Migration patterns of Pacific halibut *Hippoglossus stenolepis* in the southeast Bering Sea

NPRB Project 617 Final Report

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Abstract

Currently, it is assumed that eastern Pacific halibut *Hippoglossus stenolepis* belong to a single, fully mixed population extending from California through the Bering Sea, in which adult fish disperse randomly throughout their range during their lifetime. However, we hypothesize that Pacific halibut dispersal and behavior are more complex than currently assumed and are not spatially or temporally random. To test this hypothesis, we studied seasonal dispersal and behavior of Pacific halibut in the Bering Sea and Aleutian Islands. Pop-up Archival Transmitting tags provided no evidence that Pacific halibut moved out of the Bering Sea and Aleutian Islands region into the Gulf of Alaska during the mid-winter spawning season, supporting the concept that this region may contain a separate spawning component of adult fish. There was evidence for geographically localized groups of Pacific halibut along the Aleutian Island chain, as all of the fish tagged there displayed residency, with their movements possibly impeded by deep passes between islands. Mid-winter aggregation areas of Pacific halibut are assumed to be spawning grounds, of which two were previously unidentified and extend its presumed spawning range ~1000 km west and ~600 km north of the nearest documented spawning area. The summarized depth data transmitted via satellites was used to identify three general behavior patterns including dispersal to the continental slope, continental shelf residency, and feeding site fidelity. This behavior information may be used to refine some assumptions of Pacific halibut biology and ecology.

Keywords: Pacific halibut, *Hippoglossus stenolepis*, Bering Sea, Aleutian Islands, behavior, seasonal dispersal, migration, PAT tag, satellite tag, pop-up tag

Suggested citation:

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Study chronology:

Five semi-annual reports describing progress made during the first five semesters of this two year project were submitted to NPRB at the end of each reporting period. The current final report will summarize the progress reported in these semi-annual reports and provide a brief update of activities and progress achieved during the final four months of the project.

From May-Aug 2006, 24 Pop-up Archival Transmitting (PAT) tags were purchased, leadered, programmed and deployed. From 1 June to 15 June 2006, A. Seitz was deployed on a commercial fishing vessel chartered by the International Pacific Halibut Commission (IPHC) to conduct its Annual Setline Survey in the area of the continental shelf break, offshore of St. Matthew Island in the Bering Sea. During the survey, 12 Pacific halibut ranging from 110 to 140 cm were tagged and released with PAT tags. From 1 August to 15 August 2006, two International Pacific Halibut Commission (IPHC) Sea Samplers were deployed on a commercial fishing vessel chartered by the IPHC to conduct its Annual Setline Survey in the area of the continental shelf break north of Unimak Pass in the Bering Sea. During this survey, 12 Pacific halibut ranging from 110 to 140 cm were tagged and released with PAT tags.

In February 2007, data were recovered from 23 tags of the 24 tags released on Pacific halibut, of which 21 provided behavioral, environmental and endpoint data. From February to July 2007, data from these tags were analyzed and summarized in various presentations and reports (subsequently described).

During the summer of 2007, we were unable to complete our scheduled outreach components, two “townhall” style meetings on Atka and St. Paul Islands, because of several cancelled flights due to inclement Bering Sea weather.

From July 2007 to February 2008, the results from this study were reported through various outlets. First, an International Pacific Halibut Commission Scientific Report was submitted in July 2007, passed internal review and is currently under external peer review. A copy of this IPHC Scientific Report is provided here as Chapter 1. Results from this study were presented at the IPHC’s Annual Meeting held in Portland, OR from January 15 through January 18, 2008. At the meeting, the results were distributed in the International Pacific Halibut Commission’s 2007 Report of Assessment and Research Activities. This publication is freely available and widely distributed to fisheries researchers and the Pacific halibut fishing industry, including fishers, buyers, processors and marketers. Two PIs (Seitz and Loher) attended The International

In June 2008, two PIs were finally able to complete the outreach component of this study. After several delays, the weather in the Bering Sea and Aleutian Islands cooperated long enough to allow visits to Atka Island and St. Paul Island in mid-June. To disseminate results of the study to both communities, we held “townhall” style meetings in which we summarized the results of the Pacific halibut tagging done in the Bering Sea and Aleutian islands. The residents of both communities were extremely appreciative of the visits and were able to ask questions and to provide input, opinions, and comments on Pacific halibut in the region. Based on the success of the ongoing work, its direct relevance to regional concerns, and the relationship developed between the principal investigators and the local fishing fleets, the CDQ groups from both communities pledged financial support for addition work to investigate interannual dispersal around the islands via summer-to-summer tagging. These tag deployments are presently being conducted.

During summer and early fall 2008, the results from this study were combined with previous Pacific halibut satellite tagging results from the Bering Sea and Aleutian Islands and incorporated into a manuscript that will be submitted to Marine Ecology Progress Series. This manuscript is provided in this final report as Chapter 2.
Introduction

Pacific halibut population(s) supports one of the strongest fisheries in the Gulf of Alaska (GOA) and Bering Sea/Aleutian Islands (BSAI). Coast-wide landings over the last five years have averaged around 70 million pounds annually, with annual landed values estimated at between $100 and $170 million (IPHC, Seattle, unpublished). This represents an important resource throughout western Alaska, with over 12 million pounds of product landed during 2007 in the BSAI, about 2.5 million pounds of which were harvested by local communities under their Community Development Quotas. While individual fishers and local communities are allocated a discrete proportion of each year’s regional catch quota, the fact remains that true local area management is not possible in western Alaska because presently, our understanding of BSAI stock dynamics is not sufficient to allow the IPHC to establish quotas in the region using a stand-alone Bering Sea stock assessment. Rather, GOA abundances are used as a proxy to estimate BSAI abundances, assuming that: the entire population is panmictic, the BSAI is essentially an extension of the northern GOA, and population dynamics are similar between ocean basins. If these assumptions are false, catch-per-unit effort (CPUE) between basins may not be directly comparable. The result would be setting a BSAI quota that is not appropriate for the stock.

Determining whether the Bering Sea supports a self-recruiting population is an important component to assessing the validity of panmixis.

The present quota-setting scenario was established largely due to genetic (Grant et al., 1984; Bentzen et al., 1998) and conventional tagging (Skud, 1977; review in Kaimmer, 2000) data suggesting the existence of a single panmictic stock from northern California through the Bering Sea. According to this conceptual model, some of the adult halibut that feed during the summer in the Bering will spawn in the GOA, mixing with individuals that feed in other areas, and thus the entire halibut population is one stock. Furthermore, it is generally believed that the prevailing currents in the central GOA should carry the pelagic halibut eggs and larvae westward from the spawning ground to settle at six months of age throughout the range of halibut in the Bering Sea and Aleutian Islands (Skud, 1977). This combination of adult and larval mixing would provide a reliable, annual supply of halibut to all parts of their range ensuring a healthy fishery every year. Thus if adults from a local area in the Bering Sea were all captured during a fishing season, the cross-basin advection of pelagically-drifting eggs and larvae from adults from several feeding areas that mix on the spawning grounds should re-supply all areas.

However, in reality mixing may be more restricted than assumed, as evidenced by a number of local depletion issues that the IPHC has been confronted with in the BSAI in recent years, such as
within the halibut fishery near St. Paul Island (Dr. Steve Hare, IPHC, personal communication). Harvest shortfalls from 2000 to 2004 in area 4C were 14, 15, 41, 56, and 45% of the combined CDQ-IFQ quotas. This local depletion in the Bering Sea suggests that movement of individual halibut may be relatively limited in the Bering Sea and that the area is self-recruiting.

Migration patterns and winter spawning locations of halibut in the Bering Sea serve as possible indicators of population sub-structure. If halibut spawn in the BSAI, their pelagically drifting eggs and larvae will most likely be retained in the BSAI by the prevailing currents. In the 1930’s, halibut spawning was found to occur in the Bering Sea during the winter along the shelf break, extending at least as far north as the Pribilof Canyon (Thompson and Van Cleve, 1936). Spawning may take place farther north in the Bering Sea, but winter spawning surveys have never been conducted north of the Pribilof Islands. Additionally, winter halibut distribution has not been investigated along the Aleutian chain; therefore we are unable to draw firm conclusions regarding the extent of spawning. It is likely that fish that spawn in the BSAI region remain in these waters throughout the summer to feed and form a separate stock unit, thus supporting the fisheries of western Alaska. In this case, mesoscale population sub-structure may exist and have a substantial affect on landing patterns, especially for individuals and communities whose fishing operations are prosecuted close to their homeport, such as St. Paul Island. In the face of a declining halibut fishery, proper management is essential.

