North Pacific Anadromous Fish Commission
Bulletin No. 5: 121-130, 2009

Behavior of Yukon River Chinook Salmon in the Bering Sea as Inferred from Archival Tag Data

Robert V. Walker and Katherine W. Myers

*School of Aquatic and Fishery Sciences, University of Washington,
Box 355020, Seattle, WA 98195-5020, USA*

Walker, R.V., and K.W. Myers. 2009. Behavior of Yukon River Chinook salmon in the Bering Sea as inferred from archival tag data. N. Pac. Anadr. Fish Comm. Bull. 5: 121–130.

Abstract: Understanding the vulnerability of Chinook salmon to variability in climate and fishing mortality is complicated by a lack of information on migration and behavior. An archival tag placed on a Chinook salmon in the Bering Sea in 2002 was recovered in the Yukon River in 2004. During eight seasons the fish displayed a wide variety of behaviors. In summer, it was usually within the top 50 m. In the first winter it remained near 125 m, while in the second it remained within the top 50 m. Fall was a transition period between summer and winter, and in spring the fish underwent large (> 340 m) vertical movements. Temperatures experienced by the fish ranged from 1°C to 12°C. A comparison of sea surface temperatures and temperature profiles derived from tag data with oceanographic data indicated the fish was mostly in the central and southern Bering Sea Basin, with part of its second summer and final homeward migration on the eastern Bering Sea shelf. Data from another tag on a maturing Yukon River Chinook salmon indicated it moved directly from the Basin to the Yukon in three weeks. Neither fish spent substantial amounts of time in the area of groundfish fishery operations.

Keywords: Chinook, Bering Sea, Yukon, tags, vertical distribution, temperature, behavior

INTRODUCTION

Chinook (*Oncorhynchus tshawytscha*) and chum salmon (*O. keta*) constitute the overwhelming majority of salmon caught incidentally in U.S. groundfish trawl fisheries, creating economic and social problems for western Alaska communities (Myers and Rogers 1988; Myers et al. 2003, 2004; Berger 2008; NPFMC 2008). Although Chinook salmon are the least abundant of the Pacific salmon in North America, they contributed over 900,000 fish (nearly 50,000 per year) to the Bering Sea trawl bycatch from 1990 to 2008. The vulnerability of Chinook salmon to the trawl fishery is likely due at least partially to the fact that Chinook are the deepest diving of Pacific salmon (Walker et al. 2007).

Western Alaskan Chinook salmon stocks may also be affected by climate change. There is no evidence from tag recoveries that Chinook salmon from the Arctic-Yukon-Kuskokwim (AYK) region of western Alaska leave the Bering Sea (Myers et al. 1996). Current climate model projections indicate that by 2050 mean sea surface temperatures (SSTs) in high latitudes could increase 2°C over 1990 values (IPCC 2001, 2007).

The thermal habitat of the Bering Sea varies greatly with season. During winter, storms create a deep mixed layer of cold water in the open water portions. In spring and summer, cold bottom water from melting ice forms on the eastern shelf, and a dicothermal layer with a minimum temperature around 100–200 m forms in the basin. A warmer stratified layer with a thermocline also develops in summer, both in the basin and on the shelf. Chinook encounter all of these conditions.

Understanding the vulnerability of Chinook salmon to variability in ocean temperature and fishing mortality is complicated by a lack of information on migration and behavior. An archival tag placed on a Chinook salmon in the Bering Sea in 2002 was recovered in the Yukon River in 2004. The data from this tag cover eight seasons of the travels of this fish, and shed important light on the behavior of both immature and maturing Chinook salmon in the Bering Sea. An additional tag covers the homeward migration of a Chinook salmon from the Bering Sea Basin to the Yukon River.

MATERIALS AND METHODS

Tags

Data from two archival tags were analyzed. One tag (1401) was a model LTD_1100-300, a small circuit board potted in a clear urethane, manufactured by Lotek Marine Technologies (www.lotek.com). Model LTD_1100-300 tags are 27- x 16- x 8-mm lozenges, weigh 2 g in water, and record date, time, temperature, and pressure (depth). For this model the pre-set maximum depth from which data could be recorded was 300 m (actually functional to 340 m). The

All correspondence should be addressed to R. Walker.
e-mail: rvwalker@u.washington.edu

other tag (1899) was a DST CTD tag manufactured by Star-Oddi (www.star-oddi.com). Housed in a 46- x 17-mm cylindrical ceramic shell, these tags weigh 13 g in water and record date, time, conductivity (salinity), temperature, and depth data.

Fish were captured for tagging by Japanese research vessels in 2002 and 2006 in the eastern part of the central basin of the Bering Sea (Fig. 1). The Chinook salmon carrying tag 1401 (hereafter, "fish 1401") was caught with longline gear on 7 July 2002 (Alaska Daylight Time) at 56°30´N, 179°00´W. At tagging, the fork length of the fish was measured as 562 mm. The age of the fish was determined from a scale as 1.2 (1 winter in fresh water, 2 winters at sea). The tag was attached to the fish just anterior to the dorsal fin using two 76-mm stainless steel pins, with labeled U.S. and Japanese plastic disk tags placed on the pins on the other side of the fish. The fish carrying tag 1899 ("fish 1899") was caught by trawl on 6 June 2006 at 54°50´N, 175°08´W. The fork length of the fish at tagging was 850 mm. The tag was attached to the fish in the same body location, but was affixed with stainless steel wire and a small oval plastic plate on the opposite side of the fish.

Both fish were recaptured in fisheries in the Yukon River (Fig. 1). Fish 1401 was captured 72 km upstream from Kotlik, Alaska on 21 June 2004. Fish 1899 was captured at Mountain Village, Alaska on 30 June 2006. Tag 1401 contained 16,246 data points for both temperature and depth for the period the fish was at liberty; data were collected at 1-h (15,336 points) and 2-h (910 points) intervals. Tag 1899 contained 4,012 data points each for temperature, depth, and salinity for the time the fish was at liberty, collected at 8-min intervals.

Sources of Oceanographic Data and Data Analysis

To determine the ocean location of tagged fish after release, temperature and depth data from the tags were compared with oceanographic data from several sources in addition to published information. MODIS satellite data provided images with estimates of sea surface temperatures (SST) throughout the year (oceancolor.gsfc.nasa.gov/cgi/l3). Temperature data from tags were screened for surface (less than 5 m depth) values (for some periods, fish 1401 was not within 5 m of the surface). Surface temperatures from tags were often relatively constant for several days to over a week. Surface temperature values were visually compared to images from corresponding dates (Aqua sea surface temperature sensor, 11 μ nighttime, eight-day composite, nine-km resolution). Data from Argo floats in and near the Bering Sea yielded temperature-depth profiles, primarily in the eastern basin (floats.pmel.noaa.gov). Profile data were compared to data from tags. The Pacific Marine Environmental Laboratory (PMEL, National Oceanic and Atmospheric Administration) provided data collected from four moorings

