Abstract—We evaluated light-based geolocation estimates from pop-up satellite tags in high latitudes because some of the largest fisheries in the world are in areas where this technique has not been assessed. Daily longitude and latitude were estimated by using two Wildlife Computers software programs: 1) Argos Message Processor (AMP), which summarizes light intensity data transmitted to satellites, and 2) Time Series Processor (TSP), which uses more detailed data obtained from retrieved tags. Three experiments were conducted in the northern Gulf of Alaska using tags placed on 1) Pacific halibut in outdoor aquaria, 2) a fixed mooring line at various depths and 3) wild Pacific halibut. TSP performed better than AMP because the percentage of days with geolocation estimates was greater and the mean error magnitude and bias were smaller for TSP and increased with depth for both programs; however, latitude errors were much greater than longitude errors at all depths. Light-based geolocation enabled us to discern basin-scale movements and showed that the Pacific halibut in our study remained within the Gulf of Alaska. We conclude that this technique provides a feasible method for inferring large-scale population structure for demersal fishes in high latitudes.

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Evaluating light-based geolocation for estimating demersal fish movements in high latitudes

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Demersal fishes at high latitudes support some of the most lucrative fisheries in the world. An example is the Pacific halibut (*Hippoglossus stenolepis*) fishery off Canada and the United States. Currently, the International Pacific Halibut Commission (IPHC) manages the Pacific halibut population as a single, panmictic stock from northern California through the eastern Bering Sea based on genetic (Grant et al., 1984; Bentzen et al., 1998) and tagging data (Skud, 1977). However, Pacific halibut movements and population structure are not fully understood and mixing may be more restricted than assumed, as evidenced by a number of local depletions in recent years (Hare[1]). A method for estimating movements over large distances is needed to improve the ability to identify populations and manage the harvest. Population structure and movement information is needed for management of several other high-latitude fisheries including Atlantic halibut (*Hippoglossus hippoglossus*), Pacific cod (*Gadus macrocephalus*) and Greenland turbot (*Reinhardtius hippoglossoides*) (Godø and Haug, 1988; Shimada and Kimura, 1994; Albert, 2002).

New methods using information collected by electronic tags, which contain miniaturized onboard computers, are providing location estimates of demersal marine fishes (see review in Arnold and Dewar, 2001). One such method, the tidal location method, has been used to geolocate North Sea plaice (*Pleuronectes platessa*) (Hunter et al., 2003). This method compares the tidal range and time of high

[1] Hare, S. R. 2005. Investigation of the role of fishing in the Area 4C CPUE decline. Int. Pac. Halibut Comm. Report of Assessment and Research Activities 2004:185–198. Int. Pac. Halibut. Comm, PO Box 95009, Seattle, WA 98145-2009.

water, as measured by the depth sensor of the electronic tag, to those predicted by tide models. Unfortunately, we are unable to use this method near Alaska because the water depth is much greater than in the North Sea. Deep water necessitates that the depth sensor of a tag have a greater range, which decreases depth resolution. Thus, tags used off Alaska have a depth resolution that is greater than the tidal range; therefore the tag cannot distinguish tidal fluctuations.

Another tagging method has been used to geolocate Baltic Sea cod (*Gadus morhua*) (Neuenfeldt et al.[2]). This method is based on combined data of depth, temperature, and salinity obtained by electronic tags attached to cod. Hydrographic fields obtained from hydrodynamic modeling are used as a geolocation database to identify daily locations of fish by comparison with the environmental data collected by each electronic tag. Unfortunately, the tags that we used are not available with a salinity sensor and hydrodynamic models of the area are not accurate on the bottom (Hedstrom[3]).

Ambient light data collected by electronic tags may be used to calculate daily estimates of latitude and longitude of fish. Geolocation by light has been implemented successfully on a variety of pelagic species to discern their daily position and movement patterns (Gunn and Block, 2001; Schaefer and Fuller, 2002; Itoh et al., 2003; Sibert et al., 2003).

However, no studies have been conducted to evaluate light-based geolocation estimates from tags attached to demersal fish, nor from fish inhabiting high latitudes. Unfortunately, light levels in deep and high-latitude waters may be low and if the water is turbid, the light may be attenuated very quickly, thus hindering position estimates. Additionally, many demersal fishes inhabit a depth range where geolocation by light has not been evaluated at any latitude.

