilds. Even during the first survey, many species were present in the most heavily oiled bays. Although a few species continued to show spill impacts in late 1991, none of the community measures indicated continuing negative oiling effects. This suggests that, at the community level, recovery was well underway, consistent with observations that seabird habitat had apparently returned to normal in all but a few localized areas by mid-1991. Seabird communities appear to have considerable resiliency to such severe but relatively short-term perturbations, possibly because birds move over a regional scale. It may, therefore, be important to consider regional processes in evaluating recovery following environmental accidents.

Wiens, J. and K. Parker (1995). "Analyzing the effects of accidental environmental impacts: Approaches and assumptions." Ecological Applications **5**(4): 1069-1083.

Because studies of environmental accidents must be initiated after the fact and because the accidents cannot (or should not) be replicated, sampling cannot be entirely randomized, and investigations involve some degree of confounding and pseudoreplication. The study designs that can be used carry methodological limitations and ecological assumptions, which must be considered in evaluating results. The methodological issues relate to consistency in sampling methods and to the adequacy of sampling of levels of environmental disturbance or contamination, while the ecological assumptions derive from spatial and

temporal variation in biological resources and the factors that affect them. We assess how these methodological issues and ecological assumptions affect study designs based on before-after comparisons and on single-time or multiple-time sampling after an accident. Designs that rest on the assumption of a steady-state equilibrium in resource-environment relationships (baseline and time-series designs) must be interpreted with particular care, and baseline designs are sensitive to the effects of pseudoreplication and inconsistencies in methods. Other designs (pre/post paired samples, impact level-by-time, impact trend-by-time) assume only that environmental variations are equivalent among areas and/or contamination levels (a dynamic equilibrium) and are less affected by pseudoreplication. Single-time designs (comparisons between impact and reference sites, between matched paired sites, or over a contamination gradient) have fewer methodological limitations, but assume that other natural factors that may influence the response of a resource are equal among all samples. If measurements of other factors are included in the design, covariance analysis may help to reduce this problem. In evaluating the effects of unplanned environmental impacts, post facto study designs that document both initial effects and subsequent recovery (impact level-by-time, impact trend-by-time) or that treat effects as continuous rather than categorical variables (gradient or trend designs) may be more useful than before-after comparisons.

Willette, M. (1996). Impacts of the Exxon Valdez oil spill on the migration growth and survival of juvenile pink salmon in Prince William Sound. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 533-550.

This study investigated the effects of the Exxon Valdez oil spill on the migration, growth, and survival of juvenile pink salmon *Oncorhynchus gorbuscha* during the first 2 months of their marine residence in Prince William Sound, Alaska. Coded-wire-tagged juvenile salmon released from hatcheries in the sound in 1989, 1990, and 1991 were the principal sources of data. The growth of juvenile pink salmon in Prince William Sound appeared to be reduced by oil contamination from the Exxon Valdez oil spill in 1989. Growth rates of juveniles released from Armin F. Koernig (AFK) Hatchery in 1989 were significantly lower ($P = 0.034$) in the moderately oiled area near the hatchery than along the lightly oiled southern coast of Knight Island. In 1990 and 1991, growth rates of juvenile pink salmon released from AFK Hatchery were again lower in the moderately oiled area compared with the lightly oiled southern coast of Knight Island. However, the growth difference was not significant in 1990 ($P = 0.103$), and was only marginally significant in 1991 ($P = 0.085$). The magnitude of the growth difference in 1990 and 1991 was also one half of the growth difference in 1989. Growth rates of juveniles released from Wally H. Noerenberg (WHN) Hatchery in 1989 were significantly lower ($P = 0.019$) in the moderately oiled area near Main Bay than in the non-oiled area near WHN Hatchery. Growth rates of juveniles released from WHN Hatchery were not significantly different between oiled and non-oiled areas in 1990 ($P = 0.767$) and 1991 ($P = 0.883$). Exposure to hydrocarbons from the Exxon Valdez oil spill appeared to reduce the growth rate of juvenile pink salmon by 0.76-0.94% body weight/day in 1989. The

