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Pacific Cod Satellite Tagging Results from Gulf of Alaska Deployments: Spring 2022

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E. Dawson, A. Dowlin, and E. H. Markowitz

August 2026

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric
Administration
National Marine Fisheries Service
Alaska Fisheries Science Center

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Pacific Cod Satellite Tagging Results from Gulf of Alaska Deployments: Spring 2022

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ABSTRACT

In April 2022, the Pacific Cod Tagging Team, a collaboration among the Aleutians East Borough, Kingfisher Marine Research, and NOAA's Alaska Fisheries Science Center, conducted a Pacific cod (*Gadus macrocephalus*) tagging cruise in the western Gulf of Alaska (GOA) (170°W to 159°W).

The scientific and vessel crews tagged and released 28 Pacific cod with Wildlife Computers miniPAT pop-up satellite tags, 37 Pacific cod were released with archival Lotek tags (internally implanted) and 760 cod were released with Floy conventional T-bar tags. Additionally, 186 biological samples were collected from non-tagged Pacific cod that included length, weight, sex, maturity, otoliths for age estimation, and tissue subsamples for genetic analyses.

Of the 28 satellite tags deployed from the western GOA, 26 provided pop-up locations and 24 provided enough data for geolocation. Pop-up locations transmitted from the western GOA (n=21), eastern Bering Sea (n=4) and northern Bering Sea (n=1). There were no fish recovered with Lotek tags. This technical memorandum presents a general overview of methods, key contextual results, and each individual fish's reconstructed movement path during its time at liberty.

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SCIENTIFIC PURPOSE

Recent marine heatwaves have contributed to substantial changes in Pacific cod (*Gadus macrocephalus*) abundance in the Gulf of Alaska (GOA). These events have been linked to increased mortality, reduced recruitment, and potential summer migrations of adult fish into cooler Bering Sea (BS) waters (Barbeaux et al. 2021). Given the ecological and economic importance of Pacific cod, understanding how environmental variability influences their distribution and connectivity is critical for effective fisheries management.

Pacific cod support one of the largest groundfish fisheries in Alaska and serve an important ecological role as mid-level predators. Because stock assessments, harvest limits, and spatial management measures depend on accurate assumptions about population structure and movement, tracking Pacific cod is essential to ensure sustainable management. If fish move between the GOA and BS in response to environmental conditions, current stock boundaries and assessment frameworks may not fully reflect ecological and biological reality.

During winter, Pacific cod aggregate to spawn, and at least part of the population undertakes large seasonal migrations (Shimada and Kimura 1994; Rand et al. 2014). While winter spawning migrations are relatively well documented (Neidetcher et al. 2014), less is known about movements during the non-spawning period. Improved understanding of these movements is especially important because federal bottom trawl surveys occur during the summer months biennially in the GOA (Siple et al. 2024) and annually in the BS (Markowitz et al. 2023), and survey timing may not fully capture seasonal redistribution.

Satellite telemetry studies, using pop-up satellite archival tags (PSATs), are a powerful tool for reconstructing spatial movements, seasonal habitat use, and behavioral patterns (Nielsen et al., 2023). PSATs are attached to the fish's dorsal fin and record real-time, depth, temperature, and ambient light. After a pre-programmed deployment period, the tags detach, float to the surface, and transmit data to the Argos satellite network that can be accessed remotely by researchers. Geolocation models use these data to estimate daily positions and associated uncertainties.

Satellite tagging studies in the Aleutian Islands (Bryan et al. 2021; Nielsen et al. 2023) provided the foundation for expanding similar research into the GOA. Satellite tagging in the western GOA began in 2021 to better characterize seasonal and interannual Pacific cod movements outside the summer months and to assess connectivity between GOA and BS regions. This study is a continuation of the 2021 study.

The 2022 study had four objectives:

- To increase the sample size of satellite tagged Pacific cod from the 2021 study, and to continue to study seasonal movement from winter spawning grounds to foraging sites in the western GOA and BS.
- To examine inter-annual variation in seasonal movement patterns and connectivity between management areas.
- To examine the relationship of the tagged Pacific cod movement in this study to Pacific cod distribution across the wider GOA regions during the summer when the Alaska

Fisheries Science Center (AFSC) summer bottom trawl surveys are conducted, biennially in the GOA and annually in the BS.

- To continue collection of biological samples to characterize population age structure, length composition, genetic origin, and spawning condition of Pacific cod populations during active spawning season (January - March).

In 2022 we also tagged and released 37 Pacific cod with Lotek archival tags. These tags are implanted into the body cavity of the fish with an external antenna sticking out from the suture location. These tags record temperature, depth and ambient light. However, they are reliant on retrieval from a commercial fishery. A bright orange disc was attached to the posterior dorsal surface to alert commercial fishers to the internal tag.

In addition to satellite tagging and implanting tags, we opportunistically tagged and released 100s of Pacific cod with conventional Floy T-Bar tags across each study area. We know the release location and if the fish is recovered by fishers, a recovery location. This provides another source of information about Pacific cod movement within the GOA and BS, and significantly lower unit cost compared to satellite tagging.

Satellite tagging and modeling methods are detailed in Nielsen et al. (2019, 2023, 2025) and Bryan et al. (2021). In this Technical Memorandum, we summarize PSAT releases conducted in the GOA in April 2022, present key biological metrics, and provide reconstructed movement paths for individual tagged Pacific cod.

METHODS

A single Pacific cod PSAT release event took place in the western GOA between April 10 and April 18, 2022. Scientists from the Aleutians East Borough (AEB) and NOAA's Alaska Fisheries Science Center (AFSC) embarked on a research cruise to tag Pacific cod with satellite archival, and conventional tags across the western GOA. We selected eight sites from which to release tags, revisiting the same sites as those in 2021 (Rand et al. *In Editorial Process*). All satellite, Lotek, and conventional tags were released from the selected sites that extended across the western GOA (170°W to 159°W). This border also corresponds to the federal fishery management boundary separating the western and central GOA (Fig. 1).

Similar to 2021, the release sites were selected across the western GOA based on areas frequented by the commercial fishermen during the winter months and are known as Pacific cod winter spawning areas. The tagging platform was the 58 ft. commercial pot fishing vessel FV *Decision*, chartered for the purpose of this study by the AEB.

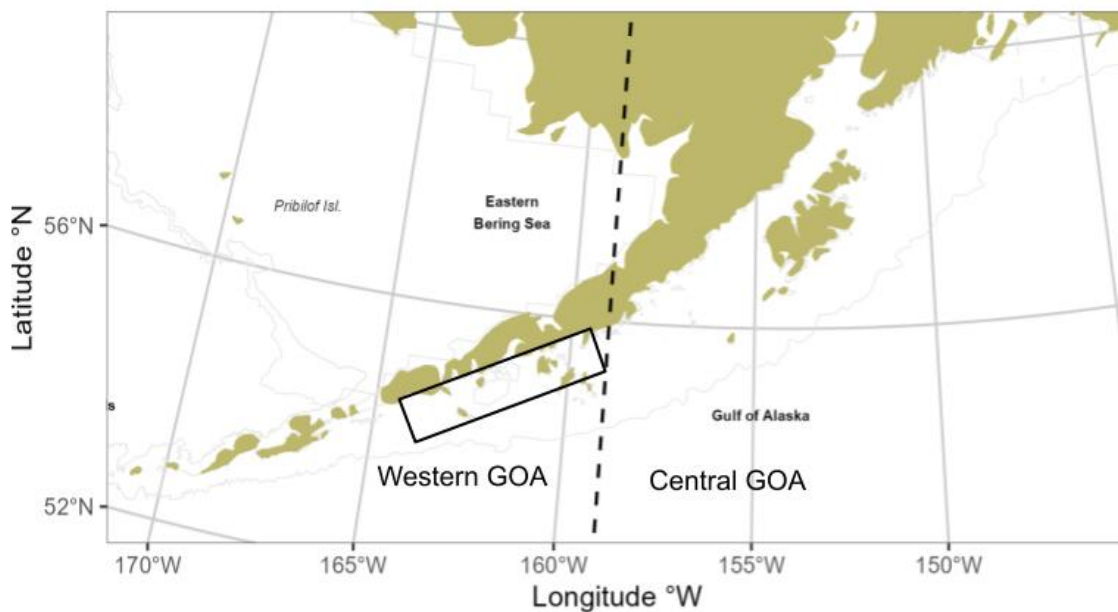


Figure 1. -- Map of Alaska water regions labeled with western Gulf of Alaska, central Gulf of Alaska, and eastern Bering Sea. The dashed line demarcates the federal fishery management boundary between the western and central GOA. The black box represents the general area for Pacific cod tagging.

TAGGING PROCEDURES

All tagging procedures, including evaluations of tagging-related, natural, and fishing mortality, were described during the 2019 pilot study (Bryan et al. 2021). In general, fish were captured using baited commercial cod pot gear, with soak times ranging from 2 to 4 h. Pot retrieval methods, fish handling procedures, and release protocols are further detailed in previous studies (Bryan et al. 2021; Nielsen et al. 2023; Nielsen et al. 2025).

Although mortality estimates are not explicitly incorporated into PSAT analyses, these evaluations were used to refine handling and release methods to minimize tagging-related impacts. In particular, retrieval and release procedures were developed to reduce the effects of barotrauma associated with rapid decompression during capture from depth.

While some external signs of barotrauma, including gas release at the surface, could not be entirely avoided, tag data provided continued feedback on post-release behavior and survival, allowing assessment of fish condition following release. High tag reporting and recapture rates across years support the conclusion that the tagging approach was minimally invasive and that most tagged fish resumed normal behavior following release.

Pop-up Satellite Archival Tags (PSATs)

The PSATs used in this study were Wildlife computer MiniPATs(<https://static.wildlifecomputers.com/MiniPAT-Product-Sheet-1.pdf>). In order to keep surface time to a minimum, only 3-4 Pacific cod per pot that looked vigorous, healthy and measured greater than 50 cm fork length were selected for satellite and internal tagging (see Lotek tags below). After being carefully brought on board, each fish was placed in a tagging cradle and had continuous sea water circulating over its gills. Length measurements, locations, and times were recorded during the tagging process. The PSATs were attached with custom harnesses by inserting coated wire through harness pads and the pterygiophores directly under the first dorsal fin (Bryan et al. 2021). Tagging procedures and release were kept below 5 minutes to prevent further damage from barotrauma while on the surface. After the fish was tagged, a weighted descending device attached to a recreational rod and reel equipped with a line counter was clipped to the lower lip of each fish. The fish was kept in the tagging cradle and lowered into the water just below the surface to recuperate and allow for a visual confirmation that the fish was recovering. The fish was lowered to and released at 50 ft using the descending device. Images of the tagging and release procedure can be found in Markowitz et al. 2025b.

Lotek Archival Tags

After the attachment of PSAT tags, the remaining 1-2 fish from the pot were surgically implanted with Lotek tags. The total amount of time the remaining fish spent in the tank was less than 10 minutes of total surface time. A Lotek archival tag was only attached if the fish from the tank were in excellent condition (e.g., no signs of barotrauma, abrasions). Similar to PSAT tagging, the fish was placed in a tagging cradle with seawater running over the gills. The Lotek tag was inserted into the body cavity of the fish through a small insertion. The lightstalk of the Lotek tag was fed through a separate opening in the ventral cavity with a large hypodermic needle. The incision was stapled shut with medical staples. A Floy disc tag was inserted through the dorsal musculature of the fish to make this fish visible as a tagged animal when recovered by the fishing fleet. All equipment was kept sterile. The tagged cod was then placed on a tag release cradle and released at depth with a descending device. We tagged 1-2 fish per pot with Lotek archival tags.

Conventional Tags (Floy T-Bar)

Pacific cod that were not used for PSAT or Lotek tagging were opportunistically tagged with conventional Floy T-bar tags. The fish were brought onboard, placed in a one cubic meter tank with running seawater and then transferred to a tagging cradle, measured and tagged with two T-bar tags, one on each side of the first dorsal fin to accommodate the potential for tag loss. The T-bar tags were inserted with a hand-held pistol grip tagging device. The fish were released back into the water near their capture point, without a descender. Conventional tagging relies entirely on recapture of the tagged fish by fishermen. If a Floy T-bar tagged fish was recaptured by a fisher(s) or fishery, information like date and time of capture, location of capture, bottom depth and size of fish was reported.

Stationary Tags

During the western GOA research cruise, three stationary PSATs were deployed near the sea floor where the fish were released (Table 1). Stationary PSATs were used to collect data at known locations to calibrate the geolocation model. These tags were programmed to pop-off and transmit data after 365 days. The stationary tags were attached to an 8-inch plastic trawl float with 1 meter of ½-inch Blue Steel braided rope, which was attached to a weight. The stationary satellite pop-up tag recorded bottom temperature and light conditions near where the satellite-tagged Pacific cod were released.

Pop-up Satellite Archival Tags (PSATs) Analysis

There are two ways data is obtained from a PSAT: the PSAT releases successfully from a fish at a pre-programmed time and begins data transmission to satellites from the open ocean, then to Wildlife Computers (transmitted tag); PSAT is physically recovered from a fish that is captured by a fishing vessel and returned to NOAA (detailed tag). Detailed PSATs provide a rich, detailed dataset compared to transmitted PSATs, however, these account for less than 3% of PSATs with available data.

For each fish with a recovered PSAT tag, basic deployment information is recorded. This information includes fish length, dates and locations of release and recovery, and the number of days at liberty. For each individual PSAT tagged fish, a map of the reconstructed travel path using the geolocation hidden Markov model (HMM) is shown. The HMM uses light and depth data recorded by the PSAT tag (Nielsen et al. 2023). Reconstructed travel paths consist of daily point location estimates generated by the Viterbi algorithm and estimated error polygons that encompass the highest 50% and 99% of the HMM posterior probability each day (Nielsen et al. 2023). Full details of the analytical methods are provided in Nielsen et al. (2023).

BIOLOGICAL SAMPLES

We collected biological samples from non-tagged Pacific cod across seven sites visited for PSAT tagging in the western GOA. Biological samples collected included sex, length, weight, otoliths, genetic samples and stomach content pictures from fish with non-empty stomachs. In addition, we were able to collect a small tissue sample (fin clip) from PSAT tagged fish for genetic processing. Genetic fin clip samples were placed in 100% ethanol. Otoliths were extracted and stored dry to be placed in a glycerol thymol solution in Seattle. Subsamples for maturity were placed in a small container of 10% formalin. All biological samples were analyzed at the AFSC Seattle, WA laboratories.

RESULTS

A total of 28 Pacific cod were equipped with PSATs and released during the research cruise across seven sites in the western GOA (Fig. 2, Table 1); one of the selected sites was not available due to weather.

Of 28 satellite tags deployed, 26 provided pop-up locations and 24 provided enough data for geolocation. Recovery or pop-off locations were as follows:

- Western GOA (n=21)
- Eastern Bering Sea (n=4)
- Northern Bering Sea (n=1)

Two of the PSATs were recovered by a fishing vessel and returned to NOAA.

A total of 760 Pacific cod were tagged with Floy T-bar conventional tags across at each of the seven sites in the western GOA. Because conventional tagging was opportunistic, the number of fish tagged at each site largely varied from 8 to 281 fish per site. Of the 760 Pacific cod tagged with conventional tags, a total of 19 tags were recovered by the commercial fishery from the western GOA and two tags were recovered from the eastern Bering Sea (Fig. 3).

The average fork length of the PSAT tagged fish ranged from 55 to 92 cm (Fig. 4, Table 1). The average fork length of all Floy T-bar tagged fish ranged from 43 to 106 cm (Fig. 4). For the 37 Lotek Archival tags deployed during the field efforts, fork lengths ranged from 54 to 87 cm (Table 1). There were no successful recoveries of Lotek archival tags since their release.

PSAT Pacific Cod Tag Release and Recovery Locations

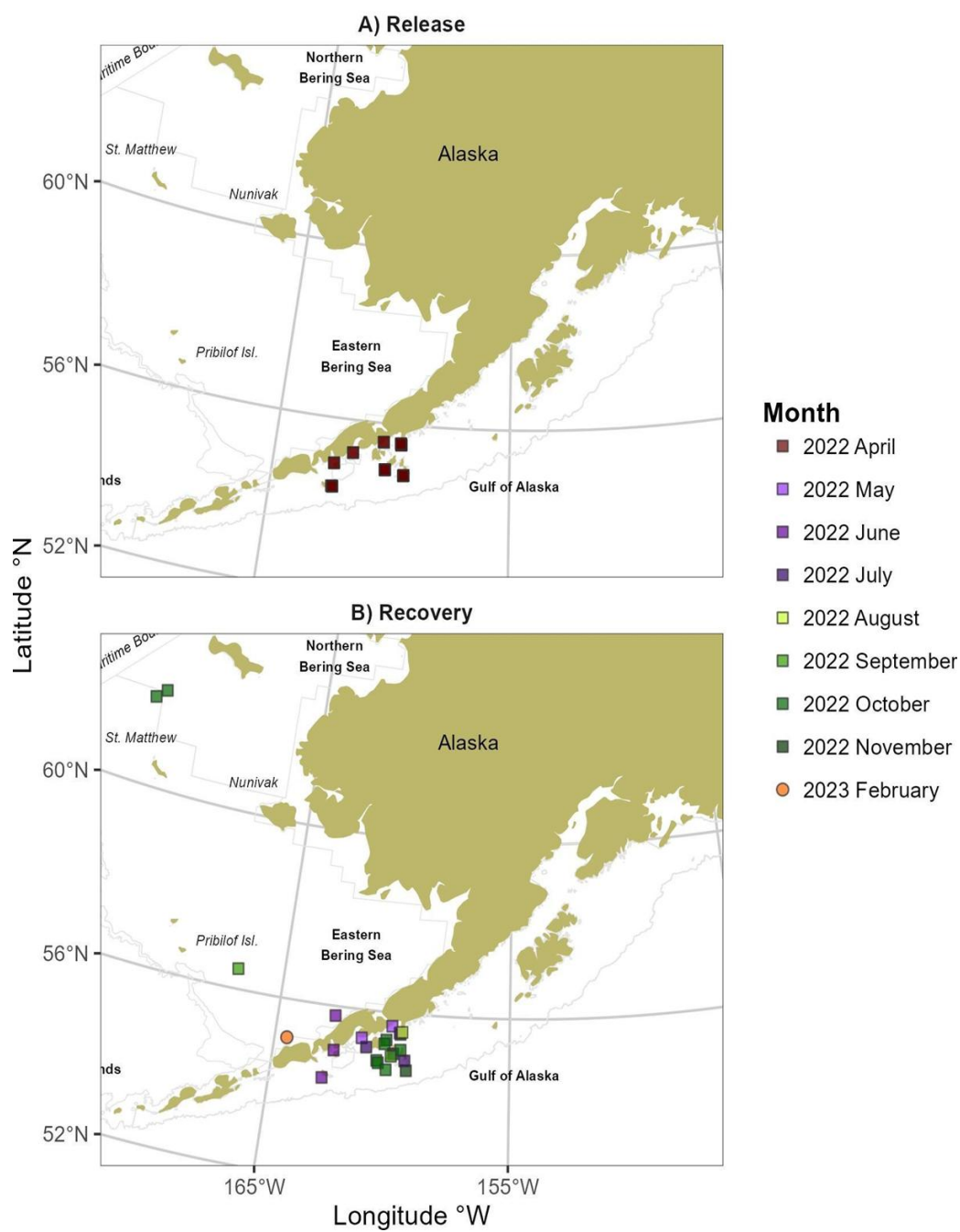


Figure 2. -- Map of where PSAT tagged Pacific cod were A) released and B) recovered, by year and month (denoted by color and shape). Colors vary by month and year of recovery. Months where there was no PSAT recovery, are not shown in the legend.