The goal of this study was to examine the feasibility of using ambient light geolocation for estimating demersal fish movements in high latitudes. This was accomplished by the following procedures: 1) by comparing daily latitude and longitude estimates from two proprietary software types developed by Wildlife Computers, 2) by examining latitude and longitude estimates as a function of depth, and 3) by examining *in situ* latitude and longitude estimates of pop-up archival transmitting (PAT) tags attached to wild Pacific halibut.

Materials and methods

The pop-up archival transmitting tag (PAT, Wildlife Computers, Redmond, WA, vers. 2.0) is a miniature computer that is attached externally to a fish. The tag contains a clock and sensors that collect depth, temperature, and ambient light intensity data at user-specified intervals (Sibert, 2001). On a programmed date, the PAT tag disengages from the fish, floats to the surface, and transmits summaries of the recorded temperature, depth, and light data to Argos satellites; the data are then retrieved by the investigator. If the tag is retrieved, the complete archival record of temperature, depth, and ambient light data may be obtained.

From October 2000 to March 2002, a pilot study was conducted to assess the feasibility of using PAT tags as a tool for identifying critical habitat of demersal fishes in high latitudes (Seitz et al., 2002, 2003). Geoposition estimates were made from light data collected in three experiments in which PAT tags were attached to 1) Pacific halibut in outside aquaria, 2) a stationary mooring, and 3) wild Pacific halibut *in situ*. The temperature and depth data from the wild Pacific halibut experiment and their Argos-based final locations have been reported previously (Seitz et al., 2003).

In the first experiment, two Pacific halibut were captured, transported live to outside aquaria at the Alaska SeaLife Center (Seward, Alaska; 60.099°N, 149.440°W) and tagged on 18 Oct. 2000 with PAT tags programmed to record light intensity every minute. The tags were retrieved on 1 May 2001, and the longitudes and latitudes of Pacific halibut estimated from the tag data were compared with the known location of the Pacific halibut in the aquaria.

A second experiment was conducted by using a fixed mooring to examine latitude and longitude estimates as a function of depth. From December 2000 to April 2002, four PAT tags were attached to a stationary mooring line (the NOAA Alaska Observing System's "GAK-1" mooring) in Resurrection Bay, Alaska (59.852°N, 149.330°W) at depths of 27, 57, 96 and 146 m. These tags were attached to four different current vanes on the mooring line so that their light sensors faced up.

In a third experiment, to evaluate the performance of the light sensor and geolocation algorithm *in situ*, fourteen wild Pacific halibut (108–165 cm fork length) were captured, tagged, and released in November 2000, March 2001, and July 2001 from a commercial longlining vessel in Resurrection Bay, AK, and off Cape Aialik, AK (for details, see Seitz et al., 2002, 2003). Light data were recovered from eight tags. PAT tags were tethered externally to each study animal by a piece of monofilament fishing line secured to a titanium dart that was inserted into the dorsal musculature of the fish. At a user-specified date and time, the PAT tag corroded the pin to which the tether was attached, thus releasing the tag from the animal. The tag floated to the surface and transmitted summarized data records through the Argos satellite system.[4] After the tag popped-up to the

[2] Neuenfeldt, S., H.-H. Hinrichsen, and A. Nielsen. 2004. A method to geolocate eastern Baltic cod by using Data Storage Tags (DSTs), 14 p. Int. Coun. Explor. Sea CM/L:06. Int. Coun. Explor. Sea, H.C. Andersens Boulevard 44-46, DK-1553, Copenhagen V, Denmark.

[3] Hedstrom, K. 2005. Personal commun. Artic Region Supercomputing Center, Univ. Alaska Fairbanks, PO Box 756020, Fairbanks, AK 99775.

[4] Service Argos, Inc. (http://www.argosinc.com). [Accessed on: 13 December 2005.]

surface, its location was determined by the Doppler shift in the transmitted radio frequency in successive uplinks (Keating, 1995). The endpoint position was the first location class (LC) estimate reported in the LC1-3 range, which all have error estimates <1.0 km.

