Exxon Valdez Oil Spill
Restoration Project Final Report

Testing Pop-up Satellite Tags as a Tool for Identifying Critical Habitat for Pacific Halibut (*Hippoglossus stenolepis*) in the Gulf of Alaska

Restoration Project 01478
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. The funds were provided to test a new technology, pop-up satellite archival transmitting (PSAT) tags, at northern latitudes in the Gulf of Alaska to explore and identify critical habitat areas of the Pacific halibut. The project was designed to evaluate the PSAT tags' ability in collecting preferred halibut habitat data, accuracy of producing geolocation estimates at northern latitudes, identification of critical habitat areas, and assessment of the impacts of tagging adult halibut with PSAT tags.

Abstract: To maintain healthy commercial and sport fisheries for Pacific halibut (*Hippoglossus stenolepis*), critical habitat must be defined by determining life history patterns on a daily and seasonal basis. Pop-up satellite archival transmitting (PSAT) tags provide a fisheries-independent method of collecting environmental preference data (depth and ambient water temperature) as well as daily geolocation estimates based on ambient light conditions. In this study, 14 adult halibut (107-165 cm FL) were tagged and released with PSAT tags in and around Resurrection Bay, Alaska. Commercial fishermen recovered two tags, while five tags transmitted data to ARGOS satellites. Horizontal migration was not consistent among fish as three halibut remained in the vicinity of release while four traveled up to 358 km from the release site. Vertical migration was not consistent among fish and over time, but they spent most their time between 150-350 m. The minimum and maximum depths reached by any of the halibut were 2m and 502m, respectively. The fish preferred water temperatures of roughly 6 °C while experiencing ambient temperatures between 4.3 °C and 12.2 °C. Light attenuation with depth prevented existing geolocation software and light sensing hardware from accurately estimating geoposition, however, information from temperature, depth, ocean bathymetry, and pop-off locations provided inference on fish movement in the study area. PSAT tags were a viable tool for determining daily and seasonal behavior and identifying critical halibut habitat, which will aid fisheries managers in future decisions regarding commercial and sport fishing regulations.

Key Words: Pop-up satellite archival transmitting (PSAT) tag, Pacific halibut, *Hippoglossus stenolepis*, geolocation estimate, Gulf of Alaska, critical habitat, migration, Resurrection Bay.

Project Data: Data from this project was assembled from text files gathered from deployed PSAT tags recovered in the commercial fishery and from log files collected from transmitted tags. Access to these data is made by arrangement with the principal investigator or agency.

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TABLE OF CONTENTS:

LIST OF TABLES

LIST OF FIGURES

Figure 7. Wildlife Computers' PSAT tag estimated longitude for the fish carrying tag 00-0740 in a stationary tank at the Alaska SeaLife Center (ASLC) from October 21, 2000 to April 19, 2001. Diamonds (♦) indicate the given estimate and bars show the range of uncertainty based on available light levels generated by a program provided by Wildlife Computers. The solid line indicates the exact location of the ASLC (-149.4^{o} longitude = 149.4^{o} west).

LIST OF APPENDICES

EXECUTIVE SUMMARY

Pacific halibut have been commercially exploited for the past century (IPHC 1998). To maintain a healthy commercial and sport fishery, critical habitat must be defined and identified by determining daily and seasonal life history patterns independent of harvest and test fisheries. This objective is important for many marine fishes in Alaska that are subject to regulated fisheries. New and innovative technologies are required to collect such data. Therefore, this study was developed to test the efficiency and accuracy of the pop-up satellite archival transmitting (PSAT) tag in the Gulf of Alaska for defining critical habitat for large marine species.

Multiple tagging studies conducted by the IPHC since 1925 have attempted to track Pacific halibut in marine habitats (Kaimmer 2000). The use of conventional tags with a numerical identifier has limited researchers to collecting geoposition and biological data at the time of release and recapture. These conventional tagging studies have addressed management issues including: migration between fishing regions, rates of natural and fishing mortality, and stock identity to delineate management units (Skud 1977; Trumble et al. 1990). These studies indicate that halibut tagged in the summer and recovered in the winter or vice versa generally migrate more than those tagged and recovered in summer, and the direction of this movement changes seasonally (Skud 1977).

To overcome the limitations of conventional tagging studies on flatfishes, electronic archival tags have been used to explore life history parameters of several species including Pacific halibut, American plaice (*Hippoglossoides platessoides)*, North Sea plaice (*Pleuronectes platessa*), Atlantic halibut (*Hippoglossus hippoglossus*) and other flatfish species (Arnold and Holford 1978; Godø and Haug 1988; Metcalfe et al. 1991). These tags can provide detailed information on one or more of the following parameters: depth, ambient temperature, light and/or swimming speed. Although electronic archival tags provide more detailed information than conventional tags, they are still dependent on fish recapture for data collection.

The pop-up satellite archival transmitting (PSAT) tag provides some solutions to the aforementioned problems of fish tagging. The PSAT tag collects temperature, depth and ambient light data while externally attached to the fish. On a user-programmable date, the tag releases from the fish, pops-up to the surface and transmits histogram-summarized data as well as daily longitude estimates to ARGOS satellites to be retrieved by the investigator. If the tagged fish is captured before the pop-up date, the full minutely archival record can be obtained. Pop-up tags are the first fisheries-independent means of studying fish *in situ* for up to one year.

This project tested the efficiency and accuracy of the newest generation of geolocating PSAT tags as a tool for studying migration patterns and critical habitat of fish in the Gulf of Alaska. Previous studies using geolocating PSAT tags have all been conducted at more southerly latitudes and this was the first investigation using geolocating PSAT tags outside of tropical and temperature latitudes.

In this study, 14 adult halibut (107-165 cm FL) were tagged and released with PSAT tags in and around Resurrection Bay, Alaska. Commercial fishermen recovered two tags, while five tags transmitted data to ARGOS satellites. Four tags had a programming error affecting the release date and three tags were unaccounted for (Appendix B). The two recaptured tags produced full archival records for up to 135 days providing detailed information on preferred habitat and behaviors both daily and seasonally. The data transmitted to the ARGOS satellite system was received as 12-hour histogram bins and daily longitude estimates and provided daily habitat information for up to 244 days.

Horizontal migration was not consistent among fish as three halibut remained in the vicinity of release while four traveled >100 km and up to 358 km from the release site. All of these halibut were most likely sexually mature (Clark et al. 1999) and undertook seasonal spawning migrations. Mature halibut are known to migrate annually from shallow summer feeding grounds to deeper spawning grounds on the continental shelf edge from November to March (St-Pierre 1984; IPHC 1998). Although spawning grounds are typically in deeper water on the shelf edge, spawning is not limited to major grounds, and may occur along the entire coast in the northeast Pacific (St-Pierre 1984; IPHC 1998).

Vertical migration was not consistent among fish and over time, but they spent most of their time between 150-350 m. The minimum and maximum depths reached by any of the halibut were 2m and 502m, respectively. Analysis of the depth data revealed three distinct vertical migration behaviors. The first was a gradual vertical migration up and down during both day and night, where the frequency, amplitude and slope changed during each vertical migration. The second was an abrupt ascending vertical migration and return to the same depth as before the vertical excursion. The third consisted of long periods of remaining at virtually the same depth.

The halibut preferred water of roughly 6 °C while experiencing temperatures between 4.3 °C and 12.2 °C. During certain times of the year, the seafloor water temperature appeared to be isothermic in the 150-350 m depth range where the halibut spent the majority of their time. Four of the halibut experienced increased water temperature that coincided with vertical migrations of increased amplitude, suggesting water temperature over 7 °C may indicate vertical ascents off of the seafloor. However, during other times of the year, the water column was isothermic from the seafloor to the surface so ambient temperature was not always a reliable indicator of water column positioning by halibut.

Light attenuation with depth prevented existing geolocation software and light sensing hardware from accurately estimating geoposition, probably for a combination of factors. Light does not penetrate past 300 m, even in clear oceanic water, and some of these halibut spent long periods deeper than 300 m. Additionally, the highly productive, coastal shelf water in which the halibut live is turbid because of suspended organic and inorganic matter and greatly thereby greatly reducing light penetration. A final factor is the low amount of ambient light at northern latitudes during the winter months. All of these factors inhibited the light sensor and the existing geolocation algorithms from accurately predicting daily position. However, information from temperature, depth, ocean bathymetry, and pop-off locations provided significant inference on fish movement in the study area to warrant further applications of these tags.

The pop-up satellite archival tag proved to be an effective tool for identifying critical habitat by examining the daily and seasonal habits for Pacific halibut in the northern Gulf of Alaska. These tags allowed determination of the timing and extent of vertical and horizontal migration as well as temperature and depth preferences of halibut. General patterns of halibut behavior will emerge from larger satellite tag deployments and rigorous data analysis in the future. A planned collaborative project with the IPHC will use PSAT tags in looking at Pacific halibut migrations and assessing critical habitat areas in the Bering Sea and other locations in the Gulf of Alaskan during summer 2002. Additionally, analysis of data collected from PSAT tags affixed to a stationary buoy in the study area will be compared to the actual buoy position to test light attenuation levels at depth and in situ light gradients during the equinox periods at northern latitudes. In a concurrent study, DNA from Pacific halibut fin clips will be used to examine biogeographic relationships and evolutionary history of halibut using microsatellite analysis. Development of genetic tools is underway at the USGS Molecular Ecology Lab in Anchorage. Populations from Resurrection Bay, Glacier Bay, and the Bering Sea will be compared genetically. Synthesis of the tagging, genetic and behavioral data developed from Pacific halibut in the Gulf of Alaska will provide important scientific contributions to our ability to maintain a sustainable fishery for this species in Alaska.

Introduction

Pacific halibut (*Hippoglossus stenolepis*) inhabit continental shelf areas from California to the Bering Sea, ranging as far as Russia and Japan. Because of their large size (>250 kg) and fine flesh quality, Pacific halibut have been commercially exploited for the past century (IPHC 1998). The fishery is managed by the International Pacific Halibut Commission (IPHC), established under a convention between Canada and the United States of America.

To maintain healthy commercial and sport halibut fisheries, critical habitat for adults must be defined by determining daily and seasonal movement and life history patterns. The IPHC has attempted to accomplish this goal by conducting several tagging studies since 1925 (Kaimmer 2000). All of the IPHC's tagging studies employed conventional tags with a numeral identifier for which geoposition and biological data of each tagged fish were recorded upon release and recapture. These investigations addressed management issues including: migration among fishing regions, rates of natural and fishing mortality, and stock identity to delineate management units (Skud 1977; Trumble et al. 1990). Tagging results have been used in management philosophy, regulations and population biology (Trumble et al. 1990). However, differential non-reporting over time and area, tag shedding and tagging mortality limit the usefulness of conventional tagging data. Additionally, correctly recovered conventional tags are limited in that they only provide beginning and end positions and estimated growth rates if length measurements were taken. IPHC conventional tag studies indicate that halibut tagged in the summer and recovered in the winter or vice versa generally migrate more than those from summer to summer and the direction of movement changes seasonally (Skud 1977).

