5.9 Deployment and reporting of pop-up archival transmitting (PAT) tags to study seasonal and interannual dispersal of Pacific halibut on the northern Bering Sea continental shelf edge

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Abstract

The International Pacific Halibut Commission (IPHC) has conducted a series of pop-up archival transmitting (PAT) tag studies in the Bering Sea and Aleutian Islands (BSAI) region in order to identify winter spawning locations, determine the timing of seasonal movements, and investigate mixing within the BSAI and between the Bering Sea and Gulf of Alaska. However, neither PAT nor PIT (passive integrated transponder) tagging has been conducted on the Bering Sea continental shelf between 59°50' north latitude and the border of the United States of America and-Russia, because this region has not been previously surveyed by the IPHC. In 2016, we took advantage of the IPHC fishery-independent setline survey ('setline survey') expansion in order to generate data for this unstudied region that will complement prior work. Thirty-one Pacific halibut ranging from 82-167 cm fork length (FL) were tagged at locations that spanned from southern Pervenets Canyon (59°30'N) to the southeastern margins of Navarin Canyon (61°10'N). Twenty tags were programmed to detach from their host fish to report their location and download environmental data to passing Argos (Advanced research and global observation system) satellites during the 2016-2017 spawning season, from late December to mid-January; 11 tags were programmed to detach and report after 365 days at liberty, in mid-June of 2017. In addition to determining the length of each tagged Pacific halibut, blood samples were obtained for future analysis of plasma hormone levels that might be predictive of individual migratory behavior, and ultrasound was employed to determine sex and the likelihood that tagged females (n = 24) were mature.

Introduction

The International Pacific Halibut Commission (IPHC) has a considerable history of conducting pop-up archival transmitting (PAT) tag studies in the Bering Sea and Aleutian Islands (BSAI) region in order to investigate both seasonal and inter-annual dispersal. In total, 188 tags have been deployed in the BSAI region in previous studies, covering the historically-surveyed range of Pacific halibut (*Hippoglossus stenolepis*) throughout IPHC Regulatory Area 4. These studies have been designed to identify winter spawning locations, gain greater understanding of the timing of movements within this stock component, and investigate mixing among regulatory areas in a fishery-independent manner. Taken together, they have resulted in an understanding of population function that is generally consistent with the spatial structure of the IPHC's Area-as-Fleets stock assessment model (Stewart and Martell 2016).

Studies of seasonal migration and winter distribution were initiated in 2002 in the shallow nearshore waters of Area 4C (Seitz et al. 2007), expanded to Area 4B in 2004 (Seitz et al. 2008), and to the northern and southern extents of the IPHC's Bering Sea continental shelf-edge survey grid in 2006 (Seitz et al. 2016). The result was an integrated 5-site design spanning from Attu

Island in the west to Unimak Pass in the east, and northward to Pervenets Canyon. With respect to stock structure, the results indicated considerable mixing on the eastern continental shelf in conjunction with relative isolation within Area 4B (Seitz et al. 2011). Additionally, the results suggested that the stock's spawning range is considerably broader than had been traditionally assumed. Prior to the initiation of the IPHC's PAT-tagging program, the best available evidence indicated that Pacific halibut in the eastern Pacific concentrate their winter spawning activity at submarine canyons from southern British Columbia to Pribilof Canyon in the southeastern Bering Sea, with no indication of spawning along the Aleutian Chain (St. Pierre 1984). PAT tag data suggest a spawning distribution that extends latitudinally from at least Cape Johnson, Washington (Loher and Blood 2009) to Pervenets Canyon, and westward to Attu Island (Seitz et al. 2016). Still, the full range of potential spawning habitats has not been studied. Navarin Canyon lies to the north of Pervenets Canyon and within the IPHC-managed range. This canyon system is of particular interest in that it straddles the waters of both the United States of America (US) and Russia, and represents one of the northern-most submarine canyons in the Bering Sea Basin. Just 100 nautical miles (185 km) to the northwest of Navarin Canyon the edge of the continental shelf turns southward along the Kamchatka Peninsula.