Floy T-Bar Pacific Cod Tag Release and Recovery Locations

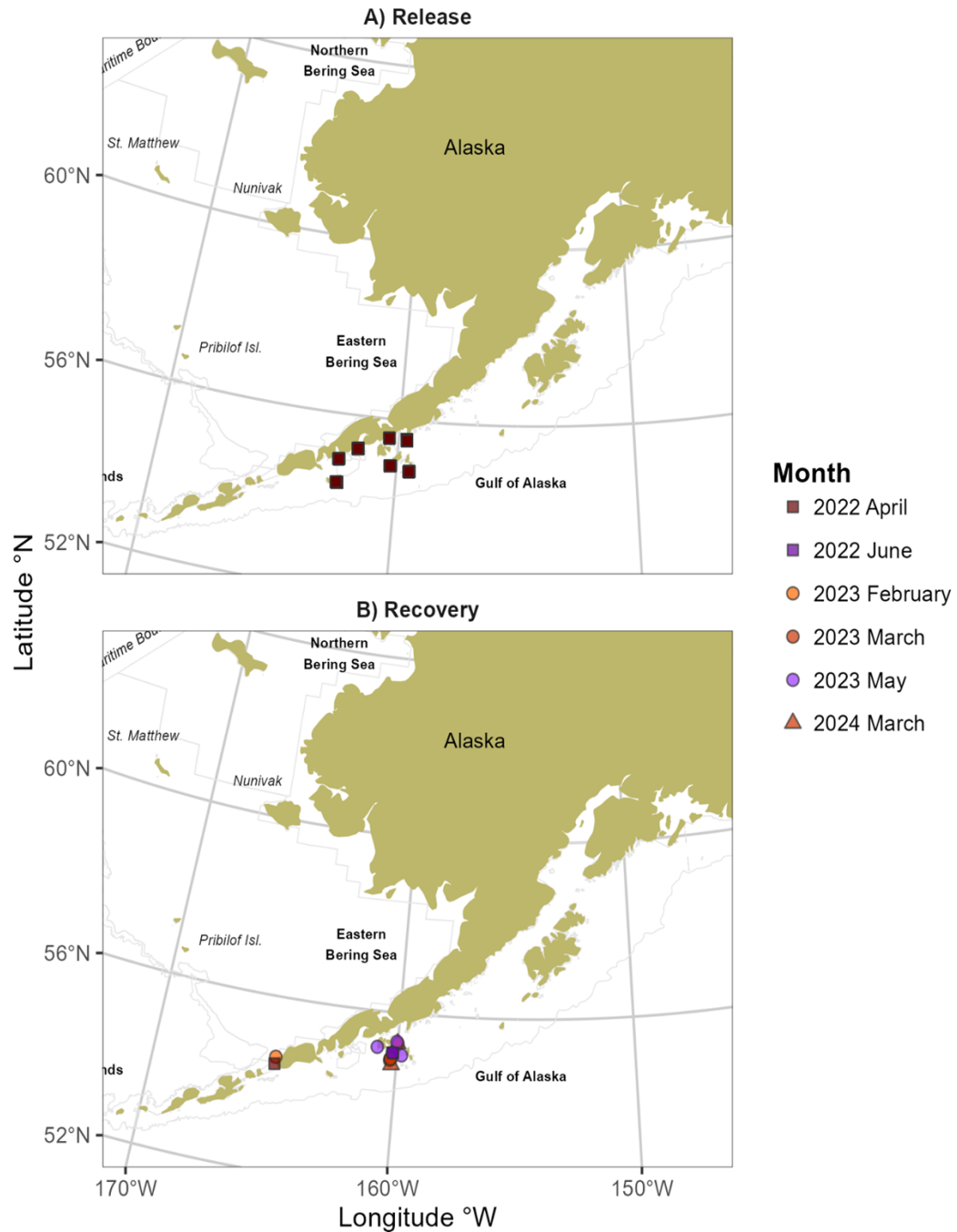


Figure 3. -- Map of where Floy T-Bar tagged Pacific cod were A) released and B) recovered, by year and month (denoted by color and shape). Months where there was no Floy T-bar tag recovery, are not shown in the legend. These recoveries are based solely on fishery capture and reporting.

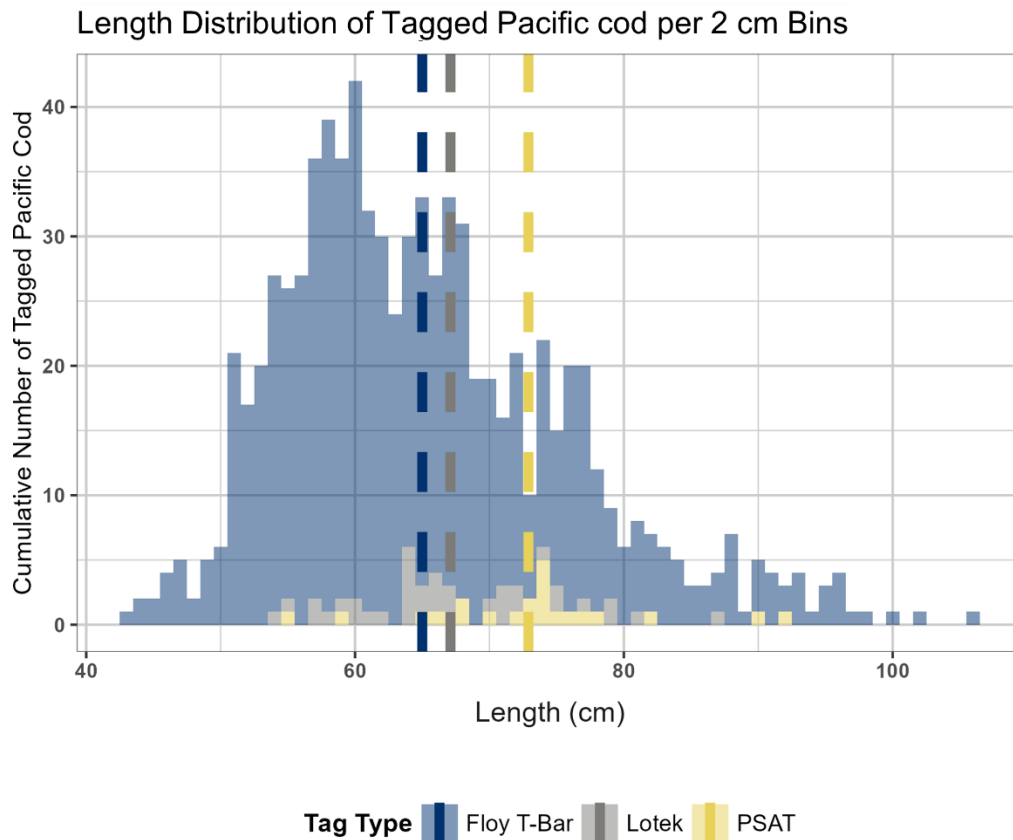


Figure 4. -- Stacked histogram of tagged Pacific cod morphometrics in 2 cm bins. Twenty-three Pacific cod tagged with pop-up satellite tags had average fork lengths of 72.9 cm (dashed yellow vertical line). Thirty-nine Pacific cod were tagged with Lotek tags with average fork lengths of 67.1 cm (grey dashed line). Seven hundred and sixty Pacific cod tagged with Floy T-Bar tags had average fork lengths of 65 cm (dashed blue vertical line).

A total of 186 biological samples were collected from non-tagged Pacific cod in April 2022. Pacific cod average length and weight from the biological samples are summarized as follows: female fish had an average length of 67.2 cm and average weight of 3.44 kg ($n = 75$), male fish had an average length of 67.1 cm and average weight of 3.12 kg ($n = 110$) (Fig. 5).

Pacific cod spawning stages from the biological samples are summarized as follows: for female fish, 1 developing, 5 immature, 8 resting, 3 spawning, and 58 spent female fish. For males, there were 12 immature, 9 resting, 11 spawning, and 78 spent male fish (Fig. 6).

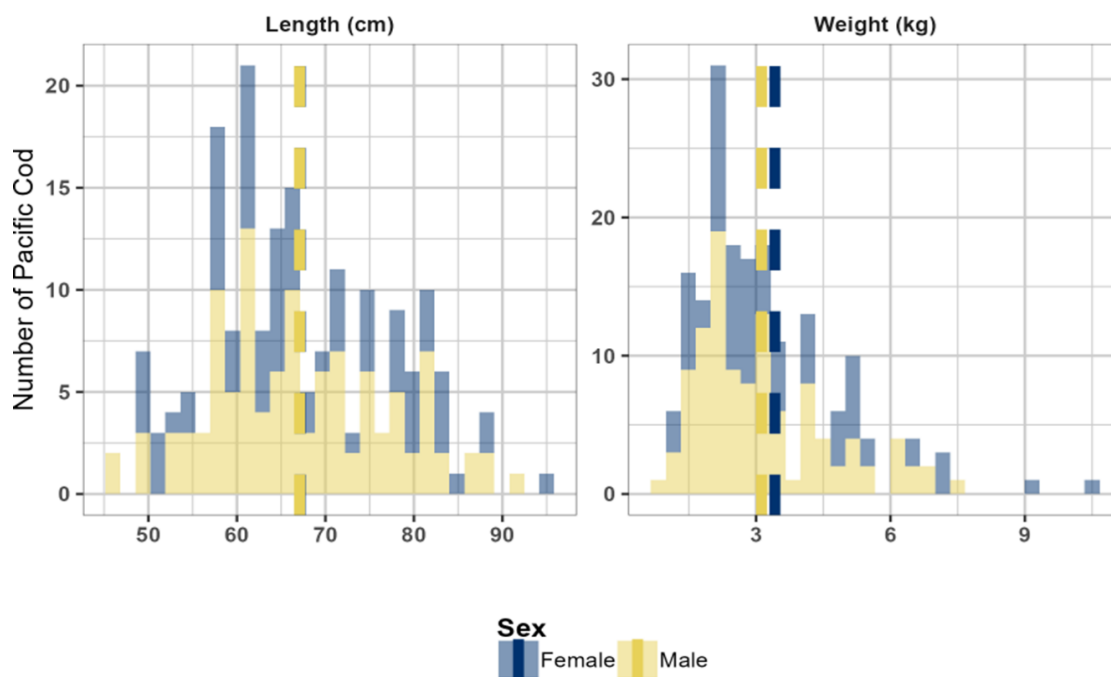


Figure 5. -- Stacked histogram of specimen fork length (cm) and weight (g) data by sex for Pacific cod only collected during the April 2022 tag release cruise. These lengths and weights were from the biological sample collection and not from tagged fish.

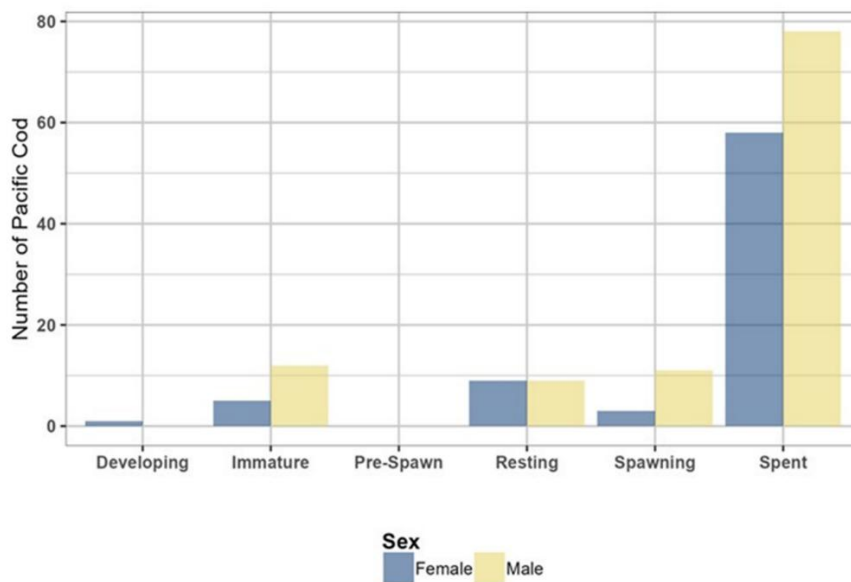


Figure 6. -- Number of male and female Pacific cod by maturity development stage from randomly collected biological specimen samples during the April 2022 tag release cruise.

Table 1. -- Summary of all 2022 western Gulf of Alaska Pacific cod tag releases and subsequent recoveries. If a tag is not recovered, it is not shown in this table (e.g. Lotek tags).

Tag No.	Tag Type	Release Date (UTC)	Release Latitude (DD)	Release Longitude (DD)	Length (cm)	Recovery Date (UTC)	Recovery Latitude (DD)	Recovery Longitude (DD)	Days at Liberty
212431	PSAT	04/11/2022	55.24913	-161.6752	77	05/27/2022	55.35000	-161.32000	46
214562	PSAT	04/11/2022	55.24967	-161.6664	74	10/09/2022	54.68280	-160.18600	180
232649	Stationary	04/11/2022	55.24528	-161.6878	-	10/10/2022	55.26580	-161.66240	181
318044	Floy T-Bar	04/11/2022	55.25128	-161.6659	61	03/26/2024	55.30067	-160.01086	715
214561	PSAT	04/12/2022	54.96127	-162.4185	55	06/06/2022	54.98900	-162.44650	55
232658	PSAT	04/12/2022	54.96107	-162.4244	74	02/18/2023	55.12306	-164.47528	311
212430	PSAT	04/12/2022	54.96085	-162.4340	60	09/27/2022	55.26840	-162.69510	168
204879	PSAT	04/13/2022	54.42478	-162.3935	73	10/11/2022	62.21650	-173.32840	180
204881	PSAT	04/13/2022	54.42447	-162.3885	82	09/19/2022	56.45666	-167.02500	159
214558	PSAT	04/13/2022	54.43090	-162.4344	74	10/11/2022	62.01250	-173.80100	180
214560	PSAT	04/13/2022	54.42435	-162.3875	90	06/06/2022	55.78490	-162.53760	53
232650	Stationary	04/13/2022	54.42928	-162.4546	-	04/14/2023	54.42500	-162.50120	365
318581	Floy T-Bar	04/13/2022	54.42447	-162.3885	62	02/12/2023	54.63233	-164.98716	305
318615	Floy T-Bar	04/13/2022	54.42447	-162.3885	50	03/11/2023	55.30000	-160.00000	332
318654	Floy T-Bar	04/13/2022	54.42478	-162.3935	82	04/26/2022	54.46998	-164.99683	13

Tag No.	Tag Type	Release Date (UTC)	Release Latitude (DD)	Release Longitude (DD)	Length (cm)	Recovery Date (UTC)	Recovery Latitude (DD)	Recovery Longitude (DD)	Days at Liberty
202189	PSAT	04/15/2022	55.53570	-159.6535	92	06/08/2022	54.33000	-162.81280	54
214554	PSAT	04/15/2022	55.56292	-160.4065	67	05/05/2022	55.68840	-160.06450	20
214555	PSAT	04/15/2022	55.53913	-159.6407	78	10/13/2022	55.35700	-160.25660	180
215396	PSAT	04/15/2022	55.56762	-160.4094	73	10/15/2022	55.27420	-160.32980	183
232651	PSAT	04/15/2022	55.56	-162.40	67	06/17/2022	55.78770	-160.02820	63
202190	PSAT	04/16/2022	54.84692	-159.4570	74	07/23/2022	55.06160	-159.93210	97
214556	PSAT	04/16/2022	54.84343	-159.4635	59	10/14/2022	55.16350	-159.62810	180
214572	Stationary	04/16/2022	54.84775	-159.4629	-	10/16/2022	54.85350	-160.75400	183
232652	PSAT	04/16/2022	55.56950	-159.6651	72	10/14/2022	55.51580	-159.67890	181
232653	PSAT	04/16/2022	54.83878	-159.4720	76	11/19/2022	54.70400	-159.33510	217
232655	PSAT	04/16/2022	55.53835	-159.6563	66	06/06/2022	55.55230	-159.72330	52
232656	PSAT	04/16/2022	55.56485	-159.6698	75	08/18/2022	55.56610	-159.60640	125
232657	PSAT	04/16/2022	54.84910	-159.4626	68	07/03/2022	54.92180	-159.42690	78
232659	PSAT	04/11/2022	55.2461	-161.6851	89	08/28/2022	55.05910	-161.60700	138
202191	PSAT	04/17/2022	54.94035	-160.2574	70	10/15/2022	54.87210	-160.61230	180
204880	PSAT	04/17/2022	54.93877	-160.2652	74	10/15/2022	54.82270	-160.54490	180
214557	PSAT	04/17/2022	54.93877	-160.2652	65	07/12/2022	55.15000	-161.08750	86

