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TELEMETRY AND GENETIC IDENTITY OF CHINOOK SALMON IN ALASKA: PRELIMINARY SUMMARY OF SATELLITE TAGS DEPLOYED IN 2020

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14. ABSTRACT
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occupied habitat, and natural mortality of Chinook salmon in the North Pacific Ocean, from which overlap with Navy training activities can be inferred.

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Abstract

Information about the spatial distribution, movement, vertical distribution, and occupied habitat of fishes is important for understanding several aspects of their ecology, including potential impacts of human activities. The U.S. Navy (Navy) conducts at-sea training in the Temporary Maritime Activities Area (TMAA) in the Gulf of Alaska (GOA). As part of the Marine Species Monitoring Program, the Navy is interested in understanding the overlap of occurrence between Chinook salmon Evolutionarily Significant Units (ESUs) and Navy training activities. Therefore, to qualitatively describe the spatial distribution, movement, vertical distribution, occupied habitat, and natural mortality of Chinook salmon in the Gulf of Alaska, we attached pop-up satellite archival tags (PSATs) to individuals near Chignik, AK (n = 20) and Kodiak, AK (n = 20). To date, 29 of the 40 PSATs have reported to satellites, providing approximately 1,600 days of depth, temperature, and location data. Reporting locations of tags were widespread across the North Pacific Ocean, ranging as far west as the Alaska Peninsula to as far east as the coast of central British Columbia, Canada. Preliminary analyses of depth and temperature data documented tagged Chinook salmon occupying waters from 0 to 237 m in depth, while experiencing a thermal environment of 4–15°C. Furthermore, diagnostic evidence from tag data provided evidence that 17 Chinook salmon experienced predation by endothermic fish(s) (n = 14), an ectothermic fish (n = 1), and a marine mammal (n = 1), 11–113 days after tagging. Currently, we are waiting for 11 PSATs deployed on Chinook salmon to transmit archived data to satellites on their programmed pop-up dates. We are also preparing to deploy 20 additional PSATs on Chinook salmon near Yakutat, AK, during late-winter of 2021. Once all transmitted PSAT data are received, comprehensive data analyses will commence. These analyses will provide insights into the spatial distribution, movement, vertical distribution, occupied habitat, and natural mortality of Chinook salmon in the North Pacific Ocean, from which overlap with Navy training activities can be inferred.

Introduction

Information about the spatial distribution, movement, vertical distribution, and occupied habitat of fishes is important for understanding several aspects of their ecology, including potential impacts of human activities. Specifically, information on distribution, diel and seasonal movements, and water masses occupied can inform Individual Based Models and life history models that are used to understand population dynamics of fishes (Brodeur et al. 2000). Additionally, this knowledge can help answer questions concerning the susceptibility of a fish species to various fishing techniques (e.g., bottom and midwater trawls), and to design spatially explicit fisheries management practices, such as time-area closures, for avoiding bycatch of various fish species (Hobday et al. 2010; Smedbol and Wroblewski 2002). Finally, information on the spatial distribution and vertical behaviors of fish, can aid in understanding potential interactions with and impacts of anthropogenic development activities or disturbances (Løkkeborg et al. 2012; Paxton et al. 2017; Slabbekoorn et al. 2019).

Chinook salmon *Oncorhynchus tshawytscha* is an iconic species found throughout the North Pacific Ocean and supports invaluable subsistence, commercial and recreational fisheries (Healey 1991; Quinn 2005; Riddle et al. 2018). In addition to valuable fisheries, Chinook salmon is an important food source for many apex marine predators, including Southern Resident Killer Whales (Adams et al. 2016; Chasco et al. 2017; Ford et al. 1998). Populations of anadromous Chinook salmon have variable life histories. In general, Chinook salmon rear in freshwater for up to 2 years before they migrate to the ocean to feed for generally 1–5 years. After growing in the ocean, Chinook salmon return to their natal river to spawn and then die.

The U.S. Navy (Navy) conducts at-sea training in the Temporary Maritime Activities Area (TMAA) in the Gulf of Alaska (GOA). As part of the Marine Species Monitoring Program, the Navy is interested in understanding the overlap of occurrence between populations of Chinook salmon and Navy training activities. The GOA is known to be habitat for various populations of Chinook salmon, including some Evolutionarily Significant Units (ESUs) which are protected under the U.S. Endangered Species Act (ESA). Currently, much of what is known about Chinook salmon occurrence in the GOA is based on bycatch data from only where commercial groundfish fisheries occur. As a result, information about Chinook salmon is spatially biased and does not exist throughout its entire range which extends beyond where groundfish fisheries occur. Therefore, an increased understanding of the spatial distribution and behaviors of Chinook salmon is extremely important when considering potential interactions between this species and human activities in the ocean such as Navy exercises in the TMAA.

