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THERMAL HABITAT OF MIGRATING SALMONIDS IN THE NORTH PACIFIC OCEAN AND BERING SEA AS RECORDED BY TEMPERATURE DATA TAGS IN 1998

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THERMAL HABITAT OF MIGRATING SALMONIDS IN THE NORTH PACIFIC OCEAN AND BERING SEA AS RECORDED BY TEMPERATURE DATA TAGS IN 1998

ABSTRACT

Fifty-five archival tags that record temperature data were placed on Pacific salmonids (*Oncorhynchus* spp.) in the North Pacific Ocean and Bering Sea during three research cruises. In May six sockeye and one coho salmon were tagged in the Gulf of Alaska and eastern North Pacific. Twelve steelhead trout were tagged in June in the central North Pacific, and 23 chum salmon were tagged in July in the Bering Sea. Thirteen salmonids (4 sockeye, 1 chum, 4 pink, 3 coho, and 1 steelhead) were tagged on transects along 165°W and 145°W in late June and early July. Six tags have been returned to date. Three salmonids, tagged in the Gulf of Alaska, were recovered in Alaska: a pink salmon at Afognak Island after 21 days of liberty; a steelhead trout at the Copper River Delta after 36 days; and a coho salmon in Togiak Bay after 52 days. Three chum salmon, tagged in the Bering Sea, were recovered in Hokkaido, on the Pacific coast after 62 days, on the Okhotsk Sea coast after 79 days, and on the Nemuro Strait coast after 85 days. These tags contain the first records of temperature data recorded from individual Pacific salmonids migrating at sea. Ambient temperature data from these tags were recorded every 7.5 minutes for the pink salmon and steelhead, every 15 minutes for the coho and one chum salmon, and every 30 minutes for two chum salmon.

The fish tagged in the Gulf of Alaska (coho, pink, and steelhead) were at warmer average temperatures (means of 9-11°C) than the chum salmon tagged in the Bering Sea (7-9°C). The chum salmon were also found at a wider range of temperatures (0-18°C vs. 5-15°C). This is probably mainly an effect of the different oceanographic regions encountered by the fish, but may also be due to species differences. Except for the coho salmon, fish generally were found at slightly higher average temperatures at night, with a lower variability (smaller temperature range and less movement between temperatures) than during the day. Steelhead trout have been assumed to be primarily in surface waters, but temperature data indicate frequent dives to cooler water during the day. Percentage of time spent by individual fish at different temperatures seemed to vary by oceanographic region and will be useful for bioenergetics and modeling studies. Temperature data from all fish showed an initial period (4-21 days) of similar day and night temperatures near those of sea surface temperatures recorded at release. This may represent a period of recovery from tagging trauma before the fish resumed normal patterns of dives to deeper, cooler water and rises to the surface. If the initial period represents anomalous behavior by tagged salmonids, temperature and vertical movement data from short-term ultrasonic and radio tag studies may not represent normal behavior of the fish. The considerable diurnal and shorter-term variation in ambient temperatures indicates that offshore ocean distribution may be more closely linked to feeding behavior (prey distribution) than to sea surface temperatures.

INTRODUCTION

Application of archival data tags to Pacific salmonids (*Oncorhynchus* spp.) has been discussed and encouraged in recent years (Boehlert 1997) and has been considered at several recent meetings of the North Pacific Anadromous Fish Commission (NPAFC 1997, 1998; Welch et al. 1998). The relatively large size and expense of presently available archival tags which provide a wide suite of parameters (including light level for geolocation) has led to recommendations for using less expensive, reduced parameter data storage tags on Pacific salmon as a demonstration of the concept (Myers 1997). Radio and ultrasonic tags have been used to understand salmon behavior and habitat at sea, both on the high seas (Ogura 1994; Ogura and Ishida 1992, 1995) and in coastal waters (Madison et al. 1972; Quinn et al. 1989; Ruggerone et al. 1990; Candy et al. 1996). However, these tags require tracking by a vessel, and the length of time before the tag's signal is lost is only a few days. Environmental data recorded concomitantly can be correlated with knowledge of fish location and depth for these few days, but it would be useful to have prolonged data records of environmental variables such as temperature and depth as encountered by individual fish.

Archival tags have been successfully used on Atlantic salmon and sea trout (*Salmo salar* and *S. trutta*; Sturlaugsson 1995; Karlsson et al. 1996; Sturlaugsson and Gudbjornsson 1997; Sturlaugsson and Thorisson 1997) and on Pacific salmon in coastal waters of Japan (Ogura 1997), but the only previously reported use on Pacific salmon in offshore waters has been the recovery of a depth-recording tag from a chum salmon (*O. keta*) migrating from the southern Kuril Islands to Hokkaido (Ishida et al. 1997). In 1998 two programs succeeded in placing different types of archival tags on salmonids in the North Pacific Ocean and Bering Sea. A Japanese scientist placed archival tags previously used on tuna on twenty-five maturing chum salmon in the Bering Sea (Ueno et al. 1998; Ueno and Ishida 1998). These tags record temperature, depth, and light levels. Another type of tag, which records temperature data, was made available to the Ocean Carrying Capacity (OCC) program of the Auke Bay Laboratory (ABL), Alaska Fisheries Science Center, National Marine Fisheries Service (NMFS). We applied these tags to Pacific salmon and steelhead trout (*O. mykiss*) during three research cruises, and report the first records of temperature data recorded from individual Pacific salmonids migrating at sea.

MATERIALS AND METHODS

Tags and Attachment

The tags are small data-logging microprocessors embedded in an environmentally-resistant clear urethane with a reward label (directing tags to be sent to NMFS at Woods Hole, MA). A version of the Kiwi Ready Logger RL-05T[1], they weigh approximately 9.5 g, and are 40 x 23 x 8 mm in dimension with two holes at the ends of the long axis. They measure temperature over a range of -5° to 30°C with an accuracy of 0.2°C, and are operational to over 1000 m depth. Battery life is about five years. Memory capacity is 8,192 samples. The memory is initially filled at a rate of one observation per 15 seconds. After the memory is full, the memory is resampled at a slower rate, replacing half of the older data and retaining the rest, thereby

[1] Use of brand name does not imply endorsement by National Marine Fisheries Service.

automatically optimizing the temporal resolution for the total time the tag is deployed. This process repeats each time the memory is full, to a maximum of one sample per two hours at the end of two years. Data collection is continuous from manufacture, and was reinitiated by tapping a magnet against a reed switch in the tag shortly before tagging. On recovery, data were downloaded to a computer with a reader that receives infrared signals from a light-emitting diode in the tag. Tags were calibrated at manufacture and tested again shortly afterwards. Accuracy of returned tags will be checked again in the near future. Temperatures recorded on the tags at release were close to sea surface temperatures (SST) recorded at release locations. Times recorded by the tags matched timing of events noted before tag release and after tag recovery (data initiation, tag release, reported time of capture, and thermal marks induced in Seattle).

The tags were attached to the fish just anterior to the dorsal fin using two 76 mm nickel pins. The pins were inserted through 6 mm diameter plastic disks (as washers, to prevent the pin head from cutting through the potting material), then through the two holes in the tag, and then through the dorsal musculature of the fish. On the other side of the fish, the pins were inserted through 20 mm diameter (U.S. or blank) or 16 mm diameter (Japanese) red-and-white Petersen disk tags. The ends of the pins were then twisted into knots lying flush against the disks.

Fish Selection and Handling

To maximize return rate, only fish judged to be maturing (based primarily on size) and likely to be intercepted by coastal or sports fisheries were tagged. Likelihood of capture was based on known high-seas distribution of stocks from previous tagging experiments (Myers et al. 1996) and expected activity of coastal fisheries for those stocks. On the May cruise of the F/V *Great Pacific*, maturing fish of all species were considered good candidates for tagging (Carlson et al. 1998). On the 165°W transect of the T/S *Oshoro maru* cruise, sockeye salmon (*O. nerka)* and steelhead trout were considered for tagging, while on the 145°W transect maturing fish of all species were considered (Walker et al. 1998). On the R/V *Wakatake maru* cruise along 180°, only steelhead were considered for tagging south of the Aleutian Islands, and maturing (judged by size) Japanese (judged by scale criteria) chum salmon were considered in the Bering Sea (Ueno et al. 1998). Fish were captured by surface trawl on the *Great Pacific* and by surface longline baited with salted anchovies on the two Japanese vessels. Only fish observed to be in good condition in a holding tank were tagged. After tagging some fish were observed again in a recovery tank before release. On the *Great Pacific*, one tagged sockeye salmon released in the Gulf of Alaska was observed swimming counterclockwise in a 4-5 m circle under the vessel before moving out of sight. Similar circling behavior was noted in another species in previous studies and may be an orientation response (Carlson et al. 1995). On the *Oshoro maru* all fish swam from view very shortly after release. Fish were tagged and released at night aboard the *Wakatake maru,* and no behavioral observations were possible.

Seven salmon were tagged in the Gulf of Alaska and eastern North Pacific in May aboard the *Great Pacific*: six sockeye and one coho salmon (*O. kisutch;* Table 1). In June twelve steelhead trout in the central North Pacific and in July 23 chum salmon in the Bering Sea were tagged aboard the *Wakatake maru* (Table 1). At 48°30'N, 165°W one sockeye salmon was tagged aboard the *Oshoro maru* and twelve salmonids (3 sockeye, 1 chum, 4 pink [*O. gorbuscha*], 3 coho, and 1 steelhead) were tagged in July along a 145°W transect in the Gulf of Alaska (Table 1). In total, 55 tags were released.