It is clear that fundamental information is lacking regarding winter halibut distribution and the degree of connectivity among geographical components throughout the range of halibut. The dearth of information exists because only from 1913 to 1924 did the IPHC allow a winter fishery, during which fishers were able to recover fish tagged during the summer feeding season. Furthermore, although fishing was open in the BSAI and the GOA, most of the winter fishery, and hence tag recoveries, occurred in the GOA because the weather was more amenable and the region was closer to major population centers than the BSAI. After 1924, the commercial fishing season was closed during the winter spawning months as a protective measure and only sparse winter distribution data of halibut have been collected since.
Hypotheses

1. Halibut that feed in the Bering Sea and Aleutian Islands in the summer do not emigrate from the region during the winter spawning season and are not spatially connected to halibut in the Gulf of Alaska
2. Bering Sea/Aleutian Island halibut belong to a separate population component from the GOA halibut on time scales relevant to exploitation and fishery management

Objectives

1. To examine the current assumption that halibut from BSAI are reproductively mixed with fish from the GOA by using pop-up satellite tags to test whether halibut tagged in the BSAI in the summer remain in the region during the winter
2. To infer migration timing and pathways used during their spawning migration
3. To infer the biological and ecological implications of the behavior and dispersal of Pacific halibut in the Bering Sea and Aleutian Islands
CHAPTER 1

Further investigation of seasonal movements and environmental conditions experienced by
Pacific halibut in the Bering Sea, examined by pop-up satellite tags

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Abstract
Currently, Pacific halibut (*Hippoglossus stenolepis*) is managed as one stock extending from California through the Bering Sea, but we hypothesize that Pacific halibut in the Bering Sea and Aleutian Islands belong to a separate sub-population from those in the Gulf of Alaska, with respect to spawning structure. We studied the putative spawning locations and seasonal migration of Pacific halibut along the southeastern Bering Sea shelf-edge as indicators of population structure, building on prior research that characterized sites on the southeast Bering Sea shelf and in the Aleutian Islands. Pop-up Archival Transmitting provided no evidence that Pacific halibut moved out of the Bering Sea into the Gulf of Alaska during the mid-winter spawning season, supporting our hypothesis of separate sub-populations. Mid-winter aggregation patterns suggest that a spawning ground may be located in Middle Canyon, which is approximately 600 km northwest of the nearest documented spawning area in the Pribilof Canyon. The summarized depth data transmitted via satellites may be useful for identifying spawning behavior. If discrete acts of spawning may be identified, they may be used to refine some assumptions of spawning characteristics of Pacific halibut, including spawning frequency and season.
Introduction

The Pacific halibut (*Hippoglossus stenolepis*) fishery is an important resource throughout western Alaska (Fig. 1), especially where it is harvested under the Community Development Quota (CDQ) program (NRC 1999). The CDQ program was established to provide income to coastal communities with access to Aleutian Island and Bering Sea marine resources. The program has been hailed by the National Research Council as a critical innovation for local economic development and Pacific halibut represent one of the key species within the program. Therefore, sound management of Pacific halibut on regional scales should represent an important management objective for the International Pacific Halibut Commission (IPHC).

Currently, the IPHC does not manage Bering Sea/Aleutian Island (BSAI) Pacific halibut on a regional scale with independent population dynamics, but as part of a single population in the eastern Pacific Ocean that is well mixed from Oregon to Alaska (see reviews in Seitz et al. *in press*; Seitz et al. *in review*). It is generally believed that throughout its range, this population of Pacific halibut feeds in shallow, nearshore areas during the summer, undertakes a spawning migration to deeper water during winter and returns to its summer grounds during spring (Dunlop et al. 1964, Best 1981). Spawning appears to be concentrated in relatively discrete winter spawning grounds near the edge of the continental shelf, from at least British Columbia, Canada through the Pribilof Canyon (Fig. 1) in the southeast Bering Sea (St. Pierre 1984). Segregation of spawning into discrete units has the potential to generate internal population structure at scales not adequately captured in a single -unit –stock management approach (Stephenson 1999, Frank and Brickman 2001). At the adult level, the paradigm of a well-mixed stock implies that Pacific halibut from several feeding areas, including fish from the BSAI region and those from the Gulf of Alaska (GOA; Fig. 1), mingle on common spawning grounds or at least display some degree of migratory interlacing between adjacent regions (e.g., Koutsikopoulos et al. 1995) without clear geographic segregation in dispersal patterns.

However, because of land masses and ocean currents that partially separate the BSAI region from the GOA, we hypothesize that Pacific halibut from these regions do not intermingle on common spawning grounds, but rather fish remain in their respective regions throughout the year. If Pacific halibut from the BSAI region do not mix on the spawning grounds with those from the GOA, the BSAI region may support a separate spawning component or sub-population of Pacific halibut (see review in Seitz et al. *in press*). If there is indeed a sub-population of Pacific halibut in the BSAI region, this may have a substantial impact on local productivity and
population dynamics in the fisheries of western Alaska, especially considering declines in catch per unit effort (Hare 2005, 2006) and exploitable biomass (Clark and Hare 2002a) which are expected to continue over the next decade (Clark and Hare 2002b).

To address the BSAI sub-population hypothesis, we began an investigation to examine the winter locations, which are considered putative spawning areas, and migratory pathways of Pacific halibut in five locations that encircle the range of Pacific halibut in the Bering Sea and Aleutian Islands region (Seitz et al. *in press*; Seitz et al. *in review*). Prior to this experiment, we tagged adult Pacific halibut with Pop-up Archival Transmitting (PAT) tags (Seitz et al. 2003) in three locations: near St. Paul Island (Fig. 1), along the southeast Bering Sea shelf-edge and near Attu and Atka Islands (Fig. 1) in the Aleutian chain. PAT tags allow us to determine winter location of the tagged fish and some aspects of their migration timing and routes, without depending upon winter fisheries to recapture the tagged individuals.

Results from these investigations indicated that none of the tagged Pacific halibut moved out of the Bering Sea and Aleutian Islands region into the Gulf of Alaska during the mid-winter spawning season, providing support for our hypothesis of spawning sub-populations (Fig. 1). Within the Bering Sea and Aleutians region, there was evidence for geographically localized sub-populations as all of the Pacific halibut tagged near the Aleutian Islands displayed residency near the islands where they were tagged. In the southeastern Bering Sea, the Pacific halibut ranged farther from their tagging location than those from the Aleutian Islands but failed to display any evidence of having crossed the Aleutian Ridge.

Although these investigations represent an advance in our knowledge of Pacific halibut biology in the BSAI region, completion of our original experimental design is imperative because three shortcomings prevent confident inference regarding population structure of these fish in the eastern Pacific Ocean. First, the sample size of tagged Pacific halibut on the southeastern Bering Sea continental shelf was small (n=7). Second, the geographical distribution of PAT tag releases was highly localized around St. Paul Island, thus a representative view of Pacific halibut behavior across the entire southeastern Bering Sea shelf was not obtained. Third, and arguably the most important, Pacific halibut were not PAT tagged and released near the strait that connects the Bering Sea and the Gulf of Alaska: Unimak Pass (Fig. 1). If interlacing between the Bering Sea and GOA occurs, one would hypothesize that it would be most strongly detectable around Unimak Pass.

The goal of the present study is to rectify the previously described shortcomings by tagging Pacific halibut at two additional areas in the southeast Bering Sea with PAT tags to
complete a five-site circum-BSAI experimental design. Using these PAT tag data, we will determine winter locations of tagged Pacific halibut and infer migration timing and pathways used during their putative spawning migration. This information can be used to refine our understanding of regional population structure and to infer whether BSAI Pacific halibut spawn locally and are likely to contribute primarily to western Alaskan recruitment potential, as well as the likelihood that summer Bering Sea residents contribute to Gulf of Alaska spawning groups and larval pools. This report represents the third installment of a continuing investigation using PAT tags on Pacific halibut in the BSAI region.

Methods

Twenty-four adult Pacific halibut were tagged with PAT tags (Wildlife Computers\(^1\)) and released on the southeastern Bering Sea continental shelf/slope: 12 in Middle Canyon during June 2006 and 12 in Bering Canyon during August 2006 (Fig. 2). These two locations were chosen as tagging sites in our experimental design because Middle Canyon is the north-westernmost fishing location in the United States Exclusive Economic Zone, while Bering Canyon is adjacent to Unimak Pass, the primary bathymetric connection between the GOA and BSAI regions.

PAT tags were externally tethered to Pacific halibut following a previously successful protocol (Seitz et al. 2003). Captured halibut were deemed appropriate for PAT tagging and release if they were in good condition (i.e., likely to survive) and were at least 110 cm fork length (FL), as this was the smallest size of Pacific halibut successfully tagged in a previous study (Seitz et al. 2003). Additionally, this study aimed to monitor spawning movements and the vast majority of Pacific halibut \(\geq\)110 cm FL are sexually mature (Clark et al. 1999).

Each PAT tag contained three electronic sensors that recorded ambient water temperature, depth of the tag and ambient light intensity (for PAT tag details, see Seitz et al. 2003). The PAT tags actively corroded the pin to which the tether was attached, thus releasing the tag from the animal (i.e., “pop-up”). The tag then floated to the surface and transmitted summarized historical data records to the Advanced Research and Global Observation Satellite (Argos) system. Upon popping up, each tag’s endpoint position was determined from the Doppler shift of the transmitted radio frequency in successive uplinks received during one satellite pass (Keating 1995). The transmitted data then were processed further by Wildlife

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Computers’ PC-based software. If the fish was captured and the tag retrieved before the pop-up date, the complete, high-resolution archival data record could be obtained.

Two generations of tags were used: older PAT4 tags (serial numbers 04P####) and newer MK-10 PAT tags (serial numbers 06A####). PAT4 tags did not have a premature release detection function. Therefore, if PAT4 tags detached from the fish before the scheduled pop-up date because of a connection malfunction, the tags would drift on the surface of the ocean until the programmed pop-up date and then report to Argos. MK-10 PAT tags had a premature release detection function which was activated by eight consecutive days of depth readings of 0 m. After the premature release detection function was activated, the MK-10 PAT tags reported to Argos. All tags were programmed to release on 1 February 2007 to determine the fishes’ winter grounds, as adult Pacific halibut are thought to spawn annually from approximately November through March (St. Pierre 1984).

The environmental data were sampled at one minute intervals and were subsequently summarized into 12-hour periods by software within the PAT tag thus providing four types of data: 1) percentage of time spent within specific depth ranges, 2) percentage of time spent within specific temperature ranges, 3) depth-temperature profiles from which minimum and maximum depths and temperatures may be extracted and, 4) daily geoposition estimates for the time the tag was attached to the fish.