To provide an improved understanding of Chinook salmon ocean ecology while occupying waters of the GOA, we are conducting a study in which large, immature Chinook salmon are captured and tagged with pop-up satellite archival tags (PSATs) at several sites along the coast of the GOA. PSATs measure and record high-resolution depth, ambient temperature, and light intensity data while externally attached to a fish. On a pre-programmed date, the tags release from the fish, float to the surface of the ocean, and transmit the archived data to satellites. Once these data are retrieved by project investigators, the spatial distribution, movement, vertical distribution, and occupied habitat of tagged Chinook salmon can be described and related to regional environmental factors. This information can provide a more complete understanding of the biology and ecology of the oceanic phase of immature Chinook salmon within the GOA, which may be useful for understanding potential interaction/impacts between this species and human activities including Navy exercises in the TMAA. In this Preliminary Summary, we describe our field efforts from 2020 in two locations in the GOA, and provide preliminary data summaries from tags that have reported to satellites through early December 2020.

Methods

Fish capture

During 1–6 August 2020, 20 Chinook salmon were captured by hook and line, tagged with PSATs, and released from a sport fishing vessel near Chignik Bay, AK (Table 1; Fig. 1). During 5–28 October 2020, 20 additional Chinook salmon were captured by hook and line, tagged with PSATs, and released near Kodiak, AK (Table 1; Fig. 1).

Fish tagging

Fish were captured using sport fishing methods (hook and line with bait or lures). After hooking, fish were retrieved quickly, brought onboard the fishing vessel in a padded net, and assessed for signs of stress or abnormal behavior, including visual injuries, loss of scales, bleeding, loss of equilibrium, pupil dilation, abnormal coloration, frayed fins, and rapid opercular movement. Only Chinook salmon deemed to be healthy according to these metrics and >60 cm fork length (FL) were selected for tagging. Tagging Chinook salmon of this size ensured that the tag is <2% of the body weight of the fish, a commonly accepted minimum size threshold for fish tagging.

Table 1. Deployment information for 40 pop-up satellite archival tags attached to Chinook salmon near Chignik and Kodiak, Alaska, during 2020. Eleven additional tags are still at-liberty and are scheduled to report to satellites in the winter/spring of 2021.

Argos ID	Tag SN	Harness ID	Deploy date	Deploy region	Programmed Pop-Up Date (days after release)	Fork Length (cm)	Reporting date	Liberty (days)	Data days	Transmitting days	Displacement (km)	Track distance (km)
202585	20P0884	2020-092	08-03-20	Chignik	220	67	09-12-20	40	35	21	50	278
202586	20P0889	2020-099	08-04-20	Chignik	220	70	10-27-20	84	79	10	259	841
202587	20P0943	2020-089	08-04-20	Chignik	200	81	12-05-20	123	120	15	85	1073
202588	20P0944	2020-091	08-01-20	Chignik	270	74	11-27-20	118	113	14	405	1295
202589	20P0945	2020-031	08-03-20	Chignik	220	67	10-12-20	70	19	7	129	143
202590	20P0946	2020-084	08-04-20	Chignik	220	70	NA	NA	NA	NA	NA	NA
202591	20P0947	2020-023	08-01-20	Chignik	270	65	10-27-20	87	84	6	228	679
202592	20P0948	2020-038	08-03-20	Chignik	220	75	09-06-20	34	30	35	1261	1317
202593	20P0949	2020-040	08-02-20	Chignik	270	65	09-13-20	42	39	16	34	355
202594	20P0952	2020-041	08-02-20	Chignik	270	92	NA	NA	NA	NA	NA	NA
202595	20P0953	2020-086	08-04-20	Chignik	200	69	NA	NA	NA	NA	NA	NA
202596	20P0954	2020-029	08-03-20	Chignik	220	73	11-22-20	111	106	13	309	787
202597	20P0955	2020-045	08-03-20	Chignik	220	72	09-25-20	53	50	7	56	649
202598	20P0993	2020-097	08-04-20	Chignik	200	101	09-23-20	50	50	9	1767	1761
202599	20P0999	2020-093	08-04-20	Chignik	220	69	10-11-20	68	62	16	90	782
202600	20P1002	2020-080	08-02-20	Chignik	270	83	10-17-20	76	58	14	1588	1765
202601	20P1029	2020-094	08-03-20	Chignik	220	62	10-08-20	66	60	18	123	395
202602	20P1053	2020-030	08-03-20	Chignik	220	70	10-04-20	62	57	16	71	497
202603	20P1055	2020-098	08-04-20	Chignik	200	71	09-07-20	34	31	13	345	653
202604	20P1056	2020-033	08-02-20	Chignik	270	88	NA	NA	NA	NA	NA	NA
205398	20P1552	2020-050	10-06-20	Kodiak	240	67	NA	NA	NA	NA	NA	NA
205399	20P1565	2020-049	10-05-20	Kodiak	240	68	10-26-20	21	15	14	123	206
205400	20P1576	2020-027	10-08-20	Kodiak	240	74	11-26-20	49	44	13	189	644
205401	20P1584	2020-048	10-06-20	Kodiak	240	68	10-30-20	24	18	15	39	100
205402	20P1586	2020-047	10-09-20	Kodiak	240	76	10-18-20	10	7	52	33	35
205403	20P1588	2020-027	10-08-20	Kodiak	210	66	12-08-20	62	54	16	275	801
205404	20P1589	2020-090	10-11-20	Kodiak	210	69	NA	NA	NA	NA	NA	NA
205405	20P1599	2020-028	10-13-20	Kodiak	210	74	NA	NA	NA	NA	NA	NA
205406	20P1625	2020-043	10-11-20	Kodiak	210	66	12-13-20	63	60	16	477	585
205407	20P1636	2020-034	10-11-20	Kodiak	210	71	NA	NA	NA	NA	NA	NA
205408	20P1637	2020-037	10-06-20	Kodiak	180	77	11-08-20	33	28	17	94	306
205409	20P1649	2020-036	10-09-20	Kodiak	180	77	10-31-20	24	15	14	97	140
205410	20P1667	2020-039	10-07-20	Kodiak	180	69	12-10-20	62	50	20	201	344
205411	20P1668	2020-051	10-15-20	Kodiak	180	85	12-12-20	58	55	16	217	336
205412	20P1670	2020-026	10-06-20	Kodiak	180	69	10-24-20	18	12	19	81	81
205413	20P1671	2020-079	10-06-20	Kodiak	150	75	NA	NA	NA	NA	NA	NA
205414	20P1672	2020-046	10-13-20	Kodiak	150	66	NA	NA	NA	NA	NA	NA
205415	20P1673	2020-095	10-05-20	Kodiak	150	81	NA	NA	NA	NA	NA	NA
205416	20P1682	2020-035	10-07-20	Kodiak	150	71	10-27-20	20	17	16	152	168
205417	20P1691	2020-078	10-06-20	Kodiak	150	64	11-12-20	37	30	30	142	198