Tag No.	Tag Type	Release Date (UTC)	Release Latitude (DD)	Release Longitude (DD)	Length (cm)	Recovery Date (UTC)	Recovery Latitude (DD)	Recovery Longitude (DD)	Days at Liberty
232654	PSAT	04/17/2022	54.93865	-160.2631	68	09/28/2022	54.99680	-160.02270	163
319091	Floy T-Bar	04/17/2022	54.94035	-160.2574	62	06/03/2022	55.08100	-160.18333	47
319101	Floy T-Bar	04/17/2022	54.94035	-160.2574	67	03/08/2023	54.94018	-160.26336	325
319118	Floy T-Bar	04/17/2022	54.94035	-160.2574	61	03/09/2023	54.94018	-160.26336	326
319155	Floy T-Bar	04/17/2022	54.94035	-160.2574	54	03/10/2023	54.89743	-160.28263	327
319168	Floy T-Bar	04/17/2022	54.94035	-160.2574	62	05/18/2023	55.03566	-159.80550	396
319204	Floy T-Bar	04/17/2022	54.93877	-160.2652	62	03/08/2023	54.94018	-160.26336	325
319243	Floy T-Bar	04/17/2022	54.93877	-160.2652	51	03/08/2023	54.94018	-160.26336	325
319270	Floy T-Bar	04/17/2022	54.93877	-160.2652	63	03/09/2023	54.94018	-160.26336	326
319294	Floy T-Bar	04/17/2022	54.93678	-160.2752	82	06/03/2022	55.08100	-160.18383	47
319309	Floy T-Bar	04/17/2022	54.93678	-160.2752	71	06/03/2022	55.08100	-160.18658	47
319326	Floy T-Bar	04/17/2022	54.93678	-160.2752	65	05/28/2023	55.33932	-160.04431	406
319345	Floy T-Bar	04/17/2022	54.93678	-160.2752	60	05/22/2023	55.18383	-160.84916	399
319373	Floy T-Bar	04/17/2022	54.93678	-160.2752	65	03/27/2024	54.80917	-160.20967	710
319384	Floy T-Bar	04/17/2022	54.93865	-160.2631	55	03/09/2023	54.94018	-160.26336	325
319388	Floy T-Bar	04/17/2022	54.93865	-160.2631	60	03/08/2023	54.94018	-160.26336	324
319451	Floy T-Bar	04/17/2022	54.93865	-160.2631	60	05/24/2023	55.08338	-160.19546	401

Tag No.	Tag Type	Release Date (UTC)	Release Latitude (DD)	Release Longitude (DD)	Length (cm)	Recovery Date (UTC)	Recovery Latitude (DD)	Recovery Longitude (DD)	Days at Liberty
319465	Floy T-Bar	04/17/2022	54.93865	-160.2631	60	06/03/2022	55.08100	-160.18383	46

Individual Fish Tag Results (PSATs)

The following maps of individual PSAT tagged Pacific cod travel paths begin at the fish's tagging release date and end when the PSAT detached from the fish and transmitted data to the Argos satellite network. For continuity between maps, all months from the first tag release event (April 2022) to the recovery of the last PSAT (April 2023) are shown in the legends.

When interpreting reconstructed pathways for individual fish, it is important to keep in mind that the daily point estimates are provided primarily for visualization of estimated locations over time. Because the actual location estimate provided by the model is a map of location probability in the study area for each day, the error polygons that encompass the highest 50% and 99% of the probability on each day are much more indicative of the possible location of the tagged fish compared to the daily point estimates.

Table 2. -- Colors in this report denote general Pacific cod life history behavior, including transition period months (which typically occurs in December and January) in blues, spawning months (February through April) in oranges, return migration months (May through July) in purples, and foraging months (August through November) in greens (Nielsen et al. 2025).

Month	Life History Stage
January	Transition period
February	Spawning
March	Spawning
April	Spawning
May	Return migration
June	Return migration
July	Return migration
August	Foraging
September	Foraging
October	Foraging
November	Foraging
December	Transition period

Tag 202189

The Pacific cod with tag 202189 (length: 92 cm) was released on April 15, 2022 in the Gulf of Alaska at 55.54°N latitude and -159.65°W longitude and the pop-up was on June 08, 2022 at 54.33°N latitude and -162.81°W longitude (Fig. 7; Table 1). This fish was at liberty for 54 days. The fish remained in the western GOA during its time at liberty.

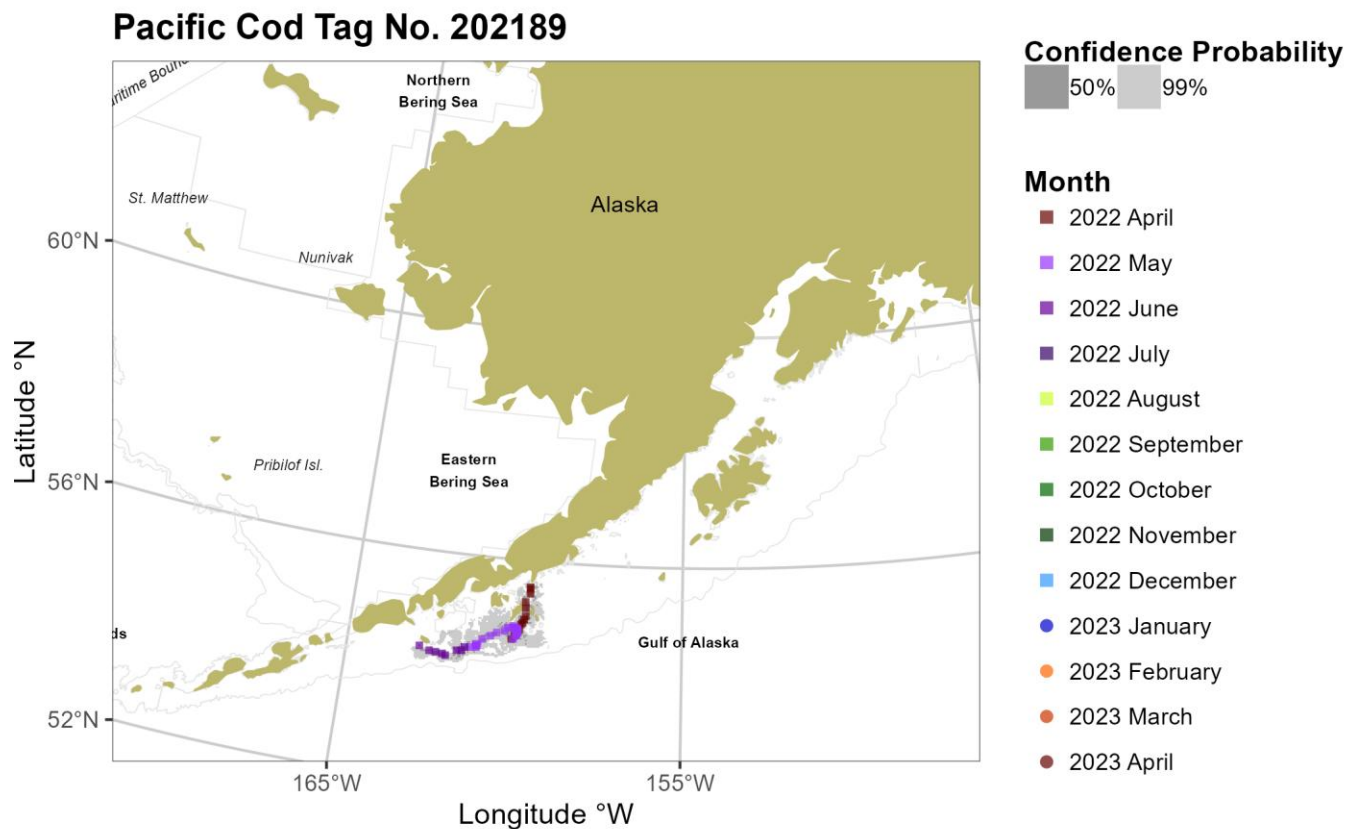


Figure 7. -- Map of Pacific cod tag 202189 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 202190

The Pacific cod with tag 202190 (length: 74 cm) was released on April 16, 2022 in the Gulf of Alaska at 54.85°N latitude and -159.46°W longitude and the pop-up was on July 23, 2022 at 55.06°N latitude and -159.93°W longitude (Fig. 8; Table 1). This fish was at liberty for 97 days. This fish remained in the western GOA during its time at liberty, in proximity to the release site.

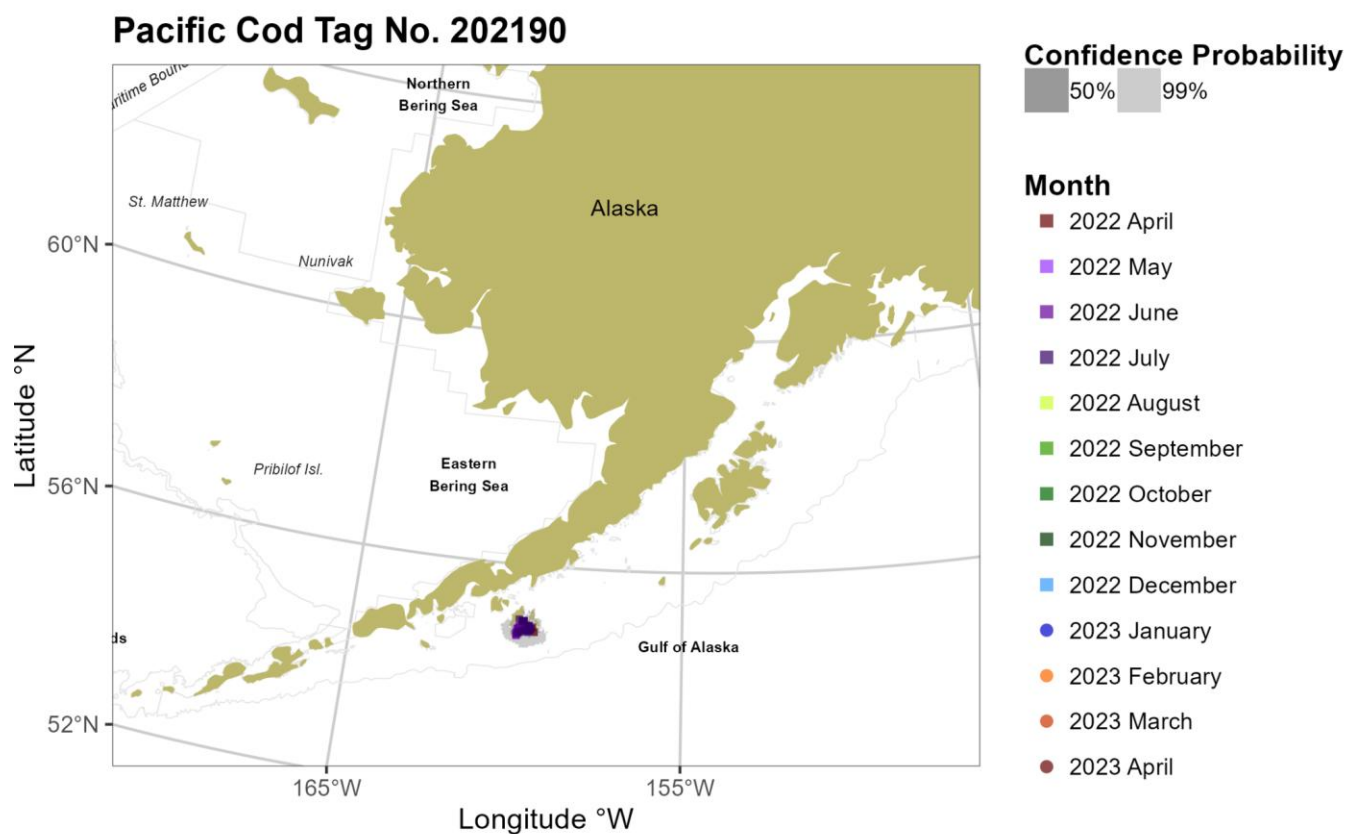


Figure 8. -- Map of Pacific cod tag 202190 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 202191

The Pacific cod with tag 202191 (length: 70 cm) was released on April 17, 2022 in the Gulf of Alaska at 54.94°N latitude and -160.26°W longitude and the pop-up was on October 15, 2022 at 54.87°N latitude and -160.61°W longitude (Fig. 9; Table 1). This fish was at liberty for 180 days. This fish remained in the western GOA during its time at liberty, in proximity to the release site.

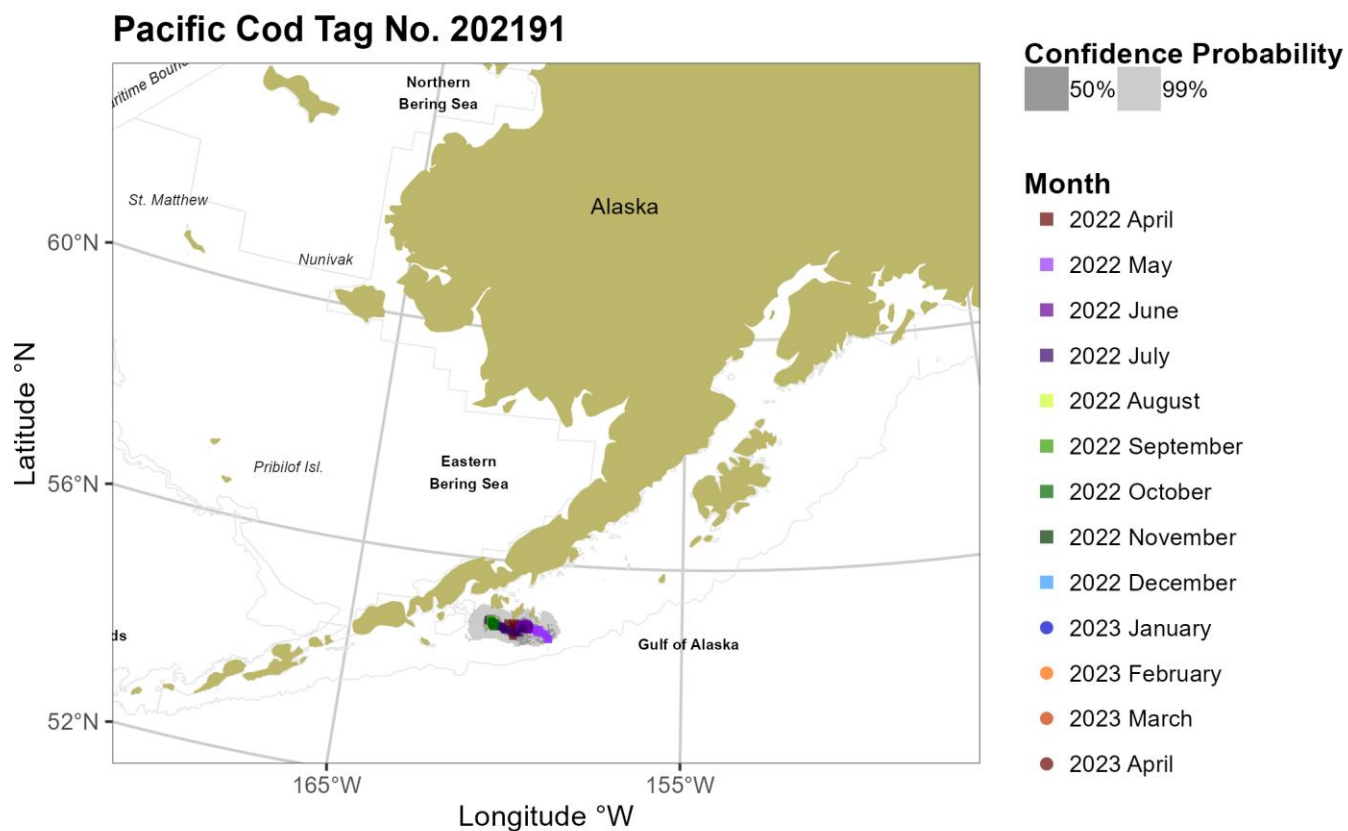


Figure 9. -- Map of Pacific cod tag 202191 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 204879

The Pacific cod with tag 204879 (length: 73 cm) was released on April 13, 2022 in the Gulf of Alaska at 54.42°N latitude and -162.39°W longitude and the pop-up was on October 11, 2022 at 62.22°N latitude and -173.33°W longitude (Fig. 10; Table 1). This fish was at liberty for 180 days. This fish traveled north within a month of release through Unimak Pass into the Bering Sea where the pop-up occurred just south of St. Lawrence Island in the northern Bering Sea.