Interpretation of data

Temperature data were compared to CTD, XBT, and other oceanographic data collected during the cruises of the tagging vessels in 1998 and previous years. Data from fish tagged in the Gulf of Alaska were also examined in relation to SSTs in the Comprehensive Ocean Atmosphere Data Set (available from the Pacific Fisheries Environmental Laboratory, NMFS; http://www.pfeg.noaa.gov/products/products.html) and to data collected from two drifting buoys and one stationary buoy in the northern Gulf of Alaska.

F-tests of differences in variance and t-tests (assuming unequal variances) for differences in means were performed to assess significance of differences between day and night values for temperature variance and mean temperature.

RESULTS

To date, six tags have been recovered: a steelhead trout and a pink and a coho salmon tagged in the Gulf of Alaska were recovered in Alaska, and three chum salmon tagged in the Bering Sea were recovered in Hokkaido, Japan (Fig. 1).

Tag 189 - Pink salmon

A pink salmon tagged with temperature tag no. 189 on 3 July 1998 at 56°N, 145°W, was caught at Cape Izhut, Afognak Island (58°06'N, 152°20'W), on 24 July after 21 days at liberty (Fig. 1, Table 2). Great circle distance was 501 km from the tagging location, which indicates a minimum travel speed of 23.9 km/day (0.28 m/s). The salmon (age 0.1) was 495 mm in length at tagging. Pink salmon caught by gillnet at the release location were feeding on pteropods, copepods, amphipods, and squid.

The tag contains 4,063 ambient temperature data points recorded every 7.5 minutes, representing water temperatures encountered by the salmon during 21 days, 4 hours at liberty (Fig. 2). The initial temperature and time were verified by those recorded on the ship at the time of release. The data on temperatures encountered by the fish show two clear phases when examined in relation to local times of sunrise and sunset (Fig. 2). During the first phase, the fish remains at relatively constant temperatures of 10-11°C during both day and night for five days (July 3-7). Similar water temperatures were recorded from the surface to 15 m in oceanographic sampling at the release location (Fig. 3). All fish in this report showed some version of this behavior. It may represent a period of recovery from tagging trauma, where the fish remains in or near surface waters, with few dives. We will refer to this as the initial phase. The second phase shows fairly constant, higher temperatures at night, and cooler but more variable temperatures during the day, with moves between cooler and warmer waters. Again, all fish showed movements between warmer and cooler temperatures, and this behavior constituted the bulk of all data collected. This may represent a normal pattern of moving to surface waters at night, possibly feeding, and diving to deeper, cooler waters during the day, but with frequent rises to warmer waters. We will refer to it as the extended phase. Within the extended phase, three intervals can be discerned in the pink salmon data. At first (July 8-11), the fish is in 11-12°C waters at night, and is in cooler waters (mostly 7-10°C) for most of the day. We think the fish is still in waters of the Dilute Domain (Alaskan Gyre). The warmer temperatures correspond to surface data collected at the tagging site, and similar cooler temperatures were found at 20-40 m (Fig. 3). During the second period (July 12-18), nighttime temperatures are slightly higher

(12-13°C) and daytime data cover a wider range of temperatures (6-14°C). This is probably when the fish is crossing the warmer waters of the Alaska Current. In the final period (July 19-23), temperatures at night are cooler (11°C) and while movements between daytime temperatures are still frequent, the temperature range is narrower (8-11°C). The fish was probably in waters on the coastal side of the Alaska Current, where surface waters are cooler, but warmer temperatures and the thermocline are found slightly deeper.

There are significant differences between day and night mean temperature and variance during the initial phase and in the following three periods of the extended phase; nights are significantly warmer, and days are significantly more variable (Table 3). The total temperature range recorded was 5.70-14.41°C. Temperatures at which the fish spent the majority of the time varied by period and time of day (e.g., 85% of the time at 7-9°C during the day in period 1, and 83% at 11-12°C at night during period 2).

Tag 52 - Coho salmon

A coho salmon tagged with temperature tag no. 52 at 56°N, 145°W on 3 July 1998 was caught in Togiak Bay, western Alaska (59°02'N, 160°20'W), on 24 August after 52 days at liberty (Fig. 1, Table 2). Combined great circle distances (via Unimak Pass) are 1,858 km from the tagging location, which indicates a minimum travel speed of 35.7 km/day (0.41 m/s). The salmon (age 1.1) was 592 mm at release. Coho salmon caught by gillnet at the release location were feeding on squid and pteropods.

The tag contained 5,857 ambient temperature data points recorded every 15 minutes, representing water temperatures encountered by the salmon during 52 days, 4 hours at liberty. The initial temperature and time were verified by those recorded on the ship at the time of release. The data on temperatures encountered by the fish show initial and extended phases when examined in relation to local times of sunrise and sunset (Fig. 4). Like the pink salmon, the coho seemed to undergo a period of recovery from tagging trauma, remaining at relatively constant temperatures of 10-11°C during both day and night for five days (July 3-7). The first part of the extended phase (July 8-August 5) shows moves between cooler and warmer waters, with night temperatures only slightly more constant than days. Within the first period, there seem to be several periods of different temperature ranges, but we have not yet identified exactly where in the ocean the fish might have been at these different temperatures. In the latter part of the extended phase (August 6-24), the fish stops most of its sharp movements between warm and cool temperatures. At this point the fish may have stopped feeding or whatever behavior necessitated the dives and started travelling to its spawning river. The change in behavior could also correspond to the period when the fish entered the Bering Sea. During these last three weeks, many days show a mid-day temperature peak approximately 0.5-3°C warmer than the early and late portions of the day, and nighttime temperatures show gradual cooling. The fish is probably swimming steadily near the surface, and the small rises and falls reflect the diurnal pattern of daytime warming of surface waters and cooling at night.

Temperature data from the coho salmon showed no significant differences between day and night mean temperature during the initial phase and first period of the extended phase (Table 4). Nights were cooler in the final period, and daytime temperatures were slightly more variable in all periods. Temperatures were slightly cooler during the last period. Total temperature range recorded was 6.24-16.21°C, but the majority of time was spent in waters of 8-12°C.

Tag 198 - Steelhead trout

A steelhead trout tagged with temperature tag no. 198 at 50°N, 145°W on 9 July 1998 was caught by drift gillnet inside Softuk Bar, Copper River delta (60°13'N, 144°40'W) on 14 August after 36 days at liberty (Fig. 1, Table 2). Great circle distance was 931 km from the tagging location, which indicates a minimum travel speed of 25.9 km/day (0.30 m/s). The steelhead was 690 mm at tagging. Its scales indicated it was age 2.3 with a spawning check at the second ocean annulus. Steelhead caught by gillnet at the release location were feeding on fish and squid.

This tag contained 6,909 ambient temperature data points recorded every 7.5 minutes, representing water temperatures encountered by the salmon during 36 days, 2 hours at liberty (Fig. 5). The initial temperature and time were verified by those recorded on the ship at the time of release. The steelhead data also show an initial adjustment phase of relatively constant day/night temperatures (10.5-11.5°C, July 9-13). Similar water temperatures were also recorded from the surface to 20 m in oceanographic sampling at the release location (Fig. 3). After the initial phase, the fish began an extended phase with a diel pattern, similar to that of the pink salmon, of fairly constant, higher temperatures at night, and more variable temperatures during the day. Unlike the pink salmon data, the daytime temperatures are frequently as high or higher than night temperatures. Within the extended phase, three periods can be discerned. At first (July 13-28), the fish is in 11°C waters at night, and is in waters ranging from 7 to 12°C during the day. We think this is when the fish was still in the Subarctic Current and the Ridge/Dilute Domains of the Alaskan Gyre. Temperatures similar to the coolest daytime temperatures (6.5-8°C) were found at approximately 40-60 m in oceanographic sampling at the tagging site (Fig. 3). During the second period (July 28-August 9), nighttime temperatures are higher (12-14°C) and daytime temperatures show a more variable range (e.g., 11-14°C some days, 6.5-15°C others). These are probably the warmer waters of the Alaska Current. In the final period (August 11-14), there is no clear pattern; the fish is probably in waters on the coastal side of the Alaska Current. During the entire time at liberty, many days show a mid-day temperature peak approximately 1°C warmer than the early and late portions of daylight hours. Steelhead are surface-oriented, and the warmer mid-day peaks may be diurnal solar heating of surface waters or even direct heating of the tag itself. Karlsson et al. (1996) found that another brand of archival tag gave errors in excess of one degree when exposed to direct sunlight while under 1 cm of water. A surprising feature of the data is frequent movement between warmer and cooler waters. Since steelhead have been assumed to be surface-oriented, such frequent dives (probably down to about 50 m) were not expected.

Daytime temperatures for the steelhead showed significantly more variability than nighttime data in all periods (Table 5). Mean temperatures look similar during both day and night as in the coho data, but t-tests reveal them to be significantly different in all but the last period. The total temperature range recorded was 6.38-15.77°C. Temperatures at which the fish spent the majority of the time varied by period (e.g., 88% of the time at 8-11°C in period 1, and about 90% at 11-14°C during periods 2 and 3).

Tag 259 - Chum salmon.