a) Argos ID refers to the transmitter identification number in each tag supplied by the Argos Satellite System
b) Tag SN refers to serial number of tag, provided by the tag's manufacturer
c) Harness ID refers to identification number displayed on tag harness system, which remains on the fish after the satellite tag releases
d) Liberty refers to the number of days between tagging and the first day of transmission to satellites
e) Data days refers to the total days of data provided by the tag while attached to a live, free-swimming Chinook salmon (i.e., not in the stomach of a predator)
f) Transmitting days refers to the number of days between the first and last day of tag transmissions
g) Displacement refers to the minimum distance (great arc circle) between tagging and end locations
h) Track distance refers to curvilinear distance swam by the fish between tagging and end locations, calculated as the sum of distances between daily position estimates produced by a Hidden Markov Model

Candidate Chinook salmon were placed in a custom-fabricated cradle and blindfolded to reduce visual stimuli that can contribute to stress and struggling (Courtney et al. 2019). Satellite tags were attached to Chinook salmon while in the cradle using a tag attachment system refined for similarly sized Dolly Varden char (Courtney et al. 2016a), Atlantic salmon (Strøm et al. 2017), Chinook salmon (Courtney et al. 2019) and steelhead trout (Seitz A., unpublished data). In short, the tag backpack system, which consists of the tag that is tethered to two padded straps, was secured with surgical-grade wire through the dorsal musculature and bony fin-ray supports of Chinook salmon (Courtney et al. 2016b). This tag attachment technique prevents muscle damage and premature rejection of the tether system caused by tearing through muscle tissue due to hydrodynamic drag of the tag. After tagging, the axillary process of each fish's left pelvic fin was removed as a tissue sample for subsequent genetic analysis. After tissue sampling, Chinook salmon were identified by tag number, photographed, and released into the ocean.

Ethical handling permits

All fieldwork was conducted under the University of Alaska Fairbanks Institutional Animal Care and Use Committee assurance 495247 and State of Alaska Aquatic Resource Permit CF-20-039.

Tag specifications data acquisition

All PSATs (MiniPAT, Wildlife Computers; Redmond, WA; https://wildlifecomputers.com/our-tags/minipat/) weighed 60 g in air and were slightly buoyant. While attached to a Chinook salmon, the PSATs measured and archived temperature, depth, and ambient light data at user-programmed intervals of between 5 and 15 seconds, depending on the duration of tag deployment. After releasing from the fish, the tags floated to the surface of the sea and transmitted, via satellite (Argos Satellite System), summarized temperature and depth data (resolution 2.5–10 min), daily dawn and dusk times determined from light data, and a highly accurate end location (Keating 1995). In this study, PSATs were programmed to release at staggered intervals between 150 and 270 days post-tagging (Table 1). This staggered pop-up

