Exxon Valdez Oil Spill

Restoration Project Final Report

Testing Electronic Archival Tags in Pacific Salmon

Restoration Project 02404

Final Report

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Study History: This project began with acceptance of the 2-year study plan by the Trustee Council in FY 2000. Funds were provided to test the feasibility of tagging juvenile coho salmon with beta-test archival tags from LOTEK Marine Technologies that measure temperature, pressure, and light at pre-assigned intervals. Recorded data are then available after the recovery of the tags from the fish. The project was designed to evaluate the effects of tagging hatchery produced pre-smolt coho salmon and the feasibility of collecting habitat data on marine migrations after tag recovery from adult fish approximately 18 months after coho smolt releases, 2001- 2003.

Abstract: This study examined the feasibility of tagging juvenile coho salmon (*Oncorhynchus kisutch)* with archival tags (model LTD_1110, LOTEK Marine Technologies, Inc.) and investigated their effectiveness in collecting data on marine migrations for adult salmon. Sixty dummy archival tags of similar weight and size were used in 2001 (active tags were not yet available from the manufacturer). Active archival tags (N = 179) that collected temperature and pressure data were surgically implanted in pre-smolt coho in 2002. Secondary marks (visible implant and PIT tags) were also used to assess potential tag loss and document recovery probabilities with larger sample size. Soft visible-implant (VI Alphanumeric) tags were applied to 227 coho in 2001. Passive integrated transponder (PIT) tags with individual identification were applied to 297 coho in 2002. Dummy and active archival tags were surgically implanted into the peritoneal cavity of coho pre-smolts (range 180-228 mm fork length) in both years. Post-implant surgery survival rate (in hatchery conditions up to four weeks) equaled 97%. Seven fish died in less than 48 hours post-surgery and one fish died approximately five days following tag implant surgery. Necropsies showed surgical error to be the cause of six tagged coho deaths. No cause of death could be determined for the remaining two. In 2001, 57 surviving coho were released with dummy archival tags and secondary VI tags and 227 additional coho received only VI tags. Tagged fish were combined with non-tagged pre-smolts of the same year class in the hatchery prior to transport to the smolt release site at Elmendorf Hatchery on Ship Creek. In 2001, 284 tagged coho were volitionally released along with approximately 230,000 coho salmon smolts released by Alaska Department of Fish and Game (ADFG). From the 2001 release, two dummy archival tags (3%) and four additional VI tagged adults (2%) were collected among the 2002 coho adult returns. A third dummy archival tag (2001 release) was found on a gravel bar immediately below the release site in 2003. It is not known if this tag was from an emigrating juvenile or a returning adult that passed through the weir unnoticed. In 2002, 174 active archival/PIT tagged and 297 PIT tag only coho salmon were released in unison with approximately 212,000 ADFG coho smolts. From the 2002 release, two adult fish (1%) carried

PIT tags that indicated loss of their respective archival tags at some point after release. One PIT-tagged adult fish (0.3%) was recovered in August 2003 in the weir trap at the mouth of Ship Creek. Four active archival tags were recovered in 2002-2003 (2%), presumably following predation during outmigration. These four tags contained a complete data archive from the time of implant until tags were recovered. Three tags were recovered from building roofs along Ship Creek near bird nests and one was recovered on a gravel bar below the release site. Data from the three roof-top tags clearly defined hatchery conditions, transfer to release site, residence in Ship Creek, and large temperature and pressure fluctuations after putative predation. No active archival tags were recovered in 2003 from adult coho, however that year's adult returns for all coho stocks in Cook Inlet, tagged and non-tagged, were exceptionally low.

Key Words: Archival tags, coho salmon, *Oncorhynchus kisutch*, pre-smolt, hatchery, predation.

Project Data: Results from this study were compiled from ADFG hatchery information, implant procedures and results, archival tag specifications, and recovered tags. Access to available data is made by arrangement with the principal investigator or agency.

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MEMORANDUM STATE OF ALASKA

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To: Brenda Hall
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From: Robert Clark, Fisheries Scientist I
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Subject: Review of final report for project 02404 ***Date*** 13-Apr-05
File

I have finished my review of the final report for EVOS Restoration Project 02404 entitled "Testing electronic archival tags in Pacific salmon." According to the email sent requesting peer review, there are five questions to be initially answered:

1. *Is the document in professional editorial order? (grammar, formatting, display of tabular and graphic information, use of literature citations to justify arguments)*
   Yes, the document is in professional editorial order.
2. *Does the document explain its objectives, and*
   The objective of the study was to "determine the feasibility of tagging juvenile salmon with small archival tags containing temperature, pressure and light sensors and investigate the effectiveness in collecting marine habitat data" This objective was explained adequately in the report.
3. *Does it meet its objectives?*
   As far as determining the feasibility of using archival tags on juvenile coho salmon, the report accomplishes this objective.
4. *Is the document a reasonably coherent permanent record of the work performed for the Trustee Council?*
   Yes.
5. *In view of the answers to 1 – 4 should the document be accepted with or without revision? If the document needs revisions, please be sure these are clear in the responses to 1 – 4.*
   The document can be accepted with minor editorial revision; no major revisions are necessary. There are some small inconsistencies in the use of the word "coho" to denote "coho salmon" and a minor inconsistency in reporting of weight of archival tags in air (4.8g in the executive summary and 5g on page 5 of the report).

Feel free to contact me if you have questions on my review. Thank you for the opportunity to review this material.

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EXECUTIVE SUMMARY

Technological advances have enabled the production of small archival data-storage tags that could potentially be implanted into the body cavity of pre-smolt salmonids and collect data on temperature, pressure, and ambient light for up to 18 months. Data collected from these archival tags could be used to provide previously unavailable information on vertical movements and preferred ambient water temperatures of individual fish, plot movement patterns in marine environments by producing geolocation estimates from light data, and identify important marine habitats for salmonids.

Hatchery coho grown by the Alaska Department of Fish and Game at Fort Richardson Hatchery, located eight kilometers upstream from the mouth of Ship Creek in Anchorage, Alaska, provided a unique opportunity to test this new technology. Unlimited fresh water heated by a power plant allowed an accelerated growth program for select hatchery coho to achieve a minimum 180 mm fork length (FL) prior to archival tagging and subsequent smolt release. In 2001, 57 (95%) coho juveniles surgically implanted with dummy archival tags survived for up to two weeks in the hatchery prior to release. These tags mimicked the approximate size and weight of active archival tags – no active archival tags had been manufactured yet. Mean dummy tag mass was slightly heavier (6.8 g in air) compared to active tags used in 2002 (4.8 g in air). Visible Implant (VI) tags with individual color and numeric codes were used to tag an additional 227 fish in 2001. However, only 69% of the VI tags remained on fish following a four-week period in hatchery conditions. Two mortalities occurred in 2002 within 24 hours and one between day six and seven following archival tagging procedures (5%).

In 2002, 179 juvenile coho salmon were implanted with active archival tags and 174 (97%) survived for up to four weeks in the hatchery prior to release. Passive Integrated

Transponder (PIT) tags (N = 476) were used to identify individually marked coho salmon in that year's smolt release. Model LTD_1110 archival tags, (LOTEK Marine Technologies) were used in 2002. These tags were cylindrical, measured 32 mm in length and 11 mm in diameter and were equipped with a non-active 5 cm flexible Teflon light stalk or antenna (LOTEK's light sensor technology was still unavailable at that time). Five mortalities occurred in 2002 within 48 hours of archival tagging procedures (2.8% total mortality). Necropsies showed surgical error to be the common cause of death in archival-tagged coho in both years.