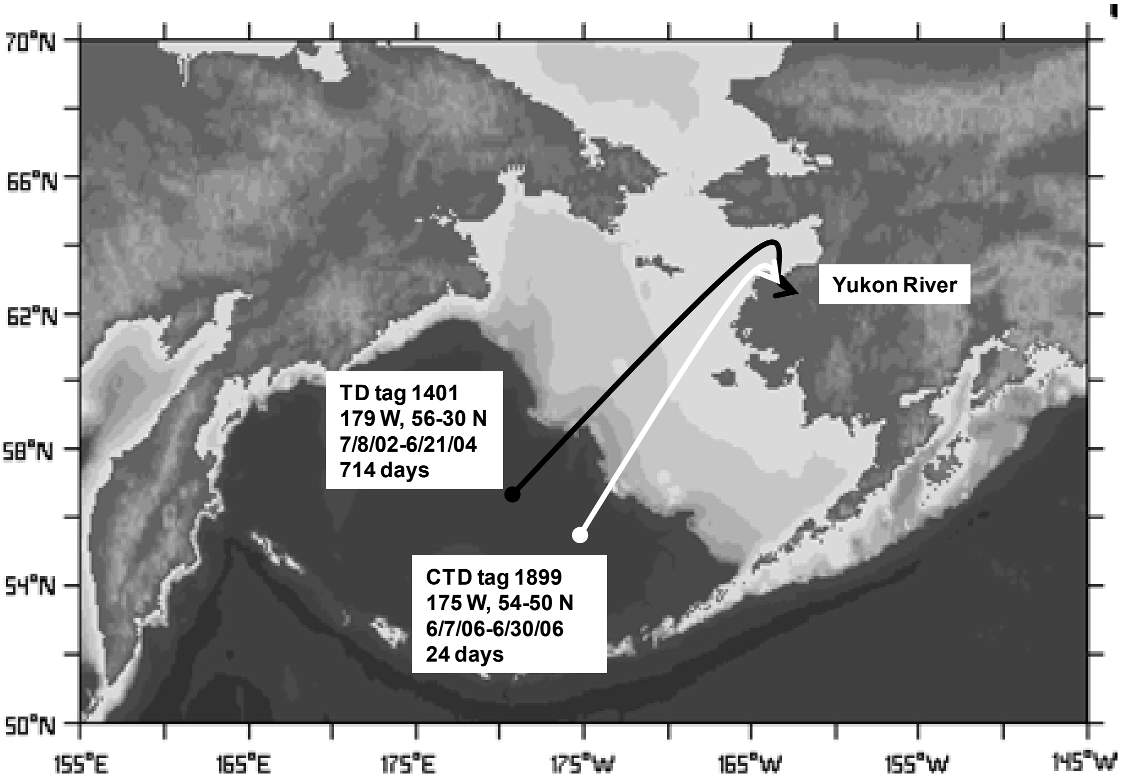

Fig. 1. Tagging and recovery locations of two Yukon River Chinook salmon tagged with archival tags in the Bering Sea. (Base map modified from a map on the PMEL website: http://www.pmel.noaa.gov/np/pages/seas/bseamap2.html).

on the eastern Bering Sea shelf: M2 (56.9°N, 164.1°W), M4 (57.9°N, 168.9°W), M5 (59.9°N, 171.7°W) and M8 (62.2°N, 174.7°W) (P. Stabeno and D. Kachel, pers. comm. Phyllis.Stabeno@noaa.gov and Dave.Kachel@noaa.gov). Only M2 and M4 collected data in 2002–2004. Temperature-depth profiles were constructed from mooring sensor data for dates of interest, and these were compared to tag data.

RESULTS

Fish 1401 underwent major changes in behavior during the two years it was at large (Fig. 2). In summer 2002, temperature/depth profiles (compiled from data on the tag) in the two months following tagging were similar to those from the tagging vessel and Argo floats in the Bering Sea Basin (Fig. 3). They did not match data from moorings in the eastern Bering Sea shelf, or sea surface temperatures as measured by satellite for most other regions of the Bering Sea. Beginning in October 2002, the fish began an overall descent in the water column that culminated in its remaining at approximately 125 m depth during the winter, until it gradually returned to surface waters in March 2003 (Fig. 4A). Because the fish remained at a constant depth well below the surface, it was not possible to construct temperature profiles or compare data to SSTs. However, the fish experienced near-constant water temperatures of 4°C at 125 m, a relatively warm temperature for the Bering Sea in winter at that depth. Temperatures of 4°C were not recorded by moorings on the eastern Bering Sea shelf or by Argo floats in the Bering Sea Basin north of about 54°N. However, moorings in the Aleutian Islands did record 4°C temperatures at depths of 142–453 m in Tanaga and Amukta passes in the winter of 2002–2003, and similar temperatures at Seguam Pass at 145–154 m in the winter of 2001–2002 (Stabeno et al. 2005).

In spring (April 2003) fish 1401 undertook a series of movements between the surface and 350 m (maximum depth the tag was capable of recording) or more (Fig. 5A). The deep vertical movements by the fish in April 2003 indicate the fish was either in the Bering Sea Basin or near the shelf break. In summer 2003 temperature profiles show three different patterns, roughly June, July, and August (Figs. 6 and 7). In all periods the water column is highly stratified with a sharp thermocline around 20–40 m. In June and August temperatures below the thermocline were 3°–4°C, while in July temperatures were 1°–2°C. Maximum depths were about 140 m in June and July, but below 300 m in August. It appears the fish moved from the basin onto the eastern Bering Sea shelf in June and moved off again later in August. The coldest (1°–2°C) waters at relatively shallow depths (40–80 m) in July were typical of the "cold pool" on the eastern Bering Sea shelf south of St. Lawrence Island, and found around 60° N in 2003 (Schumacher et al. 1983; Stabeno et al. 2001; Wang et al. 2007). Temperatures at mooring M2 (56.9°N) on the shelf (Fig. 7A) during June and August are similar to those on the tag, but in July deepwater temperatures are warmer (3.3°C), as are deep temperatures at mooring M4

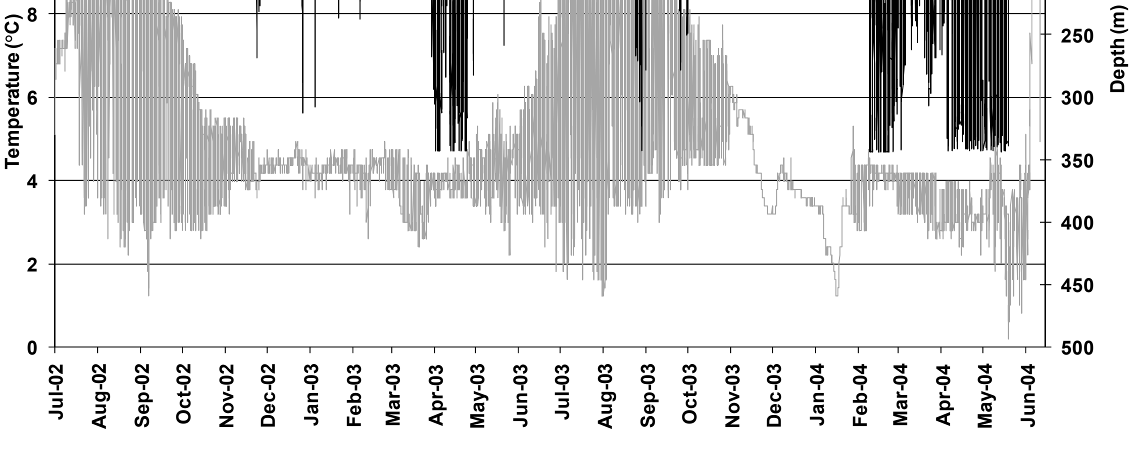

Fig. 2. Temperature (gray) and depth (black) data record from tag 1401 on a Chinook salmon tagged at 56°30´N, 179°00´W in the Bering Sea on 2 July 2002 and recovered near Kotlik, Alaska, in the Yukon River on 16 June 2004. Maximum depth the tag could record was 340 m.