observed differences in growth rate did not appear to have been caused by measurement or sampling error or by differences in food consumption rate, prey composition, or water temperature. The observed reduction in growth rate was associated with a significantly greater ($P < 0.05$) frequency of cytochrome P-4501A enzyme induction in moderately oiled areas compared with non-oiled and lightly oiled areas in 1989. The greater frequency of P-4501A enzyme induction in moderately oiled areas indicates that fish in oil-contaminated habitats expended energy to metabolize and depurate hydrocarbons, leaving less energy available for somatic growth. Sufficient data were not available to determine if the level of hydrocarbon exposure was great enough to cause the estimated reduction in growth rate attributed to oil contamination. The growth of juvenile pink salmon in 1989 was significantly related ($P = 0.016$) to survival to the adult stage. The reduction in juvenile growth rate attributed to oil contamination in 1989 probably caused a 1.7-2.2% reduction in survival to the adult stage among fish that reared in oiled areas. The adult pink salmon return to Prince William Sound in 1990 was thus lower than if the Exxon Valdez oil spill had not occurred.

Willette, M., R. Cooney, et al. (In press). "Predator foraging-mode shifts affecting mortality of juvenile fishes during the subarctic spring bloom." Canadian Journal of Fisheries and Aquatic Sciences.

Willette, M., M. Sturdevant, et al. (1997). Prey resource partitioning among several species of forage fishes in Prince William Sound, Alaska. Forage Fishes in Marine Ecosystems: Proceedings of the International Symposium on the Role of Forage Fish in Marine Ecosystems, Alaska Sea Grant College Program Report, University of Alaska, Fairbanks, Alaska.

Willette, T. (1994). Impacts of the Exxon Valdez oil spill on the migration growth and survival of juvenile pink salmon in Prince William Sound. Proceedings of the 16th Northeast Pacific Pink and Chum Salmon Workshop, Juneau, Alaska, USA, February 24-26, 1993, University of Alaska, Fairbanks, Alaska, USA.

This study focused on the effects of the Exxon Valdez oil spill (EVOS) on the migration, growth, and survival of juvenile pink salmon during the first two months of their marine residence in Prince William Sound (PWS), Alaska. Coded-wire tagged (CWT) juvenile salmon released from four hatcheries in PWS in 1989, 1990, and 1991 were the principal tool used to study migration, growth, and survival. The migration of juvenile pink salmon released from the Armin F. Koernig (AFK) Hatchery appeared to have been affected by oil contamination from the EVOS in 1989. Recoveries of juvenile CWT pink salmon and visual observations of juvenile salmon abundance indicated that much higher numbers of fry from AFK Hatchery were present along the southern coast of Knight Island in 1989 than in 1990 and 1991. Insufficient data is available to determine if hydrocarbon concentrations in the environment were at a level sufficient to cause an avoidance reaction in juvenile pink salmon. However, a greater frequency of P4501A enzyme induction in juvenile pink salmon recovered near the AFK

Hatchery indicated that the fish were exposed to hydrocarbons. There was no apparent effect of oil contamination on the migratory behavior of juvenile pink salmon released from the Wally H. Noerenberg (WHN) Hatchery in 1989.

Willette, T., G. Carpenter, et al. (1996). Early Marine Salmon Injury Assessment in Prince William Sound. Fish Shellfish Study Number 4A. EXXON VALDEZ Oil Spill, State/Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), Alaska Dept. of Fish and Game, Cordova. Commercial Fisheries Management and Development Div.: 89p.

The authors investigated the effects of the Exxon Valdez oil spill and evaluated natural environmental effects on the migration, growth, and survival of juvenile pink salmon during the first two months of marine residence in Prince William Sound using coded-wire tagged juveniles released from hatcheries in 1989-1991. Juveniles from Koernig Hatchery migrated from the nearby moderately-oiled area to the lightly-oiled southern coast of Knight Island in 1989; similar migration was not observed in 1990 and 1991. Exposure to hydrocarbons appeared to reduce the juvenile growth rate by 0.76 to 0.94% body weight per day in 1989, and was associated with a significantly greater (P<.05) frequency of cytochrome P4501A enzyme induction in moderately-oiled areas. Growth rate reduction likely caused a 1.7 to 2.2% reduction in survival to the adult stage among fish reared in oiled areas.