The basis of light-based geolocation is the estimation of times of sunrise and sunset. Two proprietary programs developed by the Wildlife Computers, Argos Message Processor (AMP, vers. 1.01.0007) and Time Series Processor (TSP, vers. 1.01.0008), were used to extract times of sunrise and sunset from light intensity data. AMP identified daily sunrise and sunset times from light data transmitted through Argos satellites or directly from complete archival light records. TSP could be used only to identify sunrise and sunset times from complete archival light data from PAT tags that were physically recovered.

In the next phase, another Wildlife Computers program, Global Position Estimator (GPE, vers. 1.01.0005), used the sunrise and sunset times to calculate the daily longitude and latitude of tags. First, we rejected days with light level curves that did not exhibit smoothly sloping light levels from high to low or low to high (Fig. 1). GPE was used to calculate longitude for the remaining data based on the local noon time of the tag (mean of the sunrise and sunset times). 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 (140°E) or to the east of Santa Barbara, CA (117°W; Mecklenberg et al., 2002)). Once longitude was estimated, latitude was estimated by GPE, which used the "dawn and dusk symmetry method" (Hill and Braun, 2001; Musyl et al., 2001). Daily latitude estimates were the theoretical location of expected light levels that best matched the observed light levels measured by the tag. Latitude outliers were removed in the same manner as that used for longitude outliers. For all three experiments, the number of days with geolocation estimates was defined as the days that produced latitude and longitude estimates, after "bad" light curves (Fig. 1) and outliers were removed.

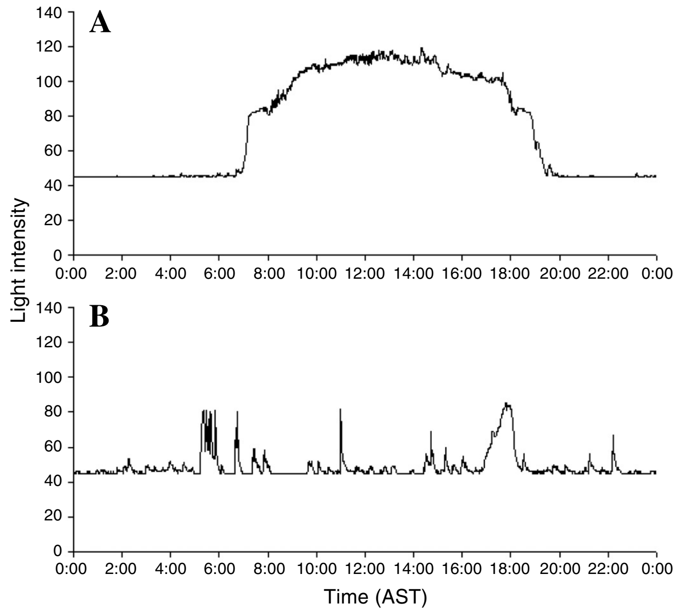

Figure 1

Examples of "good" and "bad" light curves. "Good" light curves (**A**) have smoothly sloping sunrise and sunset events. "Bad" light curves (**B**) do not have smoothly sloping sunrise and sunset events and produce outlying longitude and latitude estimates. The "good" light curve is from 2 March 2001 and the "bad" light curve is from the same tag on 10 March 2001. AST = Alaska standard time.

For the tags with known positions in the tank and mooring experiments, we calculated bias and error magnitude based on true locations. Daily positional bias was calculated as the true position minus the estimated position (signed distance between positions), and daily error magnitude was the absolute value of the bias (distance between points). For the tank experiment, we pooled the data from the two tags. Mean error magnitudes of software types were compared by using a two-tailed *t*-test. For the fixed mooring experiment, we calculated mean positional bias and mean error magnitudes for each tag and software combination. Mean biases were compared to a hypothetical bias of zero by using a two-way (tag and software) ANOVA model (vers. 8, proc GLM, SAS, Cary, NC). Mean error magnitudes were compared by using an ANOVA with a Tukey-Kramer test (Kramer, 1956; vers. 8 proc GLM). For both bias and error magnitude, the means are a measure of accuracy and the standard deviations are a measure of precision.

For wild fish, it was impossible to know the true daily position of each fish for the duration of the experiment. However, for three of the eight tags released on wild fish, geolocation estimates were produced in the first or last six days of deployment. Therefore, we compared the estimated positions of the tags for the six days immediately following release of the tags and for the six days before recapture of the tags or before tags transmitted data to Argos satellites. All three of these tags were physically recovered and TSP produced estimates for all tags. AMP produced plausible estimates for one tag only because other estimates were rejected as outliers. For each comparison, we calculated the mean bias and mean error magnitude, assuming that the fish was stationary (or nearly so) during the first and last six days of the deployment.

