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Pop-up Archival Transmitting (PAT) Tags: A Method to Investigate the Migration and Behavior of Pacific Halibut *Hippoglossus stenolepis* in the Gulf of Alaska

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Abstract: Pop-up archival transmitting (PAT) tags provide a fisheries–independent method of collecting environmental preference data (depth and ambient water temperature) and migration distance. In this study, we evaluate the use of pop-up archival transmitting tags as a method to investigate demersal fish. We report the results from eight pop-up archival transmitting tagged Pacific halibut *Hippoglossus stenolepis* (from 107 to 165 cm FL) that were released in and around Resurrection Bay, Alaska. Commercial fishermen recovered three tags, while five tags transmitted data to Argos satellites. Horizontal migration was not consistent among fish as four Pacific halibut remained in the vicinity of release while the other four traveled up to 358 km from the release site. Vertical movement was not consistent among fish or over time; however, they spent most of their time at depths of 150 to 350 m. The minimum and maximum depths reached by any of the Pacific halibut were 2 m and 502 m, respectively. The fish preferred water temperatures of approximately 6°C, but experienced temperatures between 4.3 and 12.2°C. Light attenuation with depth prevented geolocation software and light sensing hardware from accurately estimating geoposition for the majority of days. The methods, adapted from investigations on large pelagic fish, proved to be effective for studying Pacific halibut in the northern Gulf of Alaska. PAT tags allowed us to obtain high accuracy locations of the fish at the end of the tag deployments as well as preliminary data to identify approximate seasonal locations and to characterize their depth and temperature characteristics. By using PAT tags, we will be able to ensure tag returns during the winter season (which is closed to fishing) and gain valuable biological information even if fish migrate large distances or to unexpected locations.

INTRODUCTION

Pacific halibut *Hippoglossus stenolepis* inhabit continental shelf areas from California to the Bering Sea, and from Russia to Japan. Because of their large size (up to 250 kg) and fine flesh quality, Pacific halibut have experienced sustained commercial exploitation for the last century (IPHC 1998). The fishery is managed as a single stock by the International Pacific Halibut Commission (IPHC), a convention between Canada and the United States of America.

The Pacific halibut population supports one of the most valuable fisheries in the Gulf of Alaska and eastern Bering Sea. Coastwide landings over the last five years have averaged around 70 million pounds annually, with annual landed values estimated at between $100 and $170 million (T. Loher, International Pacific Halibut Commission, Seattle, Washington, personal communication). Recently, the IPHC has been confronted with a number of local depletion issues, which suggests that movement by adults may be relatively limited. If a geographic pattern of subpopulations exists, it may bear a substantial impact on landing patterns, especially for individuals and communities whose fishing operations are prosecuted close to their home port. The debate over the relative biological independence of stocks is likely to become more controversial in the near future as IPHC recruitment models indicate that total exploitable biomass has been declining since about 1999 (Clark and Hare 2001). This decline is expected to continue over the next decade as recruitment responds to changes in large-scale environmental forcing (Clark and Hare 2002). It is therefore necessary to investigate the

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movement and environmental preferences of Pacific halibut for a better understanding of their population structure so management practices can be adapted to changes in environmental forcing and predicted declines in abundance.

The IPHC has conducted hundreds of tagging studies since 1925 (Kaimmer 2000) to address management issues including migration among fishing regions and stock identity (Skud 1977; Trumble et al. 1990). All of these tagging studies employed conventional tags with a numeric identifier for which geoposition and biological data of each tagged fish were recorded upon release and recapture. Tagging results have been used in the management approach, regulations, and population biology of Pacific halibut (Trumble et al. 1990). IPHC conventional tag studies indicate the existence of a single panmictic stock from northern California through the eastern Bering Sea (Skud 1977). However, differential non-reporting over time and area, tag shedding, and tagging mortality limit the usefulness of conventional tagging data to only discerning general movement patterns. Additionally, correctly recovered conventional tags are limited in that they only provide beginning and end positions, with no information concerning the behavior of the fish while at-large. Because the commercial Pacific halibut fishing season runs from March to November, the vast majority of tag returns occur during these months when fishing takes place. This leaves a three-month gap in migration information.