From 2008-2010, a large PAT-tagging experiment was conducted in the Bering Sea to examine inter-annual dispersal of Pacific halibut (Loher and Clark 2010). This was designed as fishery-independent complemented to an earlier large-scale Passive Integrated Transponder (PIT)-tagging study (Webster et al. 2013) that had relied upon the directed commercial fishery to recapture tags. Results of the inter-annual dispersal experiment were consistent with both seasonal PAT tagging and large-scale PIT tagging in demonstrating relative isolation of Area 4B from the remainder of the stock and a relative discontinuity in dispersal across the Aleutian Ridge. With respect to the latter, Pacific halibut that were tagged in Area 4A were found to be more likely to move into Area 3, if they had been tagged south of Unimak Pass than if tagged in Area 4A north of Unimak; i.e., west-to-east movement of commercially-recruited sizes was considerably more prevalent within the western Gulf of Alaska (GOA) than was movement of Pacific halibut from the Bering Sea into the GOA. However, as with examinations of spawning distribution, geographic gaps occurred in both the PIT- and PAT-tag data due to survey coverage that did not extend to the limits of the managed range; in particular, near the Russian border and along Bowers Ridge north of the Aleutian Islands. Here, we take advantage of ongoing setline survey expansion in order to begin filling these gaps in understanding. In the current study, PAT tags were deployed at northern Area 4D expansion stations (Webster et al. 2016). Ideally, this will be followed by tagging on Bowers Ridge in the near future.

Tag specifications and biological sampling

The PSATflex (manufactured by Lotek Wireless, St. Johns, NL) is a cast epoxy satellite-transmitting archival tag (Fig. 1) that is shaped somewhat like a microphone, with a body diameter of approximately 2 cm (0.75 in), float diameter of 4 cm (1.6 in), a total body length of 12.5 cm (5.0 in). The body of the tag contains temperature (nominal recording range of -5° to 35° C; accuracy of 0.2° C at 0.05° resolution) and pressure (depth; 0-2000 m, accurate to 1% of recorded values at 1-m resolution) sensors as well as programming circuitry and a satellite transmitter. In addition, it bears a 17.3 cm (6.75 in) fiber optic stalk that serves as both a light sensor and radio-signal transmission antenna. The tag weighs 89 g in air with a submerged buoyancy of 8 g.

The tags were attached to Pacific halibut via a dart and leader assembly composed of a 12-cm (5-in) leader constructed of 300-lb (136-kg) test nylon monofilament line covered in black adhesive-lined shrink-tubing secured to a titanium dart. The darts were embedded into the dorsal musculature so as to rest against the uneyed-side of the fish's pterygiophores, with their leaders extending roughly 4 cm (1.5 in) medial to the dorsal fin where the body begins to taper towards the tail (Fig. 1). Leaders were attached to the tags' nosecones via thin metal wire, through which an electrical current will be induced after pre-programmed deployment periods that were initiated when the tagged fish was returned to the water. The induced current will cause the attachment pins to rapidly corrode, releasing tags from their leaders and allowing them to float to the surface, where data transmissions will begin. Data will be transmitted to the US National Oceanic and Atmospheric Administration's (NOAA) polar-orbiting satellites, administered by the Advanced Research and Global Observation System (ARGOS). PSATflex are not equipped with surface-detect capabilities, and so tags that detach from their host fish prematurely will not broadcast until their pre-programmed deployment period has ended. Upon broadcast, each tag's endpoint position will be determined from the Doppler shift of its transmitted radio frequency in successive uplinks received during one satellite pass (Keating 1995) and during these uplinks, daily summary data for temperature and depth, along with light-based geoposition estimates that are derived from onboard data processing, will be remotely downloaded. If a tagged fish is captured and its tag retrieved before the tag pop-up date, or if a tag is found awash following detachment from a fish, the full archival data records for each recorded parameter can be accessed.