Results

All 14 tags, with the exception of one, functioned properly for the duration of the three experiments. The one exception, attached to a halibut *in situ*, was deployed for 234 days, but it provided data for only the first 42 days because the battery failed. Tracking durations for AMP (range: 42–479 days) were always equal to or greater than the tracking durations for TSP (range: 42–348 days) because the memory for the archival data filled up before the summary data memory.

In the tank experiment, TSP was a better estimator of longitude than AMP. TSP rejected fewer outliers and produced a higher percentage of days with longitude estimates (89.5%) than AMP (82.9%). Additionally, the mean longitude error magnitude for TSP (1.0° ±1.1° SD) was significantly smaller than that of AMP (2.0° ±3.2° SD) (t=5.63, df=650, P<0.0001). Longitude errors were larger from late-fall to mid-winter in both tags when estimated by AMP, but not TSP. The mean longitude bias of TSP (–0.12° ±1.5° SD) was significantly smaller than that of AMP (–0.64° ±3.7° SD) (t=2.3, df=650, P=0.0215). TSP was not significantly biased and AMP had a significant mean longitude bias.

In the tank experiment, TSP also produced a higher percentage of days with latitude estimates (88.2%) than AMP (81.6%). However, there was not a significant difference in the mean latitude error magnitude between TSP (4.2° ±5.1° SD) and AMP (4.4° ±4.2° SD) (t=0.36, df=641, P=0.7155). The mean positional bias of TSP (–0.02° ±6.7° SD) was not significantly different (t<0.0001, df=641, P=0.9730) from that of AMP (–0.08° ±6.1° SD) and neither software type had a significant mean positional bias.

In the fixed mooring experiment, TSP was a better estimator than AMP of longitude. In general, the tags produced fewer longitude estimates as depth increased, and at each depth, TSP generated more estimates than AMP (Fig. 2). The mean longitude error magnitude for both programs increased at greater depth (Fig. 3). The mean error magnitude of AMP and TSP estimates was not significantly different at 27 m and 57 m (P>0.50), but AMP estimates quickly degraded starting at 96 m (Fig. 3). For the tags at 96 m and 146 m, the mean error magnitudes for TSP estimates were significantly smaller (P<0.0001) than the AMP estimates of the same tags. The mean longitude biases of both AMP and TSP were generally to the west (positive values) of the actual position of the tags, except for AMP at 96 m (Fig. 3). In several cases, the mean biases were relatively small for both AMP and TSP, however both had large variances.

As with the longitude estimates in the fixed mooring experiment, the percentage of days with latitude estimates decreased at greater depths (Fig. 2). Unlike longitude, latitude was not estimated accurately by the tags. Mean latitude error magnitude was significantly smaller for TSP than for AMP at all depths, except 146 m (Fig. 3). The mean error magnitude for both AMP and TSP showed no relationship to increasing depth (Fig. 3). The mean latitude biases of the tags in the fixed mooring experiment were greater than the mean longitude biases, and the biases by AMP were more variable than those of TSP (Fig. 3). Like longitude in the fixed mooring experiment, latitude was not estimated at 146 m during the winter and spring. The time span without geolocation estimates was longer for latitude (242 days) than for longitude (165 days).

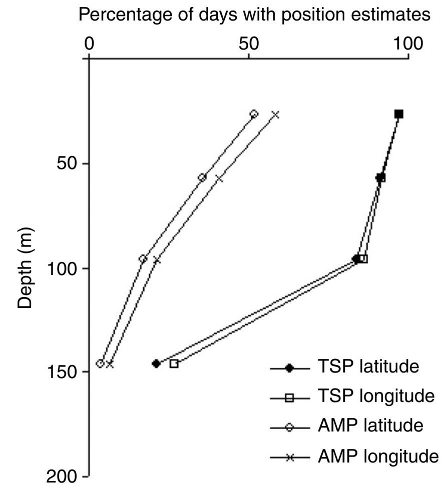

Figure 2

Percentage of days with longitude and latitude estimates as a function of depth in the fixed mooring experiment. Two programs, Argos Message Processor (AMP) and Time Series Processor (TSP), were used to calculate daily longitude and latitude.