To overcome the limitations associated with conventional tagging of flatfishes, studies using electronic tags, or tags with miniaturized onboard computers, have been conducted on species including Pacific halibut (Hooge and Taggart 1993), North Sea plaice *Pleuronectes platessa* (Arnold and Holford 1978; Metcalfe et al. 1991) and Greenland halibut *Reinhardtius hippoglossoides* (Baldur Sigurgeirsson, Star-Oddi, Vatnagardar 14, 104 Reykjavik, Iceland, personal communication). These tags have electronic sensors and can provide detailed information on one or more of the following parameters: depth, ambient temperature, light, and swimming speed. Although electronic tags provide more information than conventional tags, they still have drawbacks. One type of electronic tag uses acoustic telemetry; these tags are devices that emit a high-frequency “ping” and are attached to an animal (Siebert 2001). Data retrieval from these tags requires physically following the animal’s “ping” with a hydrophone deployed from a vessel, thus rendering the tags spatially and temporally limited. A second type, archival tags, are miniature computers containing a clock integrated with a variety of sensors (Siebert 2001) that provide detailed records on depth, temperature, and ambient light. Archival tags are dependent on fish recapture for data recovery.

The pop-up archival transmitting (PAT) tag, a third type of electronic tag, provides some solutions to the aforementioned problems of fish tagging. The PAT tag is the first method of studying fish that does not rely on data collection by commercial or research vessels. To elucidate movement patterns and behavior, PAT tags have been successfully deployed on a variety of large pelagic fish in temperate and subtropical latitudes including: tuna *Thunnus* spp. (Lutcavage et al. 1999; Block et al. 2001a, b; Gunn and Block 2001; Marcinek et al. 2001), tiger sharks *Galeocerdo cuvier* (Holland et al. 2001), white sharks *Carcharodon carcharias* (Boustany et al. 2002), sharptail mola *Masturus lanceolatus* (Seitz et al. 2002a) and blue marlin *Makaira nigricans* (Graves et al. 2002). Though PAT tags only have been deployed on pelagic fish to date, the large size of Pacific halibut suggests that PAT tags may be an appropriate technique for studying their migration and behavior. In this paper, we present the results of a preliminary study to evaluate the feasibility of using pop-up satellite tags as a method to investigate migration and behavior of Pacific halibut (hereafter referred to as halibut) in the Gulf of Alaska.

MATERIALS AND METHODS

We used Wildlife Computers (Redmond, Washington, USA) PAT tags, which had three electronic sensors that measured ambient water temperature, depth of the tag and ambient light. These sensors were fully cast in a tube (21 mm diameter, 175 mm overall length not including antenna, 75 g total weight in air) that, along with the float (40 mm at its widest point), could withstand pressure at a water depth of 1,750 m. PAT tags were externally tethered to the study animal; at a user-specified date and time the PAT tag actively corroded the pin to which the tether was attached, thus releasing the tag from the animal. The tag then floated to the surface and transmitted summarized data records via the Argos satellite system (<www.argosinc.com>). Upon popping-up, the tags’ endpoint positions were determined from the Doppler shift of the transmitted radio frequency in successive uplinks received during one Argos satellite pass (Keating 1995). The transmitted data then were processed further by Wildlife Computers’ PC-based software. If the fish was captured and the tag retrieved before the pop-up date, the full archival data record could be obtained. The design, function, data collection and data processing of PAT tags are fully described in the Wildlife Computers Pop-up Archival Transmitting (PAT) tag User's Manual (available online).

The environmental data were measured and recorded at user-specified intervals and were subsequently summarized by software onboard the PAT tag thus providing four types of data: percentage of time spent within specific depth ranges (depth histograms); percentage of time spent within specific temperature ranges (temperature histograms); depth-temperature profiles; and daily geoposition estimates calculated from a light-based geolocation algorithm. In this study, the PAT tags were programmed to sample environmental parameters every one or two minutes which provided high resolution data if the tag was recaptured, yet allowed for archival records of approximately 6 and 12 month durations, respectively. More frequent sampling would result in higher resolution data, but shorter data records and vice versa. To reduce the size of the data record transmitted to Argos satellites, the data were summarized into proportion of time spent in user-defined histogram bins for 12-hour periods. The summary period was also user-programmable, and we chose 12-hour periods to maximize the resolution of the data while minimizing gaps in the data record. Gaps in the data record exist because of incomplete transmission of the entire data set. This results from the fact that PAT tags transmit their data continuously even though Argos satellites are overhead and receive data approximately 12 times per day at latitudes in the northern Gulf of Alaska. This method of data transmission results in repeats of some blocks of data while other data are missing. Twelve-hour summaries were chosen as a compromise between high-resolution data and gaps in the tag record. The resolution of the time-at-depth and time-at-temperature summaries was fixed at 12 user-adjustable bins in PAT tags. We chose the bin limits according to known depth ranges of halibut caught in commercial and sport fisheries (IPHC 1998), but do not report the percentage of time spent in depth and temperature bins here because the histograms were of low resolution and did not provide much information.