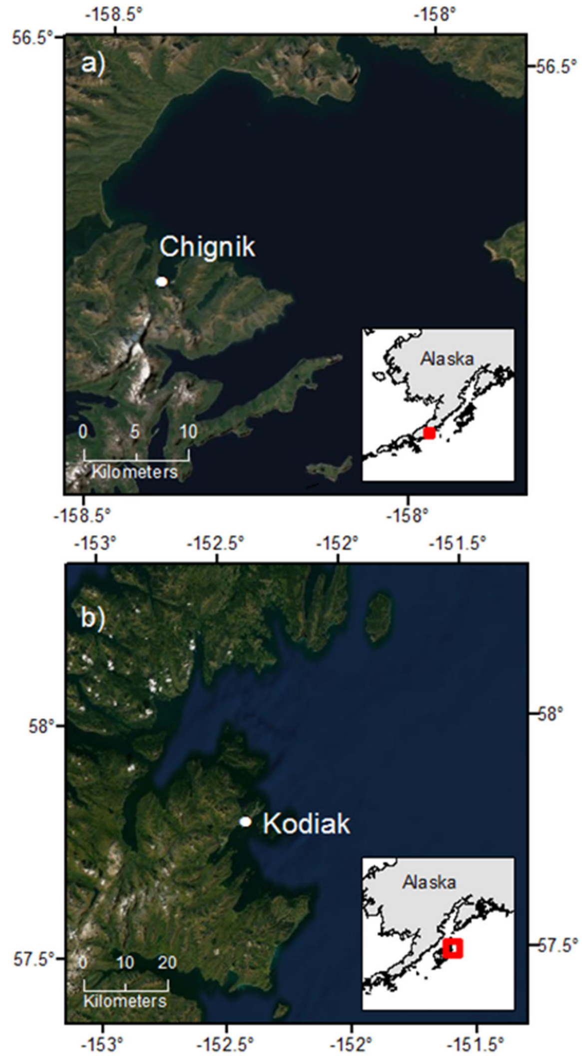

Figure 1. Tagging regions near Chignik (a) and Kodiak, AK (b) where Chinook salmon were captured and tagged with pop-up satellite archival tags in 2020. Map insets in lower right hand corners of panels indicate extent of sampling locations within Alaska. Note that the white circles are staggered from actual fishing locations to protect confidentiality of fishing knowledge.

scheduled was developed as a compromise between obtaining accurate end locations of tagged fish throughout the calendar year and maximizing duration of tag data records and tag-reporting rates. Additionally, tags were programmed to release and report before their scheduled pop-up date if they triggered a fail-safe mechanism by remaining at a constant depth (± 2.5 meters (m)) for 3 days in this study, under the assumption that live Chinook salmon in the ocean change depths frequently (Courtney et al. 2019; Hinke et al. 2005; Walker and Myers 2009) and a lack of change in depth indicates mortality and/or premature release of tag (e.g., tag remaining on sea floor or detached from fish and floating on sea surface).

Preliminary data analyses

To understand the spatial distribution of tagged Chinook salmon, end locations were assigned as the location of first transmission to satellites and were plotted in GIS software (ArcMap 10.4; Environmental Systems Research Institute Inc., Redlands, California). In addition, the most likely paths of individual tagged fish were estimated by a hidden Markov model (HMM) provided by Wildlife Computers (Wildlife Wildlife Computers 2015), similar to past and comparable research (e.g., Courtney et al. 2019; Strøm et al. 2017). To understand the depth and temperatures occupied by tagged Chinook salmon, individual depth and temperature records were visualized through boxplots. Mortality was inferred from PSAT data that departed from values typically seen while attached to live Chinook salmon, following the criteria previously published by past and comparable research (Lacroix 2014; Seitz et al. 2019; Strøm et al. 2019). In short, PSATs that recorded abrupt changes in temperature and/or depth-based behavior, and low light levels indicating complete darkness, were inferred to be in the stomach of a predator that consumed the tagged Chinook salmon and the entire tag.

Preliminary Results

Summary

Chinook salmon tagged near Chignik, AK (n = 20) ranged from 62 to 101 cm FL (74.2 ± 9.9 cm, mean ± SD) while those tagged near Kodiak (n = 20) ranged from 64 to 85 cm FL (71.7 ± 5.6 cm, mean ± SD) (Table 1). To date, 16 of 20 tags attached to Chinook salmon near Chignik, AK, and 13 of 20 tags attached to Chinook salmon near Kodiak have reported to satellites (Table 1). On average, PSATs transmitted data to Argos satellites for 17 days while floating on the surface of the ocean (Table 1). In sum, these 29 tags provided approximately 1,600 days (mean 55 days per tag) of depth, temperature, and location data. Preliminary analyses of these depth, temperature, and light data suggest that 12 tags released from fish before the programmed pop-up date for unknown reasons and floated on the surface before transmitting to satellites, while 17 tagged fish experienced predation (Seitz et al. 2019) (see *Mortality* below). The 11 remaining tags are still attached to Chinook salmon and are scheduled to report to satellites in winter/spring 2021.