Mean fork length (FL) and weight of archival-tagged fish over both years were 194 mm and 89 g, resulting in a 4-9 % tag-to-body weight ratio and a 14 – 18% tag-to-fish length ratio. All surviving tagged fish resumed normal feeding and schooling behavior 24 hours post surgery. Surviving study fish were transferred from indoor rearing tanks to a covered outdoor raceway located along Ship Creek during the last week in May 2001 and 2002. Tagged fish were held in unison with all other hatchery coho salmon from their year-class for 3-6 days before release and volition downstream movement from the raceway into Ship Creek.

The recovery of VI, PIT, and archival-tagged adult coho returning to Ship Creek included examination of commercial and sport fishery catches, daily monitoring of the Ship Creek weir trap during the period of adult returns, and public outreach efforts. From the 2001 tagged-coho release, two adult dummy archival-tagged fish (3%) and four adult VI Alpha-tagged fish (2%) were recovered in July and August 2002. The archival-tagged salmon, both males, were caught in the sport fishery during August. Both tags were reportedly found completely within the body cavity, i.e., the tags' light stalks had migrated within the body cavity. From the 2002 tagged-coho release, two adult fish (1%) were found to have lost their archival tags, but retained PIT tags that indicated archival-tagged individuals, in July and August 2003. One fish was a female recovered by an angler who reported seeing sutures but only recovered a PIT tag during a search of the body cavity (see Cooke et al. 2003). The other was a male fish recovered in the fish trap with no apparent wounds or scar tissue present to indicate a tag-expulsion location.

Four active archival tags were recovered (2%), presumably from predation during outmigration in 2002. The four tags contained a complete data archive from the time of implant until tags were recovered. An angler found one tag just upstream of the Ship Creek fish trap on an exposed gravel bar in August 2002. The three remaining tags were found on building rooftops along Ship Creek that are known herring gull nesting sites. One rooftop recovery was

made in June 2002. The remaining two were found in April and July 2003. Data from the rooftop recovered tags clearly defined hatchery conditions, transfer to release site, residence in Ship Creek, and large temperature and pressure fluctuations following removal from the fish. Although we recovered two dummy-archival tags from returning adult coho salmon in 2002, the percent of returning adult tagged coho (3%) was significantly below the overall Ship Creek hatchery returns (12-15%) for that year. No active archival tags were recovered from adult coho in 2003, but returns throughout Cook Inlet were at low levels. The overall Cook Inlet commercial harvest of coho was the lowest since 1972 (101,756 fish). 2003 was also an anomalous year with regard to the contribution of hatchery fish to the escapement (5%) with a previous mean of 12-30% (Dan Bosch, ADFG, personal communications). We passed 4225 adult coho at the Ship Creek weir trap in 2002, and only 1143 coho adults in 2003.

This study demonstrated that intraperitoneal implantation of archival tags representing 4-9% body weight can be used to successfully tag juvenile coho salmon greater than 180 mm FL in the hatchery environment. A 97% survival rate was obtained in coho held for up to 34 days in hatchery conditions and fish appeared to have no adverse affects after implantation of archival tags. Recovery of archival tags from adult coho were less successful in this study with only two dummy archival tags recovered from the sport fishery on Ship Creek. Evidence of archival tag loss to predation, archival tag expulsion from adult coho and variation in year-to-year survival for Cook Inlet coho runs during this study made it difficult to recommend further field applications for these tags in juvenile salmon until further studies on archival tag retention, tagged-fish behavior, and factors contributing to marine survival are completed.

Introduction

Although Pacific salmon (*Oncorhynchus* spp.) life histories have been studied extensively (Groot and Margolis 1991), the distribution and habitat use of juvenile and adult Pacific salmon in near-shore and ocean ecosystems remain poorly understood. Understanding the marine distribution of Pacific salmon over time and space and defining important marine habitats are critical to harvest management decisions and the conservation of Pacific salmon. Understanding marine migrations and critical saltwater habitats for Pacific salmon in Alaska will help determine the role they play in marine food webs and may define factors leading to a better understanding of ocean carrying capacity in the North Pacific Ocean.

The marine ecosystem imposes severe constraints on the type of tags that can be used to monitor the behavior of fish in this environment. Seawater is highly conductive and radio waves do not propagate very far through this medium. Remote sensing technologies have been used to study fish in marine environments for over 30 years. The oldest approach to tracking fish in saltwater, acoustic telemetry has a long track record (Priede 1986), but only a few studies involving juvenile salmon have been done in the Atlantic Ocean (Voegeli et al. 1998) and Pacific Ocean (Candy and Quinn 1999). Arnold and Dewar (2001) recently published a synthetic review of early electronic tagging in marine environments. To date, open-ocean mark-recapture studies (Myers et al. 1996), coded wire tag recoveries (CWTs; Pearcy and Masuda 1987), ultrasonic telemetry (Ogura 1999), experimental fisheries (Pearcy and Fisher 1988), cumulative harvest data (Welch et al. 1995), and acoustic telemetry (Quinn et al. 1989) have provided most of the available knowledge on Pacific salmon ocean habitat utilization. Recently developed pop-up archival data-storage tags use to record ocean movements in large pelagic fishes (Block et al. 2001a and b; Brill and Lutcavage 2001; Seitz et al. 2002) are too large and heavy for implementation on Pacific salmon (Boehlert 1997).

These techniques, however, leave large gaps in our knowledge of fish distribution, behavior and migration. High seas mark-recapture and CWT studies provide detailed data from release and recovery locations primarily after harvest, but do not explain any activity outside of the tag and recovery points or the fate of the fish not recaptured. Acoustic tags provide a glimpse of where

fish are for a short interval as they pass through the reception field (Walker et al. 2000) and acoustic arrays have been proposed to document coast-wide salmon movement and direction of travel in estuarine and coastal ocean environments (Welch et al. 2002 and 2003). Salmon have been successfully tracked on the high seas using acoustic tags and receivers mounted on vessels, however, the signal is typically lost in a few days and vessel time is expensive limiting sample size in these experiments (Madison et al. 1972; Quinn et al. 1989; Candy et al. 1996). Passive integrated transponder (PIT) tags have been used to monitor the movements of juvenile salmon in estuarine environments (Muir et al. 2001). Despite these findings, to date no tag technology has provided an integrated platform for the long-term study of Pacific salmon life histories in saltwater environments.

Recently developed electronic data storage, or archival, tags offer many advantages over the aforementioned tracking techniques and have provided new insight into the migratory behavior and habitat use of Pacific salmon on the high seas. Over the last decade, temperature and/or depth recording archival tags have been used to document salmon behavior in marine environments (Friedland et al. 1998; Ishida et al. 2001). Data-storage tag size has limited application to adult salmon captured on the high seas (Walker et al. 2000 and 2001, Murphy and Heard 2002). Natural marine mortality of Pacific salmon is thought to be highest during the first year at sea, and the effects of tagging are a critical part of survival and recruitment in any study of salmon behavior and marine migrations (Hartt 1980; Holtby et al. 1990; Pearcy 1992; Coronado and Hilborn 1998, Beamish et al. 2004).

Archival tag technology applied to Pacific salmon limited to temperature and/or pressure (depth) data leave gaps in our knowledge of distribution and migration patterns. Exact or approximate fish location is difficult to decipher using only these two variables. More recently, archival tags applied to a variety of large pelagic fish species, including tunas, sharks, and billfish have incorporated temperature, pressure and light probes. A continuous record of light level provides basic geolocation estimates using various algorithms with an average error of 1.2° of latitude and 0.9° longitude (Hill 1994; Welch and Eveson 1999; Hill and Braun 2001). These additional data have provided detailed temporal and spatial coverage of pelagic fish movements over large expanses of marine habitats (Block et al. 2001a and b; Holland et al. 2001; Graves et al. 2001).