For all tagged fish, we report fish size, release and recovery locations, and minimum and maximum depths and temperatures recorded for each 12-hour period. The minimum and maximum depths for the 12 hours immediately following release were excluded. We only report the depth-temperature profile sampled by the PAT tag if the fish moved vertically greater than 150 m and visited waters shallower than 50 m during a 12-hour summary period. This facilitates comparison to water column profiles sampled by research vessels. If the tags were recovered in the commercial fishery, we also report mean monthly temperature and depth of each fish. Post processing of data recpeived through Argos satellites is described in detail in Block et al. (2001b) and Gunn and Block (2001). Light-based geolocation estimates are not reported for any of the tags.

We followed several criteria to minimize stress of the halibut associated with applying and carrying large external tags. A PAT tag was tethered to a titanium dart using 130 kg test monofilament fishing line wrapped in adhesive-lined shrink-wrap. The tether was adapted from Gunn and Block (2001) and Block et al. (2001b). The monofilament line was secured at both ends using stainless steel crimping sleeves. The shrink-wrap was used to give the tether a larger circumference thus decreasing possible muscle and skin damage caused by a moving tag while the fish was swimming. Additionally, the shrink-wrap increased the rigidity of the tether system, which maintained its vertical position and kept the tag away from the fish. The tags were attached to the halibut by inserting a titanium dart (6.0 cm long, 1.2 cm wide, 0.5 cm thick) through the dorsal musculature and pterygiophores, anchoring it in the bony fin-ray supports. This prevented muscle damage and premature rejection of the dart caused by tearing through muscle tissue due to hydrodynamic drag of the tag. Only halibut greater than 105 cm were tagged and the position of the dart was about 2.5 cm medially from the halibuts' dorsal fin on the eyed-side of the fish where the body began to taper towards the tail. This combination of fish size and tether position ensured that the antenna did not interfere with the tail and that the float did not rub against the skin of the fish during swimming. A single cruciate suture was used to close the 1.0 cm insertion wound to minimize infection and hasten healing time.

To test the feasibility of PAT tagging halibut, wild fish were captured, transported live to aquaria, and tagged to monitor the effects of the attached PAT tags. On 7–8 August 2000, seven Pacific halibut (from 107 to 137 cm FL) were captured by a chartered commercial longline fishing vessel off Bear Glacier, Resurrection Bay, Alaska (lat 59.89° N, long 149.49° W) and transported live to the Alaska SeaLife Center (ASLC), in Seward, Alaska. Every other day, the captive halibut were fed Pacific herring *Clupea pallasii* until satiation. On 19–20 October 2000, six captive fish were tagged with PAT tags and one captive halibut was left untagged as a control. To facilitate the tagging process, 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. Once the captive fish were tagged, their response to daily feeding, skin coloration, and insertion wound size was monitored for the next month as indicators of general health to determine the feasibility of PAT tagging halibut. On 20 November 2000, the control fish was tagged with a PAT tag, and subsequently, five of the seven captive halibut were released close to the original capture location in Resurrection Bay. The tags were programmed to release from the fish on 15 June 2001. On 5 July 2001, the remaining two captive halibut were released at the same location and their tags were programmed to release on 15 November 2001.

Additional wild halibut were tagged with PAT tags and released. On 16 March 2001, three wild halibut were captured on longline gear aboard a chartered commercial fishing vessel outside of Resurrection Bay near Cape Aialik, Alaska (lat 59.59 N, long 149.74 W). 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 the halibuts' condition for post-release viability by examining their opercular movement, muscle strength, and gammarid sand flea infestation. After determining they were healthy, the fish were measured, tagged, and released (Table 1 and Figure 1). On 5 July 2001, in addition to the captive halibut that were released, four wild halibut were captured, tagged and released at the same location in Resurrection Bay following the protocol described for the previous wild fish. All of the tags on the wild halibut were programmed to pop off on 15 November 2001. Neither wild nor captive fish were sexed because we were unable to determine our accuracy rate for sexing halibut based on external morphology (St-Pierre 1992).