To overcome the limitations of conventional tagging studies on flatfish, archival electronic tagging studies have been conducted on species including Pacific halibut, American plaice (*Hippoglossoides platessoides)*, North Sea plaice (*Pleuronectes platessa*), Atlantic halibut (*Hippoglossus hippoglossus*) and other flatfish species (Arnold and Holford 1978; Godø and Haug 1988; Metcalfe et al. 1991). These tags provide detailed information on one or more of the following parameters: depth, ambient temperature, light and/or swimming speed. Although electronic tags provide more detailed information than conventional tags, they still have drawbacks. Ultrasonic telemetry tags, as used by Hooge et al. (1993), require the use of research vessels and are spatially and temporally limited. Archival data storing tags provide detailed records on depth, temperature and ambient light, but are dependent on fish recapture for data recovery.

The pop-up satellite archival transmitting (PSAT) tag provides some solutions to the aforementioned problems of fish tagging. The PSAT tag collects temperature, depth and ambient light data while externally attached to the fish. On a user-programmable date, the tag releases from the fish, pops-up to the surface and transmits histogram-summarized data to ARGOS satellites to be retrieved by the investigator. If the fish is captured and the tag retrieved before the pop-up date, the full archival record can be obtained. Pop-up tags are the first fisheries-independent means of studying fish for up to a year. To date, PSAT tags have been deployed on large pelagic fish in temperate and tropical latitudes including: tuna (Block et al. 1998; Lutcavage et al. 1999; Block et al. 2001a and b; Gunn and Block 2001; Marcinek et al. 2001), sharks (Boustany et al. 2002; Holland et al. 2001), molas (Seitz et al. 2002) and marlin (Graves et al. 2001; Block personal communication).

This project tested the efficiency and accuracy of the newest generation of geolocating PSAT tags as a tool for studying migration patterns and critical habitat of fish in the Gulf of Alaska. In the first phase of this study, Pacific halibut were caught, transported live to an aquarium and tagged with PSAT tags. During the following month, the fish were monitored to determine long-term tag effects of carrying an external tag. In the second phase, wild halibut were tagged with PSAT tags and released in and around Resurrection Bay near Seward, AK. Previous studies using geolocating PSAT tags have all been conducted at more southerly latitudes and this was the first investigation using geolocating PSAT tags outside of tropical and temperate latitudes. Additionally, this was the first investigation in which demersal, rather than pelagic fish were PSAT-tagged. Halibut were chosen because they were large enough to carry the tag, were readily available during the commercial season and monitoring the effects of tagging in captive fish was relatively easy. PSAT-tagged halibut allowed examination of seasonal movement and life history patterns on a daily and seasonal basis. Elucidation of these patterns will aid in defining critical habitat, a valuable contribution to management decisions for sustaining ecosystem function and a healthy international fishery.

Materials and methods

Bringing adult halibut into captivity

On 7-8 August 2000, eleven live halibut (107-137 cm FL) were captured by a chartered commercial longline fishing vessel off Bear Glacier, Resurrection Bay, AK (59.89 N, 149.49 W). Standard fork length (cm) and caudal fin clips were taken before the fish were placed in holding caddies with continuously circulating seawater for transport to the Alaska SeaLife Center (ASLC), Seward, AK. The holding caddies were moved by forklift from the vessel to a flatbed truck and driven to ASLC (10 minutes). Four fish died within 24 hours of capture. These fish were subsequently frozen and later used to test optimal tag anchor placement. Of the remaining seven, four were placed in an 11 m^3 tank and three were placed into two 4.5 m^3 tanks (two in one and one in the other) where they were fed Pacific herring until satiation every other day.

Tagging captive halibut with PSAT tags

On 19-20 October 2000, six captive halibut were tagged with PSAT tags (PAT, Wildlife Computers, Redmond, WA, USA); one was left untagged as a control animal. The halibut were anesthetized in a small pool of water containing buffered MS-222 (100mg/l; Malmstrøm et al. 1993) and a local anesthetic (bupivicaine, 2.0 mg) was injected at the tag insertion point. The PSAT tags were attached through the pterygiophores roughly 2.5 cm below the halibut's dorsal fin on the eyed-side of the halibut where the body began to taper towards the tail. A single cruciate suture was used to close the insertion wound. These tagged fish were then observed daily to monitor the effects of the externally attached PSAT tags.

The design, function and attachment techniques of PSAT tags were adapted from Gunn and Block (2001) and Block et al. (2001b). The PSAT tags were programmed to sample pressure, ambient temperature and light every minute and the data was binned into twelve-hour histograms for downloading to ARGOS satellites. These PSAT tags were programmed to detach on 15 June 2001.

Release of captive fish

On 20 November 2000, the control fish at ASLC was tagged with a PSAT tag programmed as described for the six previous tags. Five tagged fish were then loaded into three holding caddies (smaller fish sharing caddies while the biggest fish was alone) and driven 10 minutes to the commercial fishing vessel. During truck transport, pure oxygen was diffused through an air stone into the water and maintained at roughly 125% saturation to prevent transport mortality. Once on the vessel, seawater was continuously circulated into the caddies to maintain water quality. The vessel traveled to close proximity of the original capture location and the fish were released (Table 1 and Figure 1). All fish actively swam away from the vessel upon release. The remaining two tagged halibut, 00-0740 and 00-0741, were kept in an 11 m^3 holding tank at the ASLC as control animals to test long-term tag attachment and to calibrate geoposition estimates with

Wildlife Computers' proprietary software. The fishes remained in the outside holding tank from 21 October 2000 to 20 April 2001, when they were moved inside. On 19 June 2001, the tags were removed from the fish, archival data was downloaded, and these fish were retagged. On 5 July 2001, the tagged-halibut at ASLC were released into the wild according to previously described captive fish release procedures.

Tagging wild halibut with PSAT tags
On 16 March 2001, three additional halibut were captured on setline gear aboard a chartered commercial fishing vessel. The fish were pulled to the surface while hooked and brought onto the vessel in a net. They were placed on a pre-wetted, smooth piece of marine plywood, blindfolded to remain calm and the scientists and captain assessed their condition for post-release viability. After determining they were healthy, the fish were measured, tagged and released (Table 1 and Figure 1). The PSAT tags were programmed as previously described with the pop-off date set for 15 November 2001.

On 5 July 2001, four additional wild halibut were tagged and released following the procedure previously described for tagging wild fish. These PSAT tags sampled pressure, ambient temperature and light every two minutes and the data was binned into twelve-hour histograms. The PSAT tags were programmed to release from the fish on 15 November 2001.

The PAT User's Manual (Wildlife Computers) describes the PSAT tag's onboard data collection and processing. Longitude estimates for tags communicating through ARGOS as well as latitude and longitude estimates for recovered tags are described in the PAT Geolocation Software Manual (Wildlife Computers), Hill (1994) and Hill and Braun (2001). Post processing of data received through ARGOS is described in Block et al. (2001b) and Gunn and Block (2001). The tags endpoint positions upon popping-up were determined from the Doppler shift of the transmitted radio frequency in successive uplinks received during one ARGOS satellite pass (Schaefer and Liller 1990; Keating 1995).

Reward program
As incentive to return recaptured tags, a dual sponsored reward program was established. First, fishermen received $500 from the ASLC for the return of each recaptured PSAT tag. The costs of electronic tagging justified encouraging fishermen to return PSAT tags by offering a large monetary reward. Second, the IPHC established a quota waiver for recovered PSAT-tagged fish. Fish captured with a PSAT tag may be sold commercially and the weight of the fish does not count towards the captain's individual quota. Tagged halibut were sold as second-grade fish and did not fetch highest price because of flesh damage at the tag anchor and insertion point. The IPHC established the quota waiver to encourage fishing captains to retain PSAT-tagged fish even though the flesh was second-grade.

Results

Transport, care and monitoring adult halibut

Previous studies have shown halibut are easy to capture, domesticate and monitor (Peltonen, 1969; Stickney and Liu 1993; Martinez Cordero et al. 1994). The halibut in this study were relatively easy to capture, place in holding caddies and transport to the ASLC. However, only 7 of 11 fish survived the first 24 hours of the initial capture and transport. This was probably because, when the fish were in transport caddies between the fishing boat and the final holding tanks (roughly one hour), the water was not oxygenated, circulated or monitored for quality. These factors, combined with increased oxygen consumption and general transport stress, probably contributed to the mortalities. In subsequent transportation events, water quality was monitored and pure oxygen was diffused through an air stone to maintain 125% saturation. This technique prevented any further mortality.

The halibut appeared to adapt quickly to captive life in the holding pens. Aquaculture applications have developed commercially available halibut feeds for captive fish (Rosenlund 1996), but halibut at the ASLC preferred whole, fresh (or thawed) herring. Captive halibut fed readily at the tank surface on hand-fed herring. Feeding competition and aggressive behavior necessitated employment of several feeders in shared tanks.

Once the captive fish were tagged, the behavior, general health and insertion wounds were monitored to determine the feasibility of PSAT tagging halibut. All of the halibut quickly resumed their daily feedings and none appeared to change general behavior patterns. The insertion wounds healed in 2-3 weeks, at which point the fish were deemed fit to be returned to the wild.

PSAT tag returns

None of the tags deployed in November 2000, that were scheduled to pop-off the fish on 15 June 2001, released due to a software error on the tags. However, one fish (00-0737a) was recaptured by a commercial longliner, providing a 135-day archival record (Table 1 and Figure 1). Of the three tags deployed on 16 March 2001, one (00-0821) was recaptured shortly before the scheduled pop-off date and the remaining two (00-0818 and 00-0819) released and reported to the ARGOS satellites as scheduled. Of the six tags deployed on 5 July 2001, three (00-0737b, 00-0741 and 01-0047) released and reported to the ARGOS system as scheduled (Table 1 and Figure 1) while the remaining three were listed as missing.

The first archival recovery, tag 00-0737a, spent 106 days in captivity at ASLC and was released 21 November 2000. The fish was recaptured 20 km north of the release location after 135 days. For the three fish released 16 March 2001, 00-0821 was recaptured <1 km from the release location after 234 days, while tags 00-0818 and 00-0819 reported to ARGOS satellites 6.5 and 112.1 km, respectively, from the release location after 244 days. Both of these fish traveled in a southwesterly direction from the release point. Three tags deployed on 5 July 2001, 00-0737b, 00-0741 and 01-0047, reported to ARGOS 336.9, 190.7 and 358.3 km, respectively, from the release location after 133 days (halibut 00-0737b spent an additional 332 days in captivity at ASLC previous to release). All of these fish traveled in an easterly direction.