Williams, T., G. Antonelis, et al. (1994). Health evaluation, rehabilitation, and release of oiled harbor seal pups. Marine Mammals and the Exxon Valdez. T. Loughlin. San Diego, CA, Academic Press: 227-241.

As reported by Geraci and Smith for harp seal pups and Gales for Australian fur seal pups, we found few toxic or thermal consequnces associated with external oiling of the harbor seal pups in this study. Internal exposure to oil was of greater concern for the seal pups due to the persistent nature of petoleum hydrocarbons in the blood. However, the animals did not display behaviormal or clinical signs of organ dysfunction. Despite evidence of internal and external oil contamination, 15 of the 18 seals (83%) survived to release. It is not known if the sequestering or intermittent circulation of TPH will have a long-term detrimental effect on these animals. Clearly, further studies concerning the factors that control the turnover of petroleum hydrocarbons in marine mammal tissues are warranted.

Because the harbor seal pups showed few signs of clinical illness, the value of capturing and rehabilitating pinnipeds following an oil spill is questionable especially after the oil has weathered. Species that rely primarilty on blubber for insulation will be comparatively resistant to the thermal effects of oil contamination. Conversely, if significant levels of petroleum hydrocarbons are transferred through milk to nursing pups, a rehabilitation program may avoid undue exposure of the pups to oil. In future spills, the relative risk to the wild population must be considered a primary factor when decidng if a rehabilitation program should be undertaken.

Williams, T., R. Kastelein, et al. (1988). "The effects of oil contamination and cleaning on sea otters (Enhydra lutris) 1. Thermoregulatory implications based on pelt studies." CAN. J. ZOOL. **6**(12): 2776-2781.

The contamination of sea otter (Enhydra lutris) fur with crude oil or dispersants reduces its insulation and could subject the animal to hypothermia. This study tested methods for removing crude oil from sea otter pelts, and measured changes in insulation caused by oil contamination and subsequent cleaning. Four detergents and two pretreatments were tested on sea otter pelts soiled with fresh crude, 5-day weathered crude, and an oil-dispersant (COREXIT 9527) solution. To examine the effects of oiling and cleaning on the thermal properties of the fur, the thermal conductance of untreated, oiled, and cleaned pelt samples was determined with a heat-flow transducer. The results demonstrated that Dawn dishwashing detergent was the most effective agent in removing crude oil from sea otter fur. Oil contamination caused a two- to four-fold increase in thermal conductance over base-line levels (7.64 plus or minus 1.30 W/(m super (2) multiplied by degree C)). Following cleaning, the thermal conductance of the pelt was not significantly different from that of untreated fur.

Williams, T. and R. Wilson (1990). Blood collection and analysis during the T/V Exxon Valdez oil spill. Symposium to Evaluate the Response Effort on Behalf of Sea Otters after the T/V Exxon Valdez oil spill into Prince William Sound, Anchorage, Alaska, USA, April 17-19, 1990, U S Fish and Wildlife Service.

Wills, J. (1995). The Braer and the Exxon Valdez-cleanup comparisons. International Conference Prevention, Response, and Oversight Five Years After the Exxon Valdez Oil Spill, Anchorage, AK (USA), 23-25 Mar 1994, Sea Grant College Program Report, Alaska University. Institute of Marine Science.

Shetland and Alaska had been in touch, now and again, before the Exxon Valdez but, in the 45 months between your spill and the wreck of the tanker Braer on our coastline in January 1993, the contacts became regular and frequent. The reasons were serious and professional, but as a result we have become close friends who know, among other things, how important it is to be able to party in the midst of despair.

Wise, S., B. Koster, et al. (1993). "Current Activities Within the National Biomonitoring Specimen Bank." The Science of the Total Environment **139/140**: 1-12.