In the wild fish experiment, four tags reported only to Argos satellites and geoposition was estimated from summary data by using AMP. The percentage of days with longitude estimates ranged from 0.0% to 2.3% (mean=1.1% ±1.0% SD), whereas the percentage of days with latitude estimates ranged from 0.0% to 1.5% (mean=0.6% ±0.7% SD). The other four tags were physically recovered and geoposition was estimated by using both summary data for AMP and detailed data for TSP. For AMP, the percentage of days with longitude estimates ranged from 0.0% to 12.0% (mean=5.8% ±5.9% SD), whereas the percentage of days with latitude estimates ranged from 0.0 to 7.9% (mean=3.4% ±3.5% SD). For TSP, the percentage of days with longitude estimates was higher, ranging from 9.9% to 32.3% (mean=19.7% ±9.4% SD) and days with latitude estimates ranged from 9.9% to 26.6% (mean=16.9% ±7.2% SD).

The mean error magnitude of the longitude estimates for AMP (n=4; 2.98° ±2.43° SD) was slightly larger than that of TSP (n=10; 2.23° ±2.38 SD°). However, the mean error magnitude of the latitude estimates for AMP (n=4; 2.76° ±1.59° SD) was approximately half that of TSP (5.65° ±4.11° SD). The mean longitude bias for AMP (2.95° ±2.47° SD) was larger and to the east of that of TSP (−1.32° ±3.04° SD). The mean latitude bias was relatively small for both AMP (0.56° ±3.50° SD) and TSP (0.10° ±7.26° SD); however both had large variances and thus the estimates were not precise. In several cases, the longitude estimates were within one degree of the true position and there did not appear to be a pattern of over- or underestimating longitude.

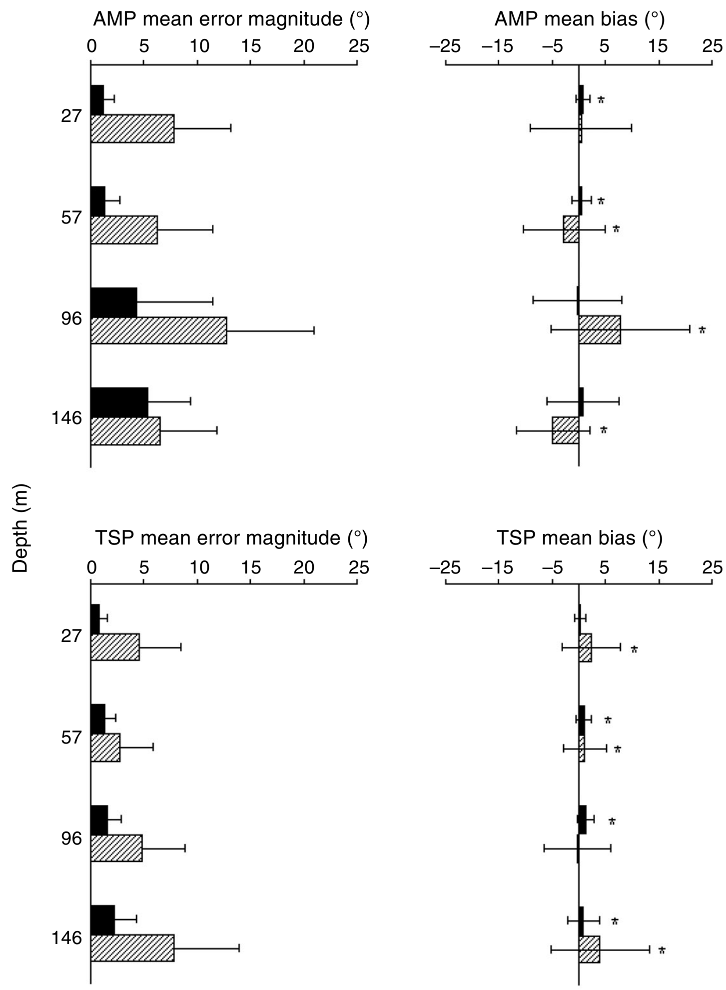

Figure 3

Mean (±SD) positional errors and bias in the fixed mooring experiment. Two programs, Argos Message Processor (AMP) and Time Series Processor (TSP), were used to calculate daily longitude (black bars) and latitude (hatched bars). Asterisks (*) indicate mean positional biases that were significantly different from zero in tests with two-way ANOVA. A negative bias indicates that a position estimate was either north or east of the known position, and a positive bias indicates that a position estimate was either south or west of the known position.