Spatial distribution

Pop-up locations of tagged Chinook salmon were spread throughout the North Pacific Ocean (Fig. 2). For tags deployed near Chignik, 11 tagged Chinook salmon reported near the Alaska Peninsula, generally east of their initial tagging location. Two other tags reported off the coast of Kodiak. In contrast to these fish that remained in the GOA, three fish demonstrated longer migrations and reported off the coast of Southeast Alaska (n =1) and British Columbia, Canada (n = 2). Displacement (straight-line distance between tagging and pop-up locations) and track distance (curvilinear distance produced from daily location estimates) for fish tagged near Chignik, AK, ranged from 34 to 1,720 km (425±571 km, mean±SD), and 143 to 1764 km (829±492 km, mean±SD), respectively (Table 1; Fig. 3). For tags deployed near Kodiak, reporting locations ranged from east of Kodiak near Seward, Alaska (n = 9), north into Cook Inlet (n = 2), to just southwest of the tagging/release location along the Alaska Peninsula (n = 2). Displacement and track distance for fish tagged near Kodiak, AK ranged from 33 to 477 km (163±117 km, mean±SD), and 35 to 800 km (303±237 km, mean±SD), respectively (Table 1; Fig. 3).

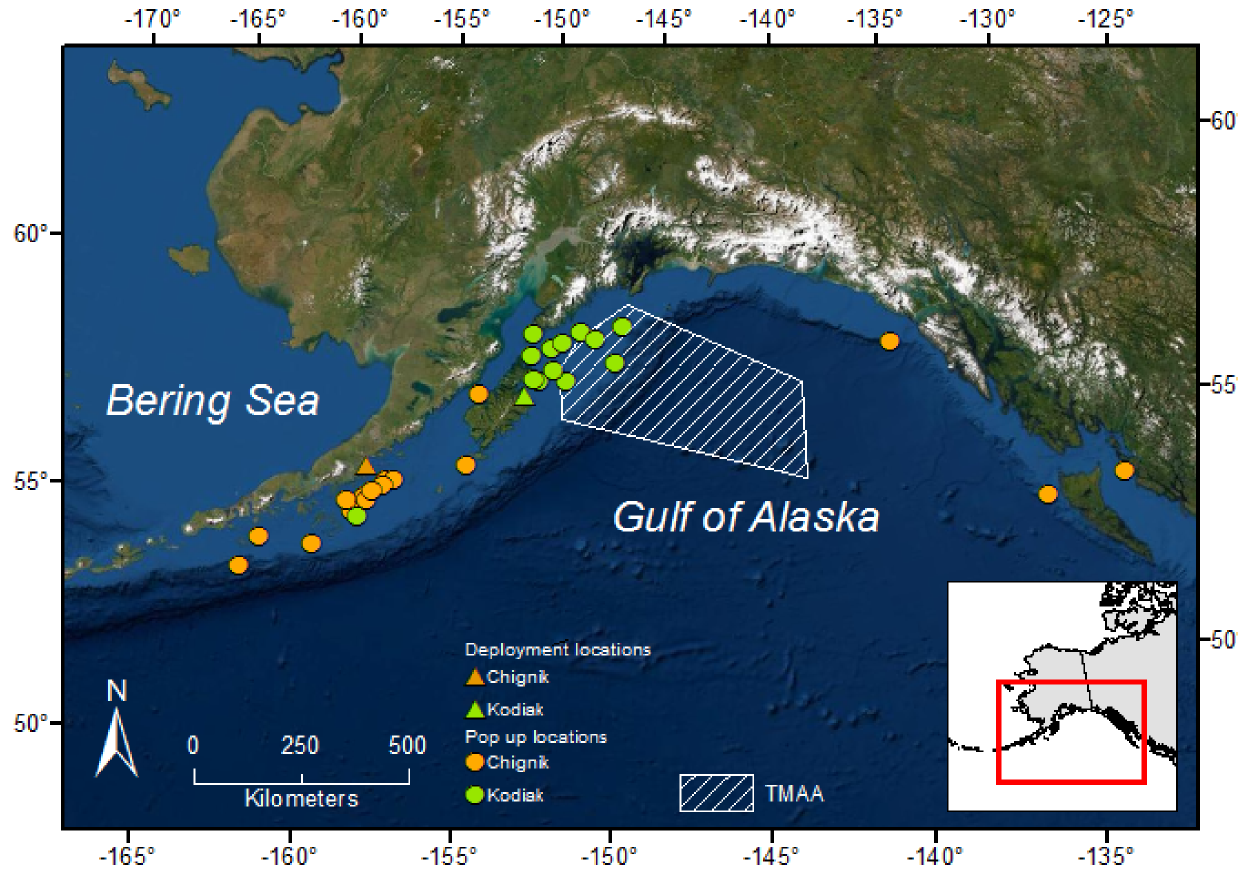

Figure 2. Deployment and end locations of Chinook salmon (n = 29) tagged with pop-up satellite archival tags near Chignik, AK in August 2020 and near Kodiak, AK in October 2020.The U.S. Navy Gulf of Alaska Temporary Maritime Activities Area (TMAA) is denoted. Map inset in lower right hand corner of figure indicates extent of map. Eleven additional tags are still at-liberty and are scheduled to report to satellites in the winter/spring of 2021.