Depth and ambient temperature of PSAT tags that reported to ARGOS

The depth preferences of the five halibut whose tags reported to ARGOS are displayed as monthly mean percentage of time spent in each depth range for each 12 hr histogram period (Table 2). The March-released halibut, 00-0818 and 00-0819, occupied the 150-250 m depth range the majority of the time, which was also the deepest range occupied by both fish. Fish 00-0818 frequently ventured out of the 150-250 m range in all months except May and June. Fish 00-0819 remained in the 150-250 m depth range 100% of the time from March through June. July was the first month the fish left the 150-250 m depth range and it visited shallower water each month from August to November. The halibut released in July showed different behavior in depth preferences (Table 2). All three occupied deeper depth ranges and showed more variation in the percent occupancy in different depth ranges. Fish 00-0737b (Table 2) showed its greatest range in depth in July and the least in September. Fish 00-0741 showed less variation in depth preference than the other two July-released halibut. From July to October, fish 00-0741 only lived in the 150-350 m range, but in November, the halibut greatly expanded its depth range and visited both shallower and deeper water. Fish 01-0047's depth preference progressively shifted to deeper water from July to November. In July and October, it showed the greatest depth range while its range of depth was the narrowest in August. Like the two previous July-released fish, 01-0047's depth range was deeper in November.

To examine the extent of the five halibuts' vertical movements, the PSAT tag recorded a daily minimum and maximum depth (Figure 2). The maximum depth occupied by both March-released fish was similar throughout the duration of the record, but the fishes behaved distinctly differently. The minimum and maximum depths of halibut 00-0819 (Figure 2a) closely corresponded for the entire period while the minimum depths visited by halibut 00-0818 (Figure 2b) were frequently much shallower than the maximum depths. Halibut 00-0818 occasionally visited the surface and recorded minimum depths as shallow as 4 m. The three halibut released in July displayed two distinct patterns of vertical migration: periods when the maximum and minimum depths were similar and periods when the maxima and minima did not closely correspond. Fish 00-0737b (Figure 2c) changed vertical migration modes several times. In contrast, fishes 00-0741 (Figure 2d) and 01-0047 (Figure 2e) drastically changed vertical migration modes on one occasion each, both on roughly 20 August**.** The three July-released fish shared a similar migration pattern as they lived at roughly 300 m until mid to late-October when they migrated over a shallower location to the deeper waters of the continental shelf edge.

In addition to depth information, PSAT tags recorded ambient water temperature and were calculated as monthly mean percentages of time spent in each temperature range for each 12 hr histogram period (Table 3). All fishes spent the majority of their time in the 5-7 °C range and rarely experienced water temperatures outside this range. For the March-released fish, 00-0818 spent 100% of its time in this temperature range during March, May, June and August while experiencing the greatest range of ambient temperatures (5-13 °C) in July. In contrast to 00-0818, halibut 00-0819 experienced no ambient water temperatures outside the 5-7 °C range. The halibut released in July also experienced a narrow range of ambient temperature for the majority of the time (Table 3). All three halibut, 00-0737b, 00-0741, and 01-0047, spent 100% of their time in the 5-7 °C range during July, August and September. Fishes 00-0737b and 01-0047 experienced both warmer and cooler water in October and experienced only cooler water in November. Fish 00-0741 experienced different ambient temperature patterns in October and November compared to the other July-released fish.

Figures 3a-3e show the daily maximum and minimum ambient temperatures experienced by the five halibut whose PSAT tags reported to ARGOS. Generally, all five of the halibut remained in 5.8-6.2 °C water, but occasionally experienced colder or warmer water. Although PSAT tags downloading to ARGOS provided temperature-depth profiles of the water column, fish 00-0818 was the only tagged-halibut that vertically migrated sufficiently to provide temperature-depth profiles (Figure 4). In contrast to 00-0818, 00-0819 (Figure 3b) never experienced any large water temperature fluctuations. Halibuts 00-0737b, 00-0741 and 01-0047 (Figures 3c-e respectively) only experienced major ambient temperature fluctuations in late autumn when they apparently migrated off the shelf edge. None of these fluctuations were as large as those seen by 00-0818.

The five tags that released and reported to ARGOS gave reasonable estimates of longitude, but only for a minority of days. The light penetration in the waters of the northern Gulf of Alaska appeared to have been insufficient for accurate daily geoposition estimates. Daily records for 133 days of the total 887 (15%) that reported to ARGOS with light data gave reasonable geolocation estimates for Pacific halibut in the northern Gulf of Alaska (Appendix A).

PSAT tags recovered on fish

Two PSAT tags were recovered while still externally attached to the fish. One tag, 00-0737a, was the only tag from which data was recovered from the tags that were scheduled to release on 15 June 2001. This tag provided a minutely-archival record of temperature, depth and light readings for 135 days. The second tag, 00-0821, was recaptured after 234 days, however, it provided only 42 days of archival record because the battery died on 27 April 2001.

The average monthly depth records of halibuts 00-0737a and 00-0821 are seen in Table 4. The average depth which fish 00-0737a inhabited showed an increasing trend from November to January and then a decreasing trend in both February and March. In April, the average depth increased once again, but the monthly depth record represented only five days as the fish was captured on 5 April 2001. The variation in depth was roughly the same in November, December and February while the fish showed less variation in vertical migration in March and April with variation being the least in January. The fish reached the shallowest depth, 2 m, one day after it was released. Although the average depth was greatest in January, the fish traveled the deepest, 502 m, in February.

Fish 00-0737a showed three distinct vertical migration behaviors (Figure 5). The first, (Figure 5, 27 November 2000,) was a gradual vertical migration up and down during both day and night. The frequency, amplitude and slope changed during each vertical migration. The halibut assumed this behavior immediately upon release and continued until the end of December. It was unknown whether the fish remained on or near the bottom and moved over the irregular bathymetry of the area or left the bottom and swam through the water column. The second vertical migration behavior, seen only in late January and early February, (Figure 5, 3 February 2001), was an abrupt ascending vertical migration and then returned back to the same depth as before the vertical excursion. On 31 December 2000, the halibut commenced the third type of behavior (Figure 5, 17 February 2001), long periods of remaining at virtually the same depth (up to 22 consecutive days).

Fish 00-0821 (Table 4) exhibited little vertical migration in the 42 days the tag functioned. The mean depths for March and April were almost identical while the variation was very similar. The monthly minimum depths were identical while the monthly maximum depths were extremely close. This halibut displayed only two of the three previously mentioned behaviors: extended stays at the same depth and gradual vertical migration. This fish remained at the same depth for up to 11 consecutive days and occasionally migrated vertically. These vertical migrations were of small amplitude (<10m) and duration (<1 hr).

The mean monthly temperatures experienced by fish 00-0737a (Table 4) were almost identical from December to April while the mean monthly temperature for November was slightly higher. The variation in temperature experienced was roughly the same in December, January and February while slightly higher in November and slightly lower in March and April. The monthly maximum temperatures ranged from 8.6 °C in November to 6.0 °C in April while the monthly minimum temperatures ranged from 5.7 °C in November to 4.3 °C in February. The mean monthly ambient water temperatures, variation, maxima and minima experienced by halibut 00-0821 were all very similar (Table 4).

Like the five PSAT tags that reported to ARGOS, the two archival recovered tags provided geoposition estimates for a minority of the days. Tag 00-0737a recorded a few reasonable estimates of geoposition (Appendix A), but the fish carrying tag 00-0821 stayed at depths with little light penetration, resulting in no geolocation estimates.

Tags 00-0740 and 00-0741, used to calibrate estimates of latitude and longitude at ASLC (60.1 N, 149.4 W) from 21 October 2000 to 19 April 2001, gave similar geolocation estimates, although only the results of 00-0740 are shown (Figures 6 and 7). Based on these data, mean error rates for PSAT tags in Alaska for latitude and longitude were $\pm 3.4^{o}$ and $\pm 1.6^{o}$ respectively. As expected, the error estimates in latitude increased noticeably around the spring equinox (Figure 6).

Discussion

Transportation and tagging techniques

Halibut were an excellent candidate for PSAT tagging experiments in Alaska. Collection of live adult halibut was relatively easy and fish were successfully captured on each longline set. The fish were hardy and remained calm throughout the capture and transport process. After 4 of 11 fish died during the truck transport to the ASLC, additional steps were taken to ensure higher survival rates in subsequent transport. Diffusing pure oxygen through air stones appeared to be sufficient to raise survival rates to 100% as no further mortalities were experienced.

Use of local and general anesthetic greatly facilitated tagging captive halibut, as the fish were uncooperative and struggled when tagged without anesthesia. The general and local anesthetics sedated the fish and they no longer struggled through the tagging process. While tagging wild halibut, anesthetic was unnecessary as the fish remained calm throughout the tagging process. The difference between tagging captive and wild fish was probably because wild fish were fatigued after they struggled against the longline before being raised to the surface. Additionally, the fish were probably disoriented as they were brought on the vessel. Apparently, these factors sedated the fish and made them more cooperative during the tagging process.

The lack of reporting of some of the PSAT tags probably did not reflect the inability of halibut to carry the tags externally. The tags that did not report to ARGOS on 15 June 2001 had an incorrect software file that interfered with the timing of release. One of these tags, 00-0737a, had already been recovered in the commercial fishery. The remaining tags are still collecting data every minute and may be recaptured by commercial and sport fishermen in the future, thereby providing long-term depth, temperature and light records. With increased awareness through public outreach and the reward program, more of these tags will probably be recovered. Three of six tags deployed on 5 July 2001 did not report to ARGOS and number of factors including predation, mortality, and tag malfunction could explain their absence. In summary, we have recovered data from seven of 14 deployments with only three tags that remain unaccounted for (21%; see Appendix B).

Horizontal Migration

Fishes, 00-0737a, 00-0737b, 00-0741, 01-0047, and 00-0819 migrated at least 100 km from their release location. All of these halibut were most likely sexually mature (Clark et al. 1999) and undertook seasonal spawning migrations. Mature halibut are known to migrate annually from shallow summer feeding grounds to spawn from November to March (St-Pierre 1984; IPHC 1998). Although spawning grounds are typically in deeper water on the shelf edge, spawning is not limited to major grounds, and may occur along the entire coast in the northeast Pacific (St-Pierre, 1984; IPHC 1998).

All of the fish released in Resurrection Bay swam east to known spawning grounds on the continental shelf edge (St-Pierre 1984), including halibut 00-0737a. Although it was recovered only 20.3 km from the release location after 135 days, it did not remain in the bay during the winter. The fish experienced a maximum depth of 450 m in January and 502 m in February which are impossible in Resurrection Bay. These depth data, combined with longitude estimates (Appendix A), indicated that the fish migrated out of the bay and east towards the continental shelf edge shortly after release. After spending the winter in deep water near the shelf edge, the fish migrated back to its summer feeding grounds in Resurrection Bay. This is a common pattern as most adult fish tend to remain on the same feeding grounds every year, leaving only to spawn in deep water (IPHC, 1998).

The fish released off of Granite Island in March, all most likely mature (Clark et al. 1999), either migrated southwest or remained in the vicinity of their release location. None of these fish showed any appreciable changes in maximum depth and therefore probably stayed on the shelf for the duration of the experiment. Fish 00-0819 migrated southwest close to a known Pacific halibut spawning ground in a depression on the continental shelf named Seward Gully (St. Pierre 1984). In contrast, fishes 00-0818 and 00-0821 remained in the vicinity of release. Adults are known to have small home ranges during summer feeding season (<0.5 km^2) and some may even display territoriality (Hooge and Taggart 1993). The 6.5 km migration to the southwest by halibut 00-0818 may have been the commencement of its winter spawning migration to a similar spawning ground as 00-0819 or the halibut did not show the home range fidelity of halibut 00-0821 on its summer feeding grounds. Fishes 00-0818 and 00-0821 possibly would have undertaken a winter spawning migration in the next month. Less probable explanations included the possibility that neither fish had reached sexually maturity or that halibut do not always make yearly migrations to a winter spawning ground. The different migration patterns displayed by fish released inside and outside of Resurrection Bay, which had no apparent size difference, may indicate separate populations of halibut with distinct behaviors.