Discussion

Geolocation estimates determined from ambient light data in high latitudes is equally effective as in lower latitudes. Similar to results from previous geolocation evaluations (Welch and Eveson, 1999, 2001; Musyl et al., 2001; Teo et al., 2004), our longitude estimates were in general more accurate and precise than latitude estimates. Therefore, longitude estimation by light is a promising technique for discerning large-scale movement of demersal fishes in coastal Alaska, but latitude estimation determined from light data only will not be adequate for these purposes.

This study was unique in testing light-based geolocation in depths greater than 60 m. The results demonstrate the importance of evaluating geolocation by light for the entire depth range of the species of interest. Testing only in the near-surface waters would be misleading because the percentage of days with estimates from tags at shallower depths was much greater than the percentage of days with estimates from tags at greater depths—the depths which halibut most frequently inhabit (Seitz et al., 2003).

The accuracies of the longitude estimates in this study were comparable to those at lower latitudes and similar water depth. Errors are discussed in linear distance (Table 1) to account for the fact that a degree of longitude varies with latitude and to facilitate comparisons to previous studies. The longitude errors from the tank experiment were generally similar to the errors produced in a comparable experiment where tags were placed on a stationary mooring at a depth of 10 m (Welch and Eveson, 1999). The tags submerged at deeper depths in the fixed mooring experiment also showed a longitude error magnitude similar to that of location estimates from tags in the offshore region of the Gulf of Alaska at 50°N, 145°W (Musyl et al., 2001; Welch and Eveson, 2001). The longitude biases were only slightly larger than those from tags on a stationary mooring near Hawaii (Musyl et al., 2001).

The minimum movement of a fish that was discerned by light-based geolocation in our experiment is the absolute sum of the error magnitude and bias. The sum of the error magnitudes and biases of TSP were generally smaller than those of AMP; therefore TSP was a better estimator of light-based geoposition than AMP and can be used to discern movement at a finer scale. The tank and fixed mooring experiments indicated that longitude estimation by TSP is able to discern movements of approximately ±200 km for depths as great as 150 m and AMP is able to discern east-west movements of approximately ±350 km at 150 m deep. Geolocation by light will be able to discern the large-scale movements

Table 1

Linear distance of mean error magnitude for the tank, fixed mooring, and wild fish experiments. Longitude and latitude were calculated from light intensity data collected by pop-up archival transmitting tags in two programs, Argos Message Processor (AMP) and Time Series Processor (TSP). Mean error magnitude was calculated by averaging the absolute value of the difference of the true position and the estimated position of the tag for each day of the experiment. Total error was the vector distance from the known location of the tag when longitude and latitude errors were combined. The great circle formula was used to convert angular errors to linear distances.

			AMP			TSP		
Experiment	Tag	Depth (m)	Longitude (km)	Latitude (km)	Total error (km)	Longitude (km)	Latitude (km)	Total error (km)
Tank	00-0740	0	139.1	500.9	519.8	62.9	500.9	504.8
Tank	00-0741	0	83.5	480.8	488.0	48.4	445.2	447.8
Mooring	00-0822	27	66.2	873.7	876.2	41.7	505.3	507.0
Mooring	00-0826	57	74.6	696.8	700.7	74.6	310.5	319.4
Mooring	00-0806	96	241.5	1421.3	1441.7	89.6	540.9	548.3
Mooring	00-0824	146	299.3	726.8	786.0	123.5	871.5	880.2
Wild fish	All tags	90–202	165.8	307.2	362.6	124.1	628.9	392.0

of Pacific halibut because this species performs spawning migrations of over 1100 km (Loher[5]). Additionally, with recovery rates as high as 50% in area-specific conventional tagging experiments (Kaimmer, 2000), TSP can could be used for a large portion of tag recoveries in future experiments.