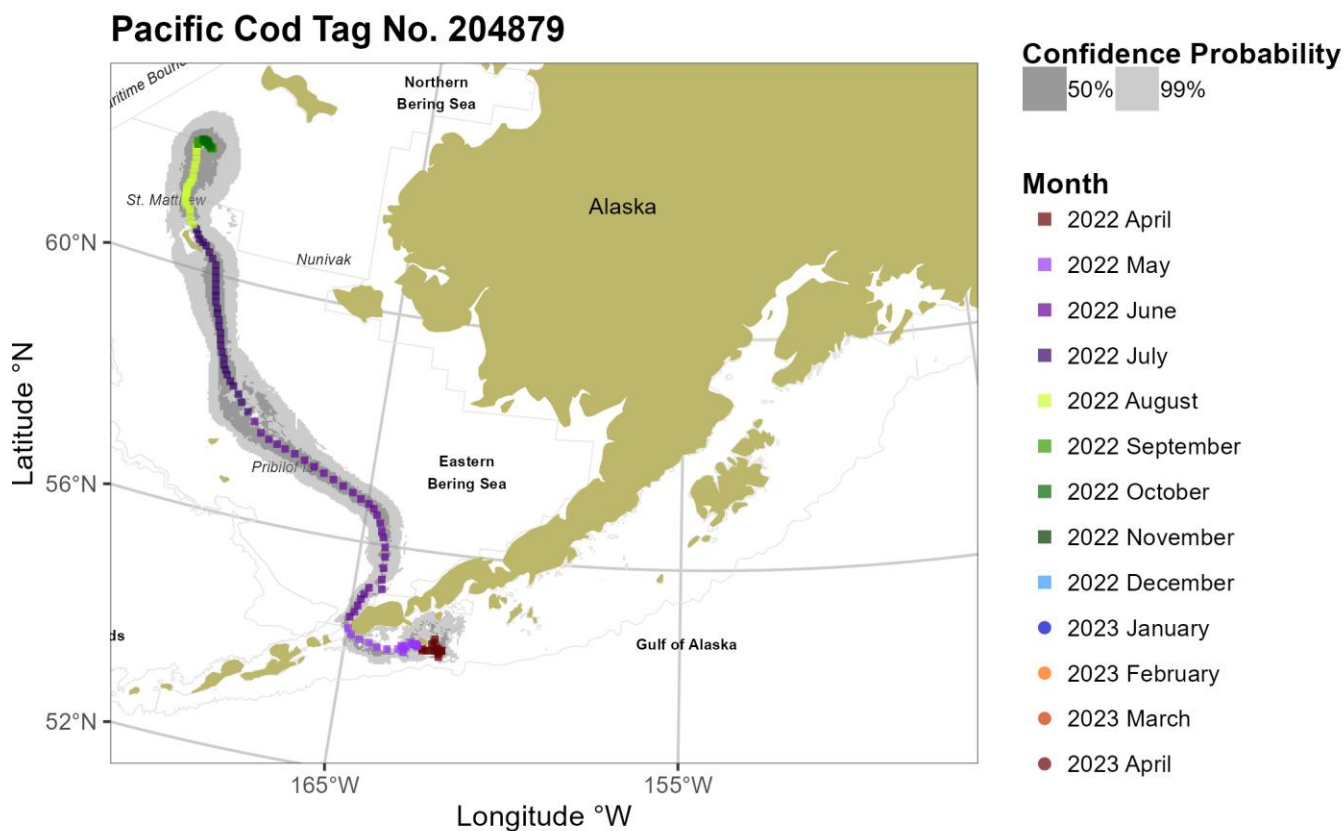


Figure 10. -- Map of Pacific cod tag 204879 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 204880

The Pacific cod with tag 204880 (length: 74 cm) was released on April 17, 2022 in the Gulf of Alaska at 54.94°N latitude and -160.27°W longitude and the pop-up was on October 15, 2022 at 54.82°N latitude and -160.54°W longitude (Fig. 11; Table 1). This fish was at liberty for 180 days. This fish remained in the western GOA during its time at liberty, in proximity to the release site.

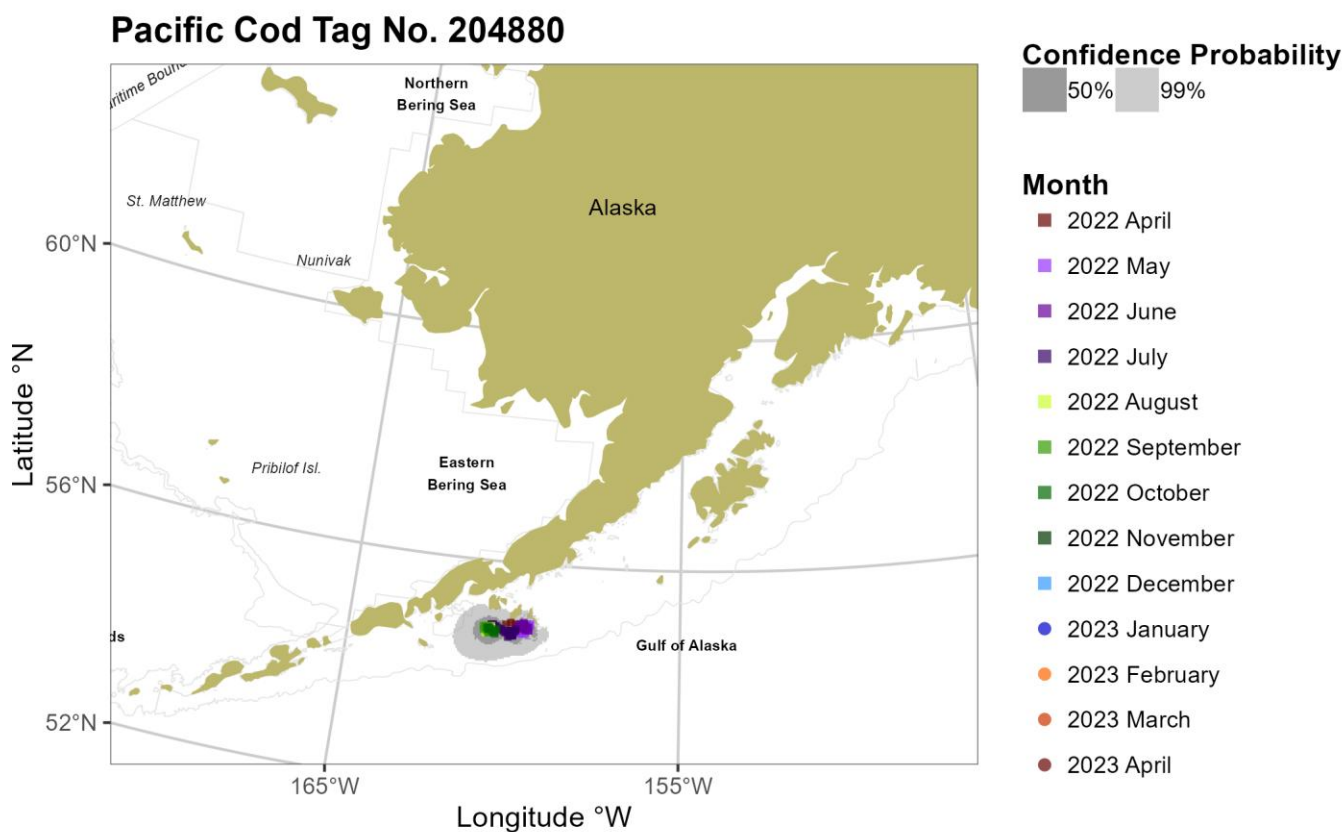


Figure 11. -- Map of Pacific cod tag 204880 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 204881

The Pacific cod with tag 204881 (length: 82 cm) was released on April 13, 2022 in the Gulf of Alaska at 54.42°N latitude and -162.39°W longitude and the pop-up was on September 19, 2022 at 56.46°N latitude and -167.03°W longitude (Fig. 12; Table 1). This fish was at liberty for 159 days. This fish started its travel north shortly within a month after release, through Unimak Pass into the Bering Sea, where the tag pop-up occurred near the shelf edge.

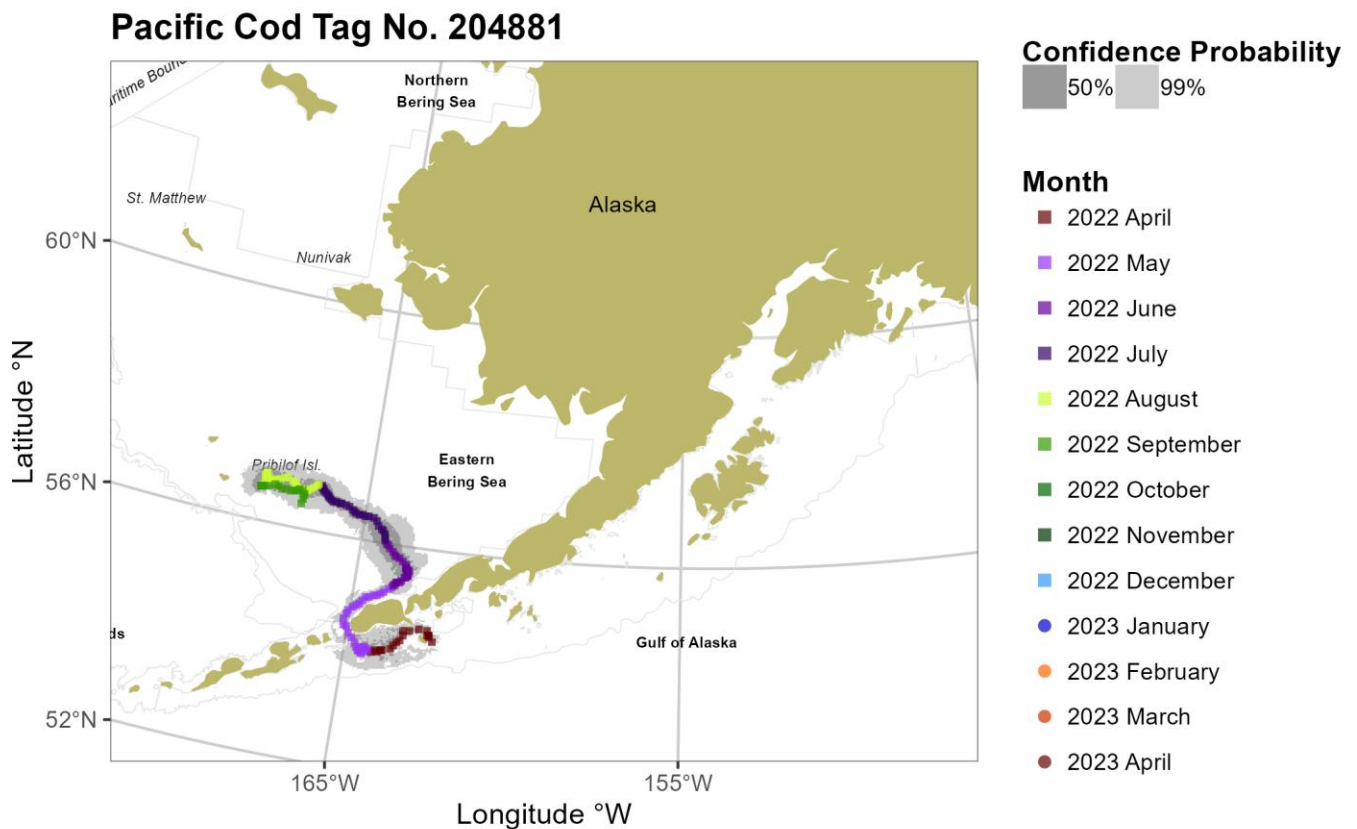


Figure 12. -- Map of Pacific cod tag 204881 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 212431

The Pacific cod with tag 212431 (length: 77 cm) was released on April 11, 2022 in the Gulf of Alaska at 55.25°N latitude and -161.68°W longitude and the pop-up was on May 27, 2022 at 55.35°N latitude and -161.32°W longitude (Fig. 13; Table 1). This fish was at liberty for 46 days. The fish remained in the western GOA during its time at liberty.

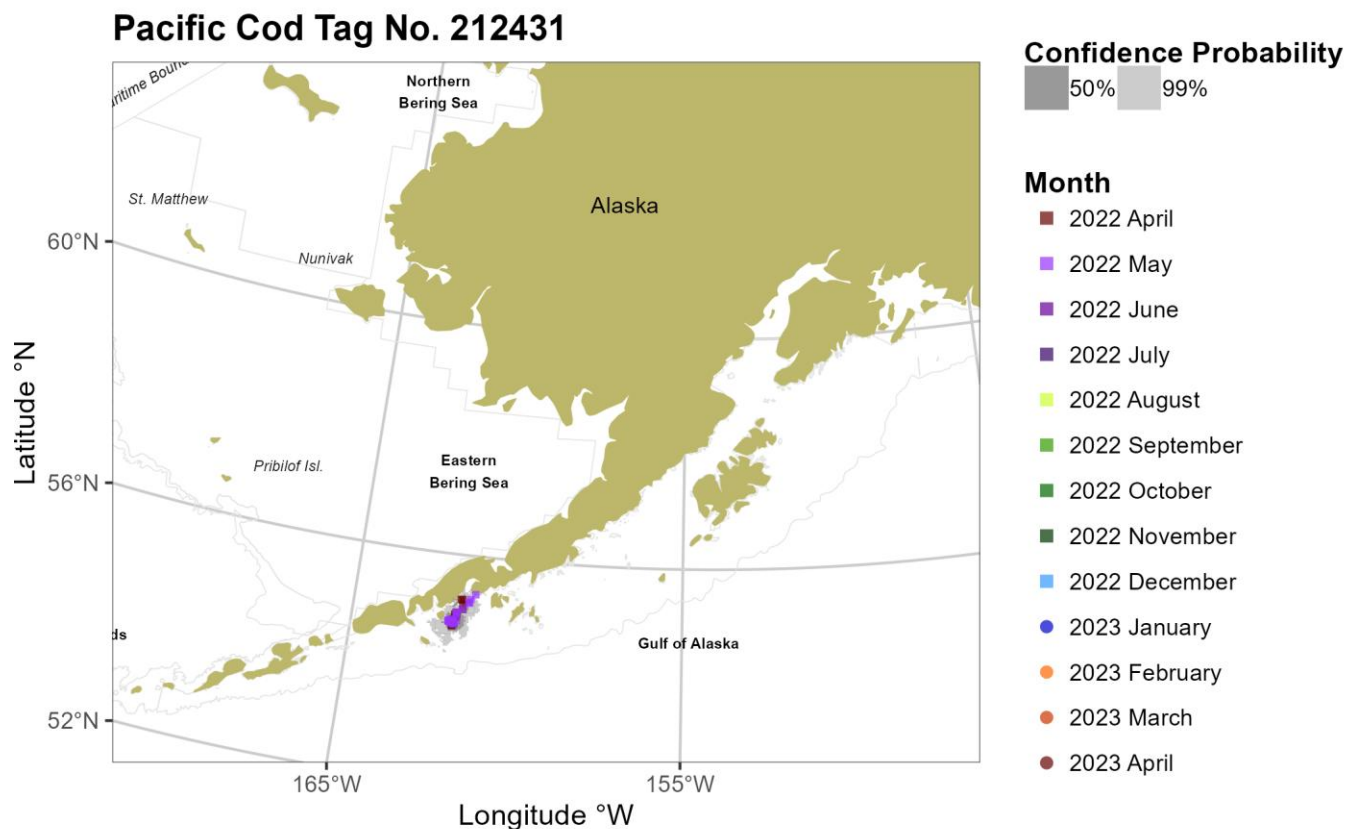


Figure 13. -- Map of Pacific cod tag 212431 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 214554

The Pacific cod with tag 214554 (length: 67 cm) was released on April 15, 2022 in the Gulf of Alaska at 55.56°N latitude and -160.41°W longitude and the pop-up was on May 05, 2022 at 55.69°N latitude and -160.06°W longitude (Fig. 14; Table 1). This fish was at liberty for 20 days. The fish remained in the western GOA during its time at liberty.

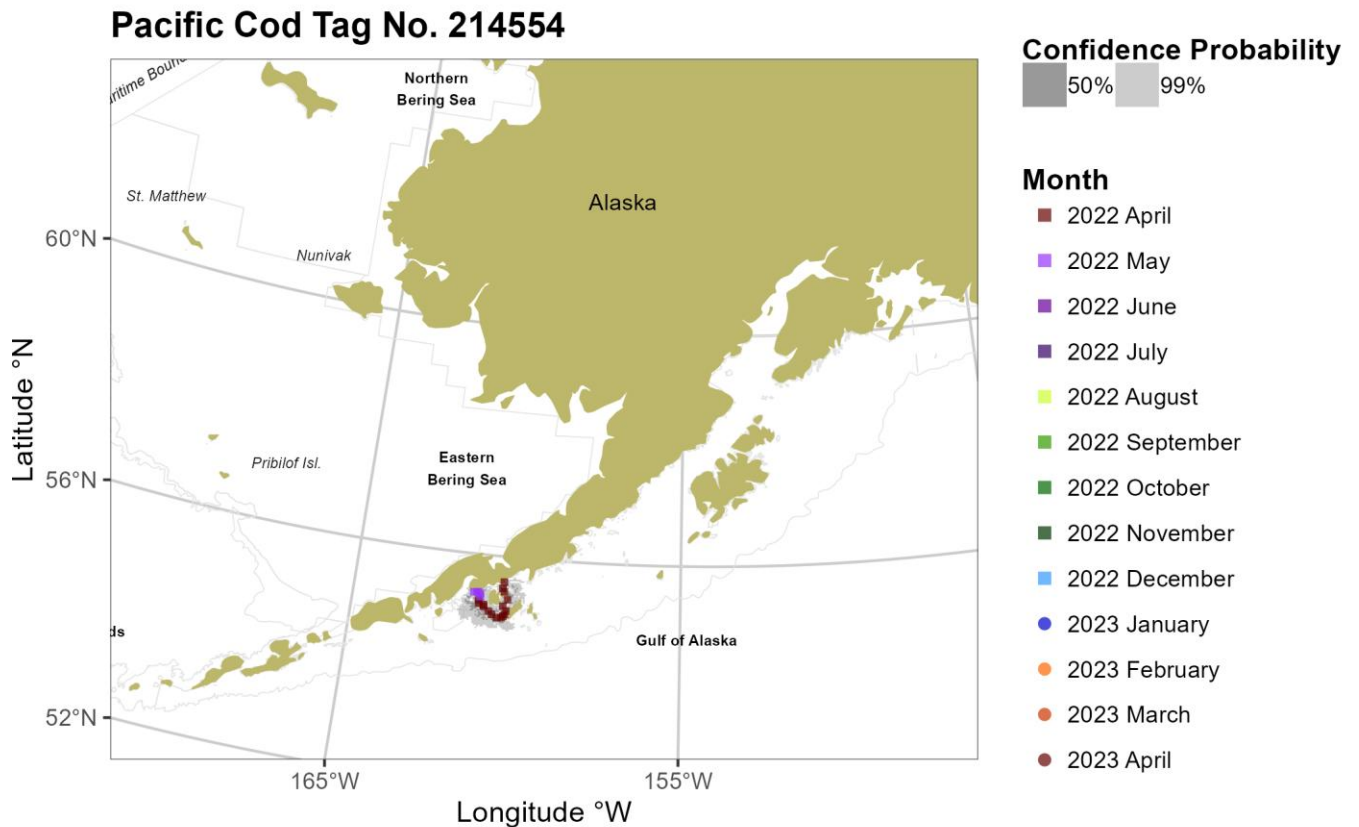


Figure 14. -- Map of Pacific cod tag 214554 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 214555

The Pacific cod with tag 214555 (length: 78 cm) was released on April 15, 2022 in the Gulf of Alaska at 55.54°N latitude and -159.64°W longitude and the pop-up was on October 13, 2022 at 55.36°N latitude and -160.26°W longitude (Fig. 15; Table 1). This fish was at liberty for 180 days. The fish remained in the western GOA, during its time at liberty.