Technological advances have enabled the production of smaller archival tags (11 mm x 32 mm, 4.8 g in air - LOTEK Marine Technologies) that could potentially be implanted into the body cavity of pre-smolt salmonids and collect data on temperature, pressure, and ambient light for up to 18 months. Data from these archival tags could be used to describe vertical movements, preferred ambient water temperature, plot marine migrations using geolocation estimates from light data, and identify important marine habitats. Such data could also be used to describe how salmonids respond to episodic events such as El Nino, periodic shifts in climate patterns, and pervasive changes such as global warming (Walker et al. 2000). Understanding how salmon respond to these physical and environmental factors will not only aid in predicting changes in the abundance and distribution of salmon, but will provide better information on salmon behavior and ecology in marine environments.

This study was the first attempt to test the application of this new tag technology in juvenile Pacific salmon using LOTEK's model LTD_1110 archival tags. Our objective was to determine the feasibility of tagging juvenile salmon with small archival tags containing temperature, pressure and light sensors and investigate their effectiveness in collecting marine habitat data. We selected coho salmon (*Oncorhynchus kisutch*) in Ship Creek, Anchorage, Alaska as the test animal because of established hatchery rearing success at the Fort Richardson Hatchery, Alaska, where hatchery coho are released into Ship Creek, and the average high rate of coho adult returns to Ship Creek. We were able to accelerate growth of these coho in hatchery environments to test the impacts of tags on a variety of pre-smolt fish sizes. These coho experience a short marine residence (up to 18 months). They support small commercial fishery and an intensive sport fishery on Ship Creek and must pass through a weir near the mouth of Ship Creek upon their return as adults – all of these factors contributed to our expectation for tag returns. All adult coho returning to Ship Creek that are not captured in the fishery must pass over a fish weir near the mouth of Ship Creek where visual and instrumented surveys for tagged fish were made on each individual.

Methods

Study Area

The Alaska Department of Fish and Game (ADFG) Fort Richardson Hatchery is located eight kilometers upstream from the mouth of Ship Creek in Anchorage, Alaska. Ship Creek drains into Cook Inlet that connects to the Pacific Ocean. Approximately 200,000 juvenile coho salmon smolts are released annually into Ship Creek. Surviving coho adults return to Ship Creek after 14 to 16 months at sea. The hatchery uses water warmed by a power plant, which allows year-round operation and accelerated fish growth. An impassible dam is located one mile upstream from Cook Inlet and all adult fish returning to the hatchery pass through a fish trap, where they are counted and released upstream of the dam. (ADFG 2001, 2002)

Hatchery Rearing

An accelerated growth program for hatchery coho was started on January 4, 2001 to achieve a large number of coho with a minimum 180 mm fork length (FL) prior to archival tagging. This size threshold was set based on LOTEK's archival tag size specifications and a review of the existing literature on tag-to-fish wet weight and length ratios (primarily derived from acoustic tag studies) and effects of tag implementation on swimming performance and predator avoidance (Brown et al. 1999; Perry et al. 2001; Anglea et al. 2004; Lacroix et al. 2004). In 2001, a study group of 300 juvenile hatchery coho salmon from the Fort Richardson Hatchery were moved from a concrete outdoor raceway into two indoor circular, fiberglass holding tanks (0.81 m^3) and supplied with circulating well water at a rate of 19 liters per minute. The water temperature was gradually increased from 3°C to 14°C over three days and subsequently maintained at a mean of 11.9°C (S.D. ± 2.3°C) for the duration of the rearing period (139 days). Fish were fed commercial pellets daily to satiation using automatic feeders. Periodic weight (g) and fork length (FL) measurements were taken throughout the rearing period to monitor growth of tagged fish (Nielsen 2002).

In 2002, a study group of 500 juvenile coho salmon were selected from the Fort Richardson Hatchery and subjected to the same rearing practices used in 2001. However, due to decreased availability of warm water and the increased number of fish, the accelerated growth program was

started approximately six weeks earlier, on November 22, 2001. Mean rearing water temperature (±S. D.) in 2002 was 8.5°C (±0.5°C) for 182 days.

Tagging

All tagged fish were adipose fin clipped. However, 10% of all hatchery fish were also adipose clipped at the hatchery for coded wire tagging, thus another marker was needed to identify study coho returning to Ship Creek as adults. Secondary marks were used to identify returning adults, increase tagging sample size, and assess archival tag loss (Table 1). Visual Implant Alphanumeric tags (VI Alpha; Northwest Marine Technology Inc.) were applied to study fish in 2001 when they reached 150 mm FL. Fish were anesthetized in 50-mg/L eugenol (clove oil) and the tags were injected with a modified syringe under the clear adipose eyelid. Each VI Alpha tag was color and numerically coded, thus permitting visual identification of individual fish. However, only 69% of the VI tags were retained during a four-week period in hatchery conditions.

In 2002, Passive Integrated Transponder tags (PIT; Biomark Inc.) were used to identify individual coho salmon due to VI Alpha tag retention problems in 2001. PIT tags were injected into the body cavity of anesthetized coho salmon greater than 65 mm using a sterile syringe and a 12-gauge needle. In total, 287 VI Alpha tagged and 476 PIT tagged fish remained in the study group in 2001 and 2002, respectively.

Dummy archival tags (N = 60) were implanted in 2001. These tags mimicked the approximate size and weight of LOTEK' s active archival tag prototypes – no active tags had been manufactured yet. Dummy tags were identical in shape and form to functioning archival tags except the battery and electronics were replaced with lead shot. Mean dummy tag mass was slightly heavier (6.8 g in air) compared to the active archival tags (5 g in air) used in 2002.

Beta-test archival tags were obtained through a special arrangement between the PI and LOTEK Marine Technologies; their small archival tags were not commercially available to the public until 2003. One hundred seventy nine active archival tags (model LTD_1110, LOTEK Marine Technologies) were used in 2002. These tags were cylindrical, measured 32 mm in length and

11 mm in diameter and were equipped with an inactive 5 cm flexible Teflon light stalk or antenna. Data sensors for temperature and depth were active, but technological problems delayed LOTEK's application of a light sensor in these early prototype beta-tags. Dummy light stalks were used to mimic required surgical procedures and test surgical protocols for exterior position of the antenna in relationship to tag location in pre-smolt coho.

Data from LTD_1110 archival tags are stored in 32 Kb of non-volatile EEPROM memory using Time Extension Recording (LOTEK Marine Technologies). Study data were downloaded from active tags through a light-emitting diode to an optical reader attached to a host computer. Active tags were equipped with temperature and pressure sensors programmed to collect data from each sensor at approximately seven-minute intervals for up to 180 days (archive tag #1496). Tags had a 3-year battery life.

Archival tags were surgically implanted from May 5-21, 2001 and from April 22 to May 7, 2002 using techniques similar to those given in Summerfelt and Smith (1990) and Mulcahy (2003). Fish were not fed 24 hours before or after surgery. Hatchery coho exceeding 180 mm FL were anaesthetized in a 50-mg/L eugenol bath solution until loss of equilibrium and reflex reaction (Anderson et al. 1997; Small 2003). Fork length (mm) and weight (g) were recorded and the adipose fin was clipped. A surgical v-board was used to support fish while the gills were ventilated with a dilute eugenol solution (10-mg/L) supplied from a tube inserted into the mouth. A topical antiseptic, chlorhexidine diacetate, was used at the incision point followed by a 2.0 cm incision made anterior to the tip of the pelvic girdle on the midventral axis. A 2.5 cm 16-gauge disposable needle was then inserted slightly posterior and below the incision and used to guide the light stalk through the body wall. The tag was inserted and gently massaged into position such that the tag was contained within the peritoneal cavity anterior to the pelvic girdle and the light stalk protruded through the fish's side, pointing posteriorly. A 3-0 polypropylene non-absorbable cutting suture was used to close the incision with four simple interrupted sutures. Sterilized surgical packs, surgical gloves, and tags were used for each fish. Post surgery, fish were immediately placed into a bath of flowing fresh water until equilibrium was regained and fish were subsequently returned to the circular rearing tanks.