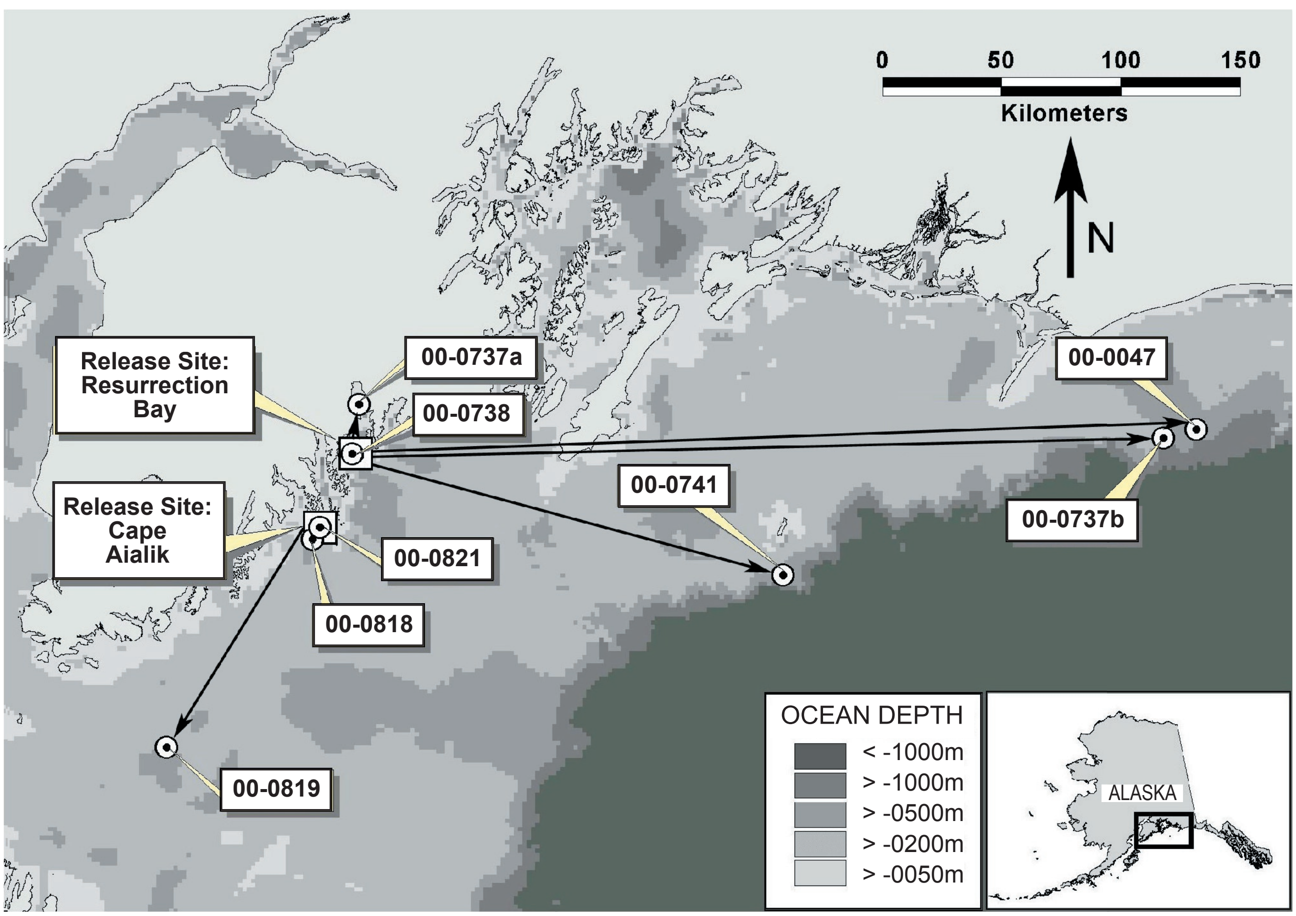

Figure 1. Release and recapture sites of PAT-tagged halibut in the Gulf of Alaska, 2000–2001. Numbers are equivalent to the PAT tag numbers given in Table 1. Circles (O) indicate locations where tags first reported to Argos satellite or were recovered by commercial fishermen; squares (□) indicate release areas.