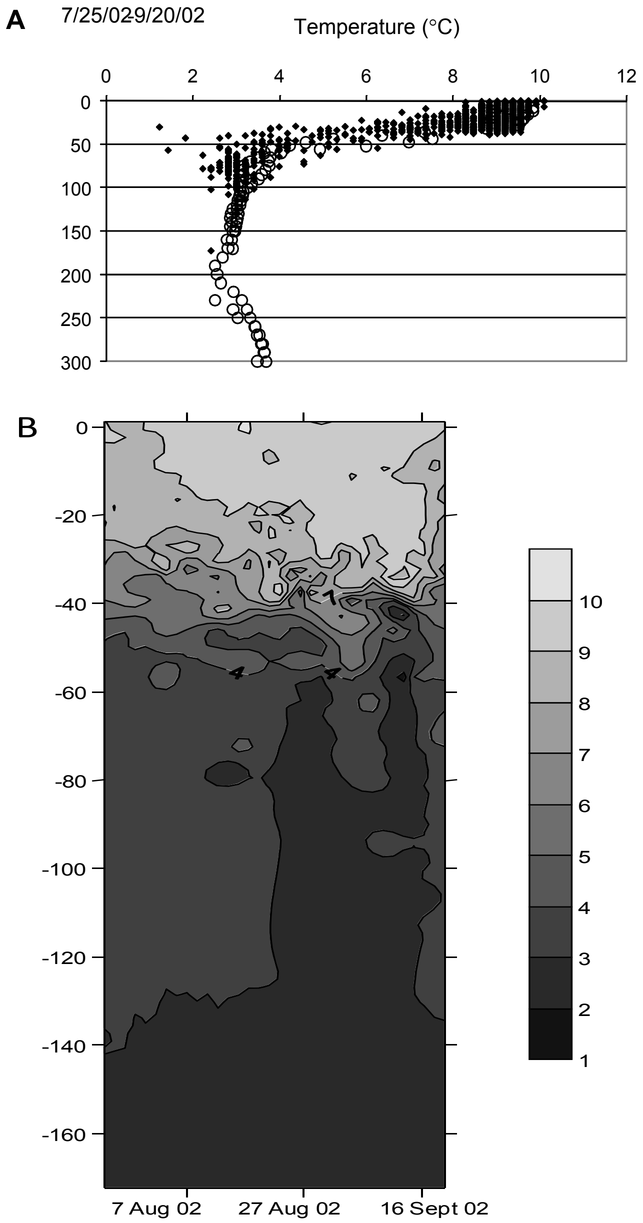

Fig. 3. Temperature-depth profiles from tag 1401 on a Chinook salmon in the Bering Sea in summer 2002. In (A) solid marks are data from tag, 25 July – 20 September; open circles are data from PMEL Argo float 11490, 26 July 2002 at 176.058° W, 57.072° N and 5 August 2002 at 175.889° W, 56.693° N. (B) includes data from the tag only and shows changes in the temperature-depth profile over time.

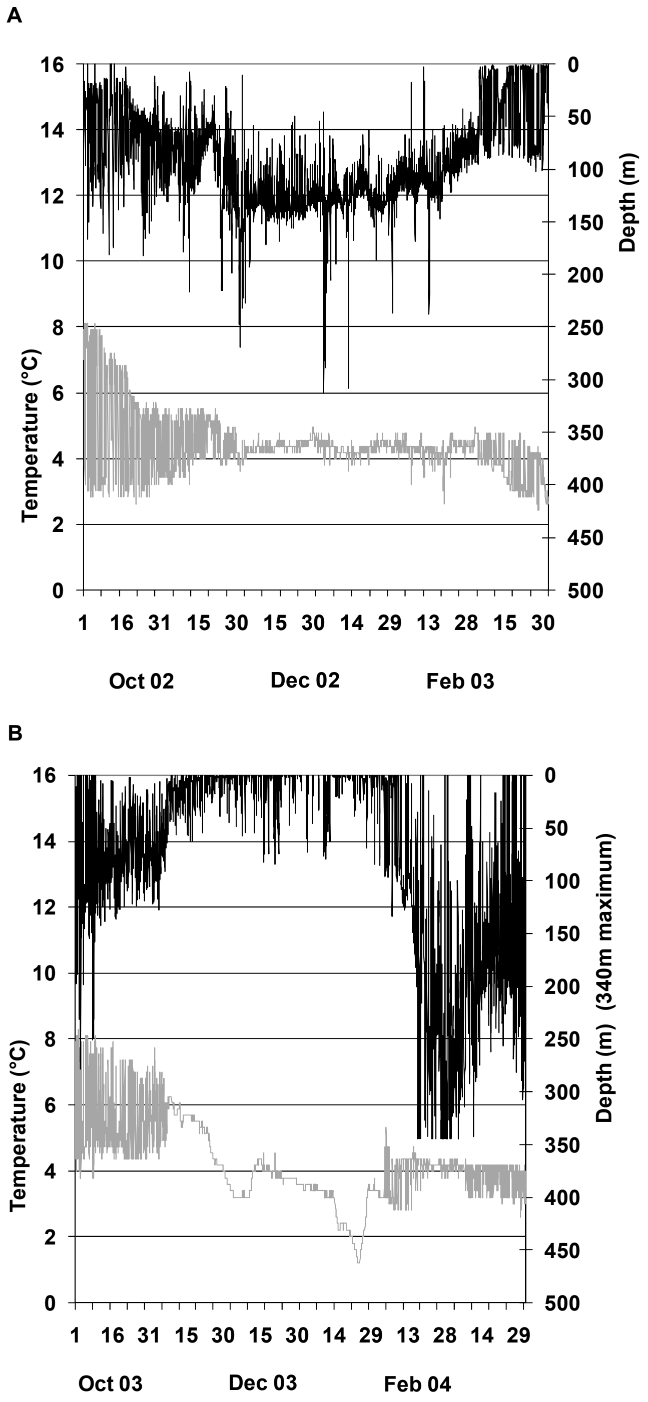

Fig. 4. Temperature (gray) and depth (black) data records from tag 1401 on a Chinook salmon tagged in the Bering Sea for (A) winter 2002-2003 and (B) winter 2003-2004. Maximum depth tag could record was 340 m.

further north (57.9°N; temperature of 2.9°C). Fish 1401 was likely both further north and farther toward the edge of the shelf. Maximum depths on the tag were greater than 80 m, while the maximum sensor depths of M2 and M4, near the bottom, are 62 m and 67 m, respectively.