Tags deployed in this study were programmed to release from their host Pacific halibut within one of two treatment groups: a) after 200 days (summer-to-winter) at liberty; b) after 365 days (i.e., summer-to-summer) at liberty. The 200-day reporting schedule was chosen in an attempt to produce location data during mid-January, as this corresponds to the peak spawning period for Pacific halibut in the GOA (Loher and Seitz 2008) and is inferred to be roughly equivalent in the Bering Sea (Seitz et al. 2011). In order to maximize data acquisition, tags set with a 200-day deployment period were programmed to archive data at 10-second intervals, while 365-day tags were programmed to record data every 20 seconds.

All Pacific halibut were captured using standardized commercial longline gear during the IPHC's 2016 fishery-independent setline survey (setline survey) (Henry et al. 2017). Briefly, gear was composed of six skates of groundline tied end-to-end, with each skate measuring 549 m (1800 ft) and fitted with 100 16/0 circle-hooks secured via 0.6-1.2 m (2-4 ft) gangions spaced 5.5 m (18 ft) apart. Each hook was baited with #2 of semi-bright chum salmon (*Oncorhynchus keta*). Gear was never set before 0500 hours and was allowed to soak for a minimum of five hours before being hauled.

Fish selection protocols for each treatment group followed the methods that were used in the prior research that these data are intended to complement. Summer-to-winter tags were deployed on female Pacific halibut ≥105 cm FL because individuals of this size have a high probability of being mature and therefore undergoing seasonal spawning migrations (*sensu* Seitz et al. 2011).

Summer-to-summer tags were applied to any halibut of any commercially-legal size (≥ 32 in (O32) or 81.3 cm FL) and without *a priori* regard to sex in order to reflect the demographics of regional exploitable biomass (*sensu* Loher and Clark 2010). These halibut were tagged only at 4D Edge North setline survey expansion stations (Webster and Henry 2017) because no satellite tags had been previously deployed in this region.

Upon capture, halibut were measured to the nearest centimeter FL and examined for physical condition. Pacific halibut were tagged only if they were in excellent condition: not substantially injured during capture, showed no evidence of predation by sand fleas (gammarid amphipods), and displayed considerable strength and opercular reflex. Sex and ovarian length were determined prior to tagging via veterinary ultrasound following the methods described in Loher and Stephens (2011). A small tissue sample was taken from the tip of the caudal fin (tail) of each individual and immediately preserved in 100% ethanol. Blood samples were extracted from the caudal vein (DFO 2004), which runs along the ventral surface of the caudal vertebrae, using pre-heparinized 1.0 ml hypodermic needles fitted with sterile 23 gauge needles 1.0" (2.54 cm) in length (i.e., B-D 23G1 needles). Following collection, blood samples were centrifuged at 3500 rpm for 12 minutes in order to separate the plasma, and the resulting plasma samples refrigerated for storage and transport.

Tag deployments

A total of 31 Pacific halibut were tagged in this study in the US waters of the southeastern Bering Sea outer continental shelf and shelf edge (Fig. 2) in IPHC Regulatory Area 4D. Tagging occurred on dates ranging from 11 June to 26 June 2016 (Table 1).

Twenty Pacific halibut (three male, 17 female) ranging from 92-167 cm FL were tagged from 11-26 June with summer-to-winter tags, resulting in scheduled reporting dates ranging from 28 December 2016 to 12 January 2017. The resulting median winter reporting date (4 January) will be approximately two weeks earlier than had been originally planned because the tag manufacturer needed to preset the tags' deployment periods prior to shipping, and before we had precise knowledge of the fishing dates associated with our target stations. PSATflex tags do not contain an internal calendar and therefore cannot be programmed to release on specific dates; only after a specified period. In addition to tagging females (n = 14) at 4D Edge North expansion stations with summer-to-winter tags, the scope of this study component was expanded by tagging an additional three females in the 4D Edge Central survey region (Henry et al. 2017). These stations were chosen in order to produce a continuous distribution of tags from the southern margin of Navarin Canyon (previously unstudied; the most northwesterly stations in the study design; Fig. 2) to previously-studied (Seitz et al. 2011) Pervenets Canyon (the most southerly stations in the study design; Fig. 2). This may allow us to infer whether halibut that spawn in these two canyon systems tend to mingle on common feeding grounds during the summer, or remain to some extent spatially segregated throughout the year; for example, with Navarin-spawning fish feeding at more northerly locations and Pervenets-spawning fish remaining to the south. Males were tagged with summer-to-winter tags in order to investigate the possibility that midwinter spawning behavior varies between the sexes (*sensu* Loher and Seitz 2008).