The National Institute of Standards and Technology (NIST) has been involved in biological environmental specimen banking activities since 1979. These activities, which are known collectively as the National Biomonitoring Specimen Bank (NBSB), include the banking of a variety of specimens (human liver, sediment, mussels/oysters, fish tissue and marine mammal tissues) from several different projects supported by different government agencies. The two most recent projects, the Alaska Marine Mammal Tissue Archival Project (AMMTAP)

and the National Marine Mammal Tissue Bank (NMMTB), focus on the collection, banking and analysis of marine mammal tissues and they are part of a comprehensive plan to address marine mammal monitoring, specimen banking and quality assurance of analytical measurements associated with contaminant analyses in marine mammals. Final rept. Sponsored by Environmental Protection Agency, Washington, DC., National Oceanic and Atmospheric Administration, Rockville, MD., and Department of the Interior, Washington, DC.

Wise, W., O. Gueven, et al. (1994). "Nutrient retention time in high-permeability, oil-fouled beach." Journal of Environmental Engineering **120**(6): 1361-1379.

Following the grounding of the Exxon Valdez in March 1989, many beaches in the Alaskan waters were fouled with oil. One of these was Kittiwake Beach of Knight Island in Prince William Sound. The U.S. Environmental Protection Agency initiated a research project to evaluate the application of nutrients to the surface of the beach to stimulate biodegradation of the surficial and infiltrated oil by indigenous microbial populations. Nutrients were dissolved in seawater and applied by sprinklers to study plots along the beach. As part of this project, a preliminary, simplified model of the beach hydraulics is developed to describe the advective fate of the applied nutrients. The retention time of nutrients in the beach is estimated to be on the order of 12 h (one tidal cycle) for the application method used. Simulations indicate that application of nutrients through a trench or sub-surface drain placed above the high-tide level, rather than directly on the beach by sprinklers, would result in significantly longer retention times. Design guidance for future remediation is provided to ensure nutrient coverage of the entire oiled profile of a permeable beach.

Wolfe, D. (1996). Fate and Toxicity of Spilled Oil from the EXXON VALDEZ. Subtidal Study Number 4. EXXON VALDEZ Oil Spill, State Federal Natural Resource Damage Assessment Final Report. Govt Reports Announcements & Index (GRA&I), National Ocean Service, Silver Springs, MD. Office of Ocean Resources Conservation and Assessment.: 132p.

Three separate papers are represented in this final report; Toxicity of intertidal and subtidal sediments contaminated by the Exxon Valdez oil spill; Comparative toxicities of polar and non-polar organic fractions from sediments affected by the Exxon Valdez oil spill in Prince William Sound, Alaska; and Fate of the oil spilled from the T Exxon Valdez in Prince William Sound, Alaska.

Wolfe, D., M. Hameedi, et al. (1994). "The fate of the oil spilled from the Exxon Valdez." Environmental Science and Technology **28**(13): 561A-568A.

Just after midnight on March 24, 1989, the 987-foot tank vessel Exxon Valdez grounded on Bligh Reef in Prince William Sound (PWS), Alaska, releasing approximately 10.8 million gallons (similar to 35,500 metric tons) of North Slope crude oil into the Sound. During the following eight weeks oil was spread by winds and currents into the Gulf of Alaska (GOA) and along about 1750 km of shoreline, extending up to 750 km from the original spill site (1-3). We have

analyzed published and unpublished information on the various processes that affected the distribution and transformations of the spilled oil and reconstructed a spatial-temporal mass balance up through the summer of 1992 (4). In this article, we present our conclusions and a brief overview of the supporting observations.

The floating oil distribution can be summarized as follows. Heavy amounts of floating oil were present in southwest Prince William Sound for about two weeks. Some shorelines were heavily oiled during this time. Significantly reduced amounts (by an order of magnitude) were present for another two weeks. After this time, light sheens--often caused by leaching from oiled beaches--were observed, but represented minor amounts of pollutant. An estimated 35% of the oil evaporated or dispersed into the water column in the Sound. An additional 40% affected the shoreline inside Prince William Sound. Perhaps 25% of the original spill left the Sound as floating oil. Only about 10% of the oil made it beyond Gore Point, and 2% actually got as far as Shelikof Strait.

Wolfe, D., M. Krahn, et al. (1996). Toxicity of intertidal and subtidal sediments contaminated by the Exxon Valdez oil spill. Proceedings of the Exxon Valdez Oil Spill Symposium. S. Rice, R. Spies, D. Wolfe and B. Wright. Anchorage, Alaska, USA, February 2-5, 1993, American Fisheries Society; Bethesda Maryland, USA. **18:** 121-139.