As autumn approached in 2003 fish 1401 did not substantially change its vertical behavior, remaining mostly above 100 m (Fig. 4B). Surface temperatures gradually declined and daily temperature ranges decreased. In early November, temperature ranges abruptly changed to a single temperature (6°C) at all depths recorded by the tag (down to 70 m), presumably following a storm that mixed waters to at least that depth. In contrast to the previous winter, the fish continued moving between the surface and relatively shallow (50–70 m) depths. Temperatures dropped over the

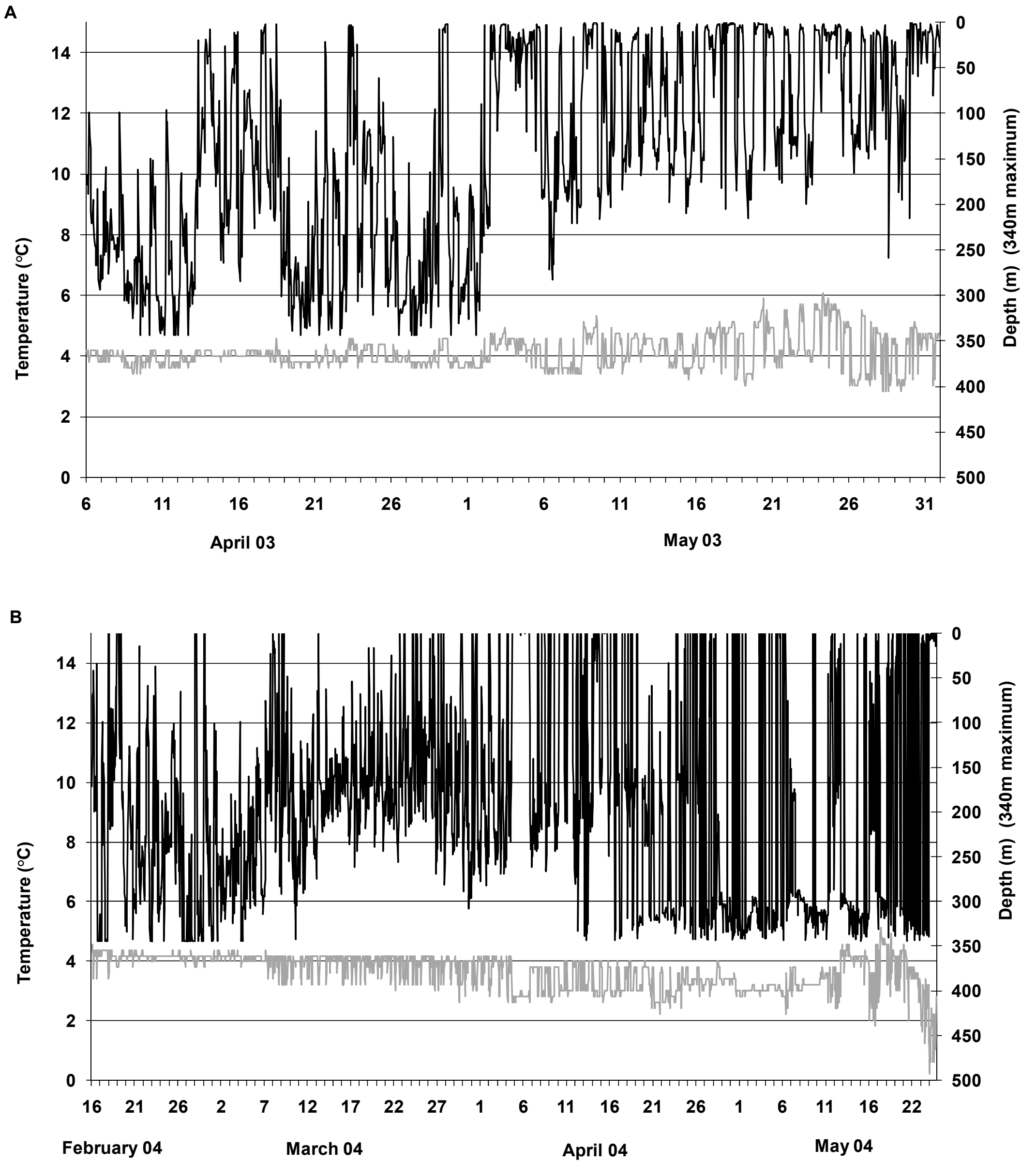

Fig. 5. Temperature (gray) and depth (black) data records from tag 1401 on a Chinook salmon tagged in the Bering Sea for deep diving periods in (A) spring 2003 and (B) late winter and spring 2004. Maximum depth the tag could record was 340 m.

course of the winter, reaching 1.2°C in January 2004. While temperatures were uniform with depth, precluding construction of informative profiles, SSTs were similar to those from satellite imagery in the southern and central portions of the Bering Sea, but were warmer than the range of SSTs in the western, northern, or eastern portions of the Bering Sea.

In late winter and spring of 2004 the fish resumed the deep vertical movements it made in spring 2003, indicating the fish was in the Bering Sea Basin or near the shelf break (Fig. 5B). During this period there are intervals when the fish does not return to the surface, though generally the fish is moving between the surface and depths of over 340 m. As in 2003 there is a relatively small temperature range (2.5°–4.4°C) despite the large range of depths. In February the fish was encountering temperatures of about 4°C even at depth. Again, these temperatures match those in the southern Bering Sea just north of the eastern Aleutians. After three months of this behavior, it abruptly ceased deep vertical movement on 26 May. Later on this day it encountered its coldest temperatures of 0.2°–1.8°C at depths of about 20 m. This may be the edge of the cold pool, which in 2004 was north of about 58°N. At this point the fish had begun its return to the Yukon, which it reached around 12 June. During this 17-day journey the fish was mostly above 30 m and temperatures were mostly 2°–4°C.