Release and Tag Recovery

All study fish were transferred from their indoor rearing tanks to a covered outdoor raceway located along Ship Creek during the last week in May 2001 and 2002. Tagged fish were held in unison with all hatchery coho salmon from their year-class for 3-6 days before release (volition downstream movement from raceway) into Ship Creek.

Recovery of VI, PIT, and archival-tagged fish returning to Ship Creek after marine residence included the following elements: examination of commercial and sport fishery catches; daily fish trap monitoring during the period of adult returns; and public outreach efforts. Informational posters and flyers describing the project and tag return information were sent out to local commercial fisherman, newspapers, and public radio stations as well as posted along Ship Creek's sport fishing grounds. Tag return information was printed on archival tags and a small reward was offered for tag recoveries through the Ship Creek Silver Salmon Derby. Daily efforts consisted of surveying sport anglers along the creek, checking and passing coho through the Ship Creek fish trap and checking with creek-side businesses for information of coho returns.

Results

Tagging

Tag recovery information for both years of this study are given in Table 2. Two mortalities occurred in our 2001 application of dummy archival tags within 24 hours and one between day six and seven following archival tagging procedures (fish were monitored daily in the hatchery). Necropsies showed surgical error (i.e., inadvertently damaging a vital organ) to be the common cause of death in tagged fish. The mean FL (± S. D.) and weight (± S. D.) of surviving archival-tagged fish were 198 mm (± 8.8 mm) and 93 g (± 10.8 g), resulting in a 6-9 % tag-to-body weight ratio (Table 3). Tagged fish resumed normal feeding and schooling behavior 24 hours post surgery.

In 2002, 179 of 476 PIT-tagged coho salmon were implanted with active archival tags and 174 (97%) survived for up to four weeks in the hatchery prior to release. Five mortalities occurred within 48 hours of surgery (Table 4). Necropsies showed surgical error to be the cause of three

deaths; no cause of death could be determined for the remaining two. The mean FL and weight of archival-tagged fish were 193 mm (± 8.6 mm) and 88 g (± 13.1 g), resulting in a 4-7% tag-to-body weight ratio. Tagged fish resumed normal feeding and schooling behavior 24 hours post surgery.

Release and Tag Recovery

2001 Release –2002 Recovery

In 2001, 57 dummy archival/VI Alpha tagged and 227 VI Alpha tagged coho salmon were released in unison with approximately 233,000 hatchery coho salmon. From the 2001 release, two adult dummy archival-tagged fish (3%) and four adult VI Alpha-tagged fish (2%) were recovered in July and August 2002. The two archival-tagged salmon were males caught in the sport fishery during August. Both tags were reportedly found completely within the body cavity, i.e., the tags' light stalks had migrated within the body cavity. These tags were discovered when the anglers processed their catch. A third dummy archival tag was found close to the release location during an ADFG stream survey of Ship Creek in July 2002. It is not known if the tag was from an emigrating juvenile or a returning adult that passed through the dam unnoticed which was possible due to the high rate of loss of VI tags in that year's coho study population. Of the four recovered VI-tagged fish, one female was caught in the sport fishery and two females and a male were found during daily fish trap surveys (Table 2).

2002 Release – 2003 Recovery

In 2002, 174 active archival/PIT tagged and 297 PIT tagged coho salmon were released in unison with 212,000 hatchery coho salmon. From the 2002 release, two adult fish (1%) were found to have lost their archival tags, but retained PIT tags that indicated archival-tagged individuals. These fish were caught in the Ship Creek fishery in July and August 2003. One fish was a female recovered by an angler who reported seeing residual sutures at the insertion location on the fish's belly. This angler only recovered a PIT tag during his search of the body cavity. The other coho was a male recovered in the fish trap with no apparent wounds or scar tissue present to indicate a surgery or tag-expulsion. One fish that was PIT-tagged only (0.3%) was also recovered. This adult, a female, was captured during a trap check in August 2003.

Four active archival tags were recovered (2%) in 2002 and 2003, presumably after predation during outmigration. The four tags contained a complete data archive from the time of implant until tags were recovered. The data clearly defined hatchery conditions, transfer to release site, residence in Ship Creek, and in tags collected from rooftops large temperature fluctuations following removal of the tag from the fish (Figure 1a). An angler found one tag just upstream of the fish trap on an exposed gravel bar in August 2002 where the data clearly indicate hatchery rearing conditions, transfer to release site and daily temperature fluctuations throughout the summer after transfer from the hatchery (Figure 2). Variations in tag #01496 temperatures recorded from mid-May to mid-August 2002 were below or equal to mean maximum stream temperatures (15.6^{o} C) monitored by the USGS Water Resources Division, Alaska Science Center in geographically adjacent Campbell Creek (no stream temperatures were monitored on Ship Creek during the study period). It is impossible to stipulate, however, if this tag was in or out side of a fish during any part of this record.

The three remaining tags were found on building rooftops along Ship Creek that are known herring gull (*Larus argentatus*) nesting sites. It is assumed that gulls transported these tags to the rooftop. Gulls tend to ingest small fish prey whole and regurgitate their prey at the nest where their young peck at the food items (Tinbergen 1960). Herring gulls along Ship Creek maintain nest throughout the summer and can be seen actively feeding on coho smolts at the mouth of the creek following coho smolt releases. One of the rooftop tags was found in June 2002 and two in April and July 2003.

All four recovered archival tags provided pressure data (psi) as well as temperature data for the period they were in the field (Figure 3). Since all four tags recorded pressure (depth) in freshwater habitats before the fish moved into deeper habitats available in saltwater, depth records provided little additional information. Once the pressure sensors were out of the water the data varied in a manner similar to temperature. For example, tag #1496 on July 2002 registered a psi of 2.7-3.0, roughly equivalent to about 3m depth in a correlation developed before tag deployment. At same time, however, the tag showed a temperature record ranging from 9.7^{o}-12.4^{o} C, probably recording air temperatures and not warm water at depth.

Year-to-year Summary

Due to our accelerated growth program, mean fish size and weight of the study coho were significantly larger (t-test $p < 0.0001$; SAS 2000) from the mean sizes of coho in the general hatchery release for both years (Table 3). ADFG suggests that in general each year Ship Creek hatchery coho are distributed with 73% harvested by sport fish, 21% harvested by commercial fish, and a 6% escapement to Ship Creek weir. Under these conditions with an average spawning escapement to the weir with a smolt-to-adult escapement of 12%, we would expect to see no archival-tagged fish at the trap, five archival-tagged fish caught in the sport fishery and one in the commercial fishery (we released 57 tags in 2001). In 2002, we recovered two dummy archival tags in the sport fishery, suggesting a bias in tagged fish survival and/or difficulty in identification and recovery of tagged fish. Recovery results for 2003 were even lower, reinforcing the fact that there was lower that expected survival in tagged fish.