A chum salmon, tagged with temperature tag no. 259 at 52°30'N, 179°30'W in the central Aleutians on 3 July 1998, was caught by setnet at the mouth of the Tokachi River, Pacific coast of Hokkaido (42°39'N, 143°31'E), on 4 September after 62 days at liberty (Fig. 1, Table 2).

Great circle distance was 2,942 km from the tagging location, which indicates a minimum travel speed of 46.7 km/day (0.54 m/s). The salmon (male, age 0.3) was 622 mm at release; at recovery it was 650 mm in length and weighed 3.0 kg. Differences in release and recovery lengths are subject to measurement error and possible differences in measurement techniques. Chum salmon caught by longline at the release location were feeding on pteropods, amphipods, medusae, and fish.

The tag contained 6,011 ambient temperature data points recorded every 15 minutes, representing water temperatures encountered by the salmon during 62 days, 14 hours at liberty. The initial temperature and time were verified by those recorded on the ship at the time of release. Initial and extended phases can be seen in the data on temperatures encountered by the fish when examined in relation to local times of sunrise and sunset (Fig. 6). The data from the initial 23 days (3-25 July) show very few moves between warmer and cooler water. The length of this phase is puzzling; it could be a very prolonged recovery from tagging trauma. The temperatures are similar to or warmer than water temperatures recorded from the surface to 10 m in oceanographic sampling at the release location (Fig. 3). Temperatures similar to those of the few coldwater excursions (to 3.3°C) of this fish during the first ten days after tagging were found deeper than 200 m at the release location, but at only 40 m at a station 55 km north. The subsequent data show a typical pattern of moves between warmer and cooler water. In the first period of the extended phase (25 July-24 August), the chum is in warmer waters with fewer dives at night, like the pink salmon and steelhead. Within this period, there are several intervals of different temperature ranges, but we have not yet identified where in the ocean the fish might have been at these temperatures. In the final period (24 August-4 September), the fish is in increasingly warmer waters, presumably as it moves toward the coast of Japan. Nighttime temperatures are more variable, and there is a narrower range of temperatures each day.

There are no significant day/night differences in mean temperature or variance during the initial phase of the chum data. In the first part of the extended phase, days are significantly cooler and more variable (Table 6). This difference carries into the last period, though the differences are less. The total temperature range recorded was very wide, 1.61-18.62°C. Temperatures at which the fish spent the majority of the time also showed a wide range and less concentration in a few temperatures in each period and time of day (e.g., 60-70% at 8-12°C during periods 2 and 3).

Tag 274 - Chum salmon

A chum salmon, tagged with temperature tag no. 274 at 56°30'N, 179°30'W in the central Bering Sea on 7 July 1998, was caught by gillnet off Akaiwa on the Shiretoko Peninsula, Okhotsk Sea coast of Hokkaido (44°30'N, 145°20'E), on 24 September after 79 days at liberty. Great circle distance was 2,779 km from the tagging location, which indicates a minimum travel speed of 35.2 km/day (0.41 m/s). The salmon (male, age 0.4) was 680 mm at release; at recovery it was 716 mm in length. Chum salmon caught by longline and gillnet at the release location were feeding on polychaetes, medusae, ctenophores, euphausiids, squid, and amphipods.

The tag contained 3,782 ambient temperature data points recorded every 30 minutes, representing water temperatures encountered by the salmon during 78 days, 19 hours at liberty. The initial temperature and time were verified by those recorded on the ship at the time of release. The overall pattern displayed by these temperature data is remarkably similar to that of tag 259, probably because both fish had to cross the same oceanographic regions at roughly the

same times on their return to Hokkaido (Fig. 7). The initial seven days (7-15 July) could be recovery from tagging trauma. This initial phase is much shorter than that found in the data from tag 259, though longer than that of the fish tagged in the Gulf of Alaska. The temperatures (about 7°C) are similar to or warmer than water temperatures recorded from the surface to 10 m in oceanographic sampling at the release location (Fig. 3). The cold temperatures immediately after release, approximately 2°C, were found at 150 m. The subsequent data show a typical pattern of moves between warmer and cooler water. In the first period of the extended phase (15 July-31 August), the chum is in warmer waters with fewer dives at night. The coldest temperatures (3-4°C) of the dives early in this period were found at 20-40 m in oceanographic sampling at the release location (Fig. 3). The pattern of these data resembles that of the data from tag 259, including comparable intervals of similar temperature ranges and increasing and decreasing maximum temperatures. Like the chum carrying tag 259, the fish then enters a period of increasingly warmer waters (31 August-12 September). The other chum was captured at the end of this period, but the data from tag 274 continues in a third period of fluctuating temperatures, including a surprising encounter with waters as cold as -0.67°C.

In the first two periods of the extended phase (representing three- fourths of the data), days are significantly cooler and more variable (Table 7). Nights are more variable in the initial phase and final period. The total temperature range recorded was -0.67-18.08°C, the widest range from the tags returned thus far. Like the data from tag 259, temperatures at which the fish spent the majority of the time also showed a wide range and less concentration in a few temperatures in each period and time of day.

Tag 299 - Chum salmon

A chum salmon, tagged with temperature tag no. 299 at 56°30'N, 179°30'W in the central Bering Sea on 12 July 1998, was caught by setnet off the Nemuro Strait coast of Hokkaido (43°41'N, 145°09'E), on 5 October after 85 days at liberty (Fig. 1, Table 2). Great circle distance was 2,969 km from the tagging location, which indicates a minimum travel speed of 34.9 km/day (0.40 m/s). The salmon (female, age 0.3) was 577 mm at release; at recovery it was 590 mm in length and weighed 2.4 kg. Chum salmon caught by longline and gillnet at the release location were feeding on amphipods, pteropods, squid, fish, polychaetes, and euphausiids.

The tag contained 4,059 ambient temperature data points recorded every 30 minutes, representing water temperatures encountered by the salmon during 84 days, 13 hours at liberty. The initial temperature and time were verified by those recorded on the ship at the time of release. We have just received these data and have not analyzed them yet. Initial plotting of the data reveals a pattern very similar to those of the data on tags 259 and 274. The initial adjustment phase of this fish lasted approximately 14 days.

The fish tagged in the Gulf of Alaska (coho, pink, and steelhead) were at warmer average temperatures than the chum salmon (Tables 3-7). The chum salmon were also found at a wider range of temperatures. This is probably mainly an effect of the different oceanographic regions encountered by the fish, but may also be due to species differences. Except for the coho salmon, fish generally were found at slightly higher temperatures at night, with a lower variability (smaller temperature range and less movement between temperatures) than during the day.

DISCUSSION

Ogura and Ishida (1995) found that swimming speed and direction of ultrasonically-tagged salmon at night were about the same as during the day on the high seas. However, sockeye in coastal waters were slower at night, though not stationary (Madison et al. 1972; Quinn 1988), and steelhead in coastal waters did not seem to be actively swimming, but drifting with tidal currents (Ruggerone et al. 1990). The relatively constant temperatures during the night displayed by most of the tagged fish in our study do not necessarily mean that the fish are passively floating. They may be actively swimming and selecting waters in a narrow temperature range, presumably the surface. Similarly, they may also be actively swimming during the postulated initial adjustment phase of recovery from tagging trauma. The fish may be simply unable or unwilling to dive during this period. Migration rates (23.9-46.7 km/day) were within the ranges calculated by species, month and recovery areas from high seas tagging data (Ogura 1994), indicating that the long term effect of these tags on travel speed was not substantially different from that of regular disk and tube tags.

There is a discrepancy between radio and ultrasonic tag studies and other information about diurnal behavior patterns of Pacific salmon. Radio- and ultrasonically- tagged fish have often not shown strong differences between day and night observations (Ruggerone et al. 1990; Ogura and Ishida 1995). In contrast, other studies using fishing gear have inferred that salmon move into surface waters at night, presumably to feed, and dive to deeper, cooler waters during the day (e.g., Manzer et al. 1965). This diurnal cycle is probably due to several driving forces, including optimal feeding, thermoregulation, searching for orientation clues during migration, and predator avoidance. In the first few days after tagging, the fish discussed in this report were in water temperatures that indicate behavior like that reported in some ultrasonic and radio tagging studies, that is, remaining in waters with temperatures near those of surface temperatures at the tagging site. After a period of four to seven days, however, the pink salmon, steelhead, and one of the chum salmon began regular daily patterns of spending nights at almost constant higher temperatures, and days with occasional movements between warmer and cooler waters. (The coho salmon also began diving after five days, but days were only slightly more variable than nights. The other two chum salmon spent two to three weeks at relatively constant temperatures before beginning a pattern of movements between warmer and cooler water.) In this behavior, the fish behaved somewhat like a chum salmon reported by Ishida et al. (1997). That salmon was tagged with an archival tag that recorded only depth. At large for 36 days while swimming 593 km from the tagging location in the southern Kuril Islands to the recovery location on the northern Hokkaido coast, the fish spent the first three and a half days after tagging with a series of dives and rises that showed no clear diel pattern. After that, the fish spent nights in surface waters with few dives and days moving between shallow and deeper waters (40-60 m).

We believe the initial phase of no clear diel pattern displayed by these fish, and by the ultrasonically- and radio-tracked fish, indicates a period of adjustment and recovery after tagging trauma. Boehlert (1997) noted that short-term behavior may be affected by the trauma of tagging. Hartt (1966) allowed one day for recovery from disk tagging when he calculated migration speeds between release and tag recovery points, but the recovery interval may actually be more on the order of three to seven days, or longer. This would indicate caution in interpreting at least vertical movement and temperature data from short-term tagging studies,

such as ultrasonic and radio-tracking experiments where the fish are typically followed for only one to five days.