For most of the period fish 1401 was at liberty it showed

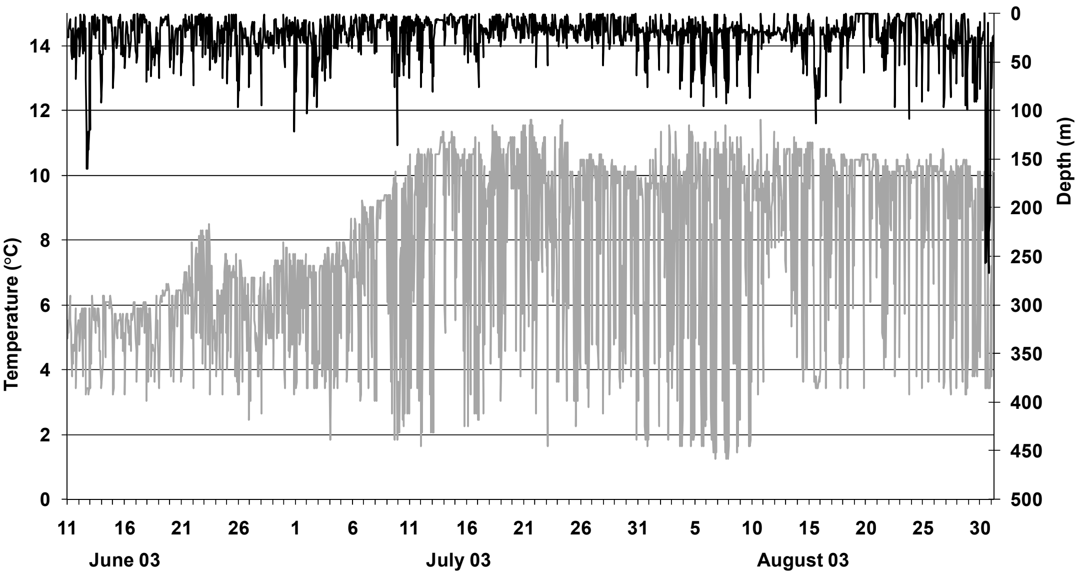

Fig. 6. Temperature (gray) and depth (black) data records from tag 1401 on a Chinook salmon tagged in the Bering Sea for summer 2003.

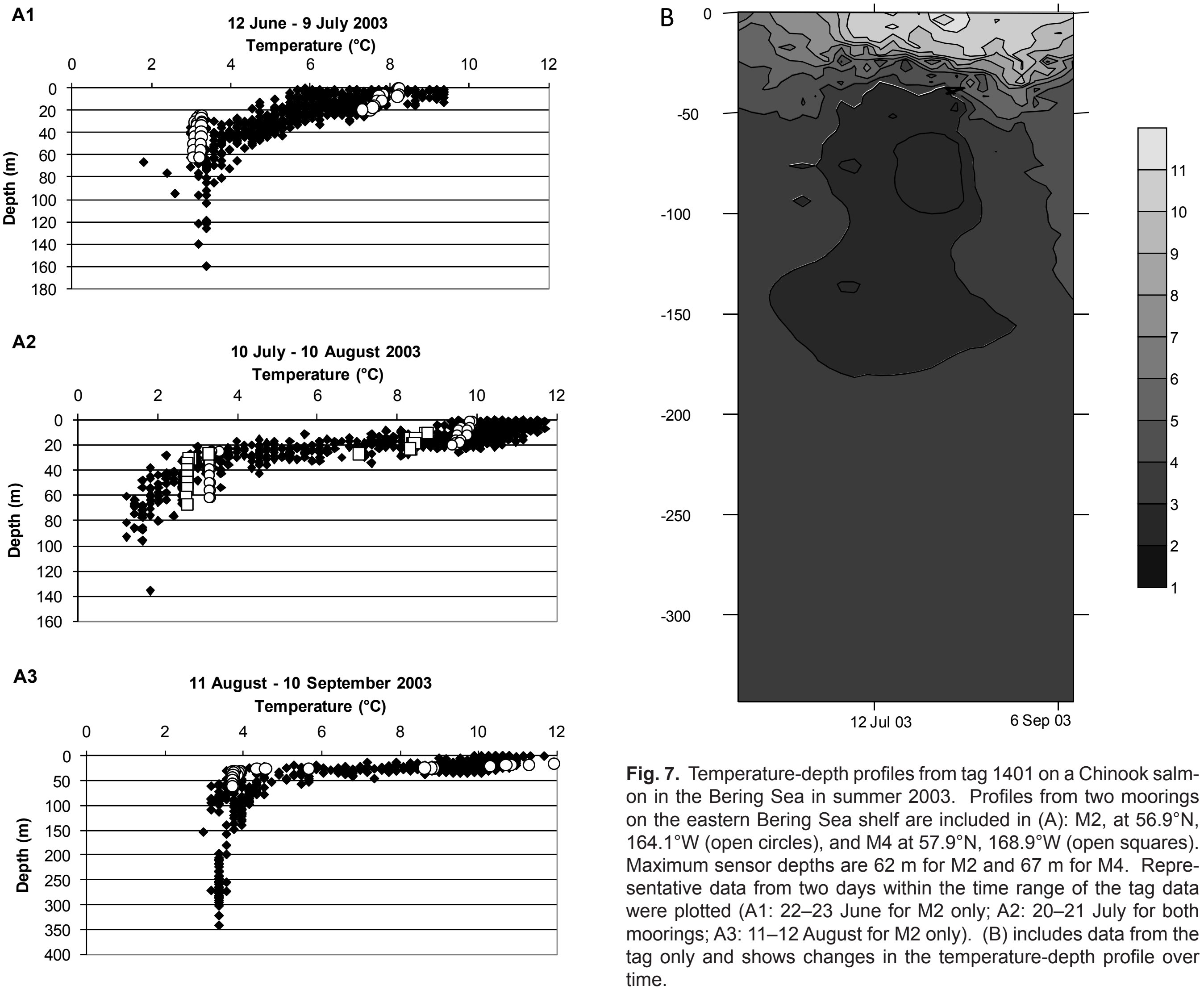

Fig. 7. Temperature-depth profiles from tag 1401 on a Chinook salmon in the Bering Sea in summer 2003. Profiles from two moorings on the eastern Bering Sea shelf are included in (A): M2, at 56.9°N, 164.1°W (open circles), and M4 at 57.9°N, 168.9°W (open squares). Maximum sensor depths are 62 m for M2 and 67 m for M4. Representative data from two days within the time range of the tag data were plotted (A1: 22–23 June for M2 only; A2: 20–21 July for both moorings; A3: 11–12 August for M2 only). (B) includes data from the tag only and shows changes in the temperature-depth profile over time.