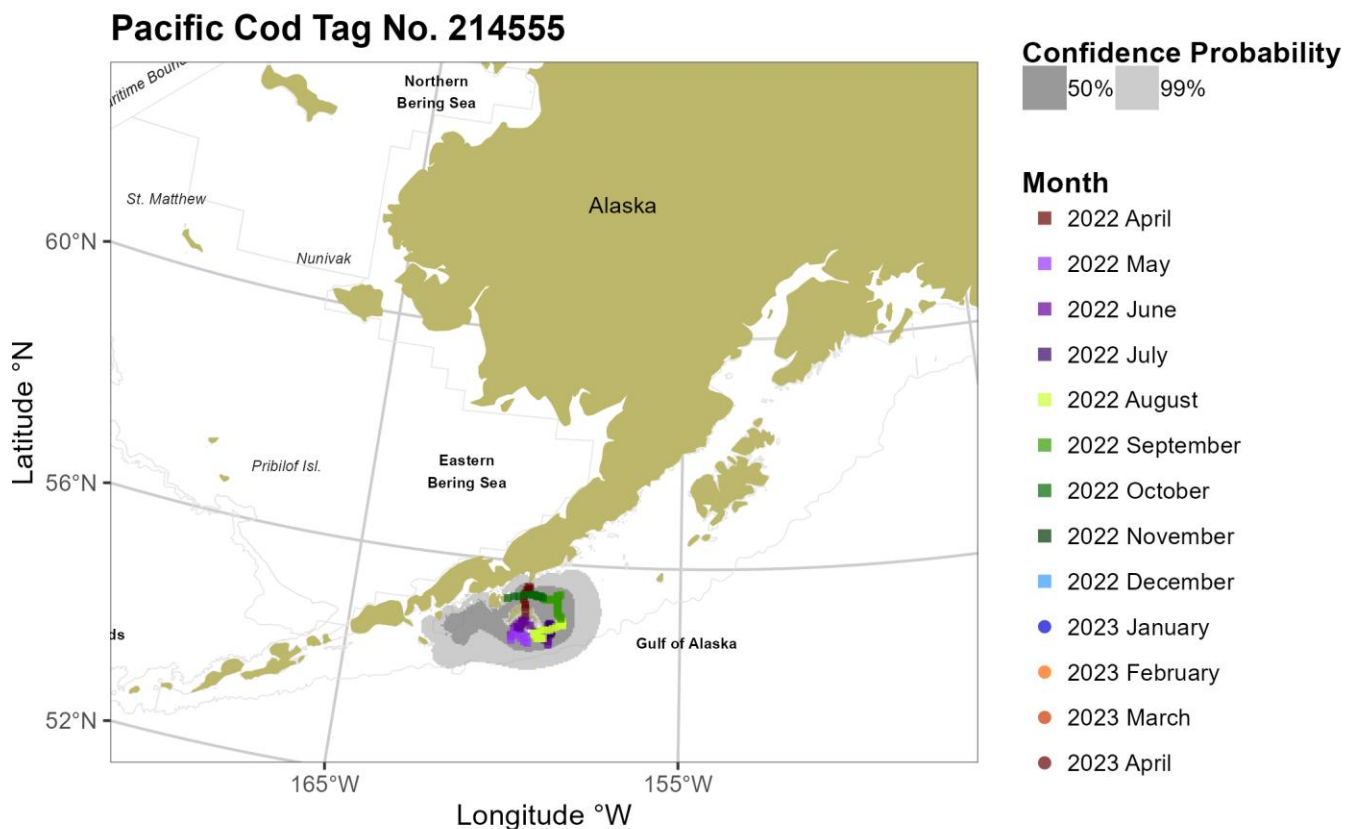


Figure 15. -- Map of Pacific cod tag 214555 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 214556

The Pacific cod with tag 214556 (length: 59 cm) was released on April 16, 2022 in the Gulf of Alaska at 54.84°N latitude and -159.46°W longitude and the pop-up was on October 14, 2022 at 55.16°N latitude and -159.63°W longitude (Fig. 16; Table 1). This fish was at liberty for 180 days. The fish remained in the western GOA, during its time at liberty.

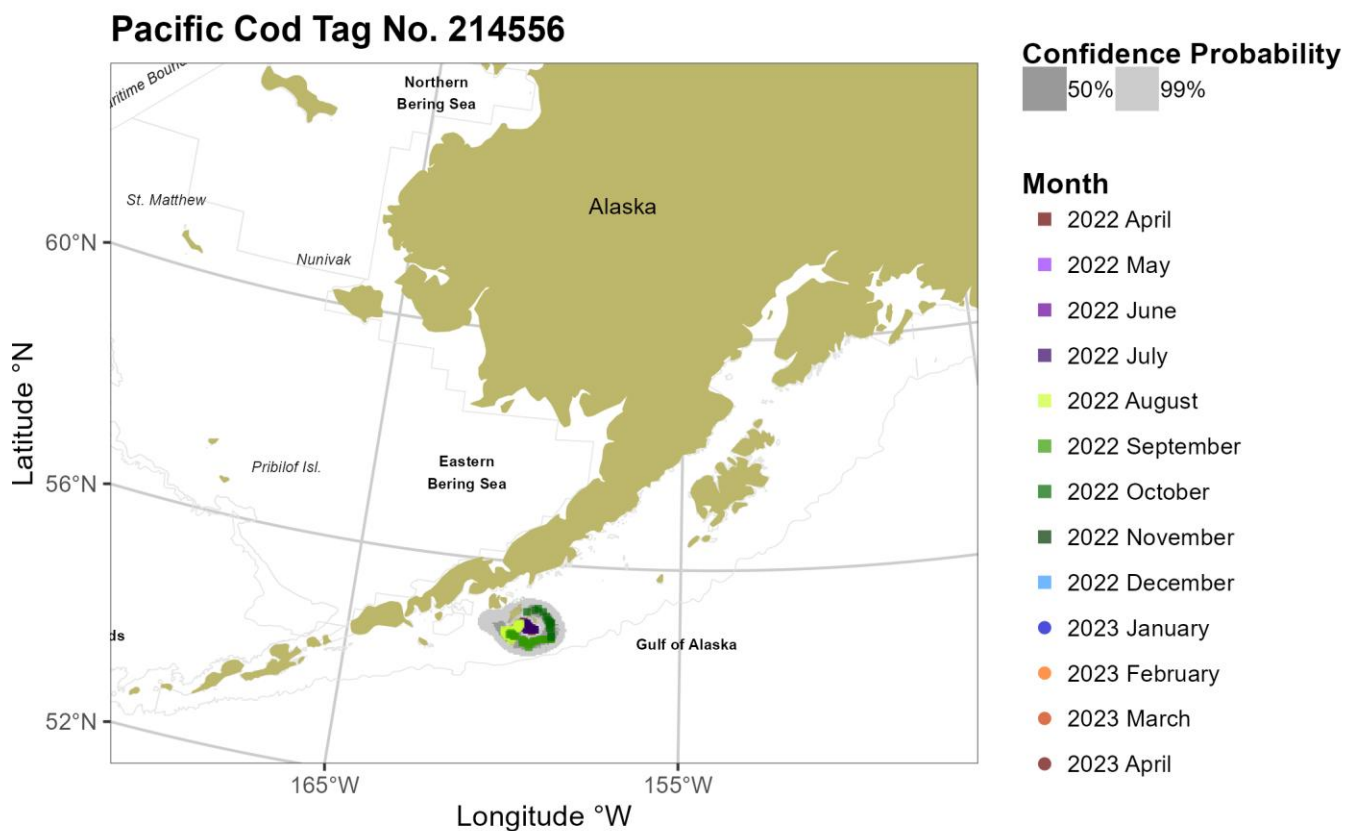


Figure 16. -- Map of Pacific cod tag 214556 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 214557

The Pacific cod with tag 214557 (length: 65 cm) was released on April 17, 2022 in the Gulf of Alaska at 54.94°N latitude and -160.27°W longitude and the pop-up was on July 12, 2022 at 55.15°N latitude and -161.09°W longitude (Fig. 17; Table 1). This fish was at liberty for 86 days. The fish remained in the western GOA during its time at liberty.

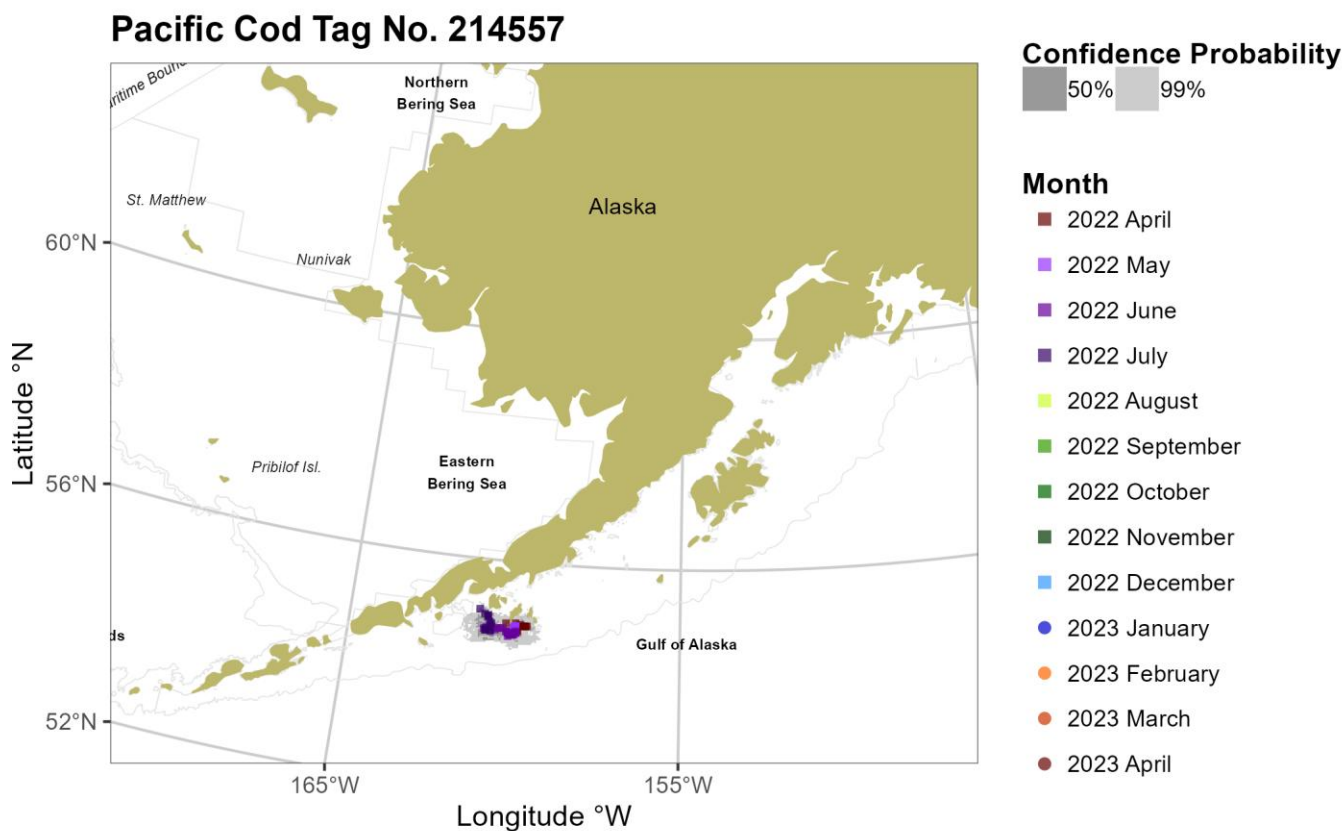


Figure 17. -- Map of Pacific cod tag 214557 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 214558

The Pacific cod with tag 214558 (length: 74 cm) was released on April 13, 2022 in the Gulf of Alaska at 54.43°N latitude and -162.43°W longitude and the pop-up was on October 11, 2022 at 62.01°N latitude and -173.8°W longitude (Fig. 18; Table 1). This fish was at liberty for 180 days. The fish traveled north within a month after release, through Unimak Pass into the Bering Sea, where the tag pop-up occurred just north of St. Mathews Island.

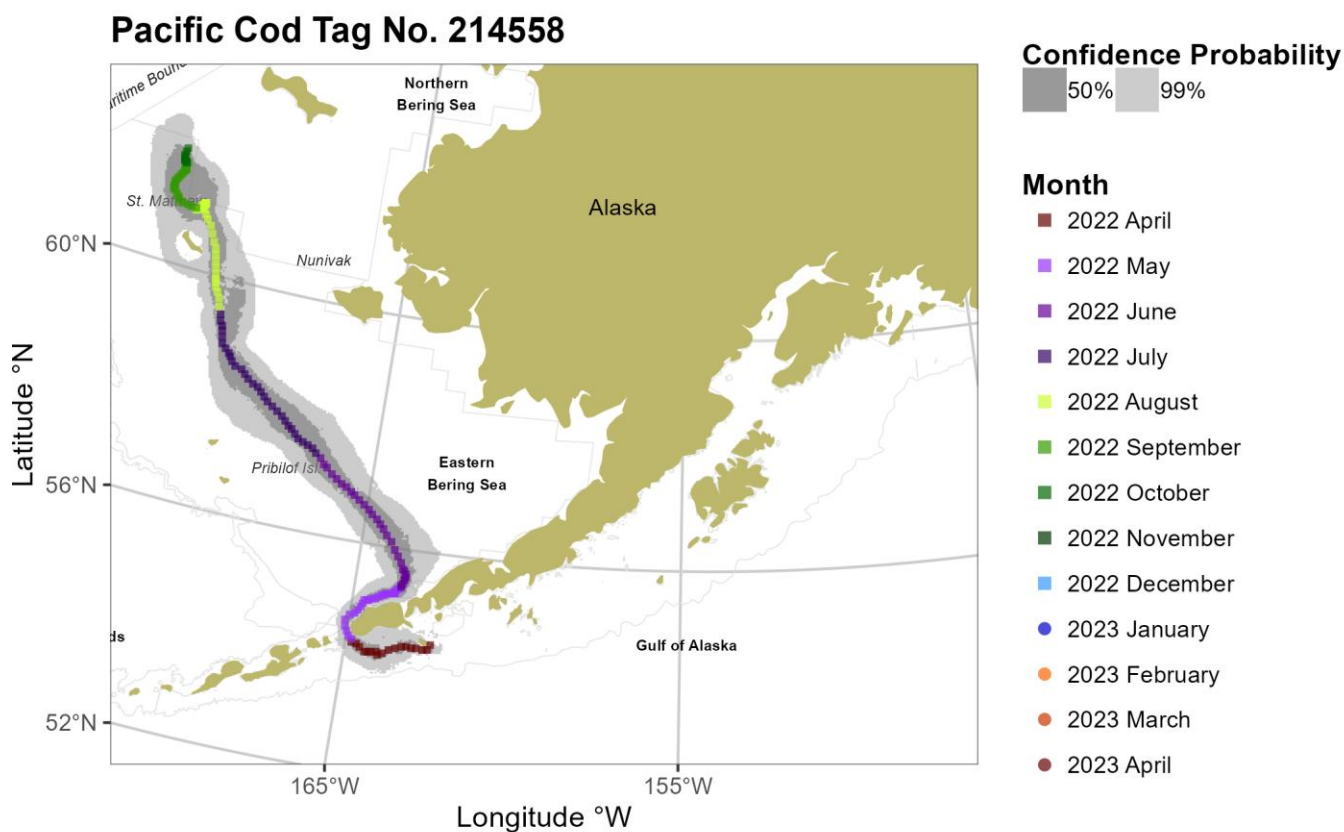


Figure 18. -- Map of Pacific cod tag 214558 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 214560

The Pacific cod with tag 214560 (length: 90 cm) was released on April 13, 2022 in the Gulf of Alaska at 54.42°N latitude and -162.39°W longitude and the pop-up was on May 23, 2022 at 55.78°N latitude and -162.54°W longitude (Fig. 19; Table 1). This fish was at liberty for 53 days. Within a month of release, the fish traveled through Unimak Pass into the eastern Bering Sea, just north of the Alaskan peninsula.