Vertical migration

The archival depth records from tags 00-0737a and 00-0821 provided high resolution vertical migration behavior and depth preferences of halibut. Only halibut 00-0737a displayed the second type of vertical migration behavior. On eight separate occasions, the halibut gradually migrated to deeper water, abruptly ascended 100-175m, returned to the original depth, and then gradually ascended. From the temperature and depth records during these forays, the fish appeared to have left the bottom and swam vertically through the water column. The fish displayed this behavior during the first three weeks of January and then erratically throughout February, which are considered the peak of spawning season (St-Pierre 1984). Because this occurred according to routine on each occasion and was found only during peak spawning season, this could represent a form of spawning behavior common in many flatfish (Devold 1938; Pete Hagen, National Marine Fisheries Service, personnel communications). Alternatively, this behavior may represent predator avoidance or predatory behavior. The first behavior, gradual vertical migrations, and the third behavior, extended periods of remaining at the same depth, were probably indicative of non-spawning behavior, as they were common to both fish.

The depth records from the five tags that reported to ARGOS did not provide the resolution of the tags recovered directly from the fish, but by combining depth range occupancy (Table 2) and maximum/minimum depths (Figure 2), they did allow examination of the vertical migration behavior as well. One must be aware that these records did not coincide perfectly because of incomplete transmission of the data to ARGOS. The tags transmitted their collected data continuously in sequential order, even though ARGOS satellites were overhead and received data only a few times per day. The data sets were compiled over the course of 8-14 days and some data sets have gaps while others have repeats. If these gaps in the data sets did not coincide, the histogram summarized records and the maxima and minima did not match perfectly. An example of this was seen in the depth record of tag 00-0818. The fish experienced a minimum depth of four meters on two occasions around 15 May 2001 (Figure 2a). However, the depth range occupancy (Table 2) showed the fish spending 100% of its time in the 150-250 m depth range for the entire month of May.

Unlike the horizontal migration patterns, the extent of vertical migration for the five fish whose tags released and reported to ARGOS did not appear release-location related. The two March-released halibut recorded the least and the most vertical migration behavior of all of the fish. Halibut 00-0818 vertically migrated through the largest depth range. It exhibited the largest difference between maximum and minimum depths, made forays into the depths of less than 10 m on several occasions and spent time in up to 5 depth ranges depending on the month. Tag 00-0818 reported to ARGOS 6.5 km from the release site, so the fish was most likely in the same area the entire time ascending off the seafloor. These forays into the water column were probably foraging trips as the fish was on feeding grounds during the summer feeding season. The vertical migration of fish 00-0819 was the least extensive of the fish. The maximum and minimum depths (Figure 2b) closely coincided for the entire depth record and the fish probably remained on or near the seafloor. The minimal vertical migration may be size-related as this was the largest in the study. The differences in amplitude of vertical migrations among fish and over time possibly reflected different foraging modes.

The vertical migration patterns may be useful for determining timing of horizontal migrations. Constant maximum depths probably indicated residence in a small area of bottom as seen in fish 00-0818, which reported only 6.5 km from its release point. Abrupt changes in maximum depths probably indicated horizontal movement as seen in fishes 00-0737b, 00-0741 and 01-0047 which were all tagged in Resurrection Bay and then migrated out of the bay to the continental shelf edge. At the end of each of the three depth records, the maximum depths got progressively shallower which probably reflected migration over a shallow location on the journey to the spawning grounds. All three fish appeared to follow a similar course to the winter spawning grounds.

Apparently, spending extended periods of time in captivity did not affect the behavior of adult fish upon release in the wild. After spending 106 days in captivity, fish 00-0737a resumed the winter migration typical of adult halibut. Fish 00-0737b spent 332 days in captivity and upon release it behaved very similarly to fish 01-0047. Both positioned themselves in a shallow spot in mid-October, then migrated to deeper water near the shelf edge by late-October and their tags reported to ARGOS roughly 20 km from each other.

Temperature preferences

All seven tagged fish spent almost all of their time in 6°C water (Table 3), but occasionally experienced warmer and colder water. From March to November 2001, the seafloor water temperature appeared to be isothermic in the 150-350 m depth range where the halibut spent the majority of their time. Fishes 00-0818, 00-0737b, 00-0741 and 01-0047 experienced increased water temperature during time periods that coincided with vertical migrations of increased amplitude. Depending on the location of the fish and the local topography, increased water temperature above 7 °C may indicate ascents from the seafloor by halibut. However, during April and May, the water column was isothermic (Figure 4) and halibut would have experienced the same water temperature regardless of depth. So at certain times of the year, ambient temperature was not a reliable indicator of water column positioning by halibut. Cooler water (3-5 °C) was only experienced by fishes 00-0737a, 00-0737b, 00-0741 and 01-0741 in late October and November when they were in deeper waters (>350m) on the edge of the continental shelf. Thus cooler water may possible be an indicator of presence on winter spawning grounds.

Geoposition estimation

Although Welch and Eveson (1999) suggest that electronic tags can potentially estimate position within an average error of 1.2° of latitude and 0.9° longitude, the geoposition estimates produced by the control tags at ASLC were reasonable estimates. The source of errors may be intrinsic to the tags as well as related to large-scale weather systems. Additionally, Welch and Eveson's (1999) error estimates are based on geoposition estimates of tags that were not affected by light refraction of land, so-called "horizon effects." The estimated positions of the tags at ASLC were almost certainly affected by the steep topography of the land surrounding the ASLC as well as the walls of the holding tanks.

These PSAT tags were not a consistent estimator of daily geoposition of halibut in their natural environment, probably for a combination of factors. The first is that light does not penetrate past 300 m, even in clear oceanic water, and some of these halibut spent long periods deeper than 300 m. Additionally, the highly productive, coastal shelf water in which the halibut live is turbid because of suspended organic and inorganic matter. This combination greatly decreases light penetration necessary for daily light curves. A final factor is the low amount of ambient light at northern latitudes during winter. All of these factors inhibited the light sensor and the existing geolocation algorithms from accurately calculating daily position. Future examination of this PSAT tag data will be directed towards comparing depth data with existing bathymetry data sets collected in and around Resurrection Bay to estimate daily positions. Additionally, a concurrent experiment is presently being conducted in which four PSAT tags are attached to a stationary buoy in the mouth of Resurrection Bay. Examination of this data set will yield clues for improving existing tag hardware and software. Although, the PSAT did not yield consistent daily geoposition estimates, ARGOS satellites provided high-accuracy end positions during the spawning season. These are otherwise unobtainable from fisheries-dependent tagging studies because the commercial fishing season is closed during the spawning season.

The pop-up satellite archival tag proved to be an effective tool for identifying critical habitat by examining the daily and seasonal habits for Pacific halibut in the northern Gulf of Alaska. These tags allowed determination of the timing and extent of vertical and horizontal migration as well as temperature and depth preferences of halibut. General patterns of halibut behavior will emerge from larger satellite tag deployments and rigorous data analysis in the future. This gain in knowledge by PSAT tags will aid fisheries managers in future decisions regarding sustainable fisheries and conservation of Pacific halibut as well as other fish stocks in the Gulf of Alaska.

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Table 1. Release and recovery information for 7 PSAT tags on Pacific halibut in and near Resurrection Bay, AK. Tag 00-0737 was recovered by a commercial fisherman and returned. After downloading the data, the tag was deployed on another fish. Boldface print denotes recapturing the tag while on the fish before the scheduled pop-off date. Tag 00-0821 was recovered by the same captain who helped release the fish.

Tag #	Date Fish Released	Fish Length (cm)	Date of Recapture or Pop-off	Days at large	Horizontal displacement (km)
00-0737a	11/21/2000	129.5	04/05/01	135	20.3
00-0818	3/16/2001	129.5	11/15/01	244	6.5
00-0819	3/16/2001	165.1	11/15/01	244	112.1
00-0821	3/16/2001	121.9	11/05/01	234	0.0
00-0737b	7/5/2001	119.4	11/15/01	133	336.9
00-0741	7/5/2001	109.2	11/15/01	133	190.7
01-0047	7/5/2001	108.0	11/15/01	133	358.3

Table 2. Average monthly depth preferences of five Pacific halibut expressed in percentage of time spent in depth intervals. Fishes 00-0818 and 00-0819 were released on 16 March 2001 outside Resurrection Bay while fishes 00-0737b, 00-0741 and 01-0047 were released on 5 July 2001 inside Resurrection Bay.

		Month								
Tag #	Depth bin (m)	March	April	May	June	July	August	September	October	November
00-0818	0-10		0.03			0.02				
	10-50		1.20			0.71				
	50-100		0.64			1.44	0.12	0.02	0.09	0.13
	100-150	0.50	4.53			2.76	8.62	2.41	3.47	0.58
	150-250	99.50	93.60	100.00	100.00	95.06	91.26	97.57	96.44	99.29
	250-350									
	350-450									
00-0819	0-10									
	10-50									
	50-100					0.03				
	100-150					12.50	6.33	7.81	0.36	0.08
	150-250	100.00	100.00	100.00	100.00	87.47	93.67	92.19	99.64	99.92
	250-350									
	350-450									
00-0737b	0-10									
	10-50									
	50-100					2.02				
	100-150					4.81	0.67		4.05	
	150-250					26.48	11.00	19.43	68.33	16.03
	250-350					66.68	88.33	80.57	27.62	61.40
	350-450									22.56
00-0741	0-10									
	10-50									
	50-100									3.93
	100-150									11.58
	150-250					45.90	27.74	38.25	37.15	37.91
	250-350					54.10	72.26	61.75	62.85	44.04
	350-450									2.54
01-0047	0-10									
	10-50									
	50-100					1.69			1.20	
	100-150					2.95		0.01	0.86	
	150-250					80.82	77.68	29.95	19.20	16.30
	250-350					14.54	22.32	70.04	78.74	73.10
	350-450									10.60

Table 3. Average monthly ambient temperature of five Pacific halibut expressed in percentage of time spent in temperature intervals. Fishes 00-0818 and 00-0819 were released on 16 March 2001 outside Resurrection Bay while fishes 00-0737b, 00-0741 and 01-0047 were released on 5 July 2001 inside Resurrection Bay. Regardless of the fishes' location on the continental shelf, the ambient water temperature on the bottom was between 5-7 C. The fishes experienced warmer water while migrating vertically to shallower water. The fishes generally experienced cooler temperatures while occupying deeper water (>350 m) on the shelf edge.