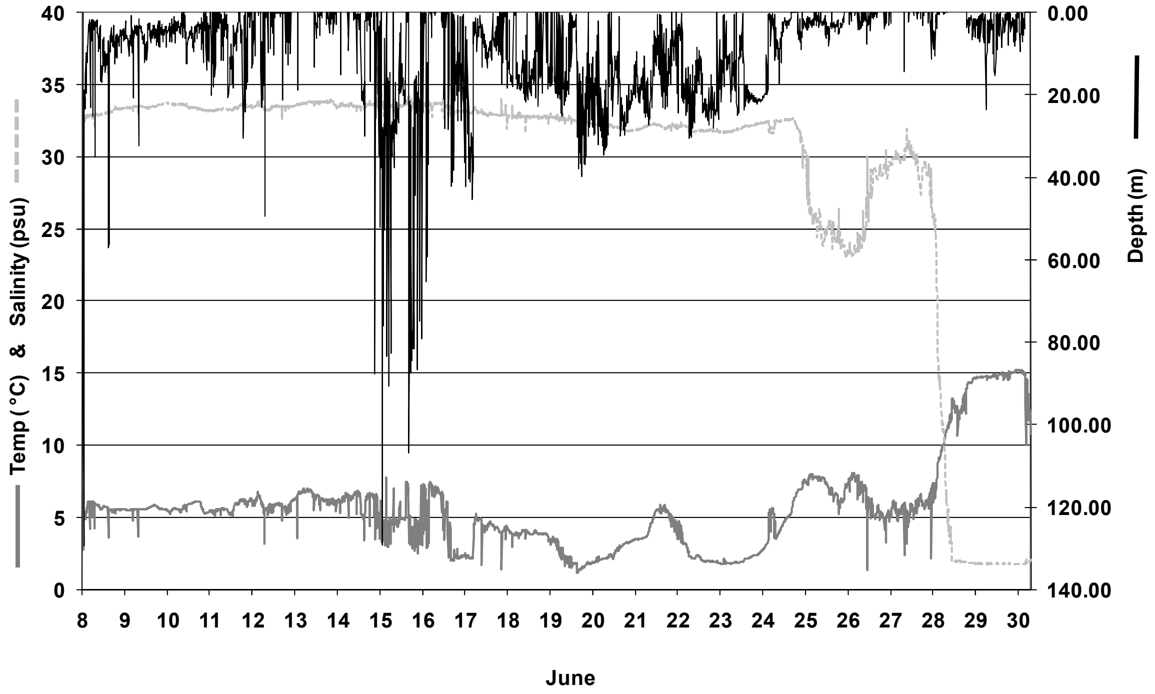

Fig. 8. Temperature (medium gray), depth (black), and salinity data (light gray, dotted line) record from tag 1899 on a Chinook salmon tagged at 54°50´N, 179°00´W in the Bering Sea on 7 June 2006 and recovered near Mountain Village, Alaska, in the Yukon River on 30 June 2006.

diel behavior patterns, with the exception of the deep diving periods of late winter and early spring. However, these patterns differed with season. In summer the fish was nearer the surface at night and moved deeper during the day. During the first autumn transition the fish remained about 25 m below the surface at night but initially made small upward vertical movements during the day, coming to the surface, and later made larger vertical movements down to 100 m. In the first winter, the fish remained at about 125 m during the night, and made small (to 50 m) vertical movements toward the surface during the day. In the second winter, fish 1401 remained near the surface, making small (40 m) movements downward during the day. During the deep dive periods of late winter and spring, there was no apparent diurnal pattern.

Fish 1899 was at liberty only 24 days after tagging. Data from tag 1899 show the fish at depths less than 40 m until it reached the mouth of the Yukon River, except for two days midway through the journey when it made dives to 100 m (Fig. 8). Temperatures ranged from 6°C to 8°C. The fish covered a minimum of 1040 km (great circle distance) in the 22 days until it entered the Yukon (as indicated by a sharp drop in salinity), implying a minimal travel rate of 1.96 km/h (0.64 body lengths/s). Given the distance and necessary rate of travel, it is likely this fish moved in a relatively direct line from the tagging location to the Yukon.

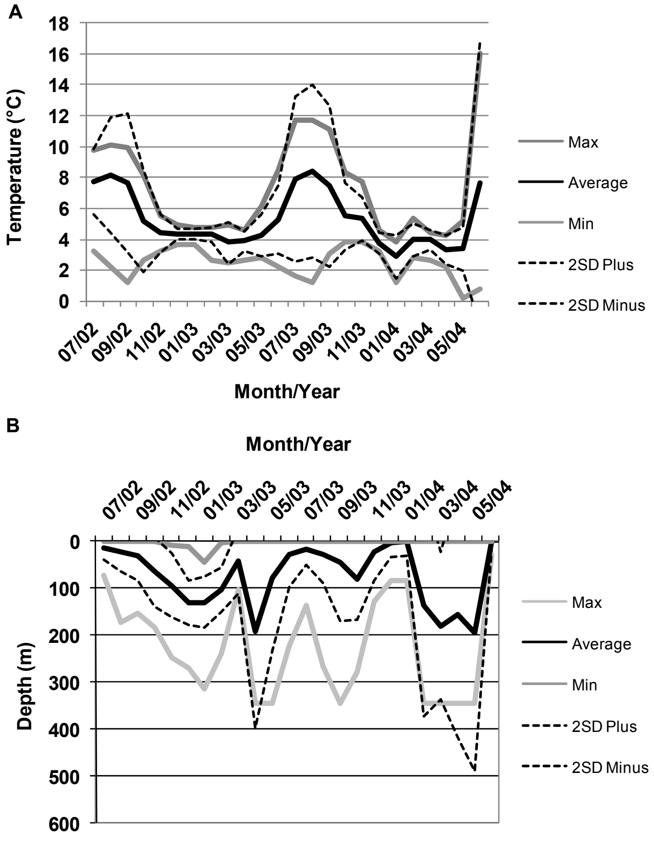

Fig. 9. Temperature and depth variation for data from tag 1401. Averages and standard deviations were calculated as means of monthly values and deviations from the monthly means. Positive value deviations for depth were constrained to zero for plotting.

DISCUSSION

The most striking feature of the data from tag 1401 is the great variability in the fish's behavior leading to large differences in the temperatures the fish experienced (Figs. 2, 9). The behavior varied between seasons and even between the same season in different years. The general pattern seemed to be one of high variance in depth but not temperature in winter and spring, when the water column is more homogeneous due to cooling and mixing, and large variance in temperature but not depth in summer and fall, due to much shallower dives through highly stratified surface waters.

Fish 1401 moved below the shallow (less than 40 m) thermocline to cooler waters below in the summer. There is a diurnal pattern to the movement, as seen in many species of Pacific salmon (Walker et al. 2000, 2007), where the fish is near the surface at night and makes occasional deeper vertical movements during the day. This may be related to feeding, with fish feeding on organisms that come to the surface at night, and moving deeper during the day to search for food or as a thermoregulatory behavior (Azumaya and Ishida 2005).

A diurnal pattern of dives continued through both winters, but was not as pronounced as in summer and fall. In the first winter, the pattern was reversed, with the fish moving toward the surface during the day. The average depth in the first winter increased, perhaps to avoid the cold turbulent surface waters and perhaps for feeding on other organisms at that depth. Water temperatures at that depth were warmer than the surface and may have been more optimal for growth. In the second winter, before it returns to spawn, the fish was much shallower, in surface waters (less than 50 m). Having obtained sufficient size to spawn, perhaps it was more important to position closer to its home river than to feed extensively or put on more somatic growth. The colder surface waters would also conserve energy.