Eleven Pacific halibut (four male, seven female) ranging from 89-135 cm FL were tagged with tags programmed to detach after 365 days, resulting in scheduled reporting dates ranging from 12-18 June 2017. All summer-to-summer tags were deployed at 4D Edge North expansion stations.

Biological sampling

Maximum posterior ovarian extent (MPOE; Loher and Stephens 2011) was determined for 23 of the tagged female halibut; evaluation of MPOE was errantly omitted for S-14029 (Table 1). MPOE is an index of the posterior length of the ovary, in which the listed value represents the

ventral fin-ray number immediately above which the ovary terminates. MPOEs of halibut that were tagged with summer-to-summer tags ranged from 15-33 while those tagged with summer-to-winter tags ranged from 21-34. Given that prior research (Loher and Stephens 2011) has estimated that 50% maturity in the Pacific halibut population in the GOA occurs at MPOE = 18, and that >90% maturity occurs at MPOEs ≥22, most of the individuals tagged in the current study are likely to have been mature. Two females tagged with summer-to-summer tags had relatively small ovaries (MPOE = 15), suggesting that they each had a <50% probability of being mature when tagged.

Blood plasma samples were obtained for 26 tagged individuals, including all of the tagged males. Failure to obtain blood samples from some of the females was associated with their large size: blood was successfully drawn from only one individual that was >135 cm FL. For halibut larger than about 120 cm FL it was not possible to reach the caudal vein from the ventral surface of the fish's caudal peduncle (i.e., tailstock) because the 23G1 needle was too short. Rather, for larger fish the vein could only be accessed using an oblique lateral insertion through the fish's eyed-side (Fig. 3). For halibut <135 cm FL, even this approach was problematic. For such large individuals it was not possible to reach the ventral surface of their caudal vertebrae without moving the point of insertion into the tail itself; however, for all but one individual (= 167 cm FL) this region was largely cartilaginous and did not yield blood. Attempts were made to draw blood from alternative locations (e.g., the base of the ventral fin or the dorsal musculature), but these attempts did not succeed. Dorsal aortic or heart punctures (DFO 2004) were not attempted because we did not want to compromise individuals prior to release. For future work, larger needles (e.g., B-D 21G1½ or 21G2) should be used for caudal venous blood draws in large halibut.

In addition to the blood samples taken from tagged halibut, plasma was obtained from an additional 13 male halibut ranging from 60-106 cm FL and from 28 females ranging from 64-99 cm FL. These samples were collected to support ongoing attempts to more fully characterize halibut maturation (e.g., Planas et al. 2017) and determine whether plasma hormone levels that are exhibited during the summer can be used as reliable indicators of individual maturity status. These additional blood samples are intended to provide baseline data that represent the range of sizes over which female Pacific halibut are believed to reach maturity (Fig. 4); and characterize males ranging from pre-recruit through commercially-legal size, all of which are currently assumed to mature prior to reaching vulnerability to longline gear.

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Table 1. Deployment details for Lotek Wireless PSATflex satellite-transmitting archival tags deployed on Pacific halibut in the eastern Bering Sea during the IPHC's 2016 setline survey (see also Fig. 2). For sex, "F" = female, "M" = Male. "MPOE" = Maximum Posterior Ovarian Extent; "n.a." = not applicable (males), "unk" = unknown (was not determined). MPOE is an index of the posterior length of the ovary; the listed value represents the ventral fin-ray number immediately above which the ovary terminated. In prior research (Loher and Stephens 2011), 50% maturity was estimated to occur at MPOE = 18 and >90% maturity at MPOE ≥ 22. "Blood sample" indicates whether blood was successfully obtained; blood draws were attempted for all taged fish.