Welch et al. (1998) cited the need for data to understand biological reasons for any thermal limits that may restrict salmon distribution and make them susceptible to possible warming of the North Pacific due to global climate change. Our data provide initial information about vertical migration and thermal habitat available to migrating salmon. One possible link of salmon distribution to ocean temperature may be through food, rather than the temperature itself. In the Gulf of Alaska, squid abundance decreases with increasing SST, and salmon distribution may show a tighter correlation with squid distribution than with SST (Aydin in prep.). Percentage of time spent by individual fish at different temperatures seemed to vary by oceanographic region and will be useful for bioenergetics and modeling studies.

Data reported here are for recoveries through 10 October 1998. We anticipate that there may be further recoveries from 1998 releases, as Japanese runs of chum salmon continue through January, and Pacific Northwest winter steelhead runs have not started yet. We hope to release similar or other archival tags during cooperative research cruises with the OCC program of ABL and Hokkaido National Fisheries Research Institute of Japan in 1999. Further, we hope to continue cooperative tagging efforts among all nations of NPAFC and collect improved, detailed information on migration, distribution, and habitat of salmon on the high seas.

A workshop convened to evaluate application of acoustic and archival tags to Pacific salmon made several recommendations on the next steps which should be taken to improve our understanding of movement and habitat utilization (Boehlert 1997). The first was to use existing data storage tags in a high-seas tagging study as a demonstration of the utility of these tags. This study addresses that recommendation and has shown that several species of salmonids are capable of carrying these tags and that return rates justify further effort. Additionally, the scientific data retrieved from the tags hold a wealth of behavioral data on how these animals utilize the ocean environment. Further research should take advantage of improved tag technology and expand the parameters measured by the tags, incorporating sensors to measure depth and other parameters.

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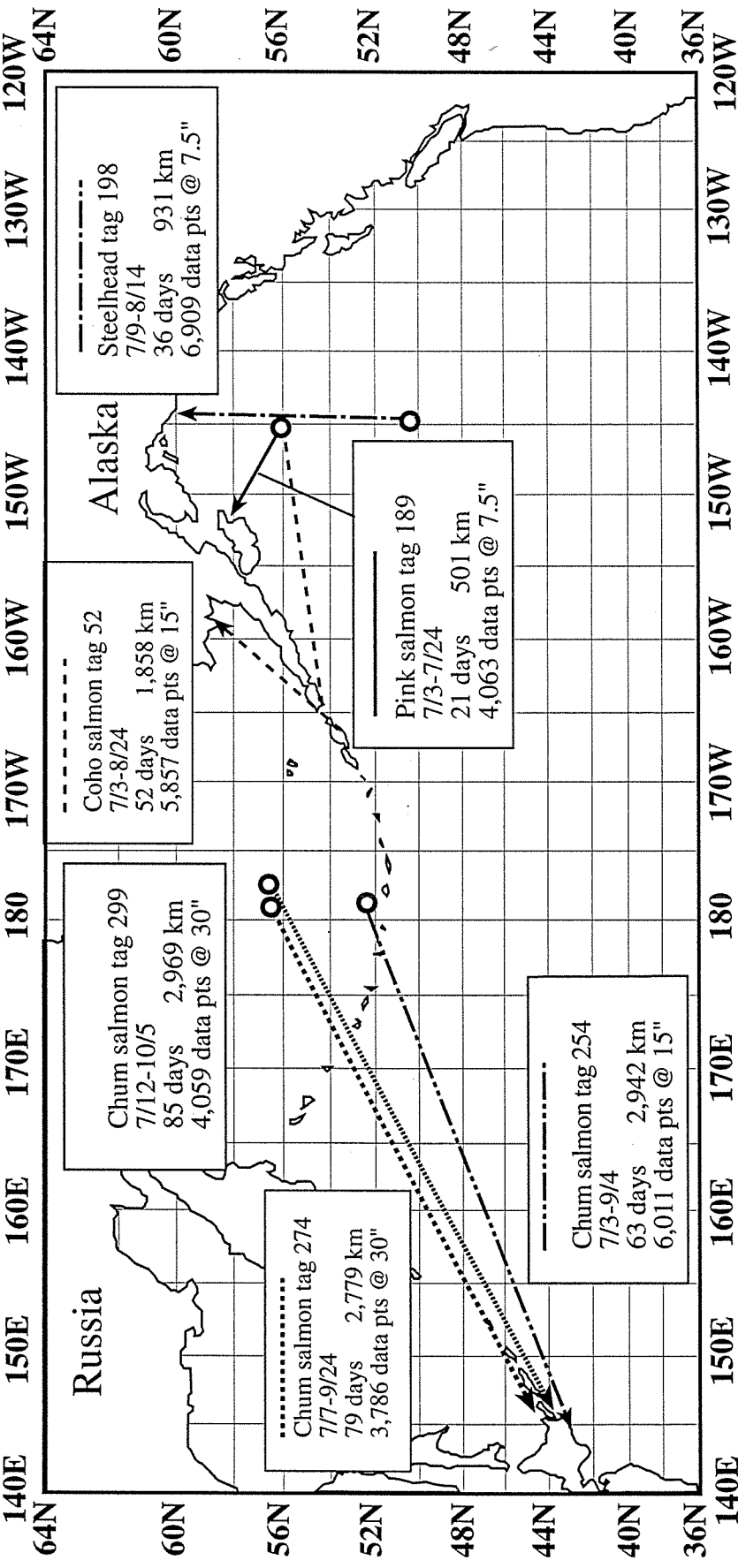

Figure 1. Tag release and recovery locations and dates for six salmonids tagged with temperature data tags in 1998.

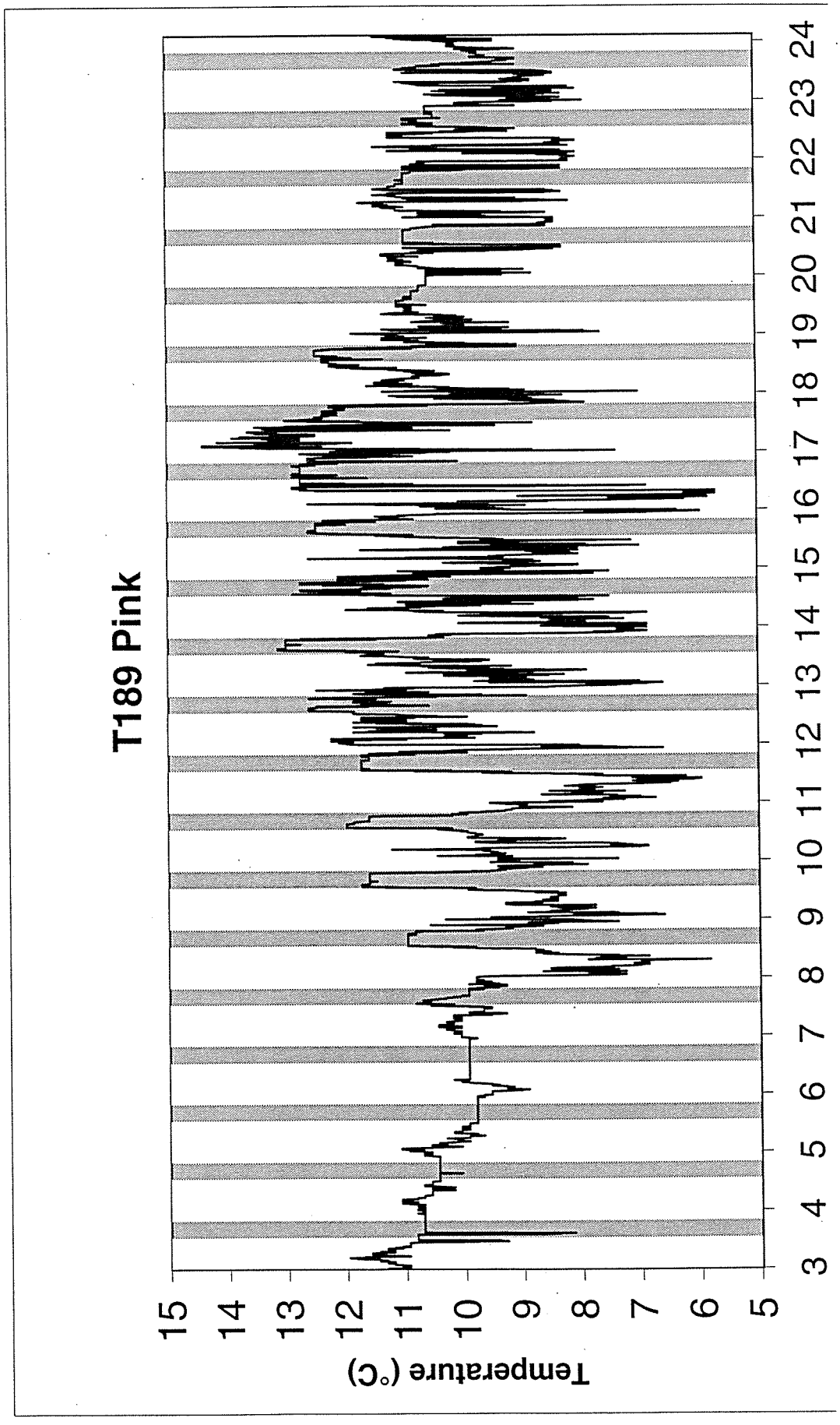

Figure 2. Temperature data from a pink salmon tagged at 56°N, 145°W on 3 July 1998 and recovered on 24 July off Cape Izhut, Afognak Island (58°06'N, 152°20'W). Data points were collected every 7.5 minutes. Shaded bars represent approximate times of local night. X-axis tick marks represent 07:43h local time (GMT -10 hrs), the approximate time of tag release.