To estimate the toxicity potential of sediments oiled by the Exxon Valdez spill, standardized toxicity tests were applied to intertidal (0 m) and subtidal (three to five depths ranging from 3 to 100 m) sediment samples from Prince William Sound and the nearby Gulf of Alaska during 1989-1991. In 1989, toxicity measured by Microtox registered in shallow subtidal (0-6 m) sediments showed a generally decreasing trend with increasing distance from the spill center. At the Prince William Sound sites, however, where the ranges of total hydrocarbon concentrations were greatest (at 0 and 3 m) and where those concentrations were related most certainly to Exxon Valdez oil, the Microtox registered test did not show clear dose-response relations to ultraviolet fluorescence signal. Laboratory tests confirmed the non-responsiveness of the Microtox registered test to Exxon Valdez oil, and the test was not used further. In 1990 and 1991, sediment toxicities at oiled and non-oiled sites were compared using a sediment elutriate test with larval Pacific oysters *Crassostrea gigas* and a whole sediment test with amphipods *Ampelisca abdita*. The 1990 amphipod results indicated that (1) mortality was correlated with hydrocarbon concentrations in intertidal sediments, (2) intertidal toxicity was substantially higher than subtidal toxicity, and (3) mean toxicity of intertidal sediments at exposed sites was significantly higher than at reference sites. Mean mortalities in subtidal sediments (at 6, 20, and 40 m) were not significantly different between exposed and reference sites, although concentrations of total hydrocarbons were generally higher at the exposed sites down to 20 m. In 1991, toxicity was generally low at all depths at all sites. Although some 1991 sediment samples (from 0, 6, and 20 m) caused mortalities of test organisms that were significantly greater than in controls, no difference in mean toxicity was demonstrated between oiled and reference sites with amphipods or oyster larvae. Between 1990 and 1991, the relative toxicity of sediments from exposed sites (compared to reference sites) decreased for intertidal (0 m) sediments

and may have increased slightly for shallow subtidal (6 m) sediments. These results suggest that residual toxicity was still present during summer 1990 in intertidal sediments from some sites that were heavily oiled in 1989. By 1991, the toxicity of these sediments had diminished to background levels. These studies demonstrated no significant toxicity to test amphipods or oyster larvae that was clearly associated with Exxon Valdez oil in subtidal sediments (6-40 m) during 1990-1991.

Wolfe, D., K. Scott, et al. (1995). "Comparative toxicities of polar and non-polar organic fractions from sediments affected by the Exxon Valdez oil spill in Prince William Sound, Alaska." Chemistry and Ecology **10**: 137-156.

Standardized tests were applied to aromatic and polar fractions of sediment extracts to determine whether polar constituents or oxidative degradation products contributed significantly to the toxicity of sediments oiled by the Exxon Valdez spill. Intertidal sediment and pore-water samples were collected in September 1990 from two heavily oiled sites and an unoiled site in Prince William Sound (PWS). Methylene chloride extracts from these samples were fractionated by liquid chromatography into aliphatic, aromatic and polar fractions, and the aromatic and polar fractions were tested for toxicity using the Microtox super(R) test, bivalve larval mortality and development (Mytilus); several measures of genotoxicity in Mytilus, including SOS Chromotest super(R), anaphase aberrations and sister chromatid exchange: and survival, anaphase aberrations and teratogenicity in coho salmon (Onchorhynchus kisutch). Microtox super(R) and SOS Chromotest super(R) protocols were applied in a screening mode to all samples, whereas other tests were applied only to selected fractions from two sites. Samples from Bay of Isles (oiled) were consistently more toxic (usually only 2 to 5-fold) than the Mooselips Bay (unoiled) samples, which gave very low responses in all tests. For both sites, however, responses to polar and aromatic fractions were about the same in most tests, suggesting that while the overall toxicity of the oil was low in these samples, at least part of that toxicity was derived from polar constituents. Compared to the parent hydrocarbons, polar oxidation products partition preferentially into pore-water and are more rapidly diluted and dispersed in the water column. These results suggest that polar oxidation products of petroleum hydrocarbons pose little risk to marine organisms, except possibly for infauna continuously exposed to pore-water in heavily oiled sediments. Independent surveys showed that sediment toxicity in PWS declined during 1989-1991 to near background levels, in accord with previous understanding of oil weathering and toxicity.