Light-based longitude estimates were produced by Wildlife Computers’ proprietary software suite, Global Position Estimator (GPE, version 1.02.0004), using the ambient light data (Seitz et al. 2006). The GPE software suite estimated the times of sunrise and sunset from the light intensity data. Daily light level curves that did not exhibit smoothly sloping light levels from high to low or low to high were rejected (Seitz et al. 2006). The GPE suite then calculated longitude for the remaining data based on the difference between the local noon of the tag (mean of the sunrise and sunset times) and Coordinated Universal Time (UTC). Estimated longitude values that were not possible for a fish released in the Gulf of Alaska were rejected from the data set. For example, an impossible longitude was one that placed the tag on land or outside the published range of the Pacific halibut (i.e., to the west of Hokkaido, Japan (140ºE) or to the east of Santa Barbara, CA, USA (117ºW; Mecklenburg et al., 2002). Latitude estimates have been found to be highly variable in previous PAT tagging experiments (Seitz et al. 2006) and therefore were not used for determining movement of Pacific halibut.
Light-based longitude estimates were qualitatively examined. The number of days with longitude estimates was defined as the days that produced longitude estimates, after outliers were removed. Daily error magnitude was estimated as the absolute value of the fish’s true position (defined subsequently) minus the estimated position. Daily positional bias was estimated as the true position minus the estimated position. If positions were accurate, they should have a bias of zero. A negative bias meant that a longitude estimate was east of the true position and a positive bias meant that a longitude estimate was west of the true position. It was impossible to know the true daily position of each fish for the duration of the experiment, thus we were unable to calculate error and bias estimates for the duration of the track. However, we did know each fish’s true position on the days of tagging and recovery (either recapture or reporting to Argos satellites) and used these as true positions. We then compared the estimated positions of the tags for the six days immediately following release and the six days previous to recovery to the respective true positions (Seitz et al. 2006). For each comparison, we calculated the mean error and bias assuming the fish was stationary (or nearly so) during this time. Because individual longitude estimates may be subject to occasional large errors, one must practice caution when using these estimates to represent the true position of the fish. However, examining trends in estimates has proven useful for determining the direction of movement (Loher and Seitz 2006), which is the approach used in this study.

For all tagged fish, we reported fish size, release and recovery locations, number of days with geolocation estimates, estimated daily longitude, and the minimum and maximum depths and temperatures recorded for each 12-hour period that the tag was attached to the fish. The minimum and maximum depths and temperatures for the 5 days immediately following release were not reported to exclude the possibility of reporting unrepresentative behavior of Pacific halibut caused by the stress of a tagging event. The percentage of time spent in specific depth and temperature ranges, as well as the full depth-temperature profiles are not reported here because of the coarse resolution of depth and temperature ranges (100–250 m and 1–10° C, respectively). Large, abrupt changes in maximum depth above or below 200 m were defined as the inshore or offshore dispersal between the continental slope and continental shelf and vice versa (Seitz et al. 2003).
Results

Middle Canyon tagging site

Data were recovered from 12 tags (100%) that were attached to fish 110–139 cm FL (Table 1; Figs. 2 and 3). One tag, 06A0061, was physically recovered in the commercial fishery on 3 October 2006 after 120 days at-liberty. Another tag, 04P1018, prematurely released sometime during the first two weeks of July 2006, drifted on the surface of the ocean for approximately 210 days and transmitted to Argos satellites as scheduled. The rest of the tags remained attached to fish for the duration of the experiment (~240 days) and reported to Argos as scheduled.

The maximum horizontal displacement (straight-line distance between release and recovery locations) of the tags that reported on 1 Feb 2007 was 815 km while the minimum was 12 km (Table 1; Fig. 2). Eight fish, including the tag that was physically recovered, were located close (<40 km) to their release locations: six in Middle Canyon and two on the continental slope between Middle and Zhemchug Canyons. One fish was located in northern Zhemchug Canyon approximately 95 km from its tagging location, and two fish were located over 800 km from their release locations: one in northern Bering Canyon and one off of Yunaska Island in the Aleutian Chain. The remaining tag, which prematurely released, was located over 1500 km from its release site, off the east coast of the Kamchatka Peninsula.

The fish released in Middle Canyon displayed a wide range of depths during their time at-liberty (Fig. 3). The shallowest and deepest depths of all fish, excluding the 5 days after release, were 8 and 752 m (Table 1) and all fish experienced depths between 160 m and 472 m. Several fish showed appreciable fluctuations in depth on both a diel and a seasonal basis. There were two fish that did not conform to this pattern. Fish 06A0062 showed very few diel depth changes, except during three isolated occasions in late December 2006 and early January 2007 when its minimum depths were much shallower than its maximum depths. Similarly, fish 06A0063 showed very little diel depth change after early November, except for five isolated occasions during the same time period (December-January) as displayed by 06A0062.

Seasonal dispersal and its timing varied considerably among individual fish (Fig. 3). Most fish undertook a clearly defined dispersal in which they moved from the continental slope to the continental shelf, and/or vice versa, and remained at their new location for longer than a month. Eight fish were released on the continental slope, of which five moved to the continental shelf with dispersal dates as early as 26 June 2006 (04P1019) and as late as 28 January 2007.
Four of the fish that moved onto the continental shelf returned to the continental slope with dispersal dates ranging from 22 August 2006 (04P1019) to 1 December 2006 (06A0064). Only one fish (06A0070) was located on the continental shelf on the pop-up date. Three fish released on the continental slope remained there or only made very brief (<3 days) forays onto the continental shelf. The three remaining fish were released on the continental shelf and moved offshore to the continental slope within three weeks after release. Of these three fish, one (06A0067) remained on the slope until the pop-up date, one (00A0069) moved back to the shelf on 18 August 2006 where it remained for 3.5 months before it returned to the deeper waters of the continental slope, and one (04P1022) remained on the continental slope for approximately one month before showing large variations in depth for the remainder of its time at-liberty.

Ambient temperatures experienced by Pacific halibut tagged in Middle Canyon were generally between approximately 2 and 5°C (Fig. 3). The coolest and warmest ambient temperatures experienced by all fish, excluding the 5 days after release, were 1.0 and 9.8°C (Table 1) and all fish experienced temperatures between 2.6 and 3.8°C. There did not appear to be any seasonal warming or cooling trends of ambient temperatures experienced by any of the fish. Five fish experienced small shifts in ambient temperatures (~2°C) that corresponded to dispersal from the continental slope to the continental shelf, or vice versa. Two fish (04P1022 and 06A0069) experienced larger changes in temperature (~4.0 to 6.0°C) within 12 hour summary periods that corresponded to rapid changes in depth during the same time periods.

For the tags that remained attached to the fish, the percentage of days with longitude estimates ranged from 0% to just over 23% (Table 1). Every light-based longitude estimate was west of Unimak Pass (-165° longitude; Fig. 3). Longitude estimates were produced for the six day period after release and the six day period before recovery for only two of the tags (Table 1). Longitude error magnitudes for these tags were 0.9° (50 km) and 4.9° (280 km) while longitude biases ranged from –0.9° to 4.9° (Table 1).

There appeared to be an obvious trend in longitude estimates indicating mesoscale (>150 km) movement of the fish out of the tagging area (Fig. 3) for only one of the tags that remained attached for the duration of the experiment. For all other fish, most of the longitude estimates were scattered around a hypothetical line connecting the release and recovery locations. Occasionally, longitude estimates for individual fish showed a large fluctuation over short time periods, but the true positions of the fish were probably a function of an average of a series of adjacent longitude estimates (Seitz et al. 2006).

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In contrast to the other fish, the longitude estimates of fish 04P1022 showed a trend of movement, albeit based on only three estimates, away from the tagging area towards the east, beginning in late summer. This trend in longitude estimates approximately corresponds with large variations in maximum depths from 200 to 750 m, possibly indicating the fish traveled at varying depths along the continental slope on its way to Yunaska Island. Tag 04P1018 also produced longitude estimates with an obvious trend of movement, in this case westward. This occurred after the tag prematurely detached from the fish and was advected in the prevailing surface currents.

_Bering Canyon tagging site_

Data were recovered from 11 tags (92%) that were attached to fish 111 to 125 cm FL (Table 2; Figs. 2 and 4). Two tags, 06A0055 and 06A0057, prematurely released on 10 September 2006 (time at-liberty=17 days) and 24 December 2006 (time at-liberty=124 days), respectively, floated on the surface for 8 days and then reported to Argos satellites. One tag, 04P0646, prematurely released during the last week of August 2006, drifted on the surface of the ocean for approximately 160 days and transmitted to Argos satellites as scheduled. One tag did not report. The rest of the tags remained attached to fish for the duration of the experiment (~165 days) and reported to Argos as scheduled.

The maximum horizontal displacement of the tags that remained attached to the fish for the duration of the experiment and reported on 1 Feb 2007 was 190 km while the minimum was 4 km (Table 2; Figs. 2 and 4). Of these tags, seven were located in Bering Canyon: six tags less than 40 km from their release locations and one tag 63 km offshore of its release location. One tag was located just north of Umnak Island, 190 km from its release location. For the tags that prematurely released and then drifted for eight days, one was located in Bering Canyon, 13 km from its release location and the other was located in Unimak Pass, 126 km from its release location. The remaining tag, which prematurely released, was located over 1200 km from its release site in the central Gulf of Alaska.