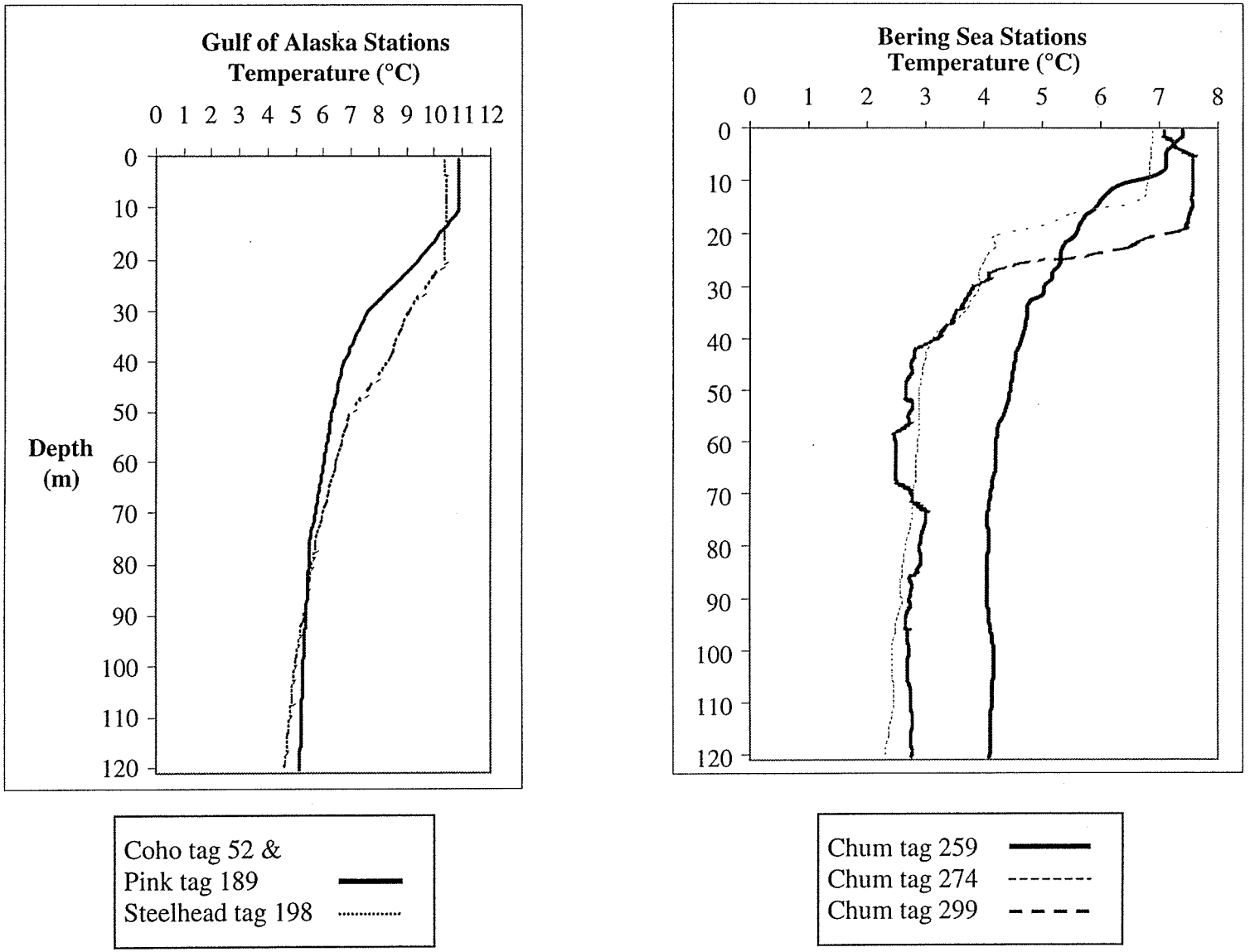

Figure 3. Temperature profiles at fishing stations where fish with temperature data tags were released.

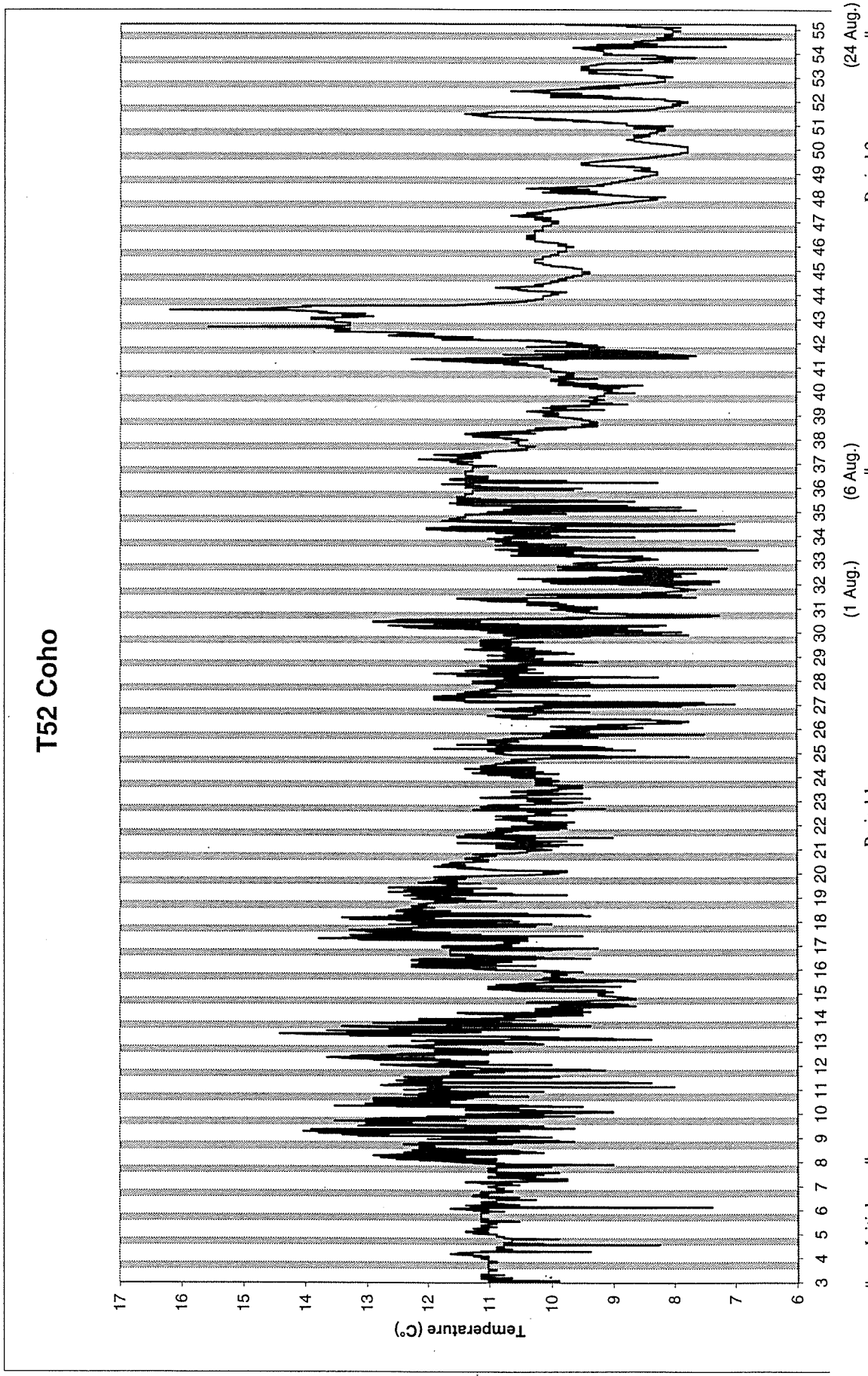

Figure 4. Temperature data from a coho salmon tagged at 56°N, 145°W on 3 July 1998 and recovered on 24 August in Togiak Bay (59°02'N, 160°20'W). Data points were collected every 15 minutes. Shaded bars represent approximate times of local night. X-axis tick marks represent 07:13h local time (GMT -10 hrs), the approximate time of tag release.