		Month								
Tag #	Temp. bin (C)	March	April	May	June	July	August	September	October	November
00-0818	1-3									
	3-5		0.7							
	5-7	100.0	99.3	100.0	100.0	98.6	100.0	99.8	96.5	62.9
	7-9					0.7		0.2	3.4	36.7
	9-11					0.4			0.1	0.3
	11-13					0.4				
00-0819	1-3									
	3-5									
	5-7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	7-9									
	9-11									
	11-13									
00-0737b	1-3									
	3-5								0.2	10.5
	5-7					100.0	100.0	100.0	98.6	89.5
	7-9								1.2	
	9-11									
	11-13									
00-0741	1-3									
	3-5									1.1
	5-7					100.0	100.0	100.0	100.0	93.5
	7-9									5.4
	9-11									
	11-13									
01-0047	1-3									
	3-5								0.1	6.8
	5-7					100.0	100.0	100.0	97.4	93.2
	7-9								2.5	
	9-11									
	11-13									

Table 4. Monthly summaries of depth and ambient water temperature data collected once per minute. Tags 00-0737a and 00-0821 were both recovered by commercial fishermen before the programmed pop-off date of the tags.

00-737a	Depth (m)				Temperature (°C)			
Month	Maximum	Minimum	Mean	St. Dev.	Maximum	Minimum	Mean	St. Dev.
November	294	2	197.2	57.4	8.6	5.7	6.4	0.7
December	414	134	272.0	56.4	7.5	4.7	6.0	0.4
January	450	270	320.6	18.0	6.9	4.7	6.0	0.4
February	502	198	287.2	61.0	6.5	4.3	5.7	0.5
March	318	94	234.1	35.3	6.3	5.6	5.9	0.1
April	294	198	265.2	21.6	6.0	5.6	5.9	0.1
00-0821								
March	206	174	192.0	7.7	6.1	5.4	5.8	0.1
April	210	174	191.7	9.7	6.3	5.5	5.7	0.1

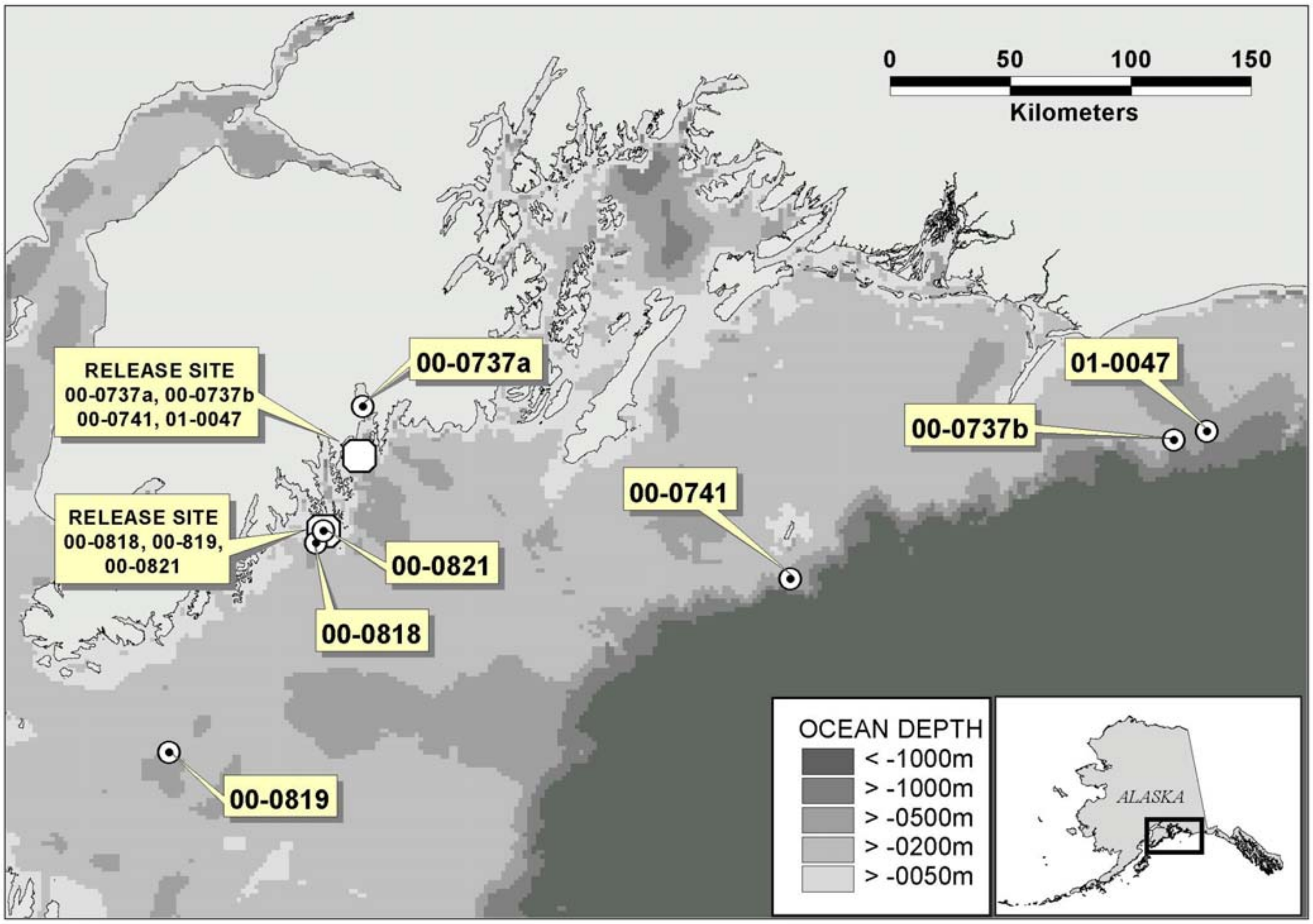
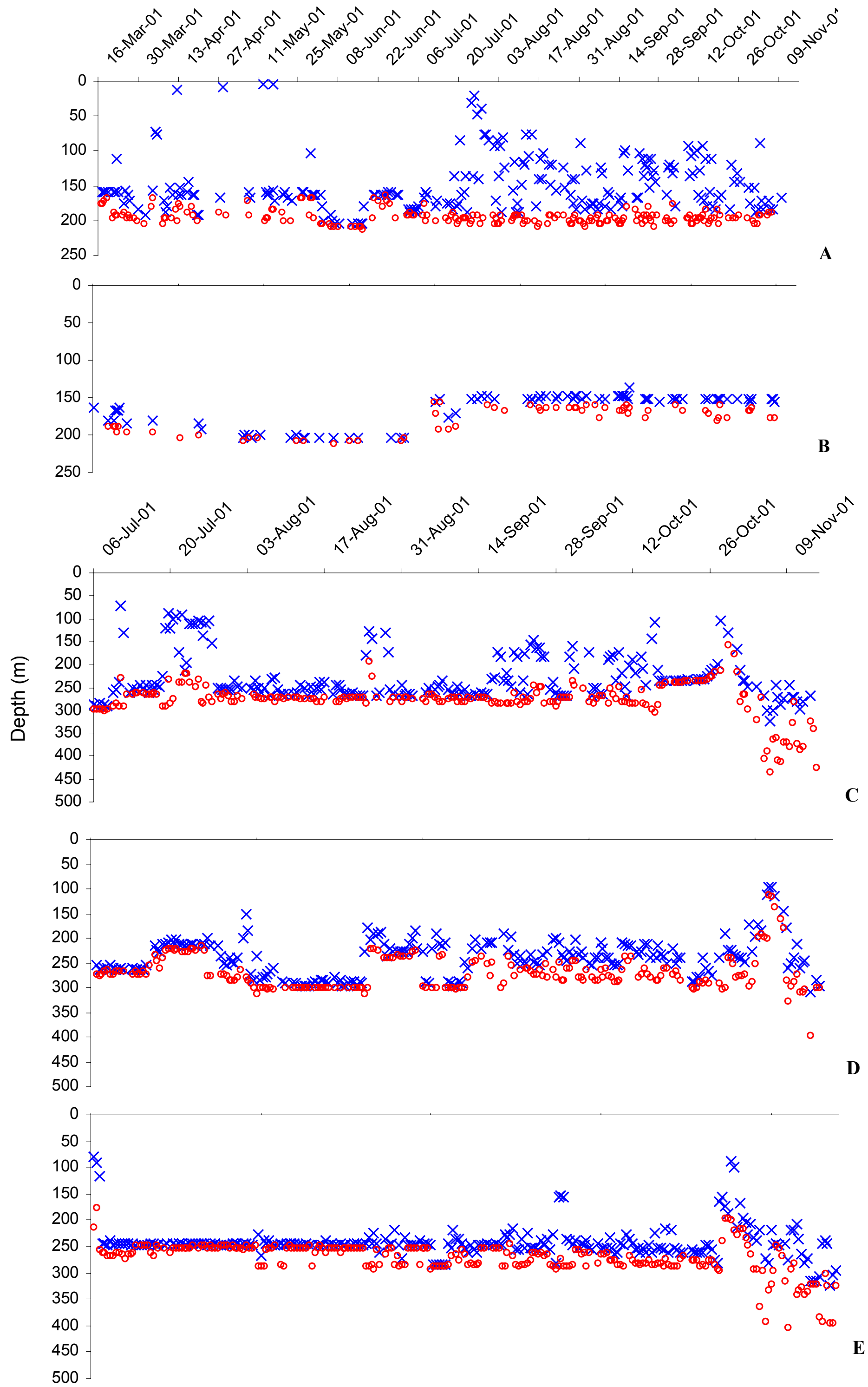
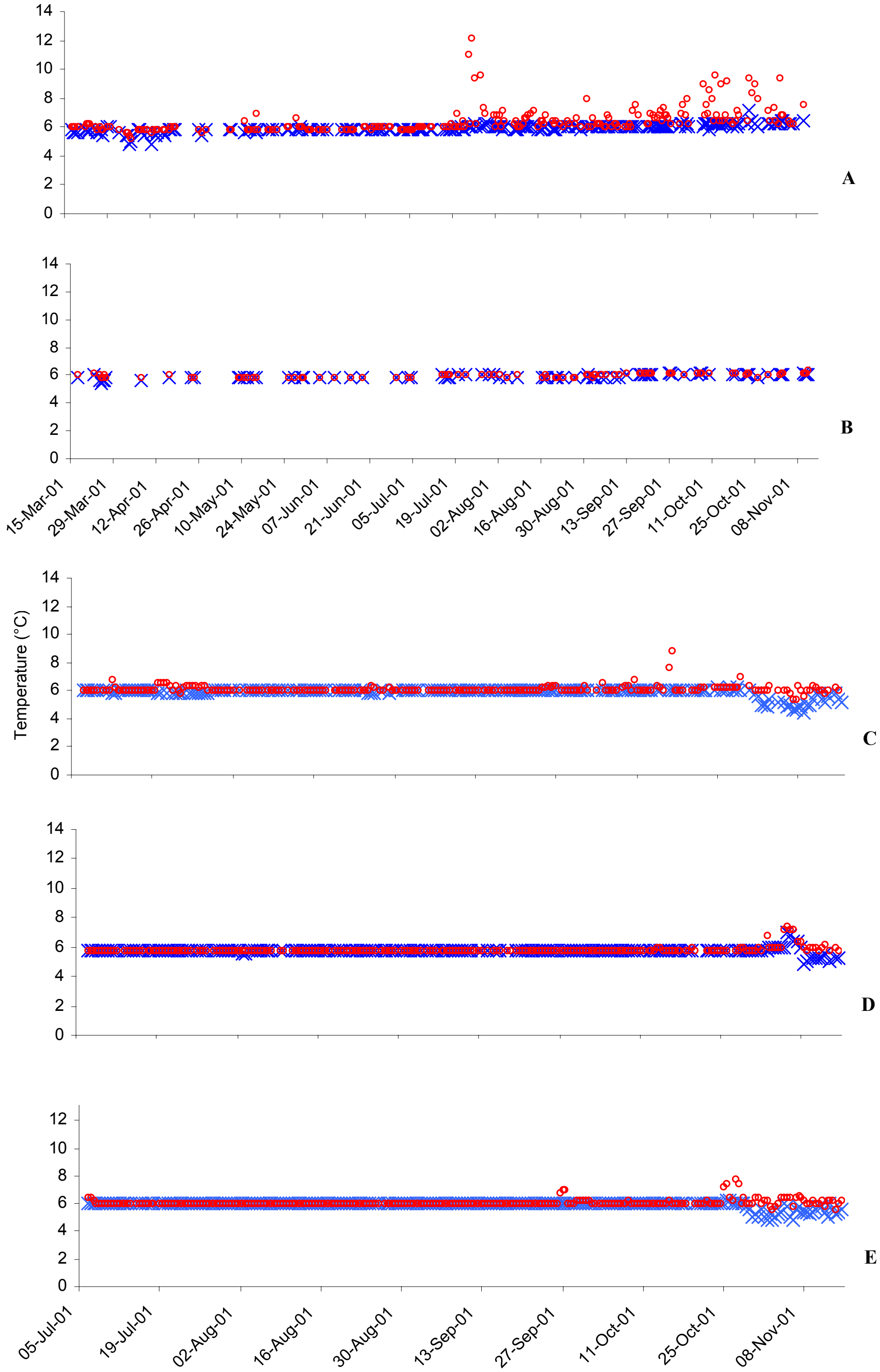