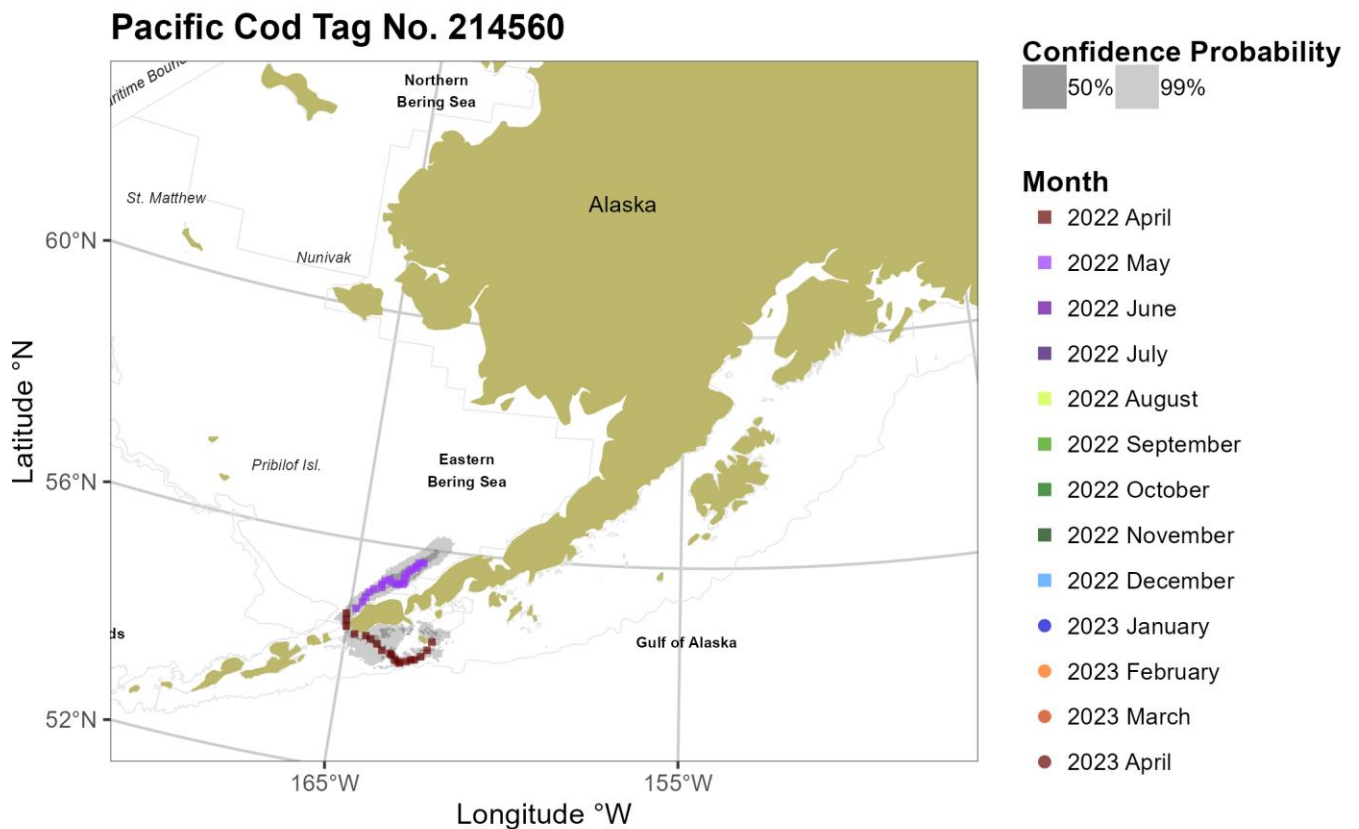


Figure 19. -- Map of Pacific cod tag 214560 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 214561

The Pacific cod with tag 214561 (length: 55 cm) was released on April 12, 2022 in the Gulf of Alaska at 54.96°N latitude and -162.42°W longitude and the pop-up was on June 06, 2022 at 54.99°N latitude and -162.45°W longitude (Fig. 20; Table 1). This fish was at liberty for 55 days. The fish remained in the western GOA during its time at liberty.

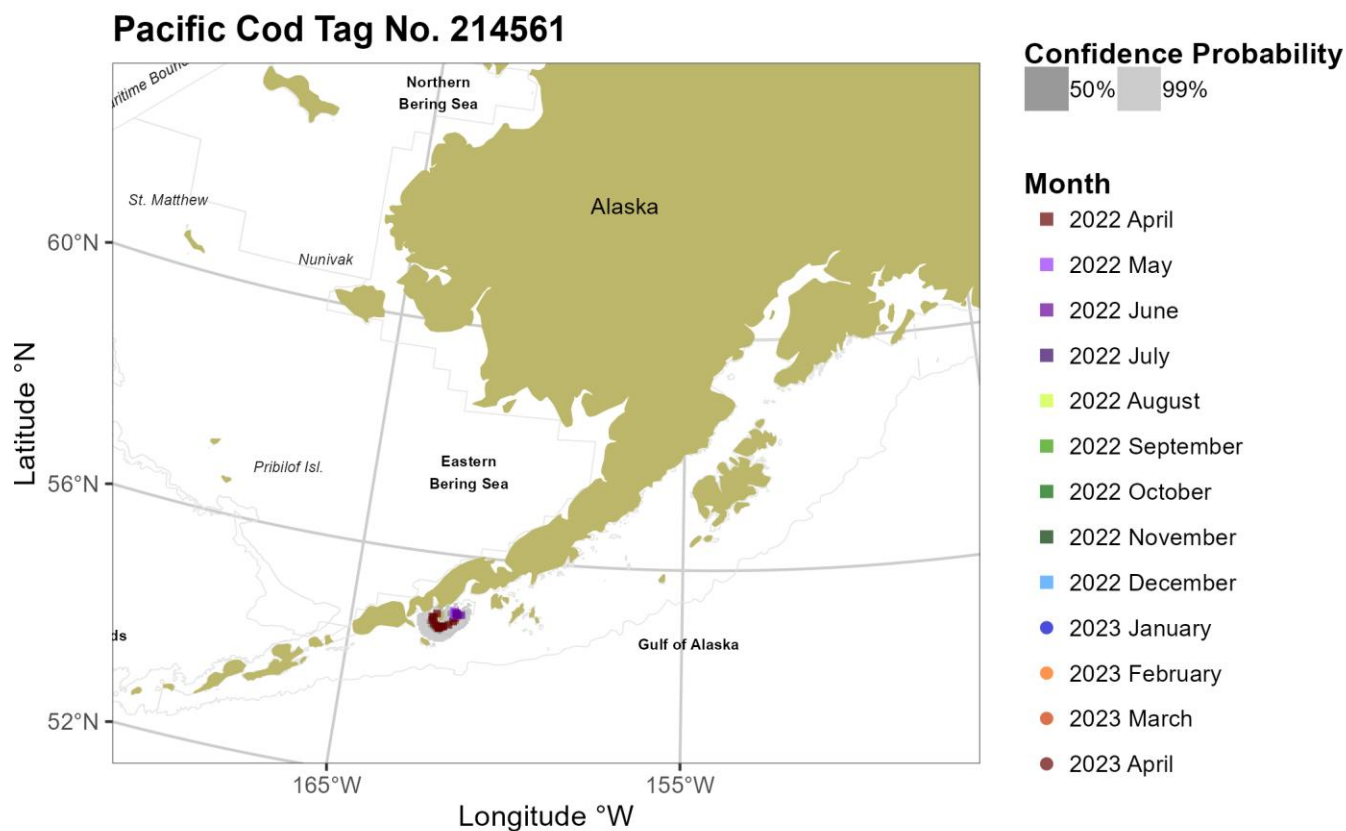


Figure 20. -- Map of Pacific cod tag 214561 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 214562

The Pacific cod with tag 214562 (length: 74 cm) was released on April 11, 2022 in the Gulf of Alaska at 55.25°N latitude and -161.67°W longitude and the pop-up was on October 09, 2022 at 54.68°N latitude and -160.19°W longitude (Fig. 21; Table 1). This fish was at liberty for 180 days. The fish remained in the western GOA, during its time at liberty.

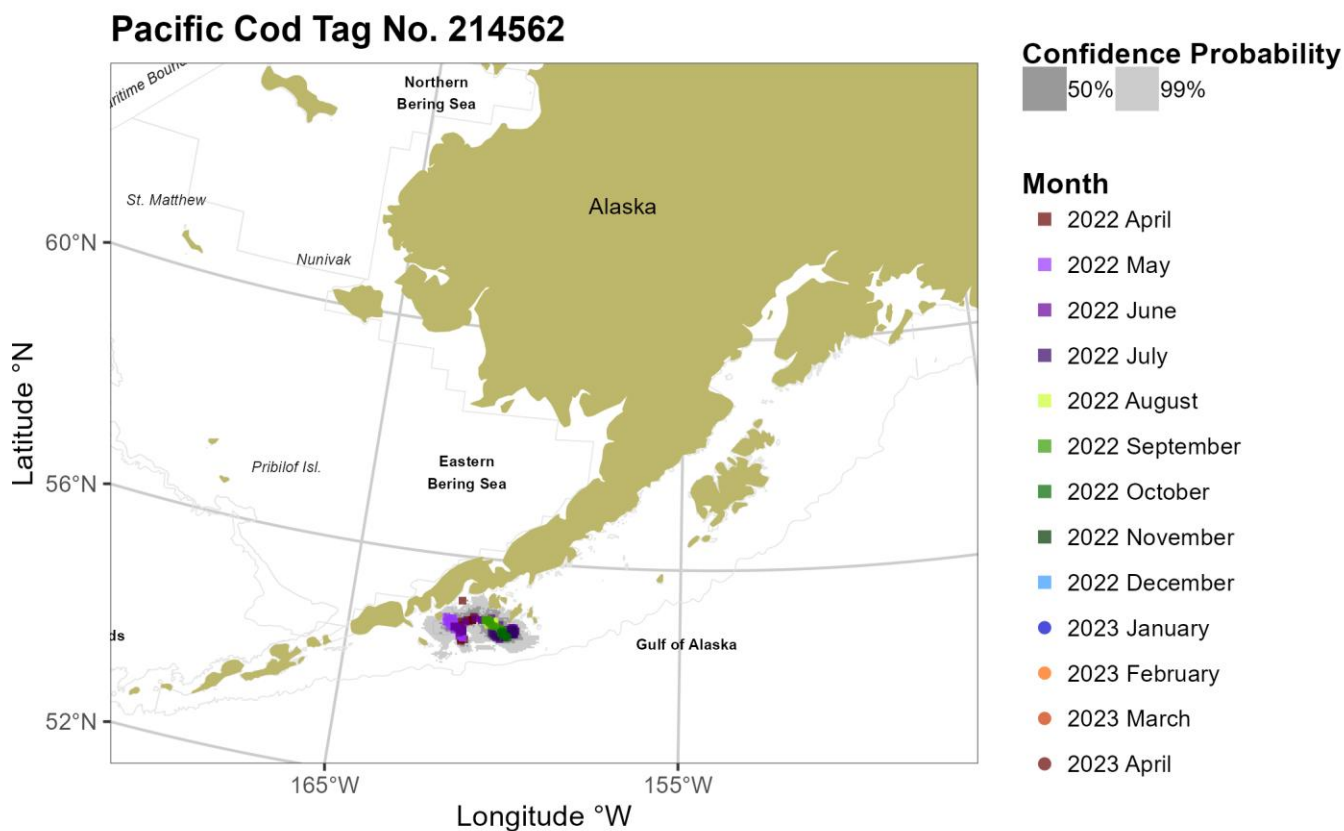


Figure 21. -- Map of Pacific cod tag 214562 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 215396

The Pacific cod with tag 215396 (length: 73 cm) was released on April 15, 2022 in the Gulf of Alaska at 55.57°N latitude and -160.41°W longitude and the pop-up was on October 15, 2022 at 55.27°N latitude and -160.33°W longitude (Fig. 22; Table 1). This fish was at liberty for 183 days. The fish remained in the western GOA, during its time at liberty.

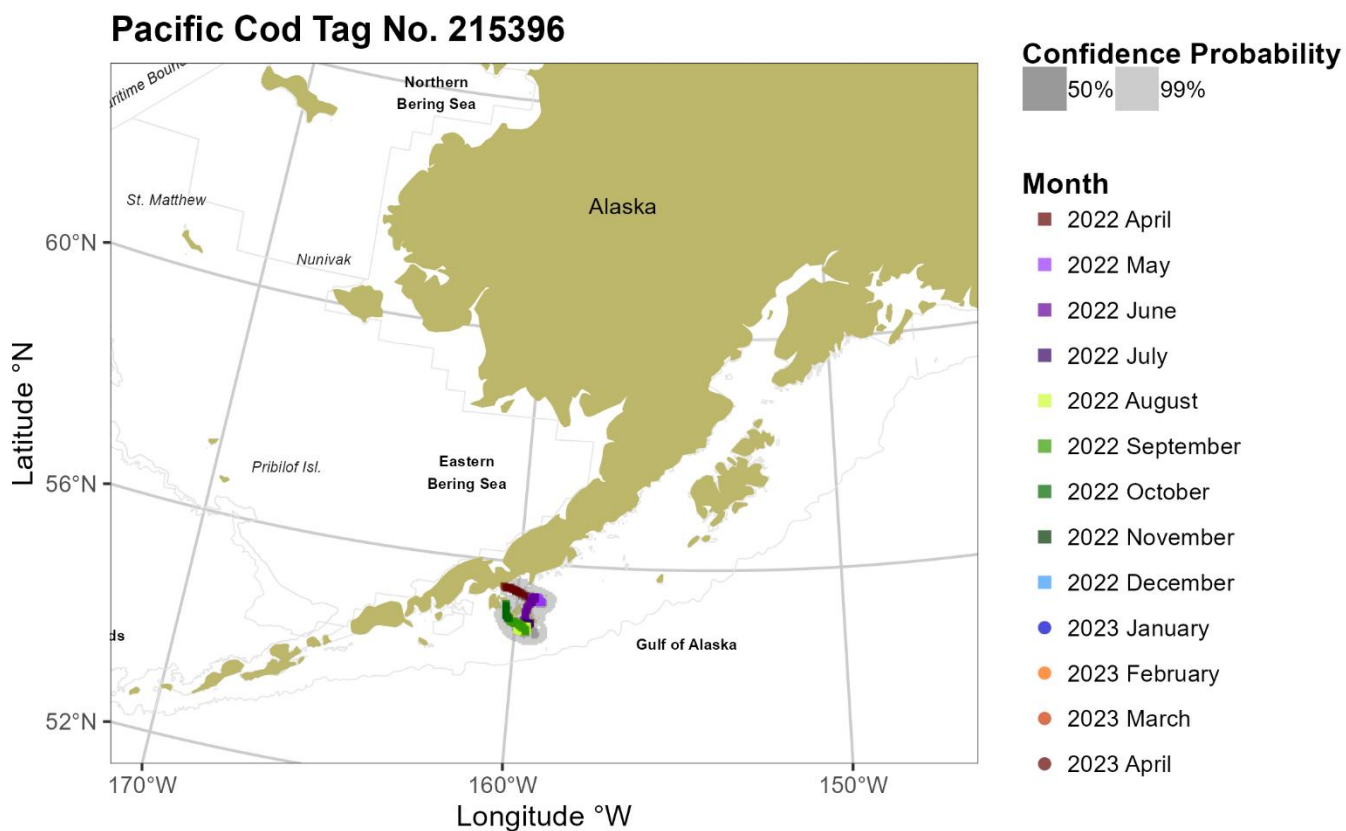


Figure 22. -- Map of Pacific cod tag 215396 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 232652

The Pacific cod with tag 232652 (length: 72 cm) was released on April 16, 2022 in the Gulf of Alaska at 55.57°N latitude and -159.67°W longitude and the pop-up was on October 14, 2022 at 55.52°N latitude and -159.68°W longitude (Fig. 23; Table 1). This fish was at liberty for 181 days. The fish remained in the western GOA, during its time at liberty.

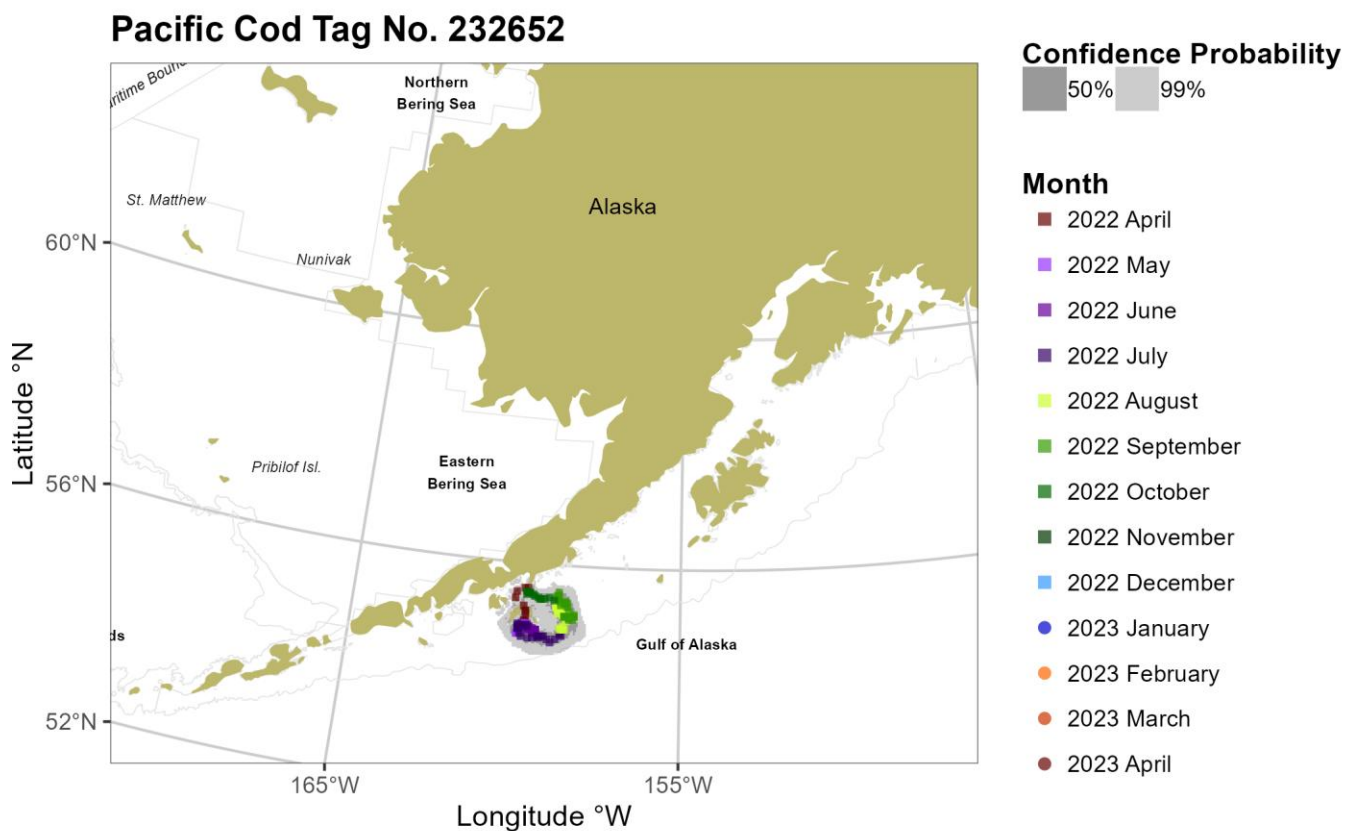


Figure 23. -- Map of Pacific cod tag 232652 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 232653

The Pacific cod with tag 232653 (length: 76 cm) was released on April 16, 2022 in the Gulf of Alaska at 54.84°N latitude and -159.47°W longitude and the pop-up was on November 19, 2022 at 54.7°N latitude and -159.34°W longitude (Fig. 24; Table 1). This fish was at liberty for 217 days. The fish remained in the western GOA, during its time at liberty.