Depth and temperature

Preliminary analyses of depth data revealed that mean depths occupied by individual tagged Chinook Salmon ranged from 22 to 106 m (50±23 m, grand mean ±SD) (Fig. 4). Depth distributions of individual tagged Chinook salmon were highly variable and dives to 100 m were common among most tagged fish. Several tagged fish demonstrated dives to >200 m. While at liberty, mean temperatures experienced by tagged fish ranged from 7 to 11°C (9.1±1.3 grand mean±SD), with tagged fish occupying an overall thermal range of 4–15°C (Fig. 4).

Mortality

Seventeen tags provided evidence that Chinook salmon (70.4±5.3 cm, mean ± SD) experienced predation (Table 2). Of these tags, one provided evidence of predation on an 83 cm Chinook salmon by an ectothermic fish predator whose species could not be determined approximately 60 days after tagging. Fifteen tags provided evidence of predation on Chinook salmon (70.0±4.5 cm, mean±SD) by endothermic fish with an internal temperature of ~25ºC, 11–113 days after tagging. Based on known visceral temperatures and species distribution (Anderson and Goldman 2001; Goldman et al. 2004), these endothermic fish predation events are likely attributed to salmon sharks (*Lamna ditropis*) (Table 2). Finally, one tag provided evidence of predation on a Chinook salmon (69 cm) by a marine mammal with a stomach temperature of ~38ºC, 58 days after tagging. Based on the location of inferred predation event, the occupation of 0 m for up to 12 hrs, and short dive bouts (~10 min), we speculate that this predator was likely a species of pinniped, such as a Steller sea lion *Eumetopias jubatus* (Call et al. 2007; Lander et al. 2011; Trites and Porter 2002). End locations of tags after predation events suggest that consumption of tagged Chinook salmon was geographically widespread (Fig. 5).