At the largest scale, we were able to discern with confidence whether the wild Pacific halibut in this study were in the Gulf of Alaska or Bering Sea. Individual estimates were subject to occasional large errors and therefore caution should be practiced when using these estimates to represent the true position of fish. Examining patterns in estimates is more useful for determining locations. To reach the Bering Sea (west of 157°W), a Pacific halibut would have to migrate from the Gulf of Alaska through False Pass (163.5°W), which is the eastern-most connection between the two areas. The wild Pacific halibut in our study appeared to remain within the Gulf of Alaska, because fewer than 5% of the longitude estimates were to the west of 163.5°W, and those appeared to be erroneous because adjacent estimates did not consistently corroborate them. Trends in longitude estimates did not provide sufficient evidence to indicate that any of the wild Pacific halibut swam to the Bering Sea.

A variety of uncontrollable factors can cause intrinsic and extrinsic errors in geolocation estimates. The predominant source of intrinsic error is refraction in the earth's atmosphere that is caused when light travels through the atmosphere and is bent by air and other molecules (Schaefer and Liller, 1990). This error limits the absolute accuracy of the estimates to a constant 0.32° longitude and a minimum of 0.7° latitude (Hill and Braun, 2001). Extrinsically, light levels may be drastically influenced by changing external conditions, such as waves, water turbidity, diving behavior of the animal, biofouling, and cloud cover (Metcalfe, 2001). In particular, the Alaska coastal region frequently experiences large changes in weather systems that change cloud cover and sea-state on a daily, or even hourly, basis. One final consideration for errors is that accurate location estimates rely on unobstructed horizons. If the horizon is obstructed, such as by the mountains surrounding the coast of Alaska, it alters the time(s) of apparent sunrise (and sunset), thus affecting geolocation estimates. The tank experiment was conducted in a deep, north-south fjord whose walls obstructed the horizon, and the fixed mooring experiment was adjacent to an island on the east and to steep coastal mountains to the west. Undoubtedly, these false horizons accounted for part of the errors and bias.

One shortcoming discovered in the fixed mooring experiment was a conspicuous gap in longitude and latitude estimates from December to June at 146 m. This six-month gap was probably the result of low ambient light levels during the winter associated with high latitudes. It is unknown why the gap lasted into the summer when ambient light drastically increased. However, for practical application in studies of Pacific halibut migration, light-based geolocation estimates will capture some individual migrations to the spawning grounds as some Pacific halibut begin migrating in October and arrive on the continental slope by early November (Seitz et al., 2003).

We may be able to increase the number of location estimates with some fine-tuning of both software types. Several days were rejected because of poor light readings. However, some days had smoothly sloping sunrise and sunset events that appeared to be sufficient for accurate geolocation estimates, but the software mis-

[5] Loher, T. 2005. Personal commun. Int. Pac. Halibut. Comm, PO Box 95009, Seattle, WA 98145-2009.

identified sunrise and sunset. This misidentification typically occurred because there were occasional aberrant light readings. The geolocation software identified these as sunrise, sunset, or both, and therefore gave bogus position estimates. There is an option to override these aberrant sunrise and sunset times when using TSP because the software allows manual selection of sunrise and sunset. For our study, we opted not to do this because we did not want to introduce subjectivity into sunrise and sunset times. We suggest that the software be modified by the manufacturer to select the next best times for sunrise and sunset so that the investigator may reject aberrant light readings and yet allow the software to objectively choose sunrise and sunset.

In future studies, we hope to improve geoposition estimates by statistically filtering (Sibert et al., 2003) or smoothing longitude estimates and by incorporating additional sensor data. For example, in conjunction with light data, tag-measured sea-surface temperature (SST) can be compared to remotely sensed SST, to significantly improve geolocation estimates (Teo et al., 2004). In the case of demersal fish that rarely, if ever, visit the sea surface, maximum daily depth can be used as representative of the total water depth in the region. We can compare the maximum daily depth sampled by an electronic tag to existing bathymetry data to estimate possible daily positions of the fish. We can then combine the geolocation estimated by light-level information with the depth information to yield a most plausible track of daily positions.

Accurate description of the movement of fish is the cornerstone of sound management plans for ensuring sustainable fisheries in the future (Hunter et al., 2003). Longitude estimation determined from ambient light data may be used to examine large-scale movements of demersal fish in high latitudes. There are several types of electronic tags—some designed for fish as small as 15 cm (Arnold and Dewar, 2001). Using this technique, we can describe large-scale spatial dynamics and migration of several commercially important demersal fish species.

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