The fish released in Bering Canyon displayed a wide range of depths during their time at-liberty (Fig. 4). The shallowest and deepest depths of all fish, excluding the 5 days after release, were 0 and 776 m (Table 2) and all experienced depths between 400 m and 440 m. Two fish showed frequent diel depth changes: the minimum depths and maximum depths did not correspond closely to one another for fish 04P1037 during December 2006 and January 2007 and
for fish 06A0056 during early September and late November 2006. The remaining fish did not show appreciable fluctuations in depth on a diel basis, except for isolated occasions during mid-winter when minimum depths were much shallower than maximum depths. These occurrences of large depth deviations within 12 hour periods occurred as early as 21 December 2006 (06A0056) and as late as 27 January 2007 (06A0060). Individual fish exhibited between two and six depth deviations each, with nearly regular time intervals between them of three to six days. The exact time intervals between depth deviations were specific to individual fish.

All but one fish were tagged on the continental slope where they generally remained for the duration of the experiment (Fig. 4). By the end of the experiment these fish were typically located in deeper water than their release locations. Four of the fish released on the continental slope visited the continental shelf. Fishes 04P1037, 06A0054 and 06A0057 were on the continental shelf for less than 10 days, while fish 06A0056 remained there from September through November 2006 before returning to the continental slope. Fish 06A0060 was released on the continental shelf but moved to the continental slope soon after tagging where it remained for the duration of the experiment. None of the fish were located on the continental shelf on the pop-up date.

Ambient temperatures experienced by Pacific halibut tagged in Bering Canyon were generally between approximately 3 and 5°C, with the exception of fish 06A0056 which occupied slightly warmer water (5–6°C) while on the continental shelf during the summer (Fig. 4). The coolest and warmest ambient temperatures experienced by all fish, excluding the 5 days after release, were 3.0 and 9.2°C (Table 2). There did not appear to be any seasonal warming or cooling trends of ambient temperatures experienced by any of the fish, probably because they were located at a depth that isolated them from seasonal temperature fluctuations.

For the tags that remained attached to the fish, the percentage of days with longitude estimates ranged from 0% to just over 1.2% (Table 2). Longitude estimates were produced for the six day period after release and the six day period before recovery for only four of the tags (Table 2). Longitude error magnitudes for these tags were generally small, averaging 0.7° (45 km), while longitude biases averaged 0.6° (39 km) (Table 2). Although there were very few light-based longitude estimates, none were east of Unimak Pass (-165° longitude; Fig. 4) and none indicated any obvious trends in movement, except tag 04P0646. However, these longitude estimates are from after the tag prematurely detached from the fish and was advected in the prevailing surface currents.
Discussion

This study fails to provide evidence that adult Pacific halibut that feed in the BSAI leave the region in the winter to spawn in the GOA. This is consistent with prior results, although previous to this study the sample size of Pacific halibut tagged in the BSAI that yielded putative winter spawning locations was small (n=24), and only 7 were tagged on the southeastern Bering Sea continental shelf. This study yielded winter locations of an additional 18 fish, all from the Bering Sea continental shelf and slope, thus increasing the total sample size of the study by 75%. None of these fish were located in the GOA on the pop-up date, nor were there any longitude estimates outside of the BSAI region. Therefore, there is no supporting evidence that the halibut may have spent time in the Gulf of Alaska and then returned to the Bering Sea between the release and pop-up dates. These dispersal observations, in conjunction with our previous investigations (Seitz et al. in press; Seitz et al. in review), indicate the possibility of a separate sub-population of Pacific halibut in the BSAI region with respect to spawning structure.

The additional fish tagged in this investigation combine with prior results to provide a more representative view of Pacific halibut dispersal patterns across the entire southeastern Bering Sea by filling two geographic gaps in the distribution of PAT tag release sites, thus completing our five site circum-Bering tagging experiment. The fish in this study showed similar dispersal patterns to Pacific halibut previously tagged on the Bering Sea continental shelf near St. Paul Island, despite having been tagged in somewhat deeper water closer to the continental slope. The percentage of fish undertaking small-scale (<200 km) vs. large-scale (>200 km) dispersals in this study (87.5% vs. 12.5%) was nearly identical to the dispersal patterns of fish tagged near St. Paul Island (86% vs. 14%; Seitz et al. in press). Another interesting similarity is the fact that one Pacific halibut from this study tagged in Middle Canyon and one fish tagged near St. Paul (Seitz et al. in press) both undertook long-distance dispersals to the continental slope west of Yunaska Island. While this observation may be merely coincidental, it calls attention to the possibility of that area as an important Pacific halibut wintering area.

Although one tag reported to Argos from Unimak Pass, we do not believe that the fish was actually located in the pass or east of it in the GOA. From the drift patterns of the tag, as well as the depth and temperate of the water in which tag 06A0055 was located, it is possible to infer that the tag prematurely released in the Bering Sea, probably Bering Canyon, and drifted south into Unimak Pass. The tag prematurely released from the fish and floated for eight days before reporting. During the eight days of floating, its exact location was unknown, but after it reported to Argos, the tag drifted on a southwesterly course before heading directly south.
Therefore it is reasonable to assume that the tag drifted the same direction before reporting, which probably transported the tag from Bering Canyon to its reporting location in Unimak Pass. Additionally, it is unlikely that the Pacific halibut swam into Unimak Pass or the GOA given the fact that the tag was not in water depths as shallow as Unimak Pass nor did it experience any abrupt changes in temperature while attached to the fish, which would have occurred had the fish swam into warmer GOA water in Unimak Pass (Ladd et al. 2005).

The mid-winter aggregation patterns of fish in Middle and Bering Canyons suggest that these are locally-important Pacific halibut spawning grounds. These PAT tag results corroborate findings from previous research surveys that identified Bering Canyon as a major spawning area (St-Pierre 1984). However, the latter research surveys did not extend as far north as Middle Canyon, therefore this location’s potential importance as a spawning area has been unknown. Unfortunately, it is impossible to know whether the fish actively spawn in this area unless future research is conducted to assess spawning condition and/or egg and larval presence in the overlying water column. However, it is reasonable to believe that these fish spawn in Middle Canyon because almost all Pacific halibut >110 cm are mature females (Clark et al. 1999), their inhabitation of the continental slope in mid-winter is consistent with spawning activity in other locations in their range (St-Pierre 1984), and given the currently-accepted paradigm of annual spawning frequency for the species (Leaman et al. 2002). If Middle Canyon is indeed an important spawning ground for Pacific halibut, it represents an extension of the known winter spawning range as it is approximately 600 km northwest of the nearest documented spawning area, Pribilof Canyon south of St. Paul Island.

Furthermore, the existence of spawning at Middle Canyon indicates a possible link between the eastern and western Bering Sea halibut populations. Prevailing currents would be expected to carry larvae out of US waters and towards the east coast of Kamchatka (Stabeno et al. 1999). It is unknown whether those larvae would be advected far enough to reach coastal nursery sites, or would instead become stranded in unsuitable deepwater habitat farther from the coast. However, estimated westward drift speeds (Stabeno and Reed 1994) suggest that such larvae would be able to reach the Russian coast, a notion that is further supported by the fact that a PAT tag which prematurely released from a halibut tagged in the Pribilof Islands reached the central eastern shore of Kamchatka in roughly six months (Seitz et al. in press), a period roughly equivalent to the larval period of Pacific halibut (Thompson and VanCleve 1936, IPHC 1998) over a distance that considerably exceeds that from Middle Canyon to Cape Navarin.
For the first time, the summarized depth data transmitted via satellites may be useful for identifying spawning behavior. Putative spawning in Pacific halibut has been previously described using minute-by-minute archival records from physically recovered PAT tags (Seitz et al. 2005). This putative spawning behavior consisted of a conspicuous routine in which a Pacific halibut conducted a series of seven abrupt ascents, or “spawning rises”, spaced regularly over 20 days during mid-winter. These abrupt ascents closely parallel the actions of other spawning flatfish observed in situ (Carvalho et al. 2003) and the regular spacing is consistent with ovulatory intervals observed in Atlantic halibut (Hippoglossus hippoglossus) during which each new batch of eggs is hydrated (Finn et al. 2002). These purported spawning rises have never been identified in summarized depth data transmitted via satellites because typically Pacific halibut undertake diel depth changes throughout the year, therefore the minimum and maximum depths are often quite different, which masks potential spawning rises. However, there were several fish in this study that undertook large diel migrations that resulted in considerable depth deviations within 12 hour summary periods on only a few occasions. These isolated depth deviations all occurred during mid-winter and had nearly regular time intervals between them, similar to the previously described purported spawning rises. Therefore, these instances may represent spawning rises with the relatively shallow minimum depth representing the apex of the rise.

If these depth deviations are indeed discrete acts of spawning, they may be used to refine some assumptions of spawning characteristics of Pacific halibut. First, it is assumed that that the spawning season of Pacific halibut lasts from November through March (St-Pierre 1984). The fish in this study did not commence putative spawning until mid-December. Unfortunately, it is not possible to infer how late in the season spawning may occur because the tags popped-up in early February. Second, it is assumed that individuals may protract spawning events through the entire winter season (St-Pierre 1984). In contrast to this, the fish in this study had putatively discrete spawning seasons lasting no longer than 21 days. Finally, in previous investigations, it was assumed that mere occupation of the continental slope may be indicative of active spawning (Seitz et al. 2003; Seitz et al. in press). However, from this study, it appears that inhabitation of the continental slope may not be a valid indicator of active spawning because several fish spent much of their time at-liberty on the continental slope and migration times to and from this area varied widely, but putative spawning was observed only in December and January. Therefore, Pacific halibut may use the continental slope as habitat for activities other than spawning, such as feeding.
This study, in conjunction with two previous studies in the BSAI region, provides evidence of possible spawning sub-structure within the eastern Pacific halibut stock, created by reproductive separation of BSAI halibut from those in the GOA. If continued for many generations in the absence of substantial mixing of early life-history stages, this observed reproductive separation may lead to some level of genetically-detectable population structure throughout the range of Pacific halibut. Even in the absence of genetically detectable segregation, structure can exist at scales relevant to prosecution and management of a fishery and populations comprised of discrete spawning units are often more accurately described using metapopulation models (Hanski and Gilpin 1997) than as homogenous single-unit-stocks (Stephenson 1999). Identifying and preserving population substructure has been identified as an important goal of modern fishery science (Stephenson 1999, Frank and Brickman 2001). If there is indeed a separate sub-population of Pacific halibut in the BSAI, its dynamics may vary from those of the GOA and determining its population dynamics will be necessary for correct modeling to predict how different population components will respond to future fishing pressure and changes in environmental conditions.