Although we recovered two dummy-archival tags from returning adult coho salmon in 2002, the percent of returning adult tagged coho (3%) was significantly below the overall Ship Creek hatchery returns (12-15%) for that year. No active archival tags were recovered from adult coho in 2003, but returns throughout Cook Inlet were at exceptionally low levels. The overall Cook Inlet commercial harvest coho was the lowest since 1972 (101,756 fish). 2003 was also an anomalous year with regard to the contribution of hatchery fish to the escapement (5%) with a previous average contribution of 12-30% (Dan Bosch, ADFG, personal communications). We passed 4225 adult coho at the Ship Creek weir trap in 2002, and only 1143 coho adults in 2003.

Discussion

Potential tag and tagging effects

Surgical implantation is regarded as the best method for long-term tagging studies (Winter 1983). This study demonstrated that intraperitoneal implantation of archival tags representing 4-9% body weight can be used to successfully tag juvenile coho salmon greater than 180 mm FL in the hatchery environment. A 96.7% survival rate was obtained in coho held for up to 34 days in hatchery conditions and all surviving fish appeared to have no adverse effects following implantation. We minimized adverse physical effects, such as reduced swimming performance, growth, feeding, and predator avoidance, by using the smallest available tags in the largest

available fish (Brown et al. 1999), and adopting careful and considered surgical methods with increased emphasis on sterilization (Mulcahy 2003). Surgical protocols used in this study were developed in collaboration with Dr. Scott McKinley at the University of Waterloo, Canada (currently at the University of British Columbia, Vancouver B. C.) and Dr. Dan Mulcahy, USGS Alaska Science Center veterinarian, experts in the field of fish veterinary science and surgery. Dr. Mulcahy also performed numerous tag implants on juvenile salmonids for this study. Tagged fish resumed active feeding 24 hours after surgery and no swimming impairment or detrimental physical effects were noted following recovery.

Tag-to-fish weight ratio (in air) is the most common index used to assess the physical effects of implanted tags on fish (Perry et al. 2001). Our 4-9% tag-to-body weight ratio was near the upper allowable threshold for implanted tags previously documented in similar size fish (McCleave and Stred 1975; Brown et al 1999). Surgical implants representing 2.2 – 5.6% of the fish's body weight have been reported as the preferred method for bio-telemetry studies of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) >10 mm FL. (Adams et al 1998). Although 6-9% tag-to-body weight ratios used in some fish in this study was at the upper end of accepted tagging thresholds, other tags of similar size surgically implanted in juvenile salmonids, including coho salmon, did not produce adverse physical effects in other studies. Radio tags 4.5-14.5% of fish body weight inserted into the stomach of juvenile coho did not significantly affect swimming performance, feeding, or aggressive behavior (Moser et al. 1990). This same study considered tags 9.5% of the mean body weight appropriate for coho salmon over 180 mm (Moser et al. 1990).

Anglea et al. (2004) found acoustic tags up to 6.7% body weight surgically implanted in juvenile Chinook salmon 122-198 mm FL did not significantly affect swimming performance and did not result in greater predation susceptibility when exposed to adult rainbow trout (*O. mykiss*). Moore et al. (1990) found juvenile Atlantic salmon (*Salmo salar*) 127-172 mm tagged with transmitters (17 mm in length and 7.5 mm in diameter) had no significant effect on growth, feeding or swimming behavior. Brown et al. (1999) also found no relationship between tag weight and swimming performance in juvenile rainbow trout (mean FL 88.9 mm ± 3.5) tagged with radio transmitters 6-12% of body weight and containing a 2.5 cm antenna. In their study of

interperitoneally implanted dummy transmitters on juvenile Atlantic salmon, Lacroix et al. (2004) recommended tag length of 16% or less in relationship to fish length. Lacroix et al.'s (2004) length criterion suggests that 61% of the implanted archival tags used in 2001 and 47% used in 2002 should have had no adverse physical effects based on tag and fish length at the time of implant. In both years, the study fish entered a period of rapid growth following tagging and by the release date all surviving fish with acoustic tags were within the general length and weight guidelines for surgical implants in fish.

Tagged coho in this study were artificially fed and held at warmer temperatures in the hatchery environment to increase growth in freshwater to obtain fish large enough to carry these tags. This additional growth made the average tagged fish much larger than their non-tagged cohorts. Archival-tagged study fish's (both years combined) mean FL equaled 194 mm (± 8.7), while hatchery coho smolts mean FL for the same period was 123 mm (± 8.8; D. Loopstra, ADFG personal communications). Larger coho are frequently dominant individuals and retain lighter coloration (Nielsen 1992). Tagged fish held in unison with other hatchery pre-smolts prior to volitional release in Ship Creek were visually larger and lighter in color than their untagged colleagues (JLN personnel observation). These factors may have influences tagged fish behavior and predation potential post-release.

Seven fish died within 24 hours and one fish died between day six and seven after archival tag implantation. Necropsies showed surgical error (i.e., inadvertently puncturing a vital organ) to be the cause of six of these deaths. No obvious cause of death was found in the two remaining fish, which all died within 24 hours. Physiological stressful conditions of tagging may have contributed to these three deaths. A similar tagging study found surgical implanting to be highly stressful for Chinook salmon smolts even several days after implantation, but the presence of a tag did not produce chronic stress in this study (Jepsen et al. 2001). Anesthesia (clove oil treatment) may not have been complete or effective in some proportion of the fish based on variation in initial fish weight or length (Woody et al. 2002; Kildae et al. 2003). The effects of isoeugenol (active ingredient in clove oil) are highly controversial with some arguments against its use in animals. Ingvast-Larsson et al. (2003) suggest that isoeugenol blocks neuromuscular transmission, producing paralysis in fish, but does not necessarily sedate or render the animal

unconscious leaving the animal with intact perception in afferent sensory nerves. Variation in the stress of surgical implantation of tags may reflect different levels of neuromuscular blockage and afferent sensory response.

A recent study by Small (2003) of plasma cortisol – a natural hormonal response to stress in fish – in channel catfish (*Ictalurus punctatus*) showed higher stress levels in fish anesthetized with clove oil (100 ppm) than fish anesthetized with quinaldine (30 ppm) or metomidate (6 ppm; see Bowser (2001) for discussion of various fish anesthetics). However, cortisol stress indicators were primarily post anesthesia effects since catfish cortisol levels treated with both metomidate and clove oil remained at baseline during 30 minutes of anesthesia (Small 2003). Sigismondi and Weber (1988) found that exposure to two or three consecutive stresses increased the delay in response time over that of a fish exposed to a single stress, indicating a cumulative stress effect. However, the fact that the majority of coho in this study did not demonstrate any observable response to the implant procedures and our high survival rate post-implant suggest surgical practices done under clove oil anesthesia were not excessively stressful.

Predation and Tag Loss

At least five of our archival-tagged fish were taken from the river before leaving Ship Creek. High natural mortality is common during smolt outmigration where predatory fishes, mammals, and bird species take advantage of a valuable food source (Schreck and Stahl 1998; Collis et al. 2001; Muir et al. 2001). Shreck and Stahl (1998) provided evidence that avian predation on radio tagged salmon smolts can be as high as 29%. More than 10,000 unique PIT tag codes previously implanted in juvenile salmonids, 1987-1999, were detected in piscivorous bird-nesting areas in the Columbia River (Ryan et al. 2001). Archival-tagged steelhead smolts were highly vulnerable to predation by eagles post-release on a stream study in British Columbia (B. Ward, Department of Fisheries and Oceans, Niniamo, B.C., personal communications).