Tag #	Deploy date	Programmed tag-reporting date	Latitude (N)	Longitude (W)	Sex	Length (cm FL)	MPOE	Blood sample
S-14001	06/11/16	12/28/16	61.167°	177.650°	F	150	25	No
S-14002	06/12/16	12/29/16	60.831°	177.983°	F	167	38	Yes
S-14003	06/12/16	12/29/16	60.831°	177.983°	F	129	21	Yes
S-14004	06/14/16	12/31/16	60.498°	177.984°	F	141	30	No
S-14005	06/14/16	12/31/16	60.666°	178.317°	F	111	29	Yes
S-14006	06/14/16	12/31/16	60.501°	178.651°	M	94	n.a.	Yes
S-14007	06/14/16	12/31/16	60.501°	178.651°	F	124	37	Yes
S-14008	06/14/16	12/31/16	60.501°	178.651°	M	92	n.a.	Yes
S-14009	06/14/16	12/31/16	60.501°	178.651°	M	113	n.a.	Yes
S-14010	06/14/16	12/31/16	60.499°	178.984°	F	138	32	No
S-14011	06/14/16	12/31/16	60.499°	178.984°	F	130	29	Yes
S-14012	06/14/16	12/31/16	60.499°	178.984°	F	140	30	No
S-14013	06/15/16	01/01/17	60.334°	178.650°	F	108	32	Yes
S-14014	06/17/16	01/03/17	60.333°	177.983°	F	109	25	Yes
S-14015	06/18/16	01/04/17	60.168°	177.650°	F	149	25	No
S-14016	06/24/16	01/10/17	59.501°	178.284°	F	131	34	Yes
S-14017	06/24/16	01/10/17	59.306°	178.234°	F	125	27	Yes
S-14018	06/24/16	01/10/17	59.833°	178.317°	F	105	38	Yes
S-14019	06/26/16	01/12/17	60.003°	178.936°	F	119	35	Yes
S-14020	06/26/16	01/12/17	60.166°	178.983°	F	116	34	Yes
S-14022	06/12/16	06/12/17	60.831°	177.983°	F	101	15	Yes
S-14023	06/12/16	06/12/17	60.664°	177.983°	F	107	20	Yes
S-14024	06/13/16	06/13/17	60.664°	177.650°	F	121	24	Yes
S-14025	06/14/16	06/14/17	60.498°	177.984°	F	135	33	Yes
S-14026	06/14/16	06/14/17	60.666°	178.317°	F	94	15	Yes
S-14027	06/14/16	06/14/17	60.501°	178.651°	M	92	n.a.	Yes
S-14028	06/14/16	06/14/17	60.501°	178.651°	M	89	n.a.	Yes
S-14029	06/14/16	06/14/17	60.499°	178.984°	F	102	unk	Yes
S-14030	06/15/16	06/15/17	60.167°	178.650°	M	89	n.a.	Yes
S-14031	06/17/16	06/17/17	60.333°	178.317°	M	100	n.a.	Yes
S-14032	06/18/16	06/18/17	60.000°	177.651°	F	107	31	Yes

Figure 1. A Lotek Wireless PSATflex satellite-transmitting archival tag attached via dart-and-tether to large female Pacific halibut. *Photo credit*: Samantha Bund.