Wolfe, D., K. Scott, et al. (1995). Comparative toxicities of polar and non-polar organic fractions from sediments affected by the Exxon Valdez oil spill in Prince William Sound, Alaska. International Ocean Pollution Symposium, Beijing (People's Republic of China), 4-8 Oct 1993, Gordon & Breach Science Publishers.

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Woodin, B., R. Smolowitz, et al. (1997). "Induction of cytochrome P4501A in the intertidal fish Anoplarchus purpurescens by Prudhoe Bay crude oil and environmental induction in fish from Prince William Sound." Environmental Science and Technology **31**(4): 1198-1205.

Cytochrome P4501A (CYP1A) induction is a sensitive and specific adaptive response in fish exposed to xenobiotics including petroleum hydrocarbons. CYP1A expression was examined in the intertidal fish Anoplarchus purpurescens collected from or caged at reference sites and sites oiled by the Exxon Valdez spill in Prince William Sound. Immunoblotting of hepatic microsomes showed that the content of CYP1A in fish at oiled sites was up to 6-fold greater than that in reference site fish. Fish injected with the CYP1A inducer beta -naphthoflavone showed a 70-fold induction of CYP1A, to levels six times the highest level seen in the field. To model the field exposure, fish were maintained over oiled sediments and/or fed amphipods collected from an oiled site. Hepatic microsomal CYP1A was induced 49-fold in fish exposed to oiled sediments but rapidly returned to control levels after fish were removed from oil exposure. Immunohistochemistry showed CYP1A induction in multiple organs. CYP1A staining in hepatic and some extrahepatic cells was highly correlated (r^2 greater than or equal to 0.95) with the hepatic CYP1A content detected by immunoblot. Oiled food induced CYP1A most strongly in intestinal mucosal epithelial and endothelial cells. Relatively low levels of CYP1A were observed in liver, gill, and gonad of fish exposed to oil through the diet, consistent with the metabolism of dietary hydrocarbons by intestinal CYP1A. Exposure to oiled sediment alone

strongly induced CYP1A in endothelial cells in all organs examined. Thus, oil present in Prince William Sound sediments more than 1 year after the spill was able to induce CYP1A in intertidal fish. The caging and laboratory experiments indicate that the induction of CYP1A observed in field specimens of A. purpurescens from oiled sites was due primarily to persistent spill-derived hydrocarbons.

Wooley, C. and J. Haggarty (1995). Archaeological site protection: An integral component of the Exxon Valdez shoreline cleanup. Exxon Valdez Oil Spill: Fate and Effects in Alaskan Waters. P. Wells, J. Butler and J. Hughes, ASTM, Philadelphia, PA (USA): 933-949.

A major cultural site identification and protection program in Prince William Sound and the Gulf of Alaska was conducted as part of the Exxon Valdez spill response. In cooperation with state and federal agencies and Native corporations with historic preservation mandates, the four-year program was designed to identify archaeological sites in the area of the spill, determine the effect of planned cleanup on them, and mitigate impacts to sites during cleanup. Archaeological site protection constraints, augmented by an extensive cultural resource training program, were an integral part of each shoreline-specific cleanup plan. As a result, impacts attributable to the cleanup were limited to minor disturbances and two vandalism incidents. Impacts from oiling were minimal largely because most intertidal cultural sites had lost their fragile constituents and contextual integrity as a result of prespill erosion. State and federal studies confirmed the efficacy of the site identification and protection program, finding negligible impacts attributable to either direct oiling or the cleanup at intact sites. The Cultural Resource Program also developed innovative management strategies with implications for future emergency responses involving complex land management and site protection issues. The program greatly enhanced the knowledge of the area's history by collecting and synthesizing considerable new archaeological information.

Worth, G. and T. Miculka (1997). Proximate Composition and Fatty Acid Signatures of Selected Forage Fish Species in Prince William Sound, Alaska. Exxon Valdez Oil Spill Restoration Project 95121, National Oceanic and Atmospheric Administration, DOC: 38.