Our study fish may have been more vulnerable to predation due to lighter coloration and increased size compared to the color and average size of other hatchery fish released at the same time. There was a significant length and weight difference between study fish and hatchery smolt releases suggesting a visible difference in target for predators. Size-dependent selection by

piscivorous water birds and predatory fish has been documented in several studies (Latta and Sharkey 1966; Kirkham et al. 1985; Wood and Hand 1985). Collis et al. (2001) showed that hatchery raised Chinook salmon and steelhead are more vulnerable to colonial bird predation than wild fish and that size selectivity (hatchery fish were larger) may play a major role.

The presence of an external antenna in archival-tagged fish may also have increased the potential for predation on our study coho. Archival tag light stalks used in our study were 2.5 mm in length and made of clear Teflon. Adams et al. (1998) and Brown et al. (1999) noted fish with external antennas are likely to be more conspicuous to predators, resulting in higher predation rates. Brown et al. (1999) also suggested that an antenna's length might have a significant effect on swim performance and predator avoidance. To our knowledge no tests have been made to date on any effects or complications leading to increased predation based on positioning a light stalk antenna through the side of the lower body cavity wall in coho smolts.

Tag expulsion

Tag expulsion has been documented in surgical implantation of radio transmitters and laboratory studies show that expulsion may be related to the size of the implant, location of the incision, holding stress, type of coating used on the implant, and/or fish species (Marty and Summerfelt 1986; Moore et al. 1990; Helm and Tyus 1992; Brown et al. 1999). Various physiological pathways have been documented leading to the shedding of implanted fish tags, primarily through fibrous tissue encapsulation of the tag and general expulsion through the intestine or a rupture in the body wall with no subsequent mortality (Summerfelt and Mosier 1984; Marty and Summerfelt 1986; Baras and Westerloppe 1999). In laboratory conditions most of these expulsions occurred within 2-3 weeks of tagging. The two adult fish recovered in 2003 had lost their archival tags, but retained their personal identification through PIT tags. Although the archival tags remained in these fish in hatchery conditions for 20-34 days, the tags were lost after release. Upon examination, no apparent wounds or scar tissue were found to indicate an expulsion location. To our knowledge no long-term studies have been done on the retention of surgically implanted archival tags in Pacific salmonids.

Moore et al. (1990) reported a 20% tag expulsion at around day 121 for Atlantic salmon parr and smolts (127-189 mm in length) implanted with polycarbonate dummy radio tags. No scars were visible and all previously tagged fish were in excellent condition. Marty and Summerfelt (1986) reported similar expulsion rates in radio-tagged channel catfish. Within 23 days, over half of the transmitters had been expelled through the intestine or body wall. Helm and Tyus (1992) were unable to detect a relationship between dummy transmitters size and expulsion rate suggesting that other factors including tag coating or mechanics may have contributed to expulsion. Moore et al. (1990) suggested using an inert polycarbonate for transmitter case construction to reduce expulsion rates. The active archival tags used in this study were made of clear plastic and dummy tags used in 2001 were made of a black plastic material. The actual composition and coating is proprietary information held by the manufacturer. Two dummy tags were recovered in the body cavity of adult coho in 2002, while both active archival-tagged fish collected in 2003 had lost their tags. Tagged fish recovered in each year-class were found to be in the middle of the size distribution of archival-tagged fish at the time they were tagged indicating that size at tagging was probably not a factor leading to their survival to adult stage. Poor recovery rates prevented testing statistical differences between expulsion rates of active versus dummy tags in this study. Clearly other factors beside the tag coating material, including general physiological, environmental and demographic conditions, may have also contributed to a difference in tag expulsion rate between study years.

Recovery trends

Although we recovered two dummy-archival tags from returning adult coho salmon in 2002, the percent of returning adult tagged coho (3%) was significantly below the overall hatchery returns for that year in Ship Creek estimated at 12-15% (Dan Bosch, ADFG, personnel communications). ADFG estimates an average smolt-to-adult survival of 8% for Ship Creek hatchery coho (1997-2001). No active archival tags were recovered in 2003, but the overall survival to adult return for coho in Ship Creek was unusually low that year (estimated at < 5%). We passed 4225 coho at the Ship Creek weir trap in 2002, and only 1143 in 2003 (27% of 2002 levels). More fish were sampled at Ship Creek weir trap in one day during 2002 than all of 2003. Coho runs were low in 2003 throughout Cook Inlet (Dan Bosch, ADFG, personal communications). We speculate that our low rate of returning adult tagged fish in both years

was due to a combination of factors, including increased predation, tag expulsion, and poor marine survival.

Additional tagged fish may have returned to Ship Creek in 2002 and 2003. Due to the high exploitation rates in the sport fishery (73% of the total run) we believe fish eluded detection by anglers because the archival tags' light stalks migrated internally or tags were expelled. Sport anglers while processing their catch found both dummy archival tags collected in 2002. However, many anglers on Ship Creek do not open the peritoneal cavity while processing their catch, and therefore would not have seen the tags. Extensive efforts were made to inform the fishers and the general public about the tags, but due to the large number of anglers each year on Ship Creek many were probably unaware any fish were tagged. It is also possible that anglers may not have returned the tags when found.

Conclusion

While our research showed that juvenile coho salmon pre-smolts successfully carried surgically implanted archival tags from 4-9% of fish weight in hatchery conditions (97% survival), other factors contributed to poor post-release survival of tagged fish. Many factors are discussed in this report including differences between dummy and active archival tags; mechanics of tag expulsion; fish and/or bird predation in relation to fish size, physiology and behavior, ocean condition, and confounding factors related the efficiency of tag recovery. Our findings provide a small component of what will be needed to successfully complete archival tags studies on juvenile Pacific salmonids. Prior to further field-based studies, the effects of archival tags on fish behavior and predation, factors contributing to tag retention and expulsion rates, and long-term survival of tagged fish must be investigated under laboratory condition to provide an adequate baseline for establishing sample size and recovery expectations using this technology.

Despite the failure of active archival tag recovery in this study, the risks associated with implementation of this technology were worth the costs. If active tags had been available from the manufacturer in 2001, we would have successfully recovered ocean migration and critical marine habitat data for two Ship Creek coho. Poor marine survival for hatchery and wild coho in Cook Inlet in 2003 confounded potential tag recoveries during the second year of this study.

Limited funding prevented any further efforts to implement this new tagging technology on Ship Creek coho. Data from archival tags showing any pattern of ocean distribution throughout development in marine habitats would be a break through in our understanding of coho life histories. Every effort should be made to further this technology and develop applications in Pacific salmonids throughout their range.

There is a 10-fold difference in marine survival for coho salmon from different localities throughout their range in the North Pacific Ocean (Welch et al. 2002). The factors contributing to this diversity and the fate of coho and other salmonids at sea from different geographic areas, including Alaska, are a mystery. Critical marine habitat, forage grounds and migration routes for North Pacific salmonids remain unknown. It is only through implementation of new tagging technologies such as archival tags, that questions so important to harvest management, conservation, and the sustainability of coho salmon in their natural habitats can be addressed.

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Table 1. Sample size, mean length, mean weight and number of tagged coho salmon released into and recovered from Ship Creek, 2001-2002.

Study Year	Tag Type	Number Coho Tagged	Number Released (survived)	Mean Length (± S.D.)	Mean Weight (± S.D.)	Number of Tagged Adult Fish Recovered	Archival Tags Recovered Independent from Tagged Fish	Total Number of Tags Recovered
2001	Dummy Archival	60	57	198 (8.8)	93 (10.8)	2	1	3
2001	VI - Alpha only	227	227	185 (9.3)	77 (11.2)	4	0	4
2002	Active Archival	179	174	193 (8.6)	88 (13.0)	2*	4	4
2002	PIT only	297	297	167 (11.9)	59 (12.3)	1	0	1

*lost archival tags

Table 2. Recovery information for tagged coho salmon released into Ship Creek, 2001-2002. "Ratio Tag/weight" gives the ration of tag weight to fish weight; "Ratio Tag/length" gives tag length to fish length ratios. Length and weight were estimated for tagged fish recovered in the sport fishery based on angler estimates. Length, weight and sex data were not available (na) for archival tags recovered independent of tagged fish.