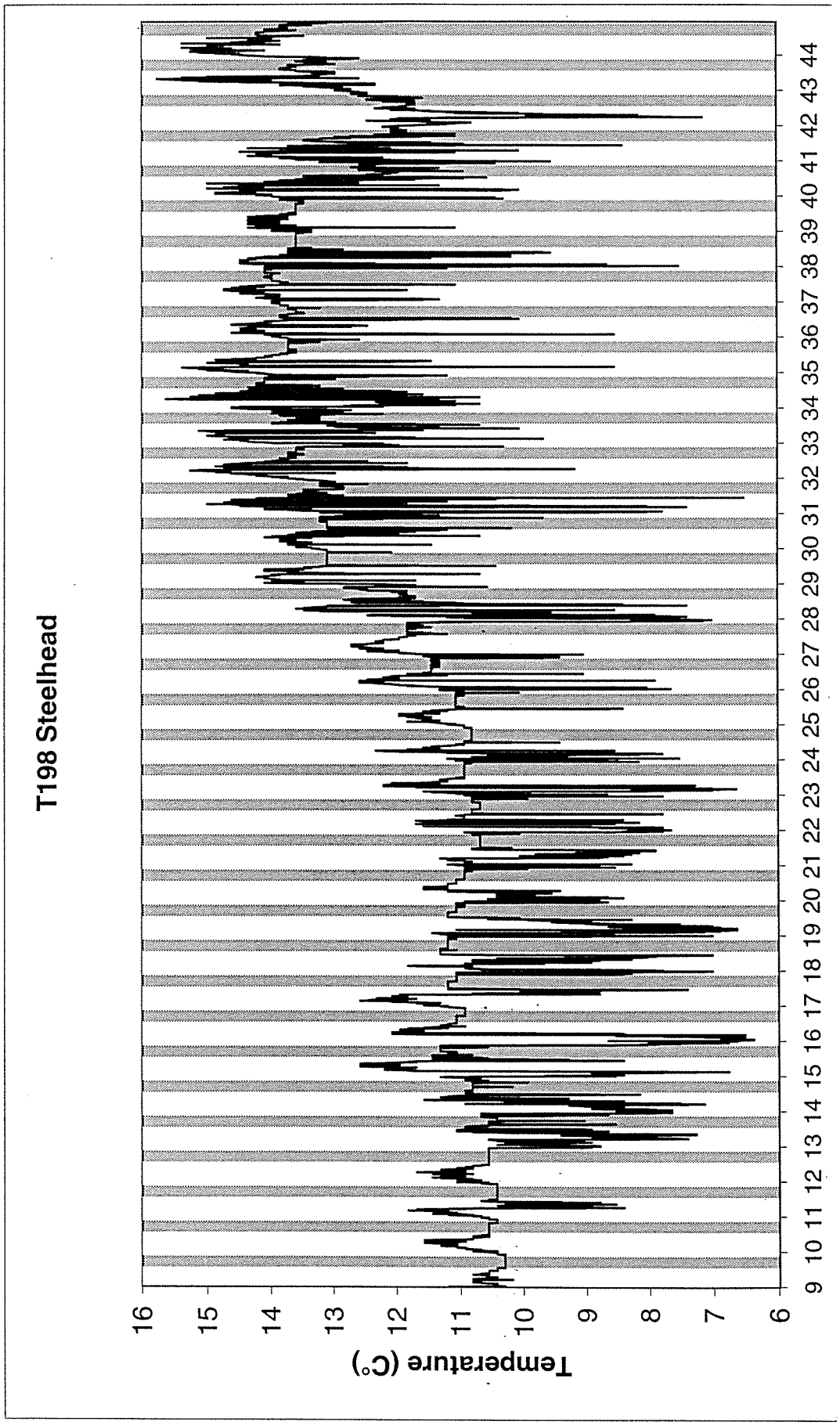

Figure 5. Temperature data from a steelhead trout tagged at 50°N, 145°W on 9 July 1998 and recovered on 14 August inside Softuk Bay, Copper River Delta (60°13'N, 144°40'W). Data points were collected every 7.5 minutes. Shaded bars represent approximate times of local night. X-axis tick marks represent 06:50h local time (GMT -10 hrs), the approximate time of tag release.

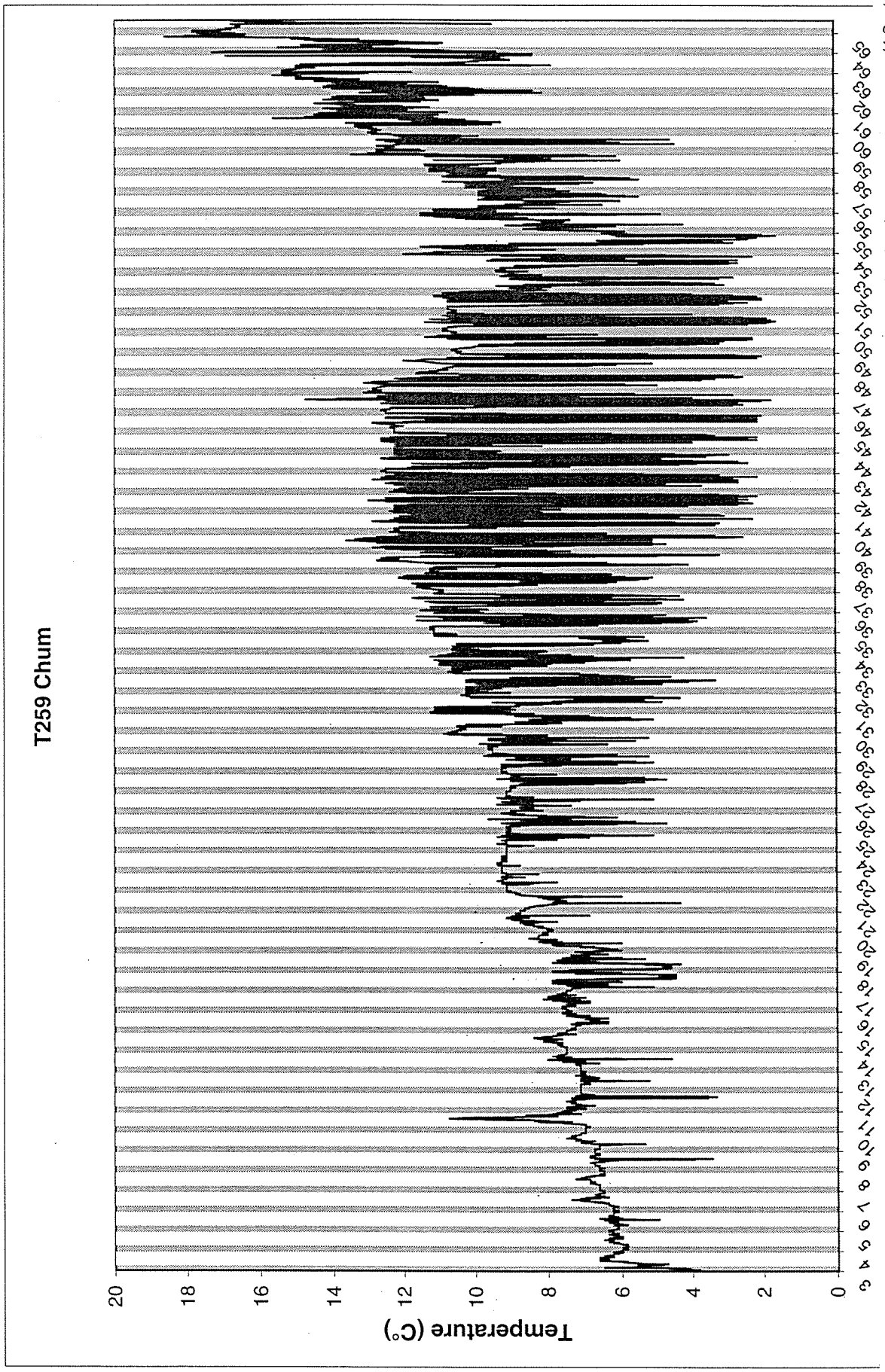

Figure 6. Temperature data from a chum salmon tagged at 52°30'N, 179°30'W on 3 July 1998 and recovered on 4 September at the mouth of the Tokachi River, Hokkaido (42°39'N, 143°31'E). Data points were collected every 15 minutes. Shaded bars represent approximate times of local night. X-axis tick marks represent 21:40h local time (GMT +12 hrs), the approximate time of tag release.