One puzzling and dramatic feature of the behavior of fish 1401 was the very deep periodic dives undertaken in late winter and spring. The frequency and constancy with which the dives occur over a period of time, and at only one period of the year, make it unlikely that they are to escape predators. The behavior occurs in years both as an immature and a maturing fish, so is not likely a feature of maturation or sensing a migratory path. The dives are quite possibly related to feeding. In late winter and early spring, some fish and squid prey species may be overwintering at depth to avoid predation, because there is less food at the surface before development of the spring phytoplankton bloom and the zooplankton that feed on it. The diet of Chinook salmon caught deeper than 200 m in trawl fisheries in the winter is almost entirely squid; fish at shallower depths fed on a mixture of euphausiids, discarded fish offal, squid, and fish (Davis et al. 2009). If food is more abundant at depth, why didn't fish 1401 simply remain there? Perhaps Chinook have difficulty enduring the continual pressure, or perhaps there is a small thermoregulatory benefit from the slight temperature differences between the surface and deeper waters. The fish reached depths over 300 m, and although at this season the mixed layer was very deep and temperatures were relatively uniform with depth, temperatures at depth were sometimes 1°C higher than at the surface, indicating that this was below the mixed layer; later in the spring, surface temperatures were slightly warmer. Thus although the temperature variation was small and the fish did not remain deep, thermoregulatory behavior cannot be ruled out.

Detailed information on behavior of Chinook salmon has come from other archival tags on fish off the coasts of southeastern Alaska and California. Chinook tagged by Murphy and Heard (2001, 2002) exhibited a wide range of behaviors, e.g., some fish remained near the surface at night and were deeper (40 m) during the day, some fish reversed this pattern, and some had mixed or no apparent patterns. Similarly, Hinke et al. (2005a) saw no consistent diel pattern but described four different patterns of vertical distribution in data from 15 Chinook salmon off northern California and southern Oregon: a shallow night pattern around 10 m; a shallow day pattern at 0–80 m; a deep (mostly night) pattern around 55 m; and a deeper pattern around 100 m (60–280 m). Data from two fish that overwintered at sea showed a seasonal shift in depth, with fish in the upper 150 m in fall and on average at 200 m in winter (rarely shallower than 100 m) (Hinke et al. 2005b). Data from fish at liberty in all months demonstrated a strong preference for waters between 8°C and 12°C throughout the year. They proposed that variation in depth use across individuals was probably due to thermoregulatory behaviors related to changes in local thermal conditions, while the seasonal cycle in depth use was regulated by bioenergetic needs (loss of surface productivity during winter drove the fish to seek prey resources at greater depths). Azumaya and Ishida (2005) also concluded that vertical movements played an important role in maintenance of an advantageous body temperature in chum salmon migrating from the Bering Sea to Japan.

The temperature preference of the California Chinook salmon was in marked contrast to the temperatures experienced by fish 1401 (1–11°C, excluding the final few days before entering the Yukon). Fish 1401 spent most of its time at temperatures below 8°C, except for summers. At another extreme, Wurster et al. (2005) used oxygen isotopes to estimate temperatures inhabited by Chinook salmon in Lake Ontario, and found that these fish inhabited waters of 19–20°C for up to two months during the summer. Otoliths cannot resolve features as fine as daily vertical movements, but clearly these fish tolerated much warmer temperatures than those off of California and Oregon or in the Bering Sea. Winter temperatures could not be determined, due to lack of otolith growth in that season, but May and November temperatures were below 10°C. The overall seasonal cycle of temperatures looked much like an annual cycle of water temperatures.

The Chinook tagged by Hinke et al. seem to have remained along the California and Oregon coast. Chinook caught incidentally by commercial trawl operations off the Washington, Oregon, and California coasts were found from the surface to 482 m (Erickson and Pikitch 1994). Few were caught in summer, mostly above 220 m; catches were larger and deeper (100–482 m) in winter. Russian trawl fisheries captured Chinook salmon incidentally on the northwestern Bering Sea shelf at depths to 360 m throughout the year, with the majority (90%) at 50 to 400 m (Radchenko and Glebov 1998a, b). In 1997–2000 over 90% of the eastern Bering Sea groundfish trawl Chinook bycatch was caught at fishing depths between 25 m and 175 m; less than 3% were deeper than 300 m. In the winter depth distribution showed a bimodal tendency, with the bulk of fish at 25–75 m and a smaller peak at 200–300 m (Walker et al. 2007). Chinook were slightly deeper in autumn than winter in both the U.S. and Russian trawl fisheries.

Most of the bycatch of Chinook by the eastern Bering Sea trawl fishery has been concentrated along the shelf break, especially just north of the easternmost Aleutian Islands ("horseshoe area"). This pattern closely follows that of fishing effort by the fleet (NPFMC 2008). The locations we have inferred from the data on tag 1401 do not overlap the fishing areas to a great degree except for the first winter, which may be near the horseshoe area. Neither do catch locations of Chinook by the Japanese mothership salmon fishery (1952–1992) which was restricted to basin waters (Major et al. 1978; Major 1984) or catches by research vessels in the central Bering Sea. Bugaev and Myers (2009) found that while Chinook salmon were sparsely distributed in the western Bering Sea, scale pattern estimates of immature fish of North American (Alaska) origin were consistently greater than those of Asian (Russia) origin, indicating that this area is an important summer–autumn foraging area for North American as well as Asian stocks. Thus it is not clear if trawl bycatch concentrations are actually concentrations of Chinook salmon or merely the result of fishing effort. In the winter of 2002–2003 fish 1401 was very likely near the Aleutian Islands in the southeastern Bering Sea (4°C temperatures at 125 m), and if other Chinook salmon choose this area, it could account for some of the bycatch in the horseshoe area. The water column through the passes is well-mixed by strong tidal currents, and northward transport provides an important source of nutrients to the Bering Sea (Stabeno et al. 2005). Chinook may seek the horseshoe area as both an area of high productivity and a thermal refuge.

The future of Chinook salmon in the Bering Sea is uncertain. Their low abundance and use of deeper habitat makes them susceptible to trawl fisheries. The geographical range of Chinook salmon is large, stretching from central California to the northern Bering Sea, and there are transplanted populations in the Great Lakes, New Zealand, and Chile. Studies of behavior and thermal habitat in several areas demonstrate a wide variety of behavior and thermal tolerances. This great flexibility gives some cause for optimism that they can adapt to changing oceanographic conditions.

ACKNOWLEDGMENTS

Many thanks to Phyllis Stabeno, Dave Kachel, and Sigrid Salo of the Pacific Marine Environmental Laboratory/NOAA (PMEL) for provision of oceanographic data and assistance in formatting it. We also thank Jim Ianelli of the Alaska Fisheries Science Center, National Marine Fisheries Service, NOAA, for information on Chinook bycatch in the eastern Bering Sea trawl fisheries. One tag was purchased by the Auke Bay Laboratory of the National Marine Fisheries Service, NOAA, which also supported scientists who tagged both fish. A grant from the North Pacific Research Board to NPAFC was used to purchase the other data tag. We thank the scientists and crew of the *Wakatake maru* and *Kaiyo maru* for their assistance in tagging the fish, and give our deep appreciation to the fishermen who returned the tags. Preparation of this paper by R. Walker and K. Myers was funded by award #NA04NMF4380162 from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, administered by the Alaska Department of Fish and Game for the Arctic-Yukon-Kuskokwim Sustainable Salmon Initiative (http://www.aykssi.org/). The statements, findings, conclusions, and recommendations are those of the authors and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration, the U.S. Department of Commerce, or the Alaska Department of Fish and Game.