Tag Type	Year Released	Ratio Tag/weight	Ratio Tag/length	Date of Recapture	Life Stage	Fish Length (mm)	Fish Weight (kg)	Sex	Recovery Location
VI Tag	2001	na	na	8/5/2002	Adult	635	3.0	F	Sport fishery
VI Tag	2001	na	na	8/13/2002	Adult	660	3.4	F	Trap
VI Tag	2001	na	na	8/14/2002	Adult	530	2.1	F	Trap
VI Tag	2001	na	na	8/16/2002	Adult	590	2.6	M	Trap
Dummy Archival #026	2001	6%	16%	8/7/2002	Adult	635-690*	3.0-3.5*	M	Sport fishery
Dummy Archival #031	2001	8%	16%	8/22/2002	Adult	590-660*	2.7-3.5*	M	Sport fishery
Dummy Archival #055	2001	7%	17%	8/22/2003	na	na	na	na	Gravel bar near release site
Active Archival #01594	2002	6%	16%	6/5/2002	Juvenile	na	na	na	Rooftop gull nest
Active Archival #01496	2002	7%	18%	8/22/2002	na	na	na	na	Gravel bar near release site
Active Archival #01583	2002	6%	17%	4/4/2003	Juvenile	na	na	na	Rooftop gull nest
Active Archival #01456	2002	6%	17%	7/9/2003	Juvenile	na	na	na	Rooftop gull nest
PIT Tag	2002	na	na	8/17/2003	Adult	600-640*	2.7-3.0*	F	Trap
PIT Tag - Archival tag lost	2002	6%	17%	8/19/2003	Adult	394	0.52	M	Trap
PIT Tag - Archival tag lost	2002	5%	16%	9/2/2003	Adult	520-550*	2.2-2.7*	F	Sport fishery

* estimated from angler information

Table 3. Ratio of tag weight to fish weight (%) and tag length to fish fork length (FL) for surviving archival-tagged coho salmon released into Ship Creek, 2001-2002.

Ratio Tag/weight	# Tagged in 2001	# Tagged in 2002	Ratio Tag/FL	# Tagged in 2001	# Tagged in 2002
4%	0	11	14%	1	5
5%	0	49	15%	11	11
6%	8	94	16%	23	66
7%	21	20	17%	22	81
8%	24	0	18%	0	11
9%	4	0			
Total count	57	174	Total count	57	174

Table 4. Ratio of tag weight to fish weight and tag length to fish length (FL) for archival-tagged coho salmon that died after tag implantation, 2001-2002.

Year	Tag type	Time of Death (hours post surgery)	Ratio Tag/weight	Ratio Tag/FL
2001	Dummy Archival	< 24	6%	15%
2001	Dummy Archival	< 24	8%	17%
2001	Dummy Archival	144 - 168	7%	16%
2002	Active Archival	< 48	6%	17%
2002	Active Archival	< 48	7%	17%
2002	Active Archival	< 48	7%	17%
2002	Active Archival	< 48	6%	17%
2002	Active Archival	< 48	7%	17%