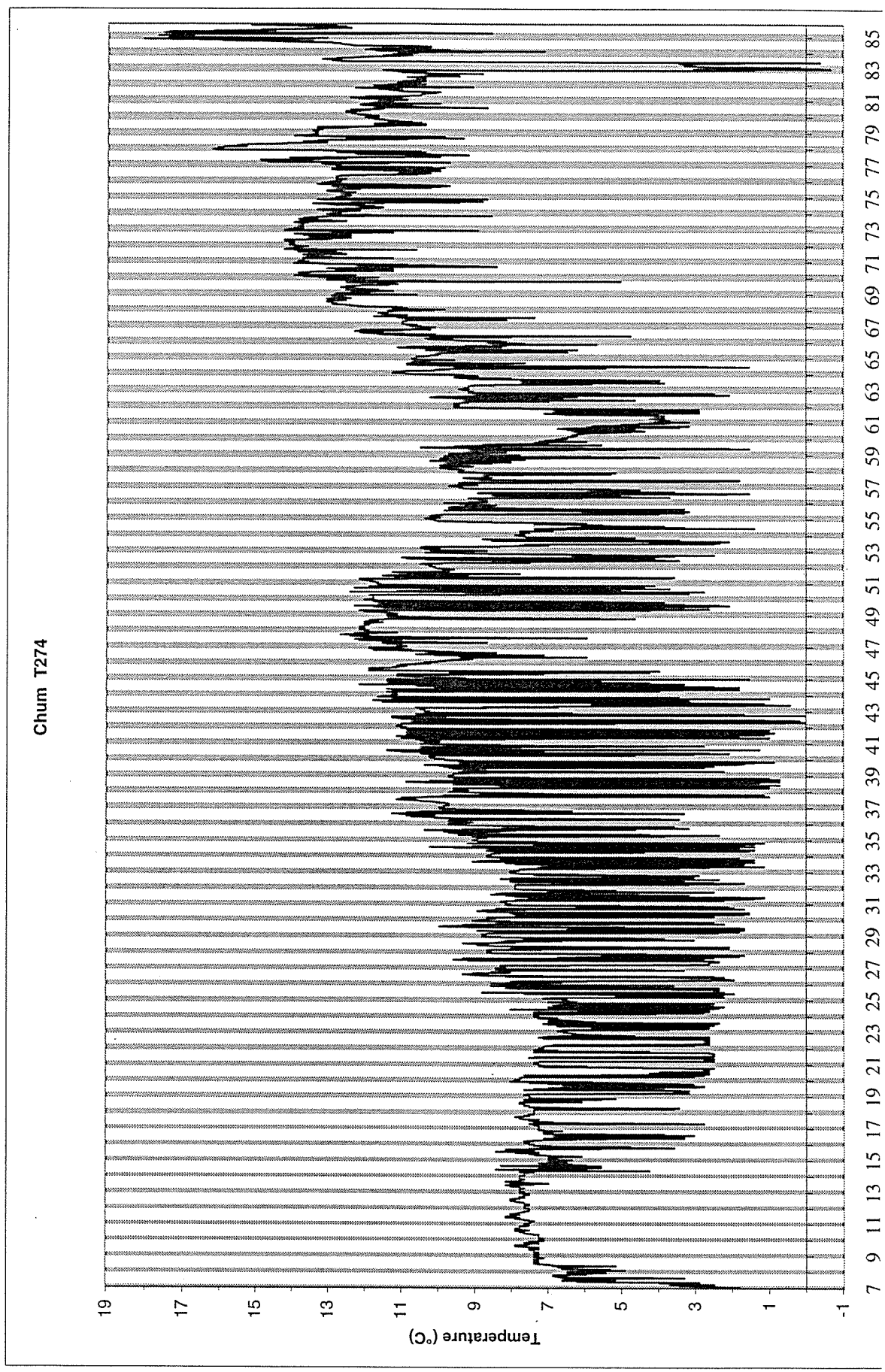

Figure 7. Temperature data from a chum salmon tagged at 56°30'N, 179°30'W on 7 July 1998 and recovered on 24 September on the Okhotsk Sea coast of Hokkaido (44°30'N, 145°20'E). Data points were collected every 30 minutes. Shaded bars represent approximate times of local night. X-axis tick marks represent 22:30h local time (GMT +12 hrs), the approximate time of tag release.

Table 1. Temperature-recording data tags released on salmonids in the North Pacific Ocean and Bering Sea in 1998. Times of tag initiation and release are approximate local (ship's) time. SST = sea surface temperature in °C (*Wakatake maru* and *Oshoro maru*); HT = headrope temperature approx. 1 m below surface (*Gt. Pacific*). FRI = Fisheries Research Institute; FAJ = Fisheries Agency of Japan.

Vessel and			Tag Initiated		Tag Released		Location		Other tags		SST
Tag No.	Species	Length	Date	Time	Date	Time	Latitude	Longitude	FRI	FAJ	or HT
F/V *Great Pacific*											
347	Sockeye	520	5/3/98	10:50	5/3/98	10:50	51°34'N	163°58'W	LL1227		4.5
166	Sockeye	575	5/3/98	10:50	5/3/98	10:50	51°34'N	163°58'W	LL1270		4.5
265	Sockeye	485	5/3/98	10:50	5/3/98	10:50	51°34'N	163°58'W	LL1223		4.5
60	Sockeye	540	5/3/98	18:50	5/3/98	18:50	50°35'N	164°03'W	LL1228		4.2
349	Sockeye	575	5/3/98	18:50	5/3/98	18:50	50°35'N	164°03'W	LL1291		4.2
360	Sockeye	605	5/3/98	18:50	5/3/98	18:50	50°35'N	164°03'W	LL1218		4.2
326	Coho	586	5/19/98	3:40	5/19/98	3:40	44°37'N	145°00'W	LL1219		8.6
R/V *Wakatake maru*											
207	Steelhead	649	6/20/98	19:40	6/25/98	21:45	45°00'N	180°00'	LL2034	MM1086	8.0
208	Steelhead	570	6/25/98	20:45	6/25/98	22:15	45°00'N	180°00'	LL2037	MM1089	8.0
210	Steelhead	652	6/25/98	20:45	6/26/98	22:00	46°00'N	180°00'	LL2061	MM1113	7.6
220	Steelhead	549	6/25/98	20:45	6/27/98	21:30	47°00'N	180°00'	LL2068	MM1120	7.1
221	Steelhead	568	6/27/98	20:35	6/27/98	21:45	47°00'N	180°00'	LL2077	MM1129	7.1
227	Steelhead	574	6/27/98	20:35	6/28/98	21:30	47°30'N	180°00'	LL2084	MM1136	6.7
228	Steelhead	710	6/27/98	20:35	6/28/98	21:30	47°30'N	180°00'	LL2085	MM1137	6.7
230	Steelhead	756	6/28/98	20:15	6/28/98	21:45	47°30'N	180°00'	LL2086	MM1138	6.7
238	Steelhead	554	6/28/98	20:15	6/28/98	21:45	47°30'N	180°00'	LL2097	MM1149	6.7
241	Steelhead	662	6/28/98	22:00	6/28/98	22:15	47°30'N	180°00'	LL2101	MM1153	6.7
242	Steelhead	570	6/28/98	22:00	6/28/98	22:15	47°30'N	180°00'	LL2102	MM1154	6.7
243	Steelhead	706	6/29/98	20:30	6/30/98	21:30	49°30'N	179°30'W	LL2124	MM1176	7.0
246	Chum	596	6/29/98	20:30	7/2/98	21:15	51°30'N	179°30'W	LL2136	MM1188	7.0
248	Chum	632	6/29/98	20:30	7/2/98	21:15	51°30'N	179°30'W	LL2143	MM1195	7.0
257	Chum	526	6/29/98	20:30	7/3/98	21:30	52°30'N	179°30'W	LL2168	MM1220	7.4
258	Chum	584	6/29/98	20:30	7/3/98	21:30	52°30'N	179°30'W	LL2169	MM1221	7.4
259	Chum	622	6/29/98	20:30	7/3/98	21:30	52°30'N	179°30'W	LL2170	MM1222	7.4
255	Chum	560	7/4/98	20:45	7/4/98	21:30	53°30'N	179°30'W	LL2222	MM1274	5.9
269	Chum	568	6/29/98	20:30	7/5/98	22:30	54°30'N	179°30'W	LL2278	MM1330	6.7
272	Chum	638	7/4/98	20:45	7/5/98	22:30	54°30'N	179°30'W	LL2279	MM1331	6.7
271	Chum	592	7/6/98	20:30	7/6/98	22:15	55°30'N	179°30'W	LL2348	MM1400	6.3
274	Chum	680	7/4/98	20:45	7/7/98	22:30	56°30'N	179°30'W	LL2403	MM1455	6.9
275	Chum	624	7/4/98	20:45	7/7/98	22:30	56°30'N	179°30'W	LL2404	MM1456	6.9
276	Chum	586	7/4/98	20:45	7/7/98	22:35	56°30'N	179°30'W	LL2405	MM1457	6.9
277	Chum	614	7/6/98	20:30	7/8/98	23:00	57°30'N	179°30'W	LL2508	MM1560	4.8
282	Chum	545	7/6/98	20:30	7/8/98	23:00	57°30'N	179°30'W	LL2509	MM1561	4.8
286	Chum	558	7/6/98	20:30	7/9/98	23:00	58°30'N	179°30'W	LL2575	MM1627	7.0
287	Chum	556	7/6/98	20:30	7/10/98	23:00	57°30'N	178°30'W	LL2655	MM1707	6.9
288	Chum	586	7/9/98	21:05	7/11/98	22:40	57°30'N	177°30'W	LL2712	MM1764	7.1
289	Chum	568	7/9/98	21:05	7/11/98	22:40	57°30'N	177°30'W	LL2713	MM1765	7.1
296	Chum	589	7/9/98	21:05	7/11/98	22:45	57°30'N	177°30'W	LL2714	MM1766	7.1
297	Chum	539	7/12/98	20:40	7/12/98	22:30	56°30'N	177°30'W	LL2770	MM1822	7.1
298	Chum	525	7/12/98	20:40	7/12/98	22:30	56°30'N	177°30'W	LL2771	MM1823	7.1
299	Chum	577	7/12/98	20:40	7/12/98	22:30	56°30'N	177°30'W	LL2772	MM1824	7.1
304	Chum	550	7/12/98	20:40	7/15/98	22:20	56°30'N	178°30'E	LL2860	MM1912	9.2

continued

Table 1. Continued.