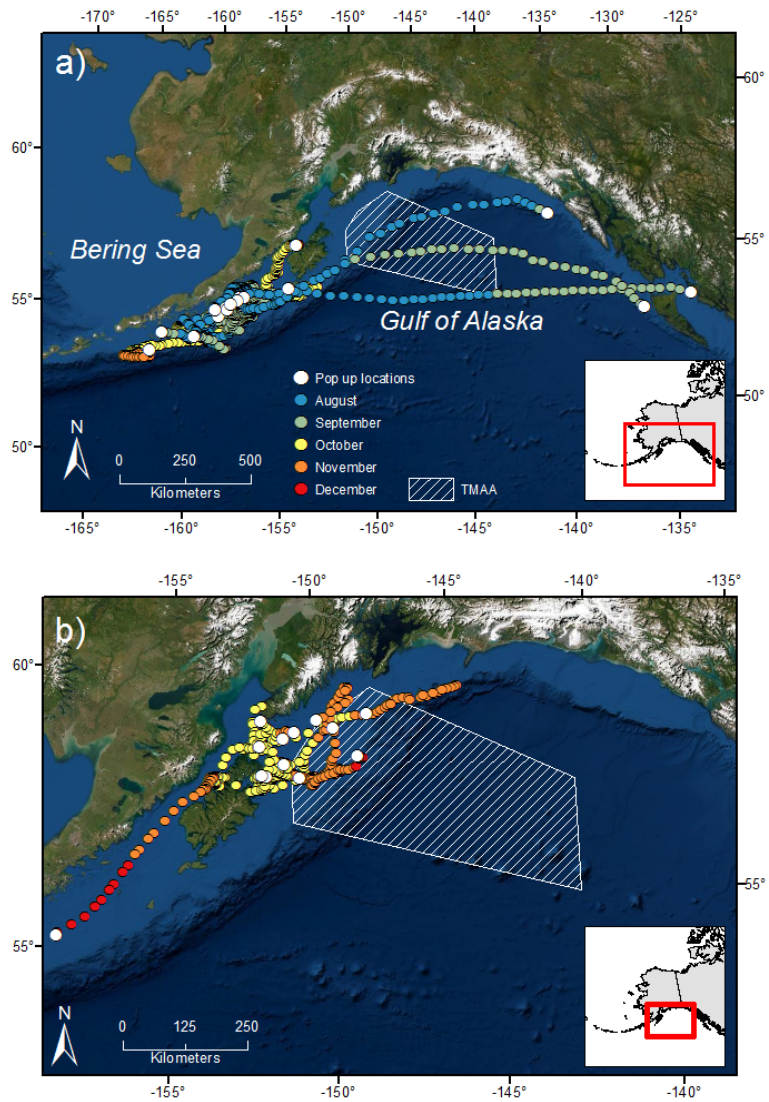

Figure 3. End locations (i.e., "pop-up locations") and most likely movement paths traveled by Chinook salmon (n = 29) tagged near Chignik, AK (a), and Kodiak, AK (b), estimated by a Hidden Markov Model. Estimated daily locations are color coded by month. The U.S. Navy Gulf of Alaska Temporary Maritime Activities Area (TMAA) is denoted. Map insets in lower right hand corners of panels indicate extent of panels.

Genetic analyses of tissue samples

After completing fieldwork, tissue samples were given to project collaborators, Joe Smith and Dave Huff, of NMFS Northwest Fisheries Science Center (NWFSC). The genetics laboratory at NWFSC was impacted by COVID-19 and did not conduct analyses for months, therefore the tissue samples from the tagged Chinook salmon have not yet been analyzed and these fish have not been assigned a natal origin. Analysis is tentatively expected to be completed by late fall of 2021.

Current project status

Data analyses

Currently, we are waiting for 11 PSATs deployed on Chinook salmon near Chignik and Kodiak to transmit depth, temperature, and light data to Argos satellites on their programmed pop-up dates. Once the transmitted data are received, full analyses of light, depth, and temperature data will commence. Additionally, tissue samples from the tagged Chinook salmon will be analyzed at the NWFSC genetics laboratory and the tagged Chinook salmon will be assigned stock-origins.

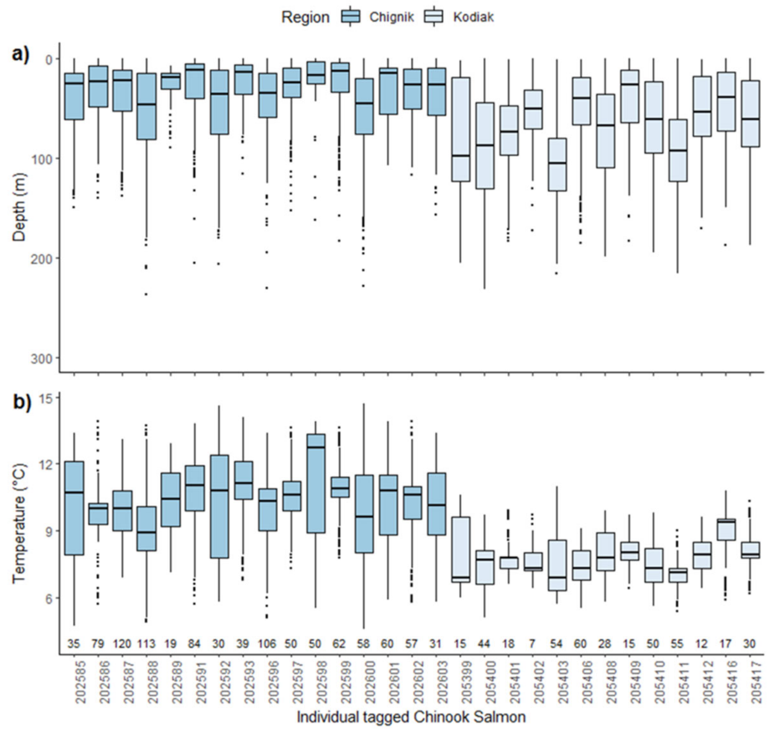

Figure 4. Box and whisker plots of depths and temperatures recorded by pop-up satellite archival tags attached to individual Chinook salmon near Chignik and Kodiak, AK in 2020. Argos ID numbers are included for reference purposes. Data days for each tag are noted above Argos ID numbers in panel b. For boxplots, median diving depths are solid lines, and boxes represent the first and third quartiles. Whiskers represent the largest observation less than or equal to the box, plus or minus 1.5 times the interquartile range, and black dots represent outliers

Table 2. Information on the preliminary inferred fates of 29 individual tagged Chinook salmon in 2020. Eleven additional tags are still at-liberty and are scheduled to report to satellites in the winter/spring of 2021.

Inferred fate of tagged fish	Sample size (n)	Fork Length cm (mean±SD, range)	Chinook salmon data days[a]
Pelagic ectothermic fish predation	1	83	60
Endothermic fish predation	15	70±4 (62–77)	37±10 (11–113)
Marine mammal predation	1	69	50
Unknown fate[b]	12	77±65 (65–101)	43±28 (7–120)
Total	29	72±8 (62–101)	48±30 (7–120)

a) "Data days" refers to the total days of data provided by the tag while attached to a live, free-swimming salmon
b) "Unknown fate" is for tags that released from fish before the programmed pop-up date for unknown reasons and floated on the surface before transmitting to satellites.