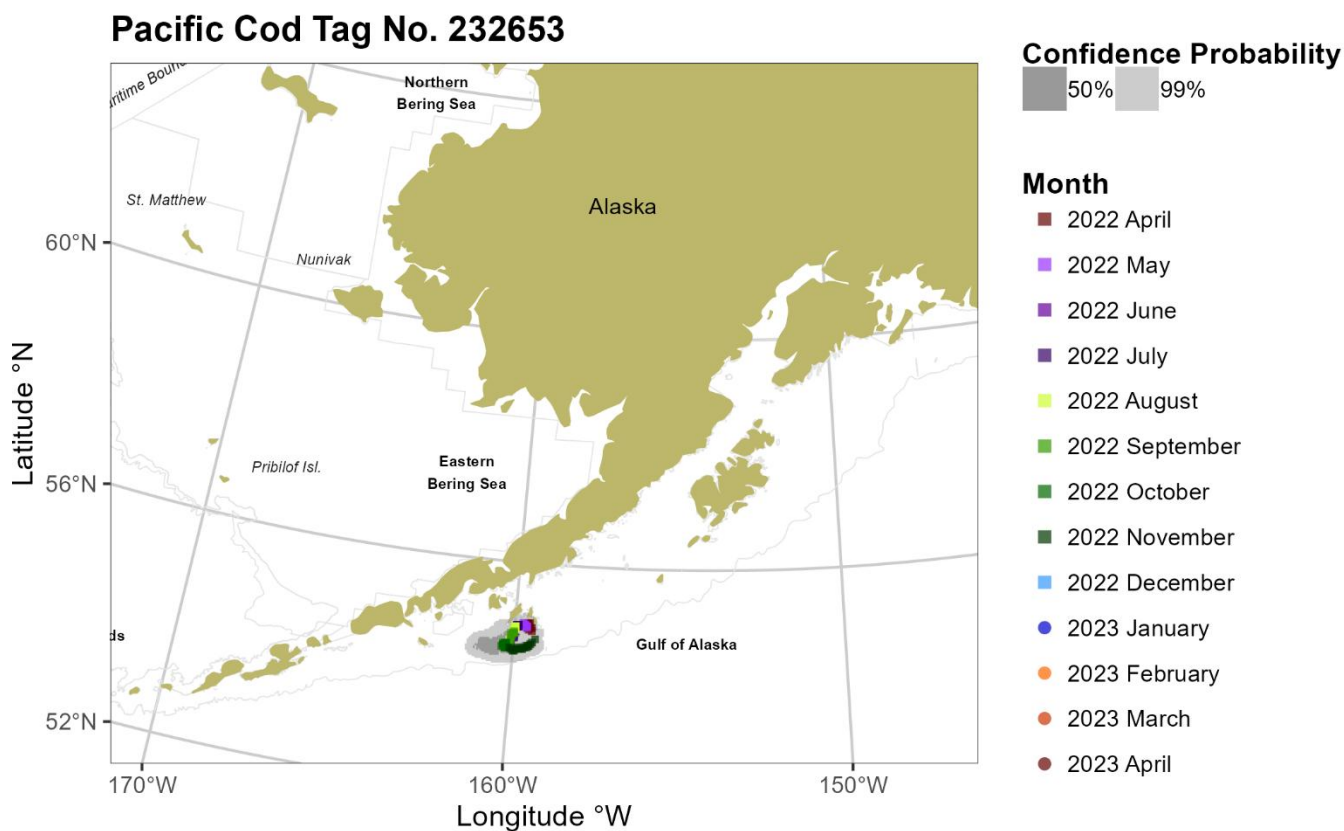


Figure 24. -- Map of Pacific cod tag 232653 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 232654

The Pacific cod with tag 232654 (length: 68 cm) was released on April 17, 2022 in the Gulf of Alaska at 54.94°N latitude and -160.26°W longitude and the pop-up was on September 28, 2022 at 55°N latitude and -160.02°W longitude (Fig. 25; Table 1). This fish was at liberty for 163 days. The fish remained in the western GOA, during its time at liberty.

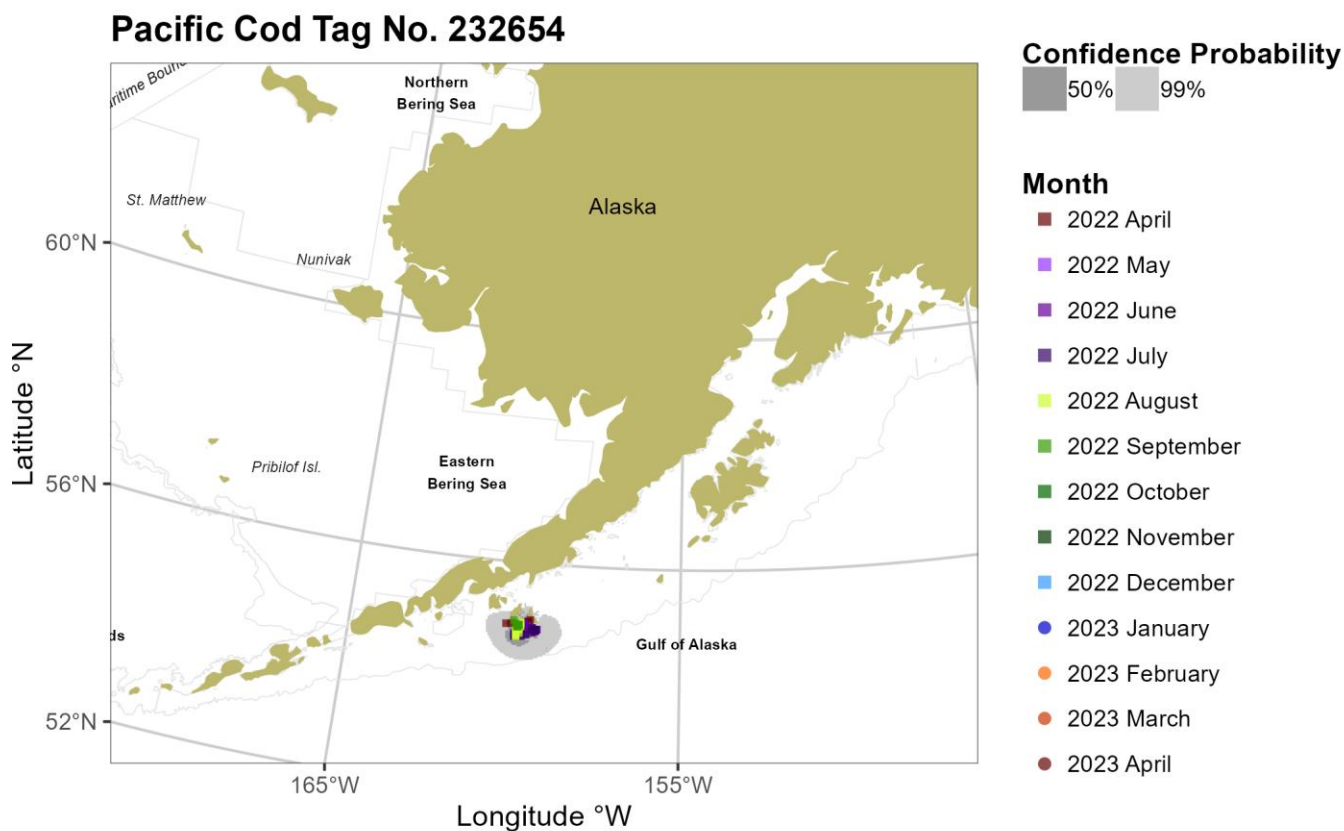


Figure 25. -- Map of Pacific cod tag 232654 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 232655

The Pacific cod with tag 232655 (length: 66 cm) was released on April 16, 2022 in the Gulf of Alaska at 55.54°N latitude and -159.66°W longitude and the pop-up was on June 06, 2022 at 55.55°N latitude and -159.72°W longitude (Fig. 26; Table 1). This fish was at liberty for 52 days. The fish remained in the western GOA during its time at liberty.

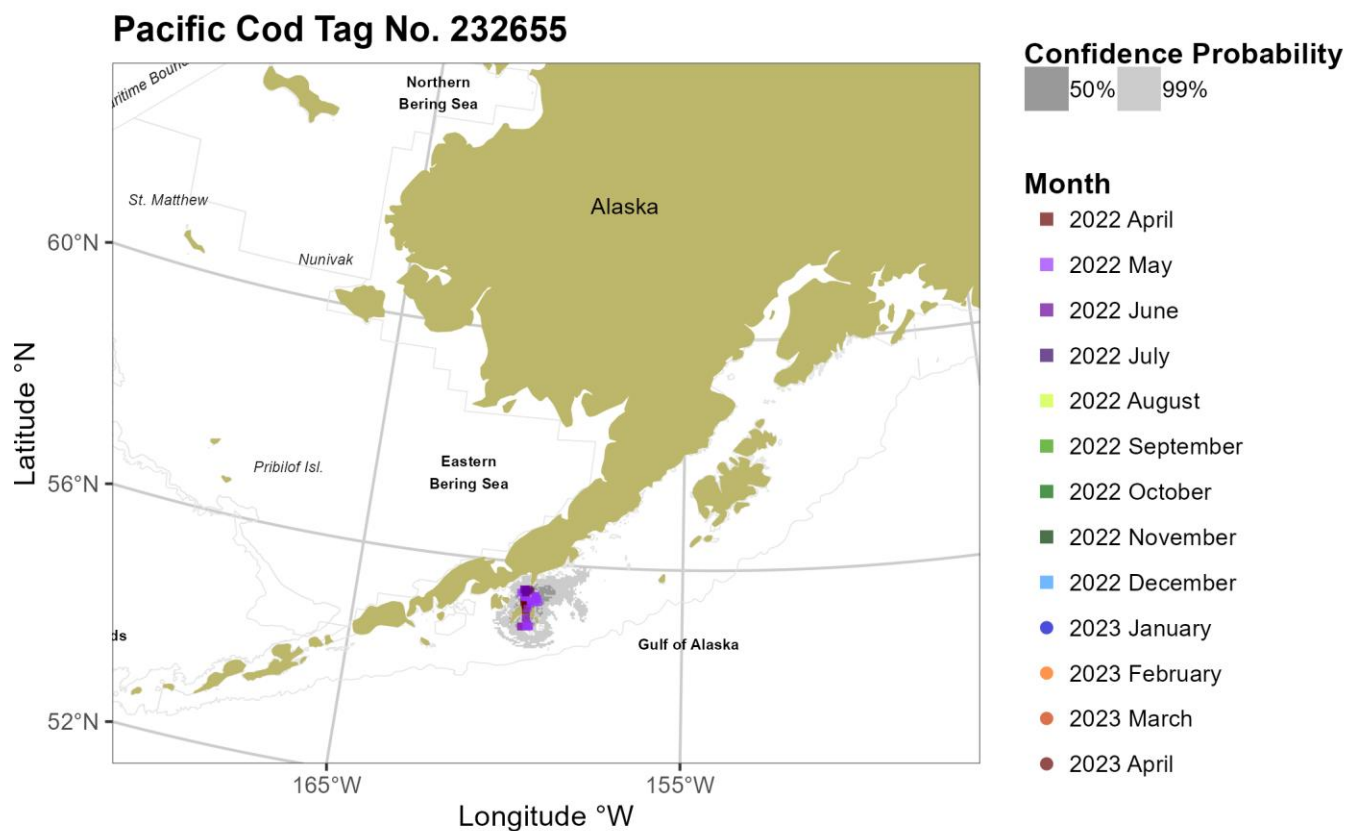


Figure 26. -- Map of Pacific cod tag 232655 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 232656

The Pacific cod with tag 232656 (length: 75 cm) was released on April 16, 2022 in the Gulf of Alaska at 55.56°N latitude and -159.67°W longitude and the pop-up was on August 18, 2022 at 55.57°N latitude and -159.61°W longitude (Fig. 27; Table 1). This fish was at liberty for 125 days. The fish remained in the western GOA, during its time at liberty.

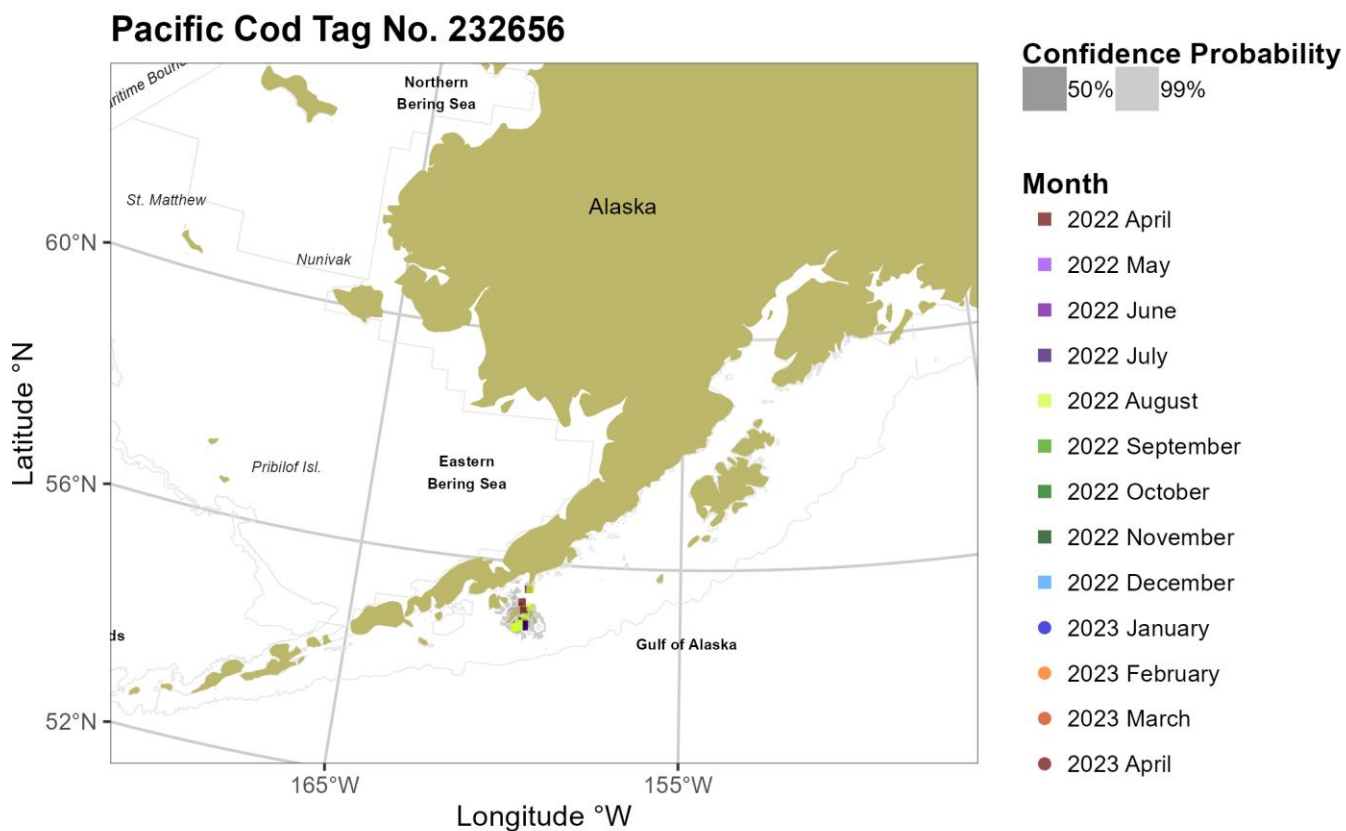


Figure 27. -- Map of Pacific cod tag 232656 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 232657

The Pacific cod with tag 232657 (length: 68 cm) was released on April 16, 2022 in the Gulf of Alaska at 54.85°N latitude and -159.46°W longitude and the pop-up was on July 03, 2022 at 54.92°N latitude and -159.43°W longitude (Fig. 28; Table 1). This fish was at liberty for 78 days. The fish remained in the western GOA during its time at liberty.