Acknowledgements

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References


Seitz, A. C., Loher, T. L. and Nielsen, J. L. In review. Seasonal movements and environmental conditions experienced by Pacific halibut along the Aleutian Islands, examined by pop-up satellite tags. Int. Pac. Halibut Comm. Sci. Rep. ##.


Table 1. Deployment summary for PAT tags on Pacific halibut released in Middle Canyon. The fish were tagged and released between 4 June and 7 June 2006, and the tags popped up on 1 February 2007, unless indicated otherwise. The first five days of tag deployment were excluded from minimum and maximum depths and temperatures. Underlining denotes the tag that was recaptured while on the fish on 3 October 2006. Italics denote the tag that prematurely released from the fish sometime during the first two weeks of July 2006, and drifted on the surface of the ocean until it reported to Argos satellites as scheduled. The horizontal displacement is reported from the location of the tag when it started transmitting to Argos because the location of the tag on the day it released from the fish is unknown, while the depth, temperature and geolocation data are reported for only the period in which the tag remained attached to the fish.

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Table 2. Deployment summary for PAT tags on Pacific halibut released in Bering Canyon. The fish were tagged and released between 22 August and 25 August 2006, and the tags popped up on 1 February 2007, unless indicated otherwise. The first five days of tag deployment were excluded from minimum and maximum depths and temperatures. Boldface denotes tags that prematurely released from the fish (06A0055 on 2 September 2006, 06A0057 on 16 December 2006) and then reported to Argos satellites after drifting on the surface of the ocean for eight days. Italics denote the tag that prematurely released from the fish during the first week after it was released and drifted on the surface of the ocean until it reported to Argos satellites as scheduled. The horizontal displacement is reported from the location of the tag when it started transmitting to Argos because the location of the tag on the day it released from the fish is unknown.

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Fig. 2

Inset A

Inset B

Middle Canyon

Zhemchug Canyon

Bering Canyon

Kamchatka Peninsula

Umnak Island

Yunaska Island

04P1018

04P1022

04P0646

see Inset A

Ocean Data View
Fig. 2 Inset A
Fig. 3
Fig. 3
Fig. 3
Fig. 3
Fig. 4
Fig. 4
Fig. 4
Fig. 4
Figure 1. Map of Bering Sea and Aleutian Islands regions with release (●) and recovery sites (o) of Pacific halibut from previous PAT tag investigations.

Figure 2. Release (●) and recovery sites (o = tags that transmitted on 1 February 2007, □ = tags that prematurely released from the fish and transmitted after drifting on the surface of the ocean for eight days) of PAT-tagged halibut in the Bering Sea, summer 2006. Solid lines indicate the straight-line path between release and recovery positions of tags that remained attached for the duration of the experiment or transmitted eight days after prematurely releasing from the fish, while dashed lines indicate the straight-line path between release and recovery positions for tags that prematurely released and drifted on the surface of the ocean until the scheduled pop-up date. Numbers are equivalent to the PAT tag numbers given in Tables 1 and 2.

Figure 3. Maximum (o) and minimum (x) depths and temperatures for each 12-hour summary period, and daily longitude estimates after outliers were rejected for Pacific halibut tagged in Middle Canyon. For longitude plots, □ = release position and location at which the tag reported to Argos and ● = estimated position. Though the same time, depth, temperature and longitude scales are used to allow comparisons among fish, data are only shown for the time period each PAT tag was at-liberty. Note the different longitude scale for tag 04P1018 that was used because the tag prematurely released from the fish and drifted into the eastern hemisphere.

Figure 4. Maximum (o) and minimum (x) depths and temperatures for each 12-hour summary period, and daily longitude estimates after outliers were rejected for Pacific halibut tagged in Bering Canyon. For longitude plots, □ = release position and location at which the tag reported to Argos and ● = estimated position. Though the same time, depth, temperature and longitude scales are used to allow comparisons among fish, data are only shown for the time period each PAT tag was at-liberty. Note the different longitude scale for tag 04P0646 that was used because the tag prematurely released from the fish and drifted into the Gulf of Alaska.
CHAPTER 2

Dispersal and behavior of satellite tagged Pacific halibut *Hippoglossus stenolepis* in the Bering Sea and Aleutian Islands region and their ecological implications

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ABSTRACT: Currently, it is assumed that eastern Pacific halibut (*Hippoglossus stenolepis*) belong to a single, fully mixed population extending from California through the Bering Sea, in which adult fish disperse randomly throughout their range during their lifetime. However, we hypothesize that Pacific halibut dispersal is more complex than currently assumed and is not spatially random. To test this hypothesis, we studied seasonal dispersal and behavior of Pacific halibut in the Bering Sea and Aleutian Islands. Pop-up Archival Transmitting tags attached to fish during the summer provided no evidence that Pacific halibut moved out of the Bering Sea and Aleutian Islands region into the Gulf of Alaska during the mid-winter spawning season, supporting the concept that this region may contain a separate spawning component of adult fish. There was evidence for geographically localized groups of Pacific halibut along the Aleutian Island chain. All of the fish tagged there displayed residency, with their movements possibly impeded by passes between islands. Mid-winter aggregation areas of Pacific halibut are assumed to be spawning grounds, of which two were previously unidentified and extend its presumed spawning range ~1000 km west and ~600 km north of the nearest documented spawning area. The summarized depth data transmitted via satellites was used to identify three general behavior patterns including dispersal to the continental slope, continental shelf residency, and feeding site fidelity. This behavior information may be used to refine some assumptions of Pacific halibut biology and ecology.

KEY WORDS: spawning component, spawning dispersal, Pacific halibut, PSAT tag, PAT tag, Bering Sea, Aleutian Islands
INTRODUCTION

Marine fish species may have complex population structures, and in many cases, management units contain population complexes with several spawning components (Stephenson 1999). For example, several stocks of Atlantic herring (*Clupea harengus*) mingle on common feeding areas, yet maintain genetic differentiation based on spatial and temporal differences in migratory behaviour and homing to spawning locations (Ruzzante et al. 2006). Segregation of spawning into discrete components has the potential to generate internal population structure at scales not adequately captured in a single -unit –stock management approach (Stephenson 1999, Frank and Brickman 2001). Therefore, knowledge of seasonal dispersal and spawning locations of a migratory fish species aids in successful fishery management.

The Pacific halibut (*Hippoglossus stenolepis*) fishery is an important resource throughout western Alaska, with almost eight million pounds (est. $25 million ex-vessel) of product landed during 2007 in the southeast Bering Sea and Aleutian Islands (BSAI) directed fishery\(^2\) (Fig. 1). Little is known about the ecology of adult Pacific halibut in the Bering Sea and along the Aleutian Islands. It is generally assumed that adult Pacific halibut feed in shallow, nearshore areas during the summer, undertake a spawning migration to deeper water during winter and return to their summer grounds during spring (Dunlop et al. 1964, Best 1981). Spawning appears to be concentrated in relatively discrete winter spawning grounds near the edge of the continental shelf in the Bering Canyon and the Pribilof Canyon (Fig. 1) in the southeast Bering Sea (St-Pierre 1984). After spawning, egg and larval stages drift pelagically for approximately six months (Thompson and Van Cleve 1936).

From the 1930s through the 1950s, at least three stocks of Pacific halibut were recognized, one in the Bering Sea and two in the Gulf of Alaska (Fukuda 1962, Skud 1977). After this period, research indicated extensive intermingling of Pacific halibut among areas and that there was only a single stock of fish. This research was based in part on two lines of evidence: (1) conventional tagging experiments (Skud 1977, review in Kaimmer 2000) in which a portion of Pacific halibut tagged in the southeast Bering Sea continental shelf migrated to the Gulf of Alaska (GOA), (2) surveys conducted during the winter spawning season that only identified major spawning grounds in the GOA and a small portion of the southeastern-most corner of the Bering Sea (St-Pierre 1984).

Currently, it is assumed that eastern Pacific halibut (*Hippoglossus stenolepis*) belong to a single, fully mixed population extending from California through the Bering Sea, in which adult fish disperse randomly throughout their range during their lifetime. At the adult level, the paradigm of a fully mixed stock implies that Pacific halibut from several feeding areas, including fish from the BSAI region and those from the Gulf of Alaska (GOA; Fig. 1), mingle on common spawning grounds or at least display some degree of migratory interlacing between adjacent regions (e.g., Koutsikopoulos et al. 1995) without clear geographic segregation in dispersal patterns.