REFERENCES

Azumaya, T., and Y. Ishida. 2005. Mechanism of body cavity temperature regulation of chum salmon (*Oncorhynchus keta*) during homing migration in the North Pacific Ocean. Fish. Oceanogr. 14: 81–96.

Berger, J.D. 2008. Incidental catches of salmonids by U.S. groundfish fisheries in the Bering Sea/Aleutian Islands and the Gulf of Alaska, 1990–2008. N. Pac. Anadr. Fish Comm. Doc. 1104. 10 pp. (Available at www.npafc.org).

Bugaev, A.V., and K.W. Myers. 2009. Stock-specific distribution and abundance of immature Chinook salmon in the western Bering Sea in summer and autumn 2002–2004. N. Pac. Anadr. Fish Comm. Bull. 5: 87–97. (Available at www.npafc.org).

Davis, N.D., K.W. Myers, and W.J. Fournier. 2009. Winter food habits of Chinook salmon in the eastern Bering Sea. N. Pac. Anadr. Fish Comm. Bull. 5: 243–253. (Available at www.npafc.org).

Erickson, D.L., and E.K. Pikitch. 1994. Incidental catch of chinook salmon in commercial bottom trawls off the U.S. West Coast. N. Am. J. Fish. Manage. 14: 550–563.

Hinke, J.T., D.G. Foley, C. Wilson, and G.M. Watters. 2005b. Persistent habitat use by Chinook salmon *Oncorhynchus tshawytscha* in the coastal ocean. Mar. Ecol. Prog. Ser. 304: 207–220.

Hinke, J.T., G.M. Watters, G.W. Boehlert, and P. Zedonis. 2005a. Ocean habitat use in autumn by Chinook salmon in coastal waters of Oregon and California. Mar. Ecol. Prog. Ser. 285: 181–192.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. [Watson, R.T., and the Core Writing Team (eds.)] Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA. 398 pp.

IPCC (Intergovernmental Panel on Climate Change). 2007: Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R.K and Reisinger, A. (eds.)]. IPCC, Geneva, Switzerland. 104 pp.

Major, R.L. 1984. Yield loss of western Alaska chinook salmon resulting from the large catch by the Japanese salmon mothership fleet in the North Pacific Ocean and Bering Sea in 1980. N. Am. J. Fish. Manage. 4: 414–430.

Major, R.L. J. Ito, S. Ito, and H. Godfrey. 1978. Distribution and origin of chinook salmon (*Oncorhynchus tshawytscha*) in offshore waters of the North Pacific Ocean. Int. N. Pac. Fish. Comm. Bull. 38: 1–54.

Murphy, J.M., and W.R. Heard. 2001. Chinook salmon data storage tag studies in Southeast Alaska, 2001. N. Pac. Anadr. Fish Comm. Doc. 555. 21 pp. (Available at www.npafc.org).

Murphy, J.M., and W.R. Heard. 2002. Chinook salmon data storage tag studies in Southeast Alaska, 2002. N. Pac. Anadr. Fish Comm. Doc. 632. 16 pp. (Available at www.npafc.org).

Myers, K.W., and D.E. Rogers. 1988. Stock origins of Chinook salmon in incidental catches by groundfish fisheries in the Eastern Bering Sea. N. Am. J. Fish. Manage. 8: 162–171.

Myers, K.W., R.V. Walker, J.L. Armstrong, N.D. Davis, and W.S. Patton. 2004. Stock origins of Chinook salmon in incidental catches by groundfish fisheries in the eastern Bering Sea, 1997–1999. N. Pac. Anadr. Fish Comm. Tech. Rep. 5: 74–75. (Available at www.npafc.org).

Myers, K.W., R.V. Walker, J.L. Armstrong, and N.D. Davis. 2003. Estimates of the bycatch of Yukon River Chinook salmon in U.S. groundfish fisheries in the eastern Bering Sea, 1997–1999. Final Report to the Yukon River Drainage Fisheries Association, Contr. No. 04-001. SAFS-UW-0312, School of Aquatic and Fishery Sciences, University of Washington, Seattle. 59 pp.

Myers, K.W., K.Y. Aydin, R.V. Walker, S. Fowler, and M.L. Dahlberg. 1996. Known ocean ranges of stocks of Pacific salmon and steelhead as shown by tagging experiments, 1956–1995. N. Pac. Anadr. Fish Comm. Doc. 192. (Available at www.npafc.org)

NPFMC (North Pacific Fishery Management Council). 2008. Bering Sea Chinook Salmon Bycatch Management: Draft Environmental Impact Statement/Regulatory Impact Review/Initial Regulatory Flexibility Analysis. U.S. Dept. Commerce, NOAA. Juneau, AK. 762 pp.

Radchenko, V.I., and I.I. Glebov. 1998a. On vertical distribution of Pacific salmon in the Bering Sea, collected by trawling data. J. Ichthyol. 38: 603–608.

Radchenko, V.I., and I.I. Glebov. 1998b. Incidental by-catch of Pacific salmon during Russian bottom trawl surveys in the Bering Sea and some remarks on its ecology. N. Pac. Anadr. Fish Comm. Bull. 1: 367–374. (Available at www.npafc.org).

Schumacher, J.D., K. Aagaard, C.H. Pease, and R.B. Tripp. 1983. Effects of a shelf polynya on flow and water properties in the Northern Bering Sea. J. Geophys. Res. 88 (C5): 2723–2732.

Stabeno, P.J., N.A. Bond, N.B. Kachel, S.A. Salo and J.D. Schumacher. 2001. On the temporal variability of the physical environment over the southeastern Bering Sea. Fish. Oceanogr. 10: 81–98.

Stabeno, P.J., D.G. Kachel, N.B. Kachel, and M.E. Sullivan. 2005. Observations from moorings in the Aleutian Passes: temperature, salinity and transport. Fish. Oceanogr. 14 (Suppl. 1): 39–54.

Walker, R.V., K.W. Myers, N.D. Davis, K.Y. Aydin, K.D. Friedland, H.R. Carlson, G.W. Boehlert, S. Urawa, Y. Ueno, and G. Anma. 2000. Diurnal variation in thermal environment experienced by salmonids in the North Pacific as indicated by data storage tags. Fish. Oceanogr. 9: 171–186.

Walker, R.V., V.V. Sviridov, S. Urawa, and T. Azumaya. 2007. Spatio-temporal variation in vertical distributions of Pacific salmon in the ocean. N. Pac. Anadr. Fish Comm. Bull 4: 193–201. (Available at www.npafc.org).

Wang, M., C. Ladd, J. Overland, P. Stabeno, N. Bond, and S. Salo. 2007. Eastern Bering Sea climate – FOCI. *In* Appendix C. Ecosystem Considerations for 2008. *Edited by* J. Boldt. North Pacific Fishery Management Council. pp. 106–113.

Wurster, C.M., W.P. Patterson, D.J. Stewart, J.N. Bowlby, and T.J. Stewart. 2005. Thermal histories, stress, and metabolic rates of Chinook salmon (*Oncorhynchus tshawytscha*) in Lake Ontario: evidence from intra-otolith stable isotope analyses. Can. J. Fish. Aquat. Sci. 62: 700–713.