Figure 1. Satellite pop-up tagged halibut release and recapture sites in the Gulf of Alaska, 2000-2001. Numbers are equivalent to the PSAT tag numbers given in Table 1. Circles (O)) indicate locations where archival tags first downloaded to ARGOS satellite; squares (□) indicate release area for each tag.



Figures 2a-2e. Maximum (o) and minimum (x) depths occupied by five Pacific halibut for each 12-hour histogram period. Fishes 00-0818 and 00-0819 both remained on the continental shelf for the duration of the tagging experiment, while 00-0737b, 00-0741 and 01-0047 migrated to the continental shelf edge. All three fish migrated over shallow seafloor, as indicated in the shallower maximum depths in late October, before reaching the shelf edge, indicated by the deeper maximum depths at the end of the track. Note the time and depth axes are different for the fishes released in March and July.



Figures 3a-3e. Maximum (o) and minimum (x) depths occupied by five Pacific halibut for each 12-hour histogram period. Except for fish 00-0818, the halibut rarely encountered ambient water temperatures less than or greater than 5.8 to 6.2 °C until the end of the tagging study. Fish 00-0818 probably made ascents from the bottom into the water column to experience warmer ambient water temperatures. Note the time axes are different for the fishes released in March and July.

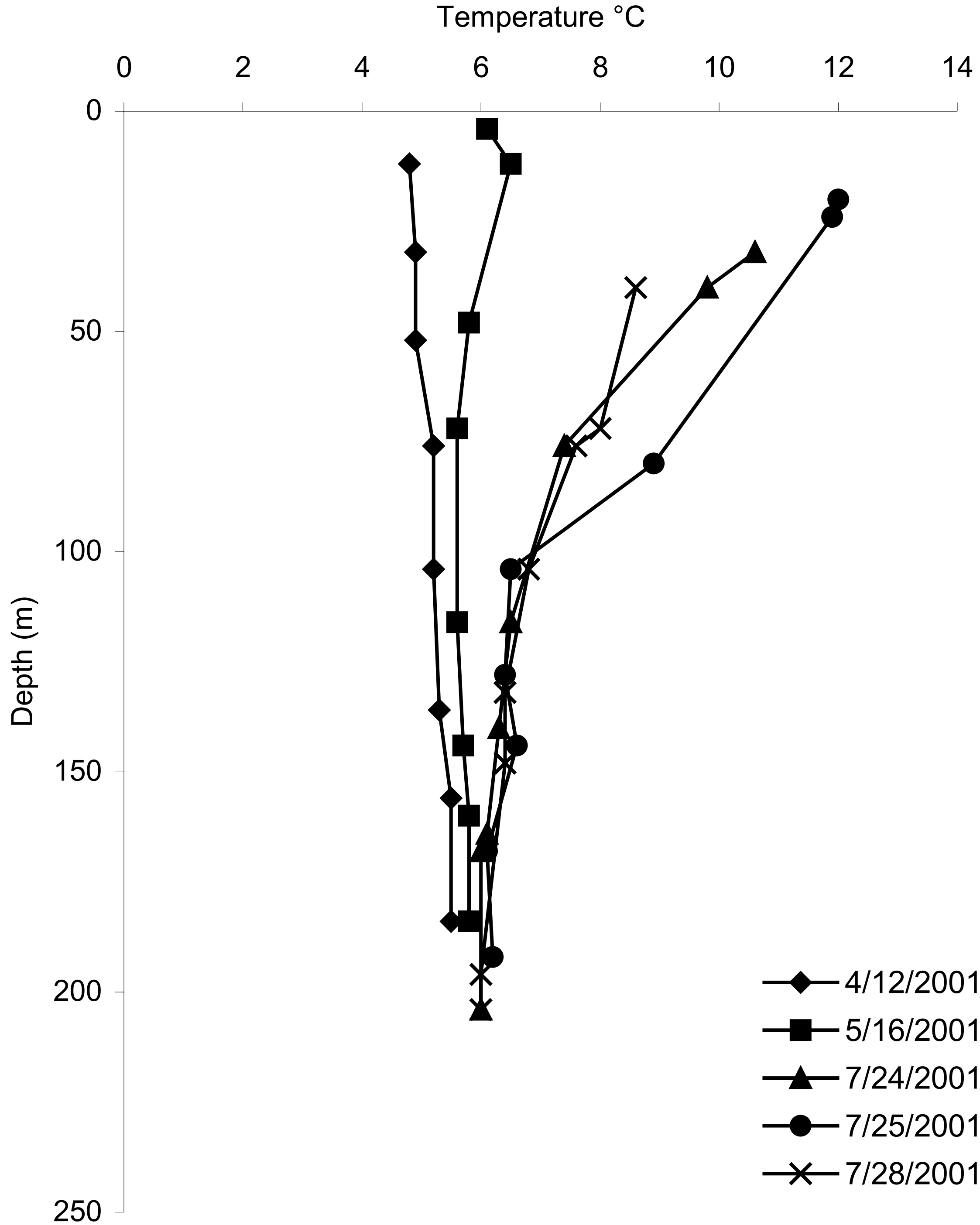


Figure 4. Water column temperature profiles for five days sampled by halibut 00-0818. This was the only fish in the study that vertically migrated sufficiently to use the temperature profile feature on the PSAT tags. The water column is isothermic in the early spring; however, as the year progresses, the surface water becomes warmer. Increased temperatures experienced by the halibut during summer may indicate ascents from the seafloor.

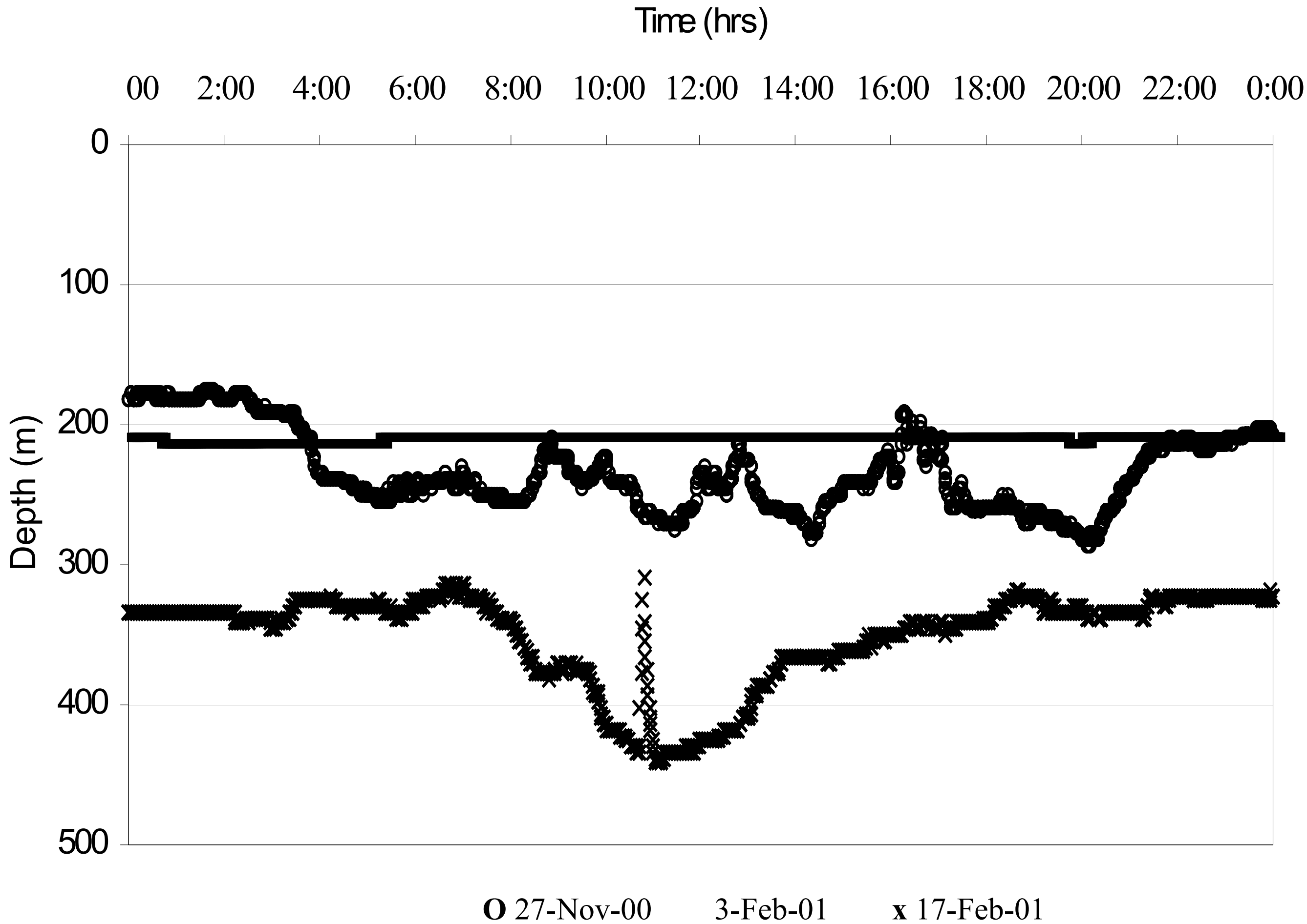


Figure 5. Three days of depth readings sampled every minute by 00-0737a. This fish displayed three distinct behaviors. The first, 27 November 2000 (o), was a gradual vertical migration to both shallower and deeper water. The slope, amplitude and frequency of the ascents and descents changed with each migration. The second, 3 February 2001 (-), represented extended periods up to 22 days of remaining at virtually the same depth. This occurred mostly in January and early February. The third, 17 February 2001 (x), was a gradual descent, an abrupt ascent of 100-175 m, an abrupt descent to the pre-ascent depth and then a gradual ascent. This routine occurred 8 times during January and February. Fish 00-0821 only displayed the first and second behaviors.