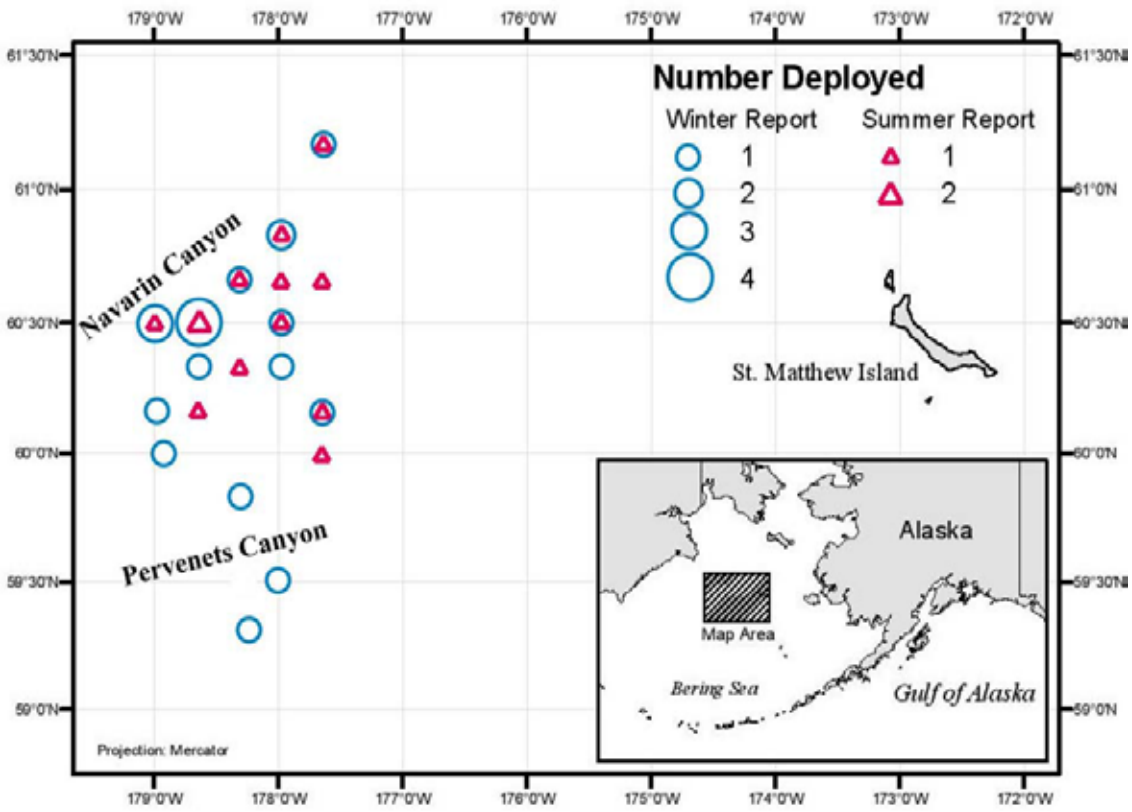

Figure 2. Deployment locations for Lotek Wireless (St. Johns, NL) PSATflex satellite-transmitting archival tags deployed on Pacific halibut on the northeastern Bering Sea outer continental shelf and shelf edge during the IPHC's 2016 standardized setline survey. Circles indicate summer-to-winter tags deployed to examine seasonal migration and spawning locations; triangles are summer-to-summer tags deployed to investigate interannual dispersal.

Figure 3. Collecting a blood sample from the caudal vein of a relatively large (~130 cm FL) Pacific halibut. The caudal vein runs along the ventral surface of the vertebrae in the fish's tailstock. For individuals shorter than ~120 cm, the needle could be inserted horizontally, through the ventral surface of the tailstock essentially parallel to the measuring cradle on which the fish is resting. This fish was too large for a 1" needle to reach the base of its caudal vertabrae via ventral insertion; instead, an oblique lateral insertion through the eyed-side of the fish was required. *Photo credit*: Samantha Bund.