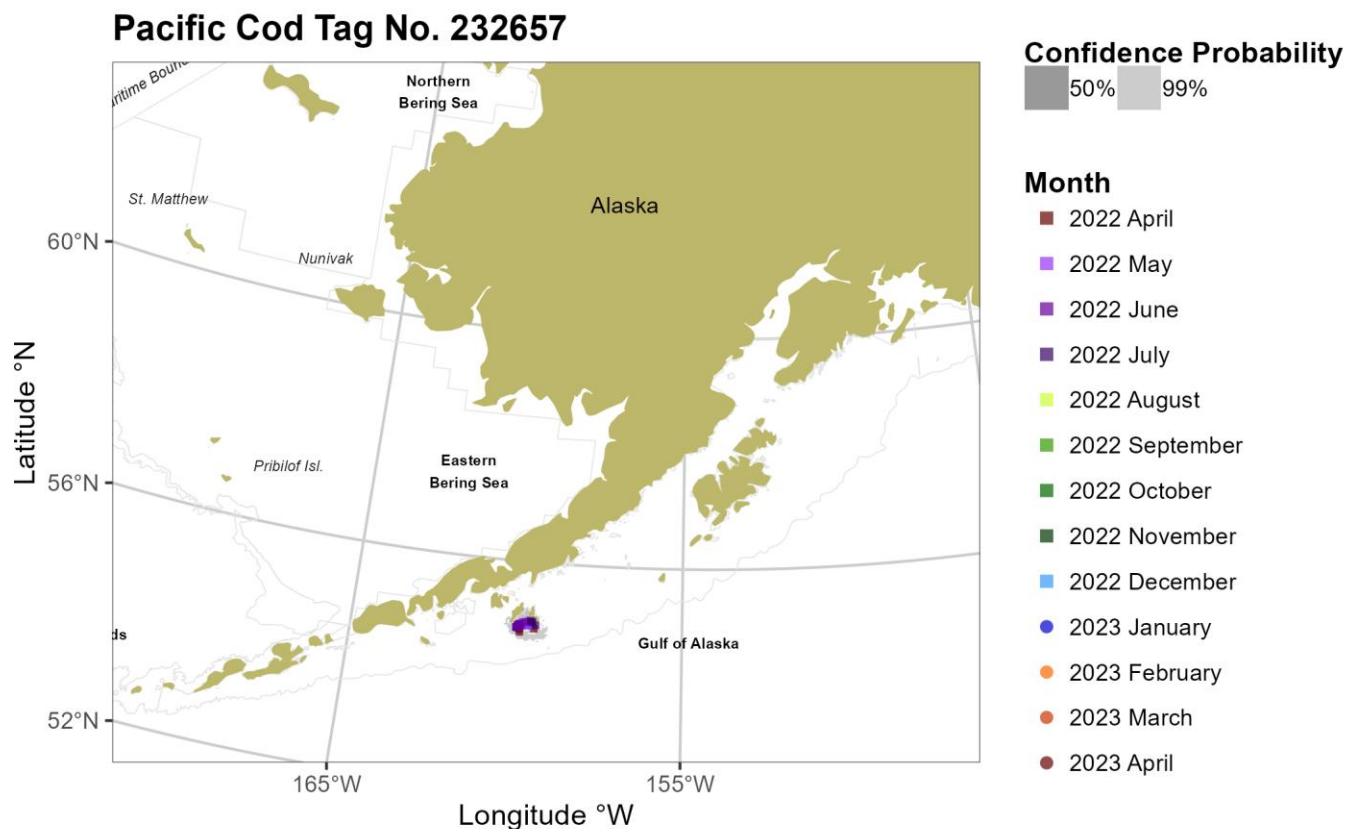


Figure 28. -- Map of Pacific cod tag 232657 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 232658

The Pacific cod with tag 232658 (length: 74 cm) was released on April 12, 2022 in the Gulf of Alaska at 54.96°N latitude and -162.42°W longitude and the pop-up was on February 18, 2023 at 55.12°N latitude and -164.48°W longitude (Fig. 29; Table 1). This fish was at liberty for 311 days. The fish traveled north within a month of release, through Unimak Pass into the Bering Sea. The fish remained in the eastern Bering Sea until February 2023 when it started to head south, when the tag pop-up occurred just north of Unimak Pass.

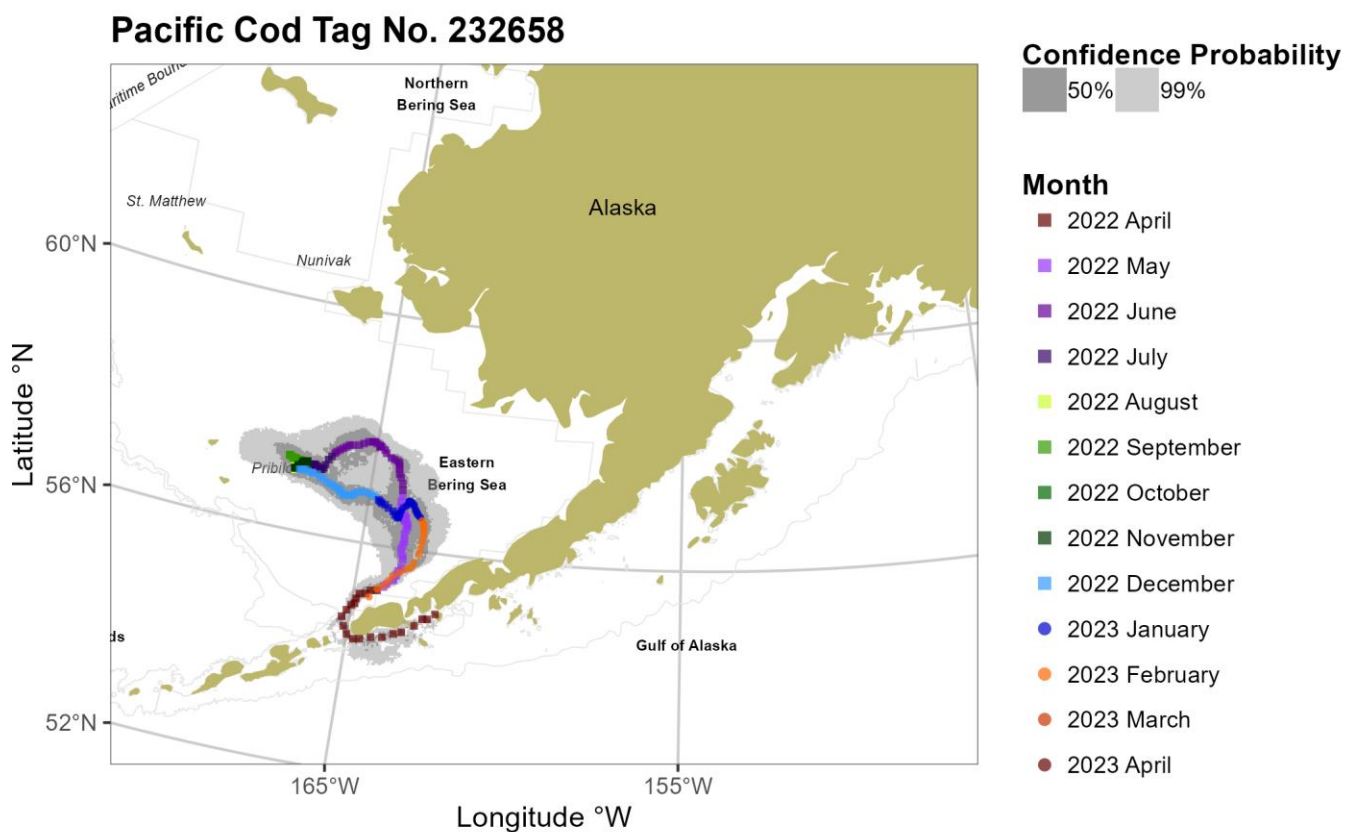


Figure 29. -- Map of Pacific cod tag 232658 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

Tag 232659

The Pacific cod with tag 232659 (length: 89 cm) was released on April 16, 2022 in the Gulf of Alaska at 55.25°N latitude and -161.69°W longitude and the pop-up was on August 28, 2022 at 55.0591°N latitude and -161.607°W longitude (Figure 30Error! Reference source not found.; Table 1Error! Reference source not found.). This fish was at liberty for 138 days. The fish remained in the western GOA during its time at liberty.

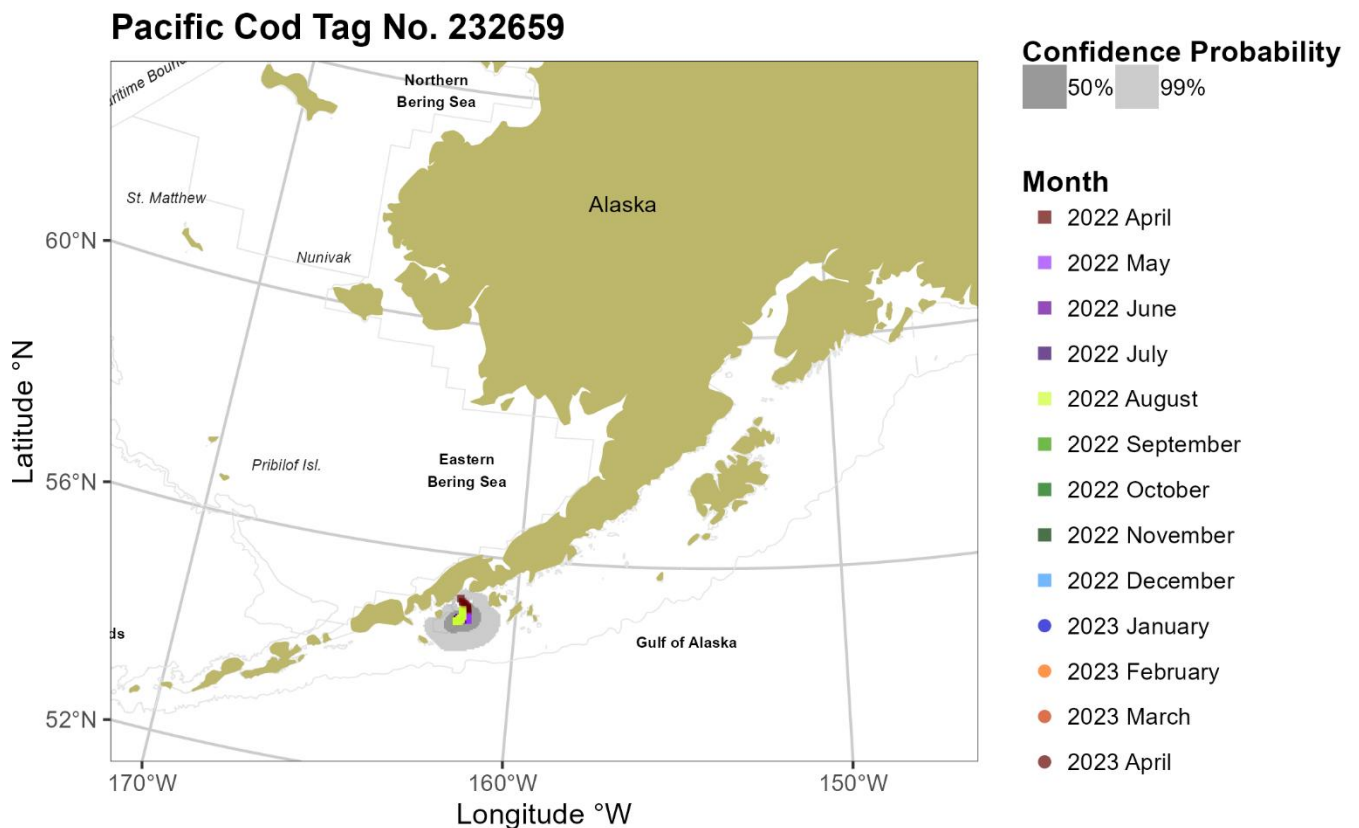


Figure 30. -- Map of Pacific cod tag 232659 with 50% (medium gray) and 99% (light gray) confidence probability shapefiles. Find color descriptions in Table 2.

DISCUSSION

This report is one of five Alaska Fisheries Science Center (AFSC) Technical Memorandums summarizing results from PSAT-tagged Pacific cod, including reconstructed individual movement paths for release years 2019 (Markowitz et al. 2025b), 2021, 2022, 2023, and 2024. With the exception of 2019, all tag releases from 2021–2024 occurred in the western and/or central GOA. This report summarizes tag releases conducted in 2022 and represents a continuation of the 2021 tagging study, using the same selected sites across the western GOA (Rand et al. *In Editorial Process*), with the exception of one site we were not able to visit in 2022 due to weather.

Cod stocks are presently managed separately in the GOA and BS which is why it is so important to understand how much movement of Pacific cod there is between the GOA and the BS. To summarize coarse interannual movement patterns for western GOA released fish, we calculated migration rates by release year, focusing on movements from the western GOA into the BS, including the eastern and northern Bering Sea, Chukchi Sea, and Russian waters. A coarse summary table of these movements is included in each subsequent AFSC Technical Memorandum (2021–2024). The following assumptions were applied to generate the movement summary table (western GOA releases only):

- Pacific cod were classified as “migratory” if their satellite tag popped up outside of the western GOA in northern waters, which includes the eastern or northern Bering Sea, Russian waters, or the Chukchi Sea (aggregated within the BS column, Table 3).
- Fish with tags that popped up in the western GOA after May 1 were presumed residents of the GOA for the remainder of their time (if applicable) at liberty, according to their programmed pop-off time.
- Early pop-up tags in the western GOA (before May 1) were designated as “unknown”, as these fish may have subsequently migrated into the BS but lacked sufficient days at liberty to confirm migration (Table 3, “Pre-May 1 Pop-Up”).
- The “% Migrated (minimum)” represents a conservative estimate of tagged Pacific cod migration.

Table 3. -- Movement summary table for pop-up satellite tags (PSATs) released during winter spawning in the western Gulf of Alaska (GOA), restricted to PSATs from which a pop-up recovery location was available. “Migrated North” are fish with pop-up locations north of the GOA (BS, CS, Rus). “In GOA May 1” are fish that have a pop-up location in the GOA sometime after May 1. “Total Known” is the total of “Migrated North” and “In GOA May 1”. The “% Migrated (minimum)” represents the number of fish that “Migrated North (BS, CS, or Rus)” divided by the “Total Known May 1”. The “Pre-May 1 Pop-Up” columns are the number of tags that surfaced in the GOA before May 1. Because the ultimate fate of these fish is unknown, they are excluded from the migration calculation. BS = eastern and northern Bering Sea, CS = Chukchi Sea, Rus = Russia.

Year	Migrated North (BS, CS, Rus)	In GOA May 1	Total Known May 1	% Migrated (minimum)	Pre-May 1 Pop-Up
2021	12	9	21	57%	2
2022	5	21	26	19%	0
2023	11	7	18	61%	1
2024	8	6	14	57%	5

Due to freezing air temperatures, like those that would cause dangerous weather and ice conditions, the 2022 tag release cruise was delayed and began 23 days later than the 2021 release event. Although peak spawning timing for Pacific cod varies annually, fishery data and anecdotal local knowledge suggest spawning generally occurs in March around Sanak Island and the Shumagin Islands (pers. comm. Kiley Thompson, captain, F/V *Decision*). While we located sufficient numbers of Pacific cod to successfully deploy all 27 tags, visual maturity assessments from biological samples indicate that tagging likely occurred after peak spawning (Fig. 6).

Compared to 2021, the 2022 samples contained a higher proportion of spent fish and relatively few pre-spawn individuals (Fig. 6), whereas 2021 samples included a substantially greater percentage of actively spawning fish. This difference may reflect interannual variability in spawning phenology, but it may also be influenced by the delayed cruise timing. Previous observations indicate that Pacific cod tagged in mid- to late- March often migrate into the Bering Sea shortly after tagging (when migration occurs). In contrast to 2021, the 2022 release year showed a lower proportion of fish migrating from the western GOA into the Bering Sea (Table 3).

It remains unclear whether the reduced migration observed in 2022 reflects true interannual differences in movement behavior or whether the delayed start of the tagging cruise resulted in missing the primary migration window. Continued tagging across multiple years will be critical for distinguishing true interannual variability in migration behavior from variability in migration rates related to release timing.

ACKNOWLEDGEMENTS

Recognition and appreciation are extended to the captains and crew of the FV *Decision* which provided the platform to tag and release Pacific cod. Without their extensive knowledge of western GOA fishing areas, terrain and limitations, this study would not have been possible. In particular, we'd like to thank the vessel crew, Kiley Thompson (Captain), Kevin Gunderson (crew), Chris Yetchmeneff (crew), and Seth Roehl (crew) for their hard work on deck and assisting with all the tagging operations.

We would like to thank the many communities of the western GOA region and their members who have supported this research. The knowledge, experiences, and insights of the western GOA region have been instrumental in expanding the scope of our science and knowledge to encompass the many issues that face this important ecosystem. We would like to thank the Aleutians East Borough and NOAA's National Cooperative Research Program for their contributions in funding these tagging efforts.

Finally, we thank the reviewers Steve Barbeaux, Ingrid Spies, and Ned Laman for their efforts and timely feedback to improve this report.

Aleutians East Borough work is conducted in the waters and along the coastlines of Alaska, which include the traditional homelands and waters of the Inupiat, Yupiit, Siberian Yupiit, Unangax, Alutiiq/Sugpiaq, Eyak, Dena'ina Athabascan, Tlingit, Haida, and Tsimshian who have stewarded their lands and waters since time immemorial. We are indebted to these peoples for their wisdom and knowledge of their lands and waters.

This document was prepared in the greater Seattle area, which is located on the traditional lands of the Coast Salish people, including the Duwamish people, past and present and Juneau, Alaska, which is located on the on the unceded territory of the Áak'w K̓wáan on Lingít Aaní, also known as Juneau and Douglas, Alaska, which also houses neighboring X̱aadas and Ts'msyen peoples. We are grateful for their continued sharing of vision, wisdom, values, and leadership.

Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

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