Evidence indicates that the single population paradigm for Pacific halibut may be simplistic and that some level of isolation occurs in the Bering Sea and Aleutian Islands region. First, because conventional tags provide limited information on dispersal and behavior as no information on location or depth occupied by the fish is obtained between tag deployments and recapture locations, there is little detailed knowledge about the biology and ecology of Pacific halibut in the Bering Sea and Aleutian Islands region. Second, conventional tagging results can be highly influenced by fishing effort and maturity status of fish (Bolle et al. 2001). To understand the structure of different spawning components in a fish population, it is necessary to determine where adults are located during the winter spawning season, the time when actual genetic exchange occurs. In the case of Pacific halibut, the vast majority of conventionally tagged fish in the Bering Sea was immature juveniles released in the summer. The bulk of the recoveries also occurred during the summer due to closure of the fishery during the winter spawning season (IPHC 1998). Thus, there are relatively few conventional tag recoveries from adult halibut from winter spawning grounds. Third, winter surveys have never been conducted along the Aleutian Islands or farther north than the Pribilof Canyon in the Bering Sea (St-Pierre 1984). Therefore, it is likely that previously unidentified spawning grounds occur along the Aleutian Islands and north of the Pribilof Canyon, and these may change our interpretation of population structure of Pacific halibut in the northeast Pacific Ocean. Finally, local depletions, in which commercial catch-per-unit-effort (CPUE) steadily decreased over several years on specific fishing grounds, are occurring in the southeast Bering Sea (Hare 2005, 2006). This phenomenon should not occur in a fully-mixed population whose abundance has remained relatively constant over the past decade. If there is indeed a discrete spawning component of Pacific halibut in the BSAI region, this may have a substantial impact on local productivity and population dynamics in the fisheries of the Bering Sea and Aleutian Islands.
On an ocean-basin scale, we hypothesize that the BSAI region contains a discrete spawning component, defined as a region from which little or no emigration occurs for purposes of spawning, of Pacific halibut in the eastern Pacific Ocean because land masses and ocean currents partially separate the BSAI region from the GOA. Therefore, the goals of this study are: 1. To investigate Pacific halibut that feed during the summer in the Bering Sea and Aleutian Islands to determine if they all remain there to spawn, or some move into the GOA; and 2. To infer the biological and ecological implications of the behavior and dispersal of Pacific halibut in the Bering Sea and Aleutian Islands. To accomplish these, we tagged adult Pacific halibut in the BSAI with Pop-up Archival Transmitting (PAT) tags. This technology allows us to determine winter location of the tagged fish and to infer behavioral patterns to refine our understanding of Pacific halibut ecology and biology in the Bering Sea and Aleutian Islands region. For the analysis in this manuscript, the area south of the Aleutian Islands is considered part of the BSAI.

MATERIALS AND METHODS

Wildlife Computers3 PAT tags were externally attached to Pacific halibut following a previous protocol (Seitz et al. 2003). The fish were captured by commercial longline gear, pulled to the surface and brought onto the vessel in a net. The Pacific halibut were deemed appropriate for PAT tagging and release if they were at least 110 cm fork length (FL), as this was the smallest size of Pacific halibut tagged in a previous study (Seitz et al. 2003), and they were likely to be sexually mature (Clark et al. 1999). The tags were connected to titanium darts with a tether that was 15 cm in length and constructed of 130 kg test monofilament fishing line wrapped in adhesive-lined shrink-wrap. The darts were inserted through the dorsal musculature and pterygiophores, anchoring them in the bony fin-ray supports of the fish. The position of the darts was about 2.5 cm medial of the Pacific halibuts’ dorsal fin on the eyed-side of the fish where the body began to taper towards the tail.

Pacific halibut were tagged and released in five locations: St. Paul Island (n=9) during August 2002; Attu Island (n=13) and Atka Island (n=12) during July–August 2004; and near Middle Canyon (n=12) and Bering Canyon (n=12) in June and August 2006 (Fig. 1). Fifty-eight tags were programmed to release in February of the following year to determine the Pacific halibuts’ winter grounds.

3 Redmond, Washington, USA
Each PAT tag contained three electronic sensors that measured ambient water temperature, depth of the tag and ambient light intensity (for PAT tag details, see Seitz et al. 2003). The PAT tags 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 historical data records to the Argos satellite system. Upon popping up, the tags’ endpoint positions were determined from the Doppler shift of the transmitted radio frequencies in successive uplinks received during one Argos satellite pass (Keating 1995). The transmitted data then were processed further by Wildlife Computers’ PC-based software.

Two generations of tags were used: older PAT4 tags (serial numbers 04P####) and newer MK-10 PAT tags (serial numbers 06A####). PAT4 tags did not have a premature release detection function. Therefore, if PAT4 tags detached from the fish before the scheduled pop-up date because of a connection malfunction, the tags would drift on the surface of the ocean until the programmed pop-up date and then report to Argos. MK-10 PAT tags had a premature release detection function which was activated by eight consecutive days of depth readings of 0 m. After the premature release detection function was activated, the MK-10 PAT tags reported to Argos. The tags were programmed to release on 15 February (2002 and 2004 deployments) or 1 February (2006 deployments) of the year following the fishes’ release to determine their winter grounds, as adult Pacific halibut are thought to spawn annually from approximately November through March (St-Pierre 1984).

The data were sampled at 30 second (MK-10 PAT tags) or one minute (PAT4 tags) intervals and were subsequently summarized into 12-hour periods by software within the PAT tag thus providing four types of data: 1. percentage of time spent within specific depth ranges; 2. percentage of time spent within specific temperature ranges; 3. depth-temperature profiles containing minimum and maximum depths and temperatures; and 4. ambient light levels during sunrise and sunset events. Light-based longitude estimates were produced by Wildlife Computers’ proprietary software, Global Position Estimator (GPE), using the ambient light intensity data (for details, see Seitz et al. 2006). In short, GPE was used to identify daily sunrise and sunset events. Next, days with sunrise/sunset data that did not exhibit smoothly sloping light levels from high to low or low to high were rejected. Finally, GPE calculated longitude for the remaining days by comparing the local noon of the tag (mean of the sunrise and sunset times) to 1200 UTC (Coordinated Universal Time). Estimated longitude values that were outside the published range of the Pacific halibut, i.e., 140° E to 117° W (Mecklenburg et al. 2002), were

rejected. Latitude estimates have been found to be highly variable in previous PAT tagging experiments and therefore were not used for determining movement of halibut (Seitz et al. 2006).

RESULTS

The fish ranged from 110 to 154 cm FL and each fish was at-liberty for 165 to 240 days (for further details of all results, see Seitz et al. 2007, Seitz et al. 2008, Seitz et al. Chapter 1 of this report). Data were recovered from 47 of 58 tags (81%), of which 41 tags provided winter locations of tagged Pacific halibut. The remainder of the tags was recovered during summer or fall in the commercial fishery (n=2), prematurely released (n=4) or did not report (n=11).

For fish whose tags remained attached until winter, horizontal displacements of the Pacific halibut (straight-line distance between release and recovery locations) ranged between 0 and 815 km (Fig. 2). On average, the horizontal displacement of Pacific halibut tagged near the Aleutian Islands was smaller ($\bar{x} \pm SD = 45 \pm 44.9$ km; range: 1–167 km) than that of the Pacific halibut tagged elsewhere in the southeast Bering Sea ($\bar{x} \pm SD = 124.1 \pm 226.5$ km; range: 4–815 km). Furthermore, all pop-up locations of fish tagged near the Aleutian Islands were within the group of islands where the fish were released (Fig. 2, insets A and B).

Five hundred forty longitude estimates were produced by all tags, of which none were outside of the published range for Pacific halibut. For all but one fish, every light-based longitude was west of Unimak Pass (164.9° W), the easternmost connection between the Bering Sea and Gulf of Alaska. For one fish tagged near St. Paul Island, there were 2 of 27 longitude estimates east of 164.9° W.

The Pacific halibut in this study occupied depths from 0 to 844 m. The majority of fish showed appreciable fluctuations in depth on a diel basis, but nine fish did not conform to this pattern. These fish did not show appreciable fluctuations in depth on a diel basis, except for isolated occasions during mid-winter when minimum depths were much shallower than maximum depths in the same 12 hour summary period (Fig. 3). These large depth deviations occurred as early as 21 December 2006 and as late as 27 January 2007. Individual fish exhibited between two and six depth deviations each, with nearly regular time intervals between them of three to six days. The exact time intervals between depth deviations were specific to individual fish.
Based on pop-up locations and depth records, behavior of individual halibut were classified into four types (Fig. 4 and Table 1): (1) Shelf residents were fish that remained on the continental shelf for the duration of the experiment and never experienced depths greater than 200 m, (2) Slope dispersers were halibut that were located on the continental slope in water deeper than 200 m on the pop-up date, (3) Long distance dispersers were halibut that moved more than 200 km from their release site and changed general areas, i.e., from the southeastern Bering Sea to the Aleutian Islands, and (4) Feeding-site returnees were fish whose pop-up locations were in close proximity to the location at which the fish were tagged and released (Loher 2008). However, they could not have remained near their tagging locations for the duration of the experiment because they experienced maximum depths greater than 200 m. Depths of this magnitude do not exist on the continental shelf, indicating that the fish moved off the shelf to the slope during their time at-liberty. For all fish, large, abrupt changes in maximum depth were defined as the spawning migration from the continental shelf to the continental slope (Seitz et al. 2003).

Pacific halibut in this study experienced ambient water temperatures from 1.0°C to 9.8°C. When fish occupied the continental shelf (<200 m), there appeared to be gradual warming and cooling trends of ambient temperatures associated with the change of seasons. When fish occupied the continental slope (>200 m), there were no trends in ambient water temperature, likely because they were located at a depth that isolated them from seasonal temperature fluctuations. Several fish experienced more abrupt shifts in ambient temperatures (~2°C to 6.0°C) within 12 hour summary periods that occurred concurrent to rapid changes in depth during the same time periods.