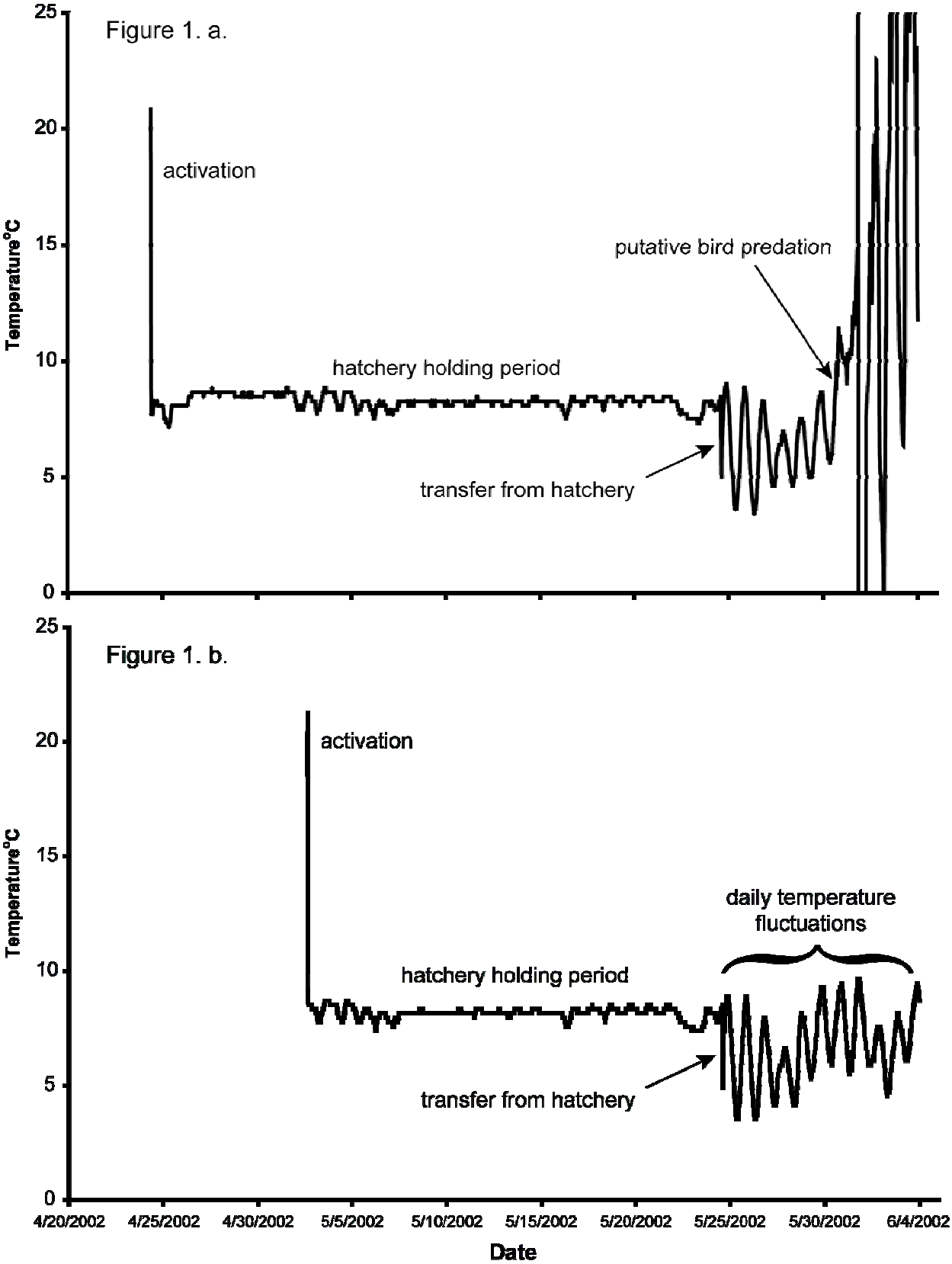
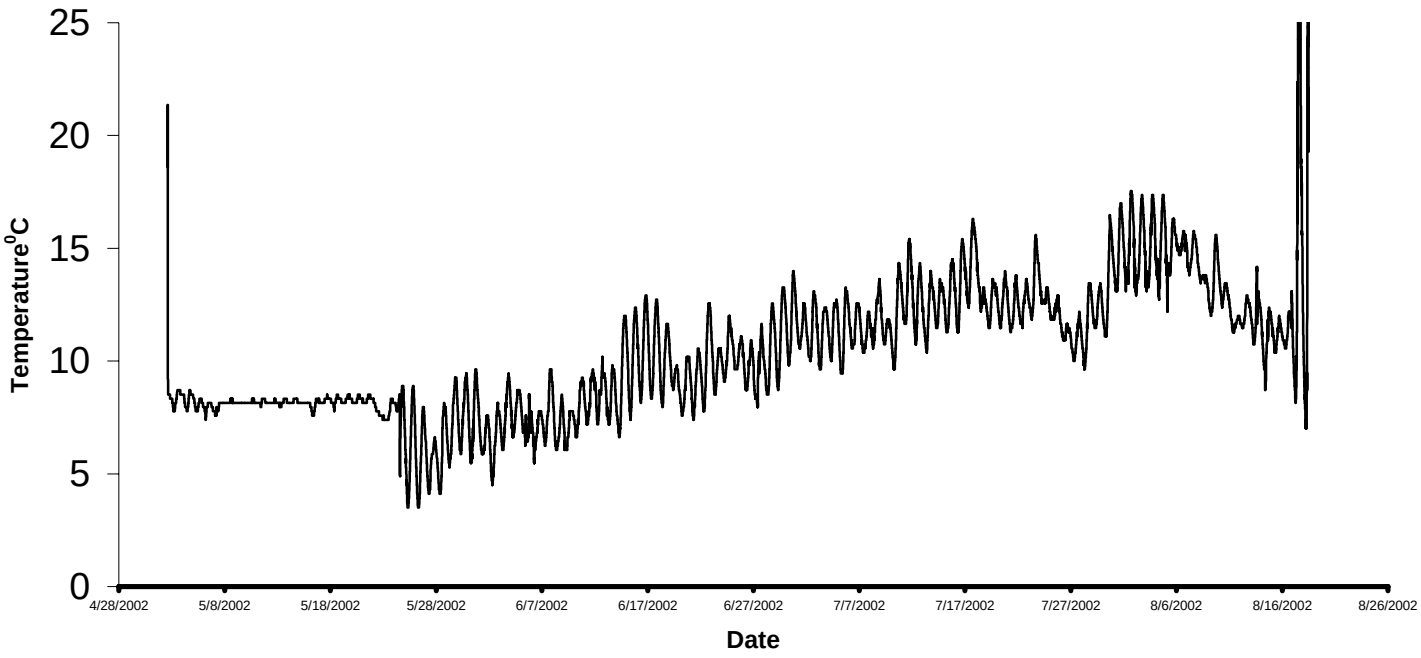
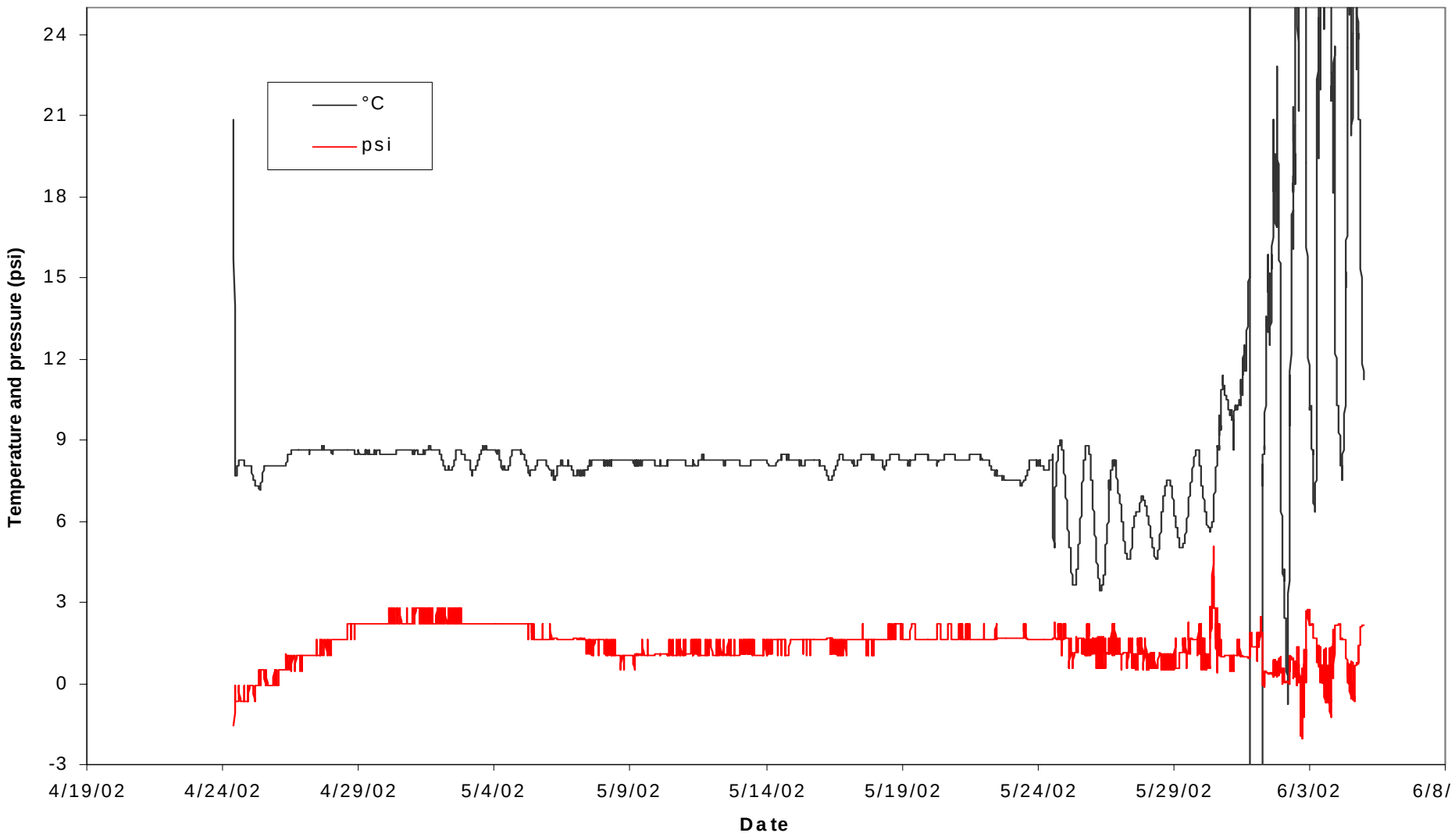


Figure 1. a.
activation
putative bird predation
hatchery holding period
transfer from hatchery
Temperature°C
25
20
15
10
5
0
Figure 1. b.
activation
daily temperature fluctuations
hatchery holding period
transfer from hatchery
Temperature°C
25
20
15
10
5
0
4/20/2002
4/25/2002
4/30/2002
5/5/2002
5/10/2002
5/15/2002
5/20/2002
5/25/2002
5/30/2002
6/4/2002
Date


25
20
15
10
5
0
Temperature ^{0}C
4/28/2002
5/8/2002
5/18/2002
5/28/2002
6/7/2002
6/17/2002
6/27/2002
7/7/2002
7/17/2002
7/27/2002
8/6/2002
8/16/2002
8/26/2002
Date


°C
psi
Temperature and pressure (psi)
24
21
18
15
12
9
6
3
0
-3
4/19/02
4/24/02
4/29/02
5/4/02
5/9/02
5/14/02
5/19/02
5/24/02
5/29/02
6/3/02
6/8/
Date