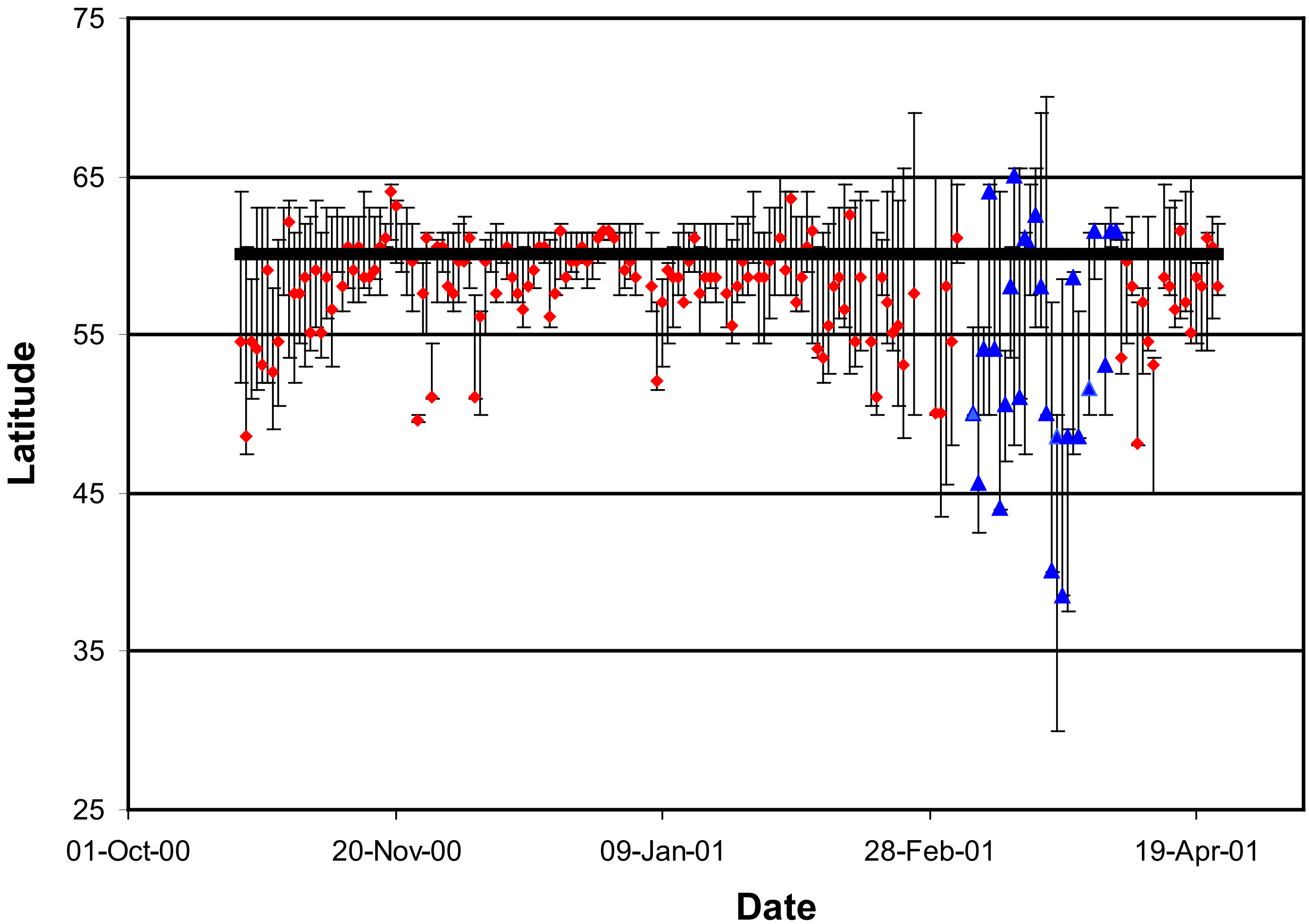


Figure 6. Wildlife Computer PSAT tag estimated latitude for fish carrying tag 00-0740 in a stationary tank at the Alaska SeaLife Center (ASLC) from October 21, 2000 to April 19, 2001. Red diamonds (♦) indicate the given estimate and bars show the range of uncertainty based on available light levels. Blue triangles (▲) indicate estimates $\underline{+}14$ days of the spring equinox. All estimates were calculated using a computer program provided by Wildlife Computers. The solid line indicates the exact location of the ASLC (60.1^{o} N).

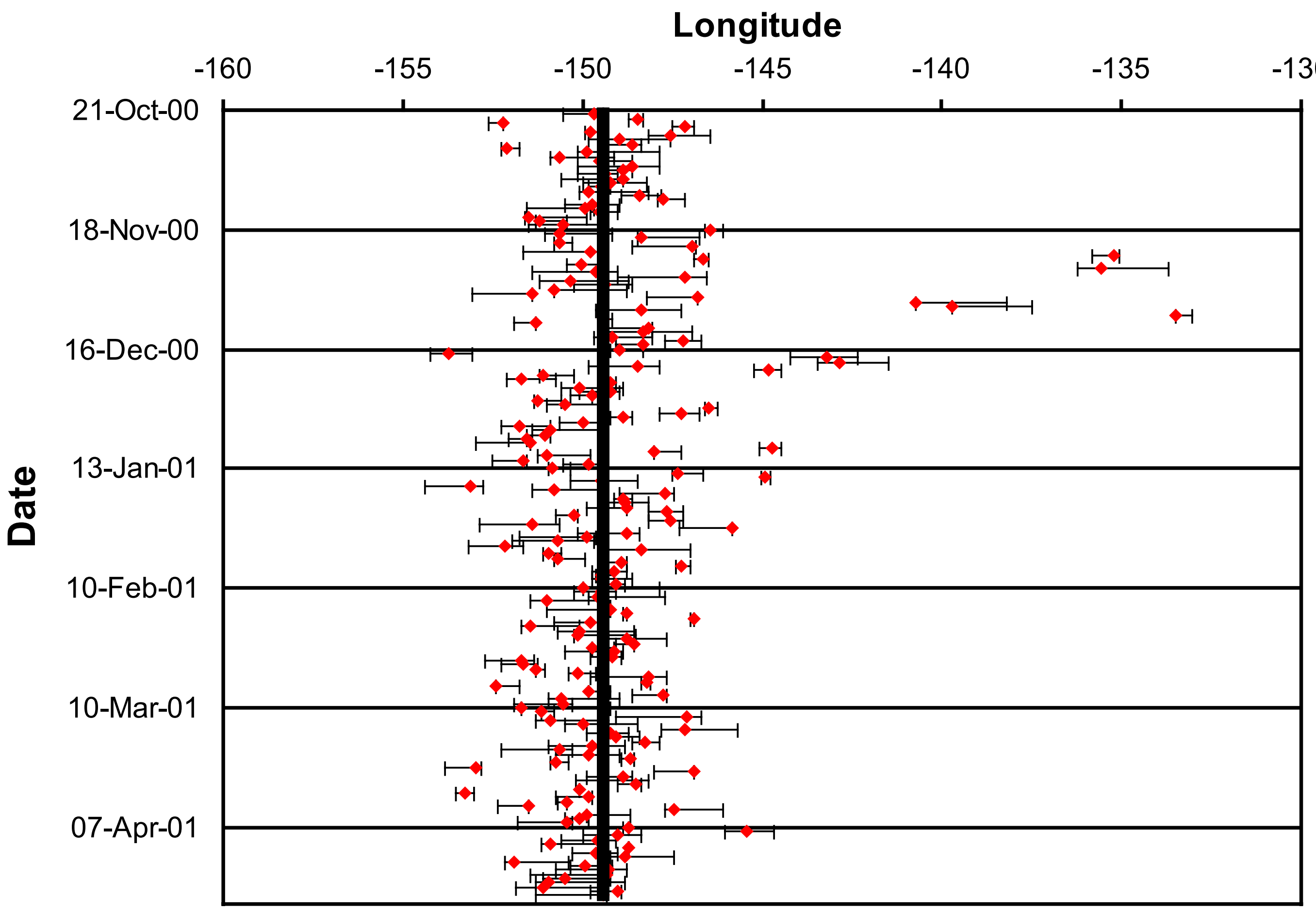


Figure 7. Wildlife Computer PSAT tag estimated longitude for fish carrying tag 00-0740 in a stationary tank at the Alaska SeaLife Center (ASLC) from October 21, 2000 to April 19, 2001. Diamonds (♦) indicate the given estimate and bars show the range of uncertainty based on available light levels generated by a program provided by Wildlife Computers. The solid line indicates the exact location of the ASLC (-149.4^{o} longitude = 149^{o} west).

Appendix I. Log of days that adequate light curves allowing estimates of sunrise and sunset were recorded from PSAT tags on Pacific halibut in the Gulf of Alaska, 2000-2001.