DISCUSSION

The results of this study are consistent with the hypothesis that Bering Sea and Aleutian Island Pacific halibut may constitute a separate spawning component from Pacific halibut in the Gulf of Alaska. We are hesitant to speculate about population differentiation of Pacific halibut throughout its range, but the isolation of a spawning component of Pacific halibut in the Bering Sea and Aleutian Islands region suggests that there is some merit to the three stock concept of Pacific halibut used in the 1930’s to the 1950’s. Parasite data further support the existence of two major groups of Pacific halibut (Blaylock et al. 2003).

None of the fish were located in the GOA on the pop-up date, and all but two of the longitude estimates were inside of the BSAI region. Therefore, there is no convincing evidence
that the Pacific halibut tagged in the Bering Sea and Aleutian Islands region dispersed to the Gulf of Alaska during their time-at-liberty. Two tags provided possible, but unconvincing evidence of movement to the Gulf of Alaska. One tag provided two longitude estimates east of Unimak Pass, but this tag had large variability among consecutive longitude estimates (Seitz et al. 2007), leading to an implausible amount of east-west movement. Because the tag’s pop-up location was close to its release location and there was no trend in longitude estimates to the east, the true positions of the fish were probably a function of an average of a series of adjacent longitude estimates (Seitz et al. 2006); therefore, the fish most likely remained in the Bering Sea and did not enter the Gulf of Alaska. Another tag reported to Argos from Unimak Pass, but we do not believe that the fish was actually located in the pass or east of it in the GOA. The tag prematurely released from the fish and floated for eight days before reporting. During the eight days of floating, its exact location was unknown, but after it reported to Argos, the tag drifted on a southwesterly course before heading directly south. Therefore it is reasonable to assume that the tag drifted in the same direction before reporting, which would mean that the current probably transported the tag from Bering Canyon to its reporting location in Unimak Pass. Additionally, prior to releasing, the tag did not record water depths as as shallow as those in Unimak Pass nor did it experience any abrupt changes in temperature while attached to the fish, both of which would have occurred had the fish swam into Unimak Pass (Ladd et al. 2005).

Interestingly, to complement this study, Pacific halibut have also been PAT tagged in the GOA during the summer with winter pop-up dates (Seitz et al. 2003, Loher and Seitz 2006). The fish tagged in the southeast and southwest GOA demonstrated a northward migration towards major spawning grounds in the GOA, but not to the BSAI region. None of those halibut moved into the BSAI from the GOA, further supporting our hypothesis that the Bering Sea contains a local, resident spawning component of Pacific halibut separate from those in the GOA.

All of the halibut tagged near Attu and Atka Islands appear to have remained in the vicinity of the island near which they were released, and the PAT tags provide no evidence that the fish crossed any passes along the Aleutian Island chain. The Pacific halibut released near Attu Island did not cross Near Strait (depth = 2000 m) to the west and Buldir Strait (depth = 640 m) to the east (Fig. 3). The halibut released near Atka Island did not cross Amchitka Pass (depth = 1155 m) to the west and Amukta Pass (depth = 430 m) to the east (Fig. 3). The long distance dispersers tagged near Middle Canyon and St. Paul Island swam to the eastern side of Amukta Pass, but like the Pacific halibut tagged near Atka, did not swim across the pass. Only the depths of Amchitka Pass and Near Straight exceed the maximum depth recorded by a Pacific halibut in
the BSAI region (844 m), but the fish in this study apparently did not cross shallower passes either. Because Pacific halibut are found in depths greater than those of both Buldir Strait and Amukta Pass, the depth of the pass does not appear to be the impediment to movement, but rather other factors such as swift currents and strong turbulence found in many Aleutian passes may deter movement (Hunt and Stabeno 2005).

Another line of evidence that corroborates the hypothesis that movement across deep passes may be limited is recent genetics results. These studies indicate that Pacific halibut captured near the Pribilof Islands in the southeastern Bering Sea are more genetically similar to halibut captured near Oregon (~4000 km to the southeast) than to halibut captured near Atka Island (~700 km to the southwest) (Hauser et al. 2006). This observation points to the presence of a reproductive discontinuity for Pacific halibut along the Aleutian Island chain, possibly at Amukta Pass and suggests that there may be more than one spawning component of Pacific halibut in the BSAI region.

The mid-winter aggregations of Pacific halibut near Attu Island and Middle Canyon suggest that locally-important Pacific halibut spawning grounds extend up to 1000 km west and 600 km north of the nearest confirmed spawning areas. Previous to this study, there have been no spawning surveys west of the Bering Canyon or north of the Pribilof canyon, both of which have been previously identified as important Pacific halibut spawning grounds (St-Pierre 1984). In this study, we assume that the Pacific halibut on the continental slope are at their spawning locations because almost all Pacific halibut >110 cm are mature females (Clark et al. 1999) and their inhabitation of the continental slope in mid-winter is consistent with spawning activity in other locations in their range (St-Pierre 1984). Peak spawning is expected during late-January and February (Thompson and Van Cleve 1936), thus the February pop-up dates maximize the likelihood that tagged fish will be located on their spawning grounds. Unfortunately, it is impossible to know whether the fish actively spawn in this area unless future research is conducted to assess spawning condition and/or egg and larval presence in the overlying water column.

However, for the first time, the summarized depth data transmitted via satellites may be useful for identifying spawning behavior. Putative spawning in Pacific halibut has been previously described using minute-by-minute archival records from physically recovered PAT tags (Seitz et al. 2005, Loher and Seitz 2008). This putative spawning behavior consists of a conspicuous routine in which a Pacific halibut conducts a series of regularly spaced, abrupt
ascents, or “spawning rises” during mid-winter. These abrupt ascents closely parallel the actions of other spawning flatfish observed in situ (Carvalho et al. 2003) and the regular spacing is consistent with ovulatory intervals observed in Atlantic halibut (Hippoglossus hippoglossus) during which each new batch of eggs is hydrated (Finn et al. 2002). These purported spawning rises have never been identified in summarized depth data transmitted via satellites because typically Pacific halibut undertake diel depth changes throughout the year, therefore the minimum and maximum depths are often quite different, which masks potential spawning rises. However, there were several fish in this study that did not undertake large diel migrations on a daily basis, but rather on only a few occasions. These isolated depth deviations all occurred during mid-winter and had nearly regular time intervals between them, similar to the previously described purported spawning rises. Therefore, these instances may represent spawning rises with the relatively shallow minimum depth representing the apex of the rise.

If these depth deviations are indeed discrete acts of spawning, they may be used to refine some assumptions of spawning characteristics of Pacific halibut. First, it is assumed that the spawning season of Pacific halibut lasts from November through March (St-Pierre 1984). The fish in this study did not commence putative spawning until mid-December. Unfortunately, it is not possible to infer how late in the season spawning may occur because the tags popped-up in early February. Second, it is assumed that individuals may protract spawning events through the entire winter season (St-Pierre 1984). In contrast to this, the fish in this study had putatively discrete spawning seasons lasting no longer than 21 days. Finally, in previous investigations, it was assumed that mere occupation of the continental slope may be indicative of active spawning (Seitz et al. 2003; Seitz et al. 2007). However, from this study, it appears that inhabitation of the continental slope may not be a valid indicator of active spawning because several fish spent much of their time at-liberty on the continental slope and migration times to and from this area varied widely, but putative spawning was observed only in December and January. Therefore, Pacific halibut may use the continental slope as habitat for activities other than spawning, such as feeding.

Several of the halibut in both locations displayed feeding site fidelity. The frequent occurrence of summer feeding site fidelity in this study and a previous study (Loher 2008) demonstrates that a large proportion of adults may return to the same area annually, making them vulnerable to local depletions in areas with intensive commercial fisheries. St. Paul Island is an example where harvest shortfalls from 2000 to 2004 have been 14–56% of the annual catch limits, suggesting sensitivity of the halibut population to locally concentrated exploitation that
eventually results in local depletion (Hare 2005). This indicates that the movement of individual halibut may be relatively limited in the Bering Sea and Aleutian Islands, in contrast to the assumption of complete mixing among the population of Pacific halibut.

There are several possible explanations for shelf residency of Pacific halibut in the BSAI. The fish may have foregone a trip to the continental slope and spawned on the continental shelf (St-Pierre 1984, IPHC 1998). It is also possible that the shelf residents would have spawned later in the year and a February pop-up date was too early to capture the spawning migration. Alternatively, these halibut may be non-annual spawners (Novikov 1964, Seitz et al. 2005, Loher and Seitz 2008). Recently, it has been recognized that several iteroparous fish species may be non-annual spawners (Rideout et al. 2005). The percentage of non-reproductive fish must be determined if stock-recruitment models are to accurately portray spawning numbers or biomass, and PAT tags may be one method to generate hypotheses regarding potential skip-spawning rates based on year-round shallow water residence. If skipped spawning is a common feature within the population, effective population size may vary even if total abundance remains static.

We experienced two problems typical to PAT tagging experiments: premature release and non-reporting. The rate of premature release in this study (7%) is well below those for other experiments on pelagic fish (Domeier et al. 2003, Stokesbury et al. 2004). We speculate that PAT tags on Pacific halibut tend to experience fewer premature release events than those on pelagic fish because Pacific halibut live a more sedentary life and swim at slower speeds than highly migratory pelagic fish. Another problem was non-reporting, mainly from the tags released near Atka Island (n=7). Considering that all of the tags in this study were deployed under similar conditions, we suspect that a portion of the Atka Island batch of tags had faulty batteries. This claim is evidenced by a Pacific halibut that was recaptured more than a year after being released with the tag still attached. This tag was diagnosed by its manufacturer as having a dead battery.