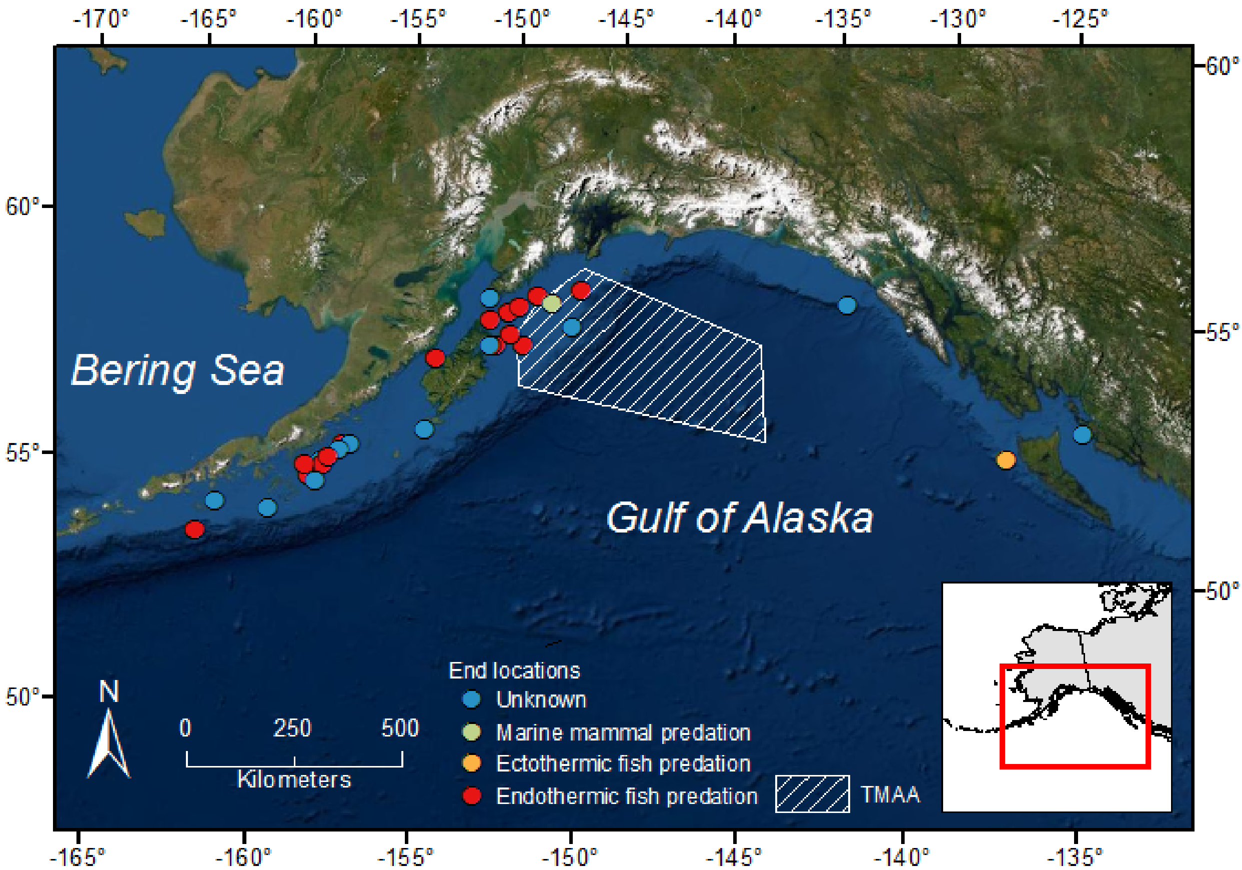

Figure 5. End locations of pop-up satellite archival tags attached to Chinook salmon, color coded by inferred fates. "Unknown" are tags that released from fish before the programmed pop-up date for unknown reasons and floated on the surface before transmitting to satellites. The U.S. Navy Gulf of Alaska Temporary Maritime Activities Area (TMAA) is denoted. Inset in lower right hand corner indicates map extent.

Option Item 2 (Yakutat)

Currently, we are preparing for Option Item 2 of this research project, which is tagging an additional 20 Chinook salmon near Yakutat, AK. The fishing charter has been arranged, a purchase order has been issued by UAF Office of Procurement and Contract Services. PSATs (MiniPATs, Wildlife Computers, Inc.) have been purchased and are scheduled to ship in early February 2021. Upon arrival, tags will be tested and programmed. We are scheduled to conduct fish capture and tagging during 1–30 March 2021 (20 days of fishing, plus weather days). This schedule should also accommodate deployment of acoustic tags on Chinook salmon by project collaborators, if desired. To date, we have not experienced any significant technical, schedule or cost problems, thus we are still on-target to meet our deliverables schedule.

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