Tag #	Release Date	Recapture Date	Date Geolocation Produced	Longitude (W) Estimate	Latitude (N) Estimate	Days at Large	Including ASLC	Depth (m) Min	Max
00-*0737a*	11/21/2000	4/5/2001	30-Nov-00	150.628	61.6	135	168	174	194
			2-Dec-00	147.943	61.6			178	202
			4-Dec-00	145.613	62.1			134	178
			5-Dec-00	148.513	62.1			134	198
			18-Feb-01	147.235	64.1			202	214
			19-Feb-01	146.610	63.6			202	214
			20-Feb-01	147.388	63.6			210	218
			21-Feb-01	146.039	64.6			214	418
			23-Feb-01	145.480	64.6			202	294
			24-Feb-01	147.144	64.1			210	322
			25-Feb-01	150.809	64.1			214	310
			27-Feb-01	155.015	64.1			214	234
			28-Feb-01	152.936	64.1			198	222
			2-Mar-01	145.776	65.1			110	154
			3-Mar-01	147.463	64.6			106	206

% Days With Geolocation Estimates = 11.1 % **Min** 106 **Max** 418

Tag #	Release Date	Recapture Date	Date Geolocation Produced	Longitude (W) Estimate	Latitude (N) Estimate	Days at Large	Including ASLC	Depth (m) Min	Max
00-0818	3/16/2001	11/15/2001	03/17/01	153.859		244	0	160	168
			03/23/01	154.525				na	196
			03/26/01	170.640				72	204
			04/05/01	155.678				160	172
			04/07/01	138.628				160	200
			04/17/01	134.876				200	208
			05/05/01	149.359				136	192
			06/14/01	135.577				128	184
			06/23/01	167.106				120	204
			06/25/01	157.628				92	196
			06/30/01	161.805				92	196
			07/01/01	153.757				112	200
			07/04/01	142.577				168	204
			07/05/01	165.202				164	196
			07/07/01	132.330				132	196
			07/08/01	160.043				152	196
			07/16/01	157.432				176	196
			07/19/01	163.126				180	196

	07/20/01	159.251	84	204
	07/23/01	144.960	188	196
	07/24/01	152.581	32	204
	07/27/01	136.207	140	192
	07/28/01	172.588	40	204
	07/30/01	138.982	84	na
Tag # 00-0818 Continued	Date	Longitude (W)	Min	Max
	07/31/01	166.107	na	na
	08/01/01	155.746	92	192
	08/04/01	137.677	80	200
	08/06/01	157.631	na	na
	08/10/01	170.148	188	192
	08/11/01	154.565	116	192
	08/13/01	140.282	108	200
	08/17/01	135.312	112	208
	08/18/01	159.368	104	na
	08/22/01	159.933	na	na
	08/25/01	166.521	124	na
	08/28/01	139.125	140	204
	08/29/01	157.705	140	204
	09/01/01	142.953	172	200
	09/02/01	151.663	128	208
	09/03/01	154.874	na	na
	09/14/01	142.624	168	204
	09/17/01	148.403	128	180
	09/21/01	165.144	104	196
	09/24/01	135.537	112	200
	09/30/01	141.542	na	na
	10/01/01	138.746	124	200
	10/03/01	144.399	124	204
	10/12/01	133.111	128	200
	10/13/01	145.039	92	196
	10/14/01	143.214	112	200
	10/17/01	146.099	180	196
	10/20/01	139.332	164	192
	10/21/01	142.612	na	na
	10/23/01	143.913	120	196
	10/26/01	145.840	144	192
	10/27/01	167.101	na	na
	11/01/01	140.730	188	204
	11/02/01	148.845	88	204
	11/04/01	148.941	na	na
	11/06/01	141.921	184	188
	11/09/01	152.717	na	na
	11/10/01	150.559	168	na
	11/11/01	152.108	na	na

			11/12/01	141.940				na	na

% Days With Geolocation Estimates = 26.2% **Min** 32 **Max** 208

Tag #	Release Date	Recapture Date	Date Geolocation Produced	Longitude (W) Estimate	Latitude (N) Estimate	Days at Large	Including ASLC	Depth (m) Min	Depth (m) Max
00-0819	3/16/2001	11/15/2001	3/27/2001	143.015		244	0	na	na
			3/30/2001	158.380				na	na
			7/17/2001	148.536				152	156
			8/21/2001	165.616				148	168
			8/23/2001	153.377				148	164
Tag # 00-0819 Continued			Date	Longitude (W)				Min	Max
			8/25/2001	145.521				na	na
			8/30/2001	141.286				na	na
			9/5/2001	154.962				152	168
			9/21/2001	132.178				136	172
			9/23/2001	140.984				na	na
			9/28/2001	156.670				152	168
			9/29/2001	143.336				na	na
			9/30/2001	147.711				na	na
			10/6/2001	151.865				na	na
			10/13/2001	150.289				na	na
			10/20/2001	152.549				na	na
			10/23/2001	153.913				152	180
			11/4/2001	156.816				na	na

% Days With Geolocation Estimates = 7.37 % **Min** 136 **Max** 180

Tag #	Release Date	Recapture Date	Date Geolocation Produced	Longitude (W) Estimate	Latitude (N) Estimate	Days at Large	Including ASLC	Depth (m) Min	Depth (m) Max
00-0737b	7/5/2001	11/15/2001	7/10/2001	164.293		133	0	240	292
			7/14/2001	135.160				244	260
			7/20/2001	162.018				100	284
			8/10/2001	145.572				264	272
			8/15/2001	138.782				252	280
			9/14/2001	123.531				260	272
			9/17/2001	123.435				172	284
			9/21/2001	168.053				184	288
			9/24/2001	153.037				148	260
			10/4/2001	130.449				172	280
			10/5/2001	157.399				252	284
			10/15/2001	130.111				144	296
			10/29/2001	147.976				132	156

			10/30/2001	149.608				na	176
			10/31/2001	146.362				168	280
			11/2/2001	147.361				248	296
			11/3/2001	156.605				248	320
			11/6/2001	160.191				300	364

% Days With Geolocation Estimates = 13.53 % **Min** 132 **Max** 364

Tag #	Release Date	Recapture Date	Date Geolocation Produced	Longitude (W) Estimate	Latitude (N) Estimate	Days at Large	Including ASLC	Depth (m) Min	Depth (m) Max
00-0741	7/5/2001	11/15/2001	7/11/2001	132.223		133	0	260	268
			7/27/2001	165.582				200	276
			7/29/2001	141.971				216	272
			7/30/2001	137.732				252	276
			9/13/2001	151.188				204	248
			9/27/2001	153.795				204	264
			10/4/2001	155.774				252	280
			10/8/2001	142.432				252	288
Tag # 00-0741 Continued			Date	Longitude (W)				Min	Max
			10/22/2001	155.832				288	304
			10/28/2001	159.590				192	304
			10/30/2001	150.351				232	280
			11/6/2001	125.566				96	116
			11/9/2001	171.122				252	328

% Days With Geolocation Estimates = 9.77 % **Min** 96 **Max** 328

Tag #	Release Date	Recapture Date	Date Geolocation Produced	Longitude (W) Estimate	Latitude (N) Estimate	Days at Large	Including ASLC	Depth (m) Min	Depth (m) Max
01-0047	7/5/2001	11/15/2001	7/7/2001	175.580		133	0	92	256
			7/9/2001	151.830				240	268
			7/12/2001	130.507				244	272
			7/13/2001	135.848				244	264
			7/15/2001	151.604				248	248
			7/28/2001	146.082				244	252
			8/3/2001	163.552				248	252
			8/12/2001	152.735				248	252
			8/17/2001	129.312				244	252
			8/23/2001	152.502				244	288
			8/27/2001	163.096				236	264
			8/31/2001	132.703				248	252
			9/12/2001	179.346				248	284
			9/14/2001	142.156				244	na

9/15/2001	154.467	244	252
9/27/2001	130.420	152	288
10/21/2001	162.707	260	288
11/2/2001	133.105	272	232
11/11/2001	151.273	308	384
11/12/2001	155.648	240	392

% Days With Geolocation Estimates = 15.03% **Min** 92 **Max** 392

Appendix II. PSAT Tag Summary

Current Programming Status			Deployment Information				Recovery Information		
Tag #	Last date programmed	Current Pop-Off date	Date Fish Released	Fish Length (cm)	Release Latitude (N)	Release Longitude (W)	Date Recaptured or Reported	Recapture Latitude (N)	Recapture Longitude (W)
00-0736	10/17/2000	6/15/2041	11/21/2000	149.86	59.858	149.439			
00-0737a	10/17/2000		11/21/2000	129.54	59.858	149.439	4/5/2001	60.039	149.386
00-0737b	7/3/2001		7/5/2001	119.38	59.815	149.408	11/15/2001	59.570	143.431
00-0738	10/17/2000	6/15/2041	11/21/2000	129.54	59.858	149.439			
00-0739	10/17/2000	6/15/2041	11/21/2000	142.24	59.858	149.439			
00-0740	7/3/2001		7/5/2001	134.62	59.817	149.409	6/19/2001	60.099	149.440
00-0741	7/3/2001		7/5/2001	109.22	59.879	149.493	11/15/2001	60.099	149.440
00-0818	3/13/2001		3/16/2001	129.54	59.590	149.742	11/15/2001	59.547	149.803
00-0819	3/13/2001		3/16/2001	165.1	59.590	149.742	11/15/2001	58.800	150.955
00-0820	11/17/2000	6/15/2041	11/21/2000	152.4	59.858	149.439			
00-0821	3/13/2001		3/16/2001	121.92	59.590	149.742	11/5/2001	59.334	149.478
00-0822	11/22/2000	6/15/2002	12/1/2000	Buoy 27m	59.852	149.333			
00-0824	11/22/2000	6/15/2002	12/1/2000	Buoy 146m	59.852	149.333			
00-0826	11/22/2000	6/15/2002	12/1/2000	Buoy 57m	59.852	149.333			
00-0806	11/22/2000	6/15/2002	12/1/2000	Buoy 96m	59.852	149.333			
01-0046	7/3/2001		7/5/2001	121.92	59.879	149.493			
01-0047	7/3/2001		7/5/2001	107.95	59.879	149.493	11/15/2001	59.583	143.182
01-0048	7/3/2001		7/5/2001	118.11	60.047	149.358			

Tags that popped-up and transmitted (grey)
Tags on stationary buoy (green)
Recovered in commercial fishery (yellow)
Tags that did not transmit (orange)
41 year release date (pink)

Tag #	Comments
00-0736	Tagged ASLC. Stayed at ALSC until released 11/21/2000. Pops-off in 41 years
00-0737a	Tagged ASLC. Stayed at ALSC until 11/21/2000. Commercial recovery, redeployed 7/5/2001 as 00-0737
00-0737b	Tagged on Rocinante 7/5/2001. Reported to ARGOS 11/15/2001
00-0738	Tagged ALSC. Stayed at ALSC until released 11/21/2000. Pops-off in 41 years
00-0739	Tagged ALSC. Stayed at ALSC until released 11/21/2000. Pops-off in 41 years
00-0740	Control tag at ASLC, cut off fish; redeployed 7/5/2001. Missing
00-0741	Control tag at ASLC, cut off fish; redeployed 7/5/2001, reported to ARGOS 11/15/2001
00-0818	Tagged on Rocinante 7/5/2001. Reported to ARGOS 11/15/2001
00-0819	Tagged on Rocinante 7/5/2001. Reported to ARGOS 11/15/2001
00-0820	Control fish from ASLC. Tagged immediately before release. Pops-off in 41 years
00-0821	Tagged on Rocinante 7/5/2001. Recaptured 11/05/2001
00-0822	On GAK-1 buoy
00-0824	On GAK-1 buoy
00-0826	On GAK-1 buoy
00-0806	On GAK-1 buoy
01-0046	Warranty tag from Wildlife Computers, tagged on Rocinante 7/5/2001. Missing
01-0047	Warranty tag from Wildlife Computers, Tagged on Rocinante 7/5/2001. Reported to ARGOS 11/15/2001
01-0048	Warranty tag from Wildlife Computers, tagged on Rocinante 7/5/2001. Missing

	Tags that popped-up and transmitted
	Tags on stationary buoy
	Recovered in commercial fishery
	Tags that did not transmit
	41 year release date