This study was subject to limitations which prevent us from drawing definitive conclusions on population differentiation across the range of Pacific halibut. First, we received less than a year of data from a fish that may live up to 50 years. These tag deployments are unable to capture observations necessary for maintaining population structure, such as interannual regional fidelity to spawning areas dispersal. Second, we were able to observe only a small demographic component of Pacific halibut. Because of the large size of the tags and concern for the health of the fish, we did not attach tags to any fish smaller than 105 cm, which could be any male or immature female. Finally, we are unable to examine early life history of Pacific halibut.
and their dispersal by oceanic currents which is necessary for examining potential population
differentiation.

Nonetheless, this study provides evidence of possible spawning components within the
eastern Pacific halibut population, created by reproductive separation of BSAI Pacific halibut
from those in the GOA. Even if there is mixing of early life-history stages, this observed
reproductive separation may lead to some level of population sub-structure that is relevant to
prosecution and management of a fishery. In this case, a population comprised of discrete
spawning units is often more accurately described using a metapopulation model (Hanski and
Gilpin 1997) than as a homogenous single-unit-stock (Stephenson 1999). Identifying and
preserving population substructure has been identified as an important goal of modern fishery
science (Stephenson 1999, Frank and Brickman 2001). If there is indeed a separate spawning
component of Pacific halibut in the BSAI, its dynamics may vary from those of the GOA and
determining its population dynamics will be necessary for correct modeling to predict how
different population components will respond to future fishing pressure and changes in
environmental conditions.

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Figure 1. Map of North Pacific Ocean. Dotted lines indicate the dominant circulation pattern in the Bering Sea (Stabeno et al. 1999).

Figure 2. Release (●) and recovery sites (○) of PAT-tagged halibut in the Bering Sea and Aleutian Islands. Dotted lines indicate passes between the Aleutian Islands.

Figure 3. Example of a Pacific halibut whose maximum (o) and minimum (x) depths correspond closely to each other for each 12-hour summary period, except for a few isolated occasions during mid-winter.

Figure 4. Examples of the four general behavior types of Pacific halibut. For depth plots, o = Maximum depth for 12-hour summary periods. For longitude plots, □ = release position and location at which the tag reported to Argos and ● = estimated position. Note that the feeding site returnee was not included in the analysis in this report because its tag popped-up on 1 May, but rather it is included to illustrate this behavior type.
Table 1. Behavior types of Pacific halibut in the Bering Sea and Aleutian Islands.

<table>
<thead>
<tr>
<th>Location</th>
<th>Shelf resident</th>
<th>Short distance slope disperser</th>
<th>Long distance slope disperser</th>
<th>Feeding site returnee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attu Island</td>
<td>2</td>
<td>7</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>Atka Island</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>3</td>
</tr>
<tr>
<td>Bering Canyon</td>
<td>0</td>
<td>8</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>St. Paul Island</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Middle Canyon</td>
<td>0</td>
<td>8</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
**Conclusions**

This study has provided a major advance in our knowledge of Pacific halibut biology and ecology in the Bering Sea and Aleutian Islands. Using Pop-up Archival Transmitting (PAT) tags we were successfully able to determine winter locations of Pacific halibut, to infer migration timing and depth of seasonal migration, and to determine the environmental conditions experienced by the fish. PAT tags provided no evidence that Pacific halibut in the southeastern Bering Sea and Aleutian Islands dispersed to the Gulf of Alaska during the mid-winter spawning season, supporting the hypothesis that there are separate spawning component of Pacific halibut in the Bering Sea/Aleutian Islands.

The study was subject to several limitations that should be used to direct future research. Additional PAT tags are needed to increase the sample size of tagged Pacific halibut in the Gulf of Alaska, Bering Sea and Aleutian Islands. To address this problem, additional PAT tags have been deployed by the International Pacific Halibut Commission in both the Gulf of Alaska and the Bering Sea/Aleutian Islands (Loher and Blood 2008, Loher and Clark *in press*).

Monitoring of other demographic components of the Pacific halibut population is needed. The fish that were tagged in this study were most likely all sexually mature females (Clark et al. 1999). Because of the large size of the tags and concern for the health of the fish, tags were not attached to any fish smaller than 105 cm, which could be any male or immature female. Most of the knowledge about the dispersal and seasonal locations of small Pacific halibut (<105 cm) comes from conventional tagging experiments, which are subject to several limitations and their conclusions are questionable.

Alternative technology such as archival tags will allow examination of the dispersal, seasonal locations and behavior of males and immature females. Archival tags contain the same sensors as PAT tags, but do not contain a release mechanism; therefore they are dependent on fish recapture for data recovery (Arnold and Dewar 2001). Geolocating archival tags are approximately 60% smaller than PAT tags and could be attached to the smallest Pacific halibut, 45 cm, captured on longline fishing gear. Archival tagging techniques have been tested on captive Pacific halibut and experiments are currently underway in the Gulf of Alaska (Loher and Rensmeyer *in press*). Similar experiments should be conducted in the Bering Sea and Aleutian Islands region.

Alternative methodologies to PAT tags are needed to examine potential separate populations of Pacific halibut in the Gulf of Alaska, Bering Sea and Aleutian Islands on interannual, lifetime and intergenerational timescales. The PAT tag deployments in this study provided less than a year of data from a fish that may live up to 50 years. These tag deployments are unable to capture observations necessary for maintaining population structure, such as regional fidelity to spawning areas and interannual
dispersal. Longer deployments of PAT tags are not recommended because of premature release of the tags caused by stress on the tether assembly (Arnold and Dewar 2001).

For interannual timescales, archival tags can provide fine scale behavioral information as these tags are able to store up to 4.5 years of data when sampled every minute and battery life exceeds the memory capacity of the tag. Archival tags have successfully confirmed migration route and spawning site fidelity in successive spawning seasons in European plaice (Pleuronectes platessa) (Hunter et al. 2003) and could be used to answer the same questions about Pacific halibut. The battery life of acoustic tags may provide up to 20 years of movement data if a Pacific halibut swims past acoustic receivers during its time at-liberty.

For lifetime scales, the study of otolith chemistry, in which the chemical signature of the fish's earbone is matched with the unique chemical signature of different areas of the ocean, should enable assignment of nursery areas for individual fish (Thorrold et al. 2001), as well as the areas occupied during different stages of a fish's life (Kennedy et al. 2002). Using otolith chemistry, movement among regions can be examined for individual fish. Otolith chemistry of Pacific halibut from select locations in the Gulf of Alaska and southeast Bering Sea is being examined to test the feasibility of assigning nursery origin of adult Pacific halibut and the movement of juveniles (Loher and Wischniowski 2006). If otolith chemistry proves feasible for assigning nursery areas and studying juvenile movement, this technique should be used to study Pacific halibut throughout their range in the Gulf of Alaska, Bering Sea and Aleutian Islands.

For intergenerational timescales, genetic techniques may be used to examine possible population differentiation in different regions of the range of Pacific halibut. Two independent genetic analyses are currently being conducted on Pacific halibut from select locations in the Aleutian Islands, Bering Sea and Gulf of Alaska to optimize genetic markers and determine whether significant genetic differences occur among fish from each region (J. Nielsen, United States Geological Survey-Alaska Science Center, Anchorage, AK, personal communication; Hauser et al. 2006). Once genetic markers are optimized, both male and female Pacific halibut from several year classes should be sampled in the Gulf of Alaska, Bering Sea and Aleutian Islands to test for genetic difference among sexes, year classes and regions.

The timing of tagging and sampling needs to be considered for discerning population structure in Pacific halibut. Tagging and sampling are accomplished most easily during the International Pacific Halibut Commission Summer Setline Survey (Dykstra et al. 2006). In this survey, a regular grid of stations in the Gulf of Alaska, eastern Bering Sea and Aleutian Islands is fished annually during the summer for stock assessment purposes. Ancillary projects are readily accommodated during the survey; hence most Pacific
halibut research is conducted during the summer. However, Pacific halibut are on their feeding grounds during the summer and are not spawning, therefore genetic mixing does not occur during this time. A concerted effort needs to be made to tag Pacific halibut and collect biological samples during the winter on the spawning grounds where the actual genetic exchange among individuals occurs. It is during this time that actual population components are defined.

Given the economic importance of Pacific halibut in the North Pacific Ocean, accurate description of their population structure is paramount to a sound management plan. If Pacific halibut in the Gulf of Alaska, Bering Sea and the Aleutians Islands belong to different populations, it would be biologically appropriate to divide the entire range of Pacific halibut into smaller sub-units with independent population dynamics, catch quotas and/or exploitations rates. Each region could be managed independently essentially producing local area management plans that more accurately reflect population structure. Obtaining resolution on these issues has never been more important, in light of the IPHC’s recent adoption of an assessment model that assumes a single and essentially homogenous coastwide population, in which local dynamics are subordinate to overall abundance (Clark and Hare 2007).


**Publications**


Outreach

Conference presentations:


Community and Fishing Fleet Meetings:


Workshop Participations:
Seitz, A. 2008. Served on steering and program committees and as a session chair at:

Advances in Tagging and Marking Technology for Fisheries Management and Research


Presentations in Schools (K-12, undergraduate):
Seitz, A.C. 2006. Electronic tagging technology for marine animals. Guest lecturer in Fisheries Science (FISH 400) at School of Fisheries and Ocean Sciences, University of Alaska Fairbanks. October 2006.

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Literature cited