The proximate composition and fatty acid signatures of several prey species, which are important for sea birds and marine mammals in Prince William Sound, Alaska, were determined. Fish were collected as part of the SEA cruises in the fall of 1995 and were frozen immediately and then shipped to Galveston for analysis. Fatty acid signatures of herring, pollock, and tomcod were consistent with previously reported data, Three different species of sole (English, rock, and flathead) were also consistent with previously reported data for yellowfin sole. Detailed analyses of individual rock fish suggest that this species may exhibit trends in some specific fatty acids (20:5 n-3, 22:6 n-3) which differ from herring or pollock.

Woytowich, D., C. Dalrymple, et al. (1993). "Electrocoagulation (CURE) treatment of ship bilgewater for the U.S. Coast Guard in Alaska." Marine Technology Society Journal **27**(1): 62-67.

A wide variety of contaminants (i.e., heavy metals, suspended solids, colloids, oil) have been successfully removed from wastewater using various electrocoagulation systems. An innovative electrocoagulation system developed by Cleanup and Recovery (CURE) Corporation is described. The results of a field study for the U.S. Coast Guard (USCG) to treat 176,200 liters of bilgewater from two abandoned ships, La Pocena and Incentive , are presented. The CURE process was effective in removing oil and heavy metals (aluminum, boron, iron, and zinc) with removal efficiencies ranging between 71 and 99 percent. The mobility of the CURE equipment eliminated the need to transport the ship bilgewater for treatment off the island, which resulted in an estimated 90 percent (U.S. $185,000) cost savings.

Wright, B. A. (1999). The Alaska Predator Ecosystem Experiment (APEX): An integrated seabird and forage fish investigation, PICES Press.

Zador, S. and J. Piatt (1998). "Time-budgets of common murres at a declining and increasing colony in Alaska." Condor **101**: 149-152.

We observed Common Murres (Uria aalge) at two breeding sites in lower Cook Inlet, Alaska, to determine whether food availability was reflected in their time-budgets at each colony. Catches of forage fish in nets and relative biomass were greater around a murre colony that has been increasing for the past 25 years than around a colony that has been decreasing over the same time period. Murres spent much more time "loafing" on their breeding ledges at the increasing colony, particularly during the incubation period and during evening hours. However, there was little or no difference between colonies in chick feeding rates, chick growth rates, or productivity. It appears that murres at the declining colony devote more time to foraging and have less discretionary time ashore. Because this had little apparent affect on their ability to feed and rear chicks, the population decline must be due to other factors. In any case, attendance time-budgets provide a more sensitive index of food availability than other breeding parameters at murre colonies.

Zarnke, R., T. Harder, et al. (1997). "Serologic survey for phocid herpesvirus-1 and -2 in marine mammals from Alaska and Russia, 1978-1994." Journal of Wildlife Diseases **33** (3): 459-465.

Blood samples were collected from 1,042 marine mammals off the coast of Alaska (USA) and Russia during the period 1978 to 1994. Eight species of pinnipeds were represented. Sera were tested for presence of neutralizing antibodies to both the PB84 isolate of phocid herpesvirus-1 (PhHV-1) and the 7848/Han90 strain of phocid herpesvirus-2 (PhHV-2). Species-specific antibody prevalences ranged from 22% to 77% for PhHV-1 and 11% to 50% for PhHV-2. Species-specific antibody prevalences for PhHV-1 were greater than or equal to

prevalences for PhHV-2. For both viruses and each host species, differences in antibody prevalences were not related to: (1) sex, (2) location of capture, or (3) year of collection. Antibody prevalence of PhHV-1 in walruses (Odobenus rosmarus) could be quantitatively predicted as a function of age. These two viruses have distinct biological properties and based on current data the epizootiology of the two viruses is different, as well. No evidence of herpesvirus-induced mortality has been detected in areas included in this survey. Based on results of this survey, neither PhHV-1 nor PhHV-2 are considered significant mortality tatters in mammals which inhabit the marine environment off the coast of Alaska or Russia.