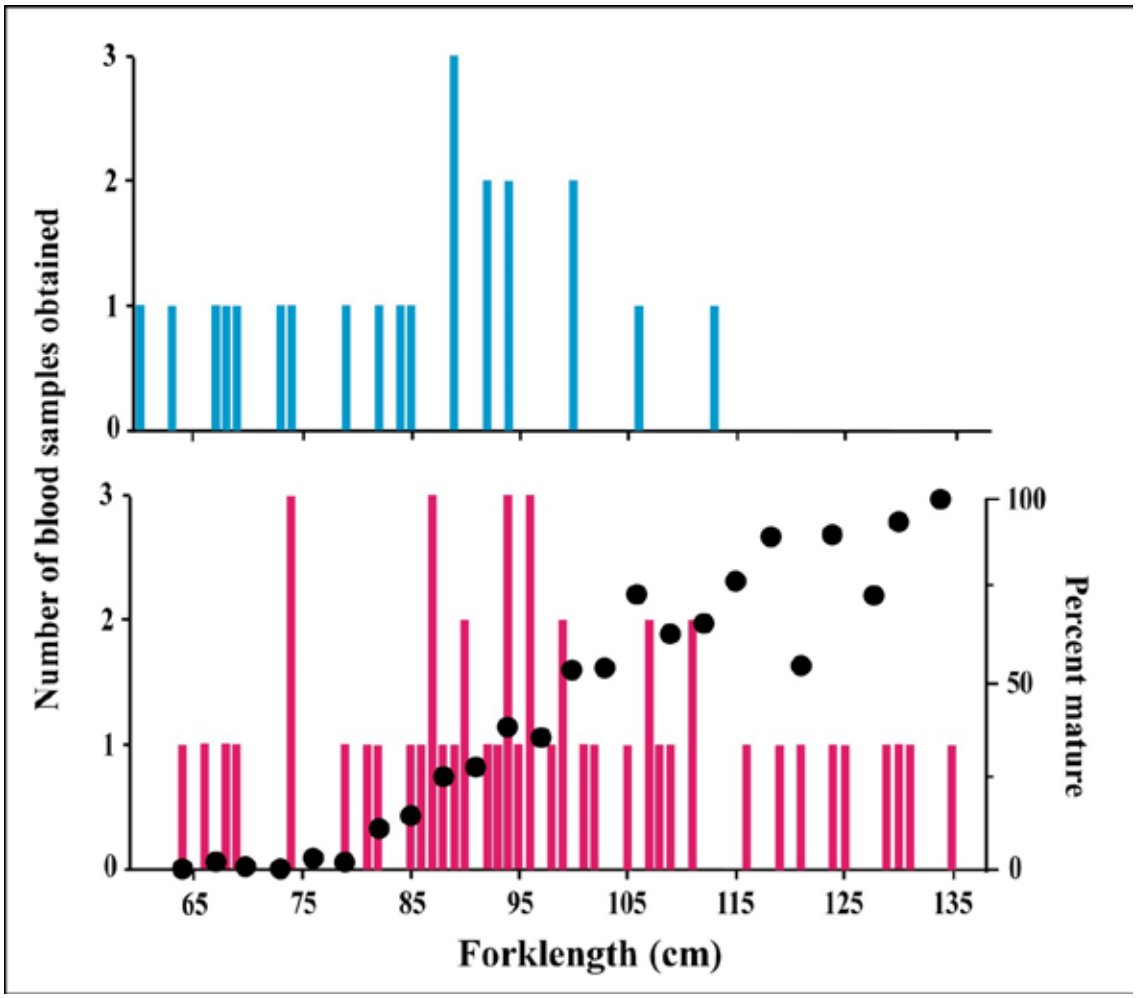

Figure 4. Size-frequency distribution of male (upper panel) and female (lower panel) Pacific halibut from which blood plasma samples were obtained during the IPHC's 2016 standardized setline survey on the northeastern Bering Sea outer continental shelf and shelf edge. These plots include tagged inidividuals and supplemental samples that were taken in order to generate a contiguous distribution of sampled fish lengths. In addition to the individuals shown here, plasma was obtained from a 167-cm forklength (FL) female. Dots on the lower panel indicate the percentage of all female halibut (n = 1676) that were sampled at IPHC eastern Bering Sea setline survey stations, aggregated over 3-cm size-increments, that were determined to be mature. The blood samples that were taken from females were intended to characterize the range of sizes over which Pacific halibut are expected to reach maturity. Based on current IPHC maturity criteria, male Pacific halibut are assumed to be fully mature at all sizes that are vulnerable to both survey and commercial longline gear.