Zeisler, R., R. Demiralp, et al. (1993). "Determination of inorganic constituents in marine mammal tissues." Science of the Total Environment **139-140**: 365-86.

Analyses of selected tissues from the Alaska Marine Mammal Tissue Archival Project (AMMTAP) have provided comprehensive information related to levels of 36 trace elements and methyl-mercury in marine mammal tissues. Liver, kidney and muscle tissues from two northern fur seals, four ringed seals and six belukha whales were analyzed. The bulk of the investigated tissues and additional tissues from a total of 65 marine mammals are banked in the AMMTAP. The results are compared to literature values for trace element concentrations in marine mammal tissues and their relevance to environmental studies is discussed.

Zenteno-Savin, T. and M. Castellini (1998). "Plasma angiotensin II, arginine vasopressin and atrial natriuretic peptide in free ranging and captive seals and sea lions." Comparative Biochemistry and Physiology **119C**(1): 1-6.

We used radioimmunoassay methods to quantify arginine vasopressin (AVP), atrial natriuretic peptide (ANP), and angiotensin II (Ang II) in plasma samples from harbor seals (Phoca vitulina richardsii), Weddell seals (Leptonychotes weddellii), northern elephant seals (Mirounga angustirostris), ringed seals (Phoca hispida), California sea lions (Zalophus californianus), and Steller sea lions (Eumetopias jubatus). Plasma concentrations of AVP, ANP, and Ang II in these pinniped species were within the ranges reported for other vertebrates under resting conditions. However, there were species, geographic and developmental variations in these hormones: Levels of AVP in plasma samples from adult Steller sea lions and harbor seals were higher than in pups of the same species; higher levels of plasma ANP were found in wild captured Alaskan Steller sea lions and in hunted ringed seals; differences in plasma levels of all three hormones were found throughout the geographic distribution of harbor seals and Steller sea lions in Alaska. This is the first report on circulating concentrations of vasoactive hormones in pinnipeds, and demonstrates that further studies are needed to ascertain the natural variability in these levels with the impact of molting, fasting, diving and environmental factors in seals and sea lions.

Zenteno-Savin, T., M. Castellini, et al. (1997). "Plasma haptoglobin levels in threatened

Alaskan pinniped populations." Journal of Wildlife Diseases **33**(1): 64-71.

We evaluated the plasma concentration of the acute phase protein haptoglobin (Hp) from Steller sea lions (Eumetopias jubatus) and harbor seals (Phoca vitulina) in regions of Alaska (USA) where the populations of these pinnipeds were declining and compared the values with concentrations of Hp from the same species in areas where the populations were stable. Samples were collected from 1992 through 1994 at sites in Southeast Alaska, Prince William Sound, the Gulf of Alaska, and the Aleutian Islands. Significantly higher levels of Hp were found in the samples from the areas of decline compared to those from stable populations. Based on these findings, we propose that one may be able to distinguish these compromised pinniped populations using Hp as a biomedical indicator.

Zimmerman, S., C. Gorbics, et al. (1994). Response activities. Marine Mammals and the Exxon Valdez. T. R. Loughlin. San Diego, California, USA; London England, UK., Acadmeic Press, Inc.: 23-45.

At approximately 12:04 am on March 24, 1989, the oil tanker Exxon Valdez ran aground on Bligh Reef in Prince William Sound (PWS), Alaska, resulting in the largest oil spill to date in United States waters. Approximately 11 million gallons of the approximately 62 million gallons of oil on board were spilled from the tanker during the days following the spill. Federal and state agencies and the oil industry immediately began sending response personnel to Valdez. Initial objectives were to determine the extent of the oil spill and identify resources, including marine mammals, that were at risk. When the oil spread to waters outside PWS, these agencies expanded their efforts to include the Gulf of Alaska, lower Cook Inlet, the Kodiak Archipelago, and the Alaska Penninsula. In this chapter we summarize response activities by the Trusteee agencies resulting from the spill.

Sections: The Regulatory Framework for Response; Start-up Problems; Initial Surveys; Response Activities Supporting the FOSC; Wildlife Rescue and Rehabilitation; Collection and Disposal of Dead Animals; Initial Decisions Regarding Assessment Studies.