Vessel and Tag No.	Species	Length	Tag Initiated Date	Time	Tag Released Date	Time	Location Latitude	Longitude	Other tags FRI	FAJ	SST or HT
T/S *Oshoro maru*											
8	Sockeye	480	6/23/98	9:15	6/27/98	7:30	48°29'N	164° 59'W	LL1117	DD6517	8.4
28	Chum	686	7/3/98	4:30	7/3/98	7:15	55° 59'N	145° 00'W	LL1153	DD6553	11.0
52	Coho	592	7/3/98	4:30	7/3/98	7:15	55° 59'N	145° 00'W	LL1156	DD6556	11.0
157	Coho	630	7/3/98	4:30	7/3/98	7:15	55° 59'N	145° 00'W	LL1158	DD6558	11.0
158	Pink	445	7/3/98	4:30	7/3/98	7:15	55° 59'N	145° 00'W	LL1160	DD6560	11.0
167	Sockeye	596	7/3/98	7:30	7/3/98	7:45	55° 59'N	145° 00'W	LL1162	DD6562	11.0
189	Pink	495	7/3/98	7:30	7/3/98	7:45	55° 59'N	145° 00'W	LL1165	DD6565	11.0
164	Pink	510	7/3/98	7:30	7/4/98	7:00	54° 59'N	145° 00'W	LL1167	DD6567	10.6
184	Sockeye	646	7/3/98	19:00	7/4/98	7:00	54° 59'N	145° 00'W	LL1169	DD6569	10.6
191	Sockeye	612	7/3/98	19:00	7/4/98	7:00	54° 59'N	145° 00'W	LL1172	DD6572	10.6
196	Coho	592	7/3/98	19:00	7/6/98	7:00	53° 01'N	144° 53'W	LL1176	DD6575	10.0
198	Steelhead	690	7/9/98	6:45	7/9/98	7:00	49° 58'N	144° 58'W	LL1179	DD6579	10.9
199	Pink	529	7/9/98	7:00	7/9/98	7:15	49° 58'N	144° 58'W	LL1180	DD6580	10.9

Table 2. Release and recovery information for six salmonids tagged with temperature data tags in the North Pacific Ocean and Bering Sea in 1998 and recovered in Alaska and Japan. SST=sea surface temperature at release. Days=days fish was at large after tagging. Distance is great circle distance between release and recovery points (for Tag 52, two segments via Unimak Pass). Speed is directional speed, great circle distance divided by days at large. Data points are temperature data points recorded while the fish was at large and do not include data before release or after recovery.

		Release					Recovery									
Tag No.	Species	Date	Location	SST (°C)	Length (FL; mm)	Age	Date	Location	Days	Distance (km)	Speed (km/day)	Data Points	Data Interval	Length (mm)	Weight (kg)	Sex
52	Coho	7/3/98	Gulf of Alaska 55°59'N 145°00'W	11.0	592	1.1	8/24/98	Togiak Bay 59°02'N 160°20'W	52	1,858	23.8	5,857	15"			M
189	Pink	7/3/98	Gulf of Alaska 55°59'N 145°00'W	11.0	495	0.1	7/24/98	Afognak Island 58°06'N 152°20'W	21	501	35.7	4,063	7.5"		1.4	
198	Steelhead	7/9/98	Gulf of Alaska 49°58'N 144°58'W	10.9	690	2.3	8/14/98	Copper R. Delta 60°13'N 144°40'W	36	931	25.9	6,909	7.5"		3.4	M
259	Chum	7/3/98	Bering Sea 52°30'N 179°30'W	7.4	622	0.3	9/4/98	Tokachi R. mouth 42°39'N 143°31'E	62	2,942	46.7	6,011	15"	650	3.0	M
274	Chum	7/7/98	Bering Sea 56°30'N 179°30'W	6.9	680	0.4	9/24/98	Shiretoko Peninsula 44°30'N 145°20'E	79	2,779	35.2	3,782	30"	716		M
299	Chum	7/12/98	Bering Sea 56°30'N 177°30'W	7.1	577	0.3	10/5/98	Nemuro Strait 43°41'N 145°09'E	85	2,969	34.9	4,059	30"	590	2.4	F

Table 3. Mean temperature, standard deviation, maximum and minimum temperatures, and percent of time in 1°C categories for temperature data from a pink salmon tagged with temperature data tag no. 189 in the Gulf of Alaska 7/3/98 and recovered at Afognak Island, Alaska on 7/24/98. Data were recorded at 7.5 minute intervals. Periods based on examination of graph of temperature by day (see text). Statistics for last 15.5 hours (7/23-24) before capture not shown. *** = significant differences between day and night values, p>0.001.

Temperature (°C)	Initial phase			Extended phase									All Data		
	7/3-8			Period 1: 7/8-12			Period 2: 7/12-19			Period 3: 7/19-23					
	Day n=686	Night n=280	All n=966	Day n=519	Night n=224	All n=743	Day n=978	Night n=392	All n=1370	Day n=636	Night n=224	All n=860	Day n=2,876	Night n=1,176	All n=4,052
Mean	10.29	10.18 ***	10.25	8.51	11.28 ***	9.34	10.26	12.13 ***	10.79	9.94	10.82 ***	10.17	9.88	11.14	10.25
Std. Dev.	0.56	0.42 ***	0.53	1.06	0.58 ***	1.58	1.78	0.73 ***	1.77	1.09	0.22 ***	1.02	1.43	0.98	1.44
Maximum	11.97	10.82	11.97	11.59	11.97	11.97	14.41	13.13	14.41	11.72	11.08	11.72	14.41	13.13	14.41
Minimum	8.91	8.14	8.14	5.83	9.55	5.83	5.70	8.78	5.70	7.63	9.80	7.63	5.70	8.14	5.70
Temperature interval															
5	0.0%	0.0%	0.0%	0.8%	0.0%	0.5%	1.4%	0.0%	1.0%	0.0%	0.0%	0.0%	0.6%	0.0%	0.4%
6	0.0%	0.0%	0.0%	8.9%	0.0%	6.2%	3.8%	0.0%	2.7%	0.0%	0.0%	0.0%	2.9%	0.0%	2.0%
7	0.0%	0.0%	0.0%	23.7%	0.0%	16.6%	5.8%	0.0%	4.2%	0.5%	0.0%	0.3%	6.4%	0.0%	4.5%
8	0.1%	1.8%	0.6%	29.7%	0.0%	20.7%	12.3%	0.3%	8.8%	28.1%	0.0%	20.8%	15.8%	0.5%	11.4%
9	38.8%	49.6%	41.9%	32.2%	4.5%	23.8%	17.5%	1.3%	12.8%	13.1%	0.9%	9.9%	24.5%	16.8%	22.3%
10	50.4%	48.6%	49.9%	3.9%	31.3%	12.1%	23.2%	5.9%	18.2%	40.9%	92.0%	54.2%	30.7%	38.3%	32.9%
11	10.6%	0.0%	7.6%	1.0%	64.3%	20.1%	19.6%	27.0%	21.8%	17.5%	7.1%	14.8%	13.6%	22.6%	16.2%
12	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	11.9%	56.6%	24.7%	0.0%	0.0%	0.0%	4.0%	18.9%	8.3%
13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	4.0%	8.9%	5.4%	0.0%	0.0%	0.0%	1.4%	3.0%	1.8%
14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%	0.0%	0.4%	0.0%	0.0%	0.0%	0.2%	0.0%	0.1%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 4. Mean temperature, standard deviation, maximum and minimum temperatures, and percent of time in 1°C categories for temperature data from a coho salmon tagged with temperature data tag no. 52 in the Gulf of Alaska 7/3/98 and recovered in Togiak Bay, Alaska on 8/24/98. Data were recorded at 15 minute intervals. Periods based on examination of graph of temperature by day (see text).
* = significant differences between day and night values, p>0.05; *** p>0.001.

Temperature (°C)	Initial phase			Extended phase						All Data		
	7/3-8			Period 1: 7/8-8/6			Period 2: 8/6-24					
	Day n=316	Night n=155	All n=471	Day n=1,886	Night n=899	All n=2,785	Day n=1,197	Night n=558	All n=1,755	Day n=3,399	Night n=1,612	All n=5,011
Mean	10.92	10.89	10.91	10.71	10.74	10.35	9.92	9.46 ***	9.77	10.45	10.31	10.41
Std. Dev.	0.38	0.33 *	0.36	1.25	1.19 *	1.38	1.42	1.31 *	1.40	1.32	1.33	1.32
Maximum	11.64	11.27	11.64	14.42	13.53	16.21	16.21	15.57	16.21	16.21	15.57	16.21
Minimum	7.38	8.26	7.38	6.62	7.00	6.24	7.13	6.24	6.24	6.62	6.24	6.24
Temperature interval												
6	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.4%	0.1%	0.0%	0.1%	0.1%
7	0.3%	0.0%	0.2%	2.2%	3.2%	2.5%	4.2%	2.5%	3.6%	2.7%	2.7%	2.7%
8	0.0%	0.6%	0.2%	6.4%	4.9%	5.9%	19.5%	34.1%	24.1%	10.4%	14.6%	11.7%
9	2.8%	1.3%	2.3%	14.2%	14.8%	14.4%	30.6%	37.1%	32.6%	18.9%	21.2%	19.7%
10	42.1%	43.2%	42.5%	36.1%	29.1%	33.9%	28.3%	18.3%	25.1%	33.9%	26.7%	31.6%
11	54.7%	54.8%	54.8%	25.8%	34.3%	28.5%	9.7%	2.0%	7.2%	22.8%	25.1%	23.5%
12	0.0%	0.0%	0.0%	12.0%	12.1%	12.0%	1.8%	0.2%	1.3%	7.3%	6.8%	7.1%
13	0.0%	0.0%	0.0%	3.1%	1.6%	2.6%	4.5%	5.2%	4.7%	3.3%	2.7%	3.1%
14	0.0%	0.0%	0.0%	0.2%	0.0%	0.1%	1.2%	0.2%	0.9%	0.5%	0.1%	0.4%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.2%	0.2%	0.1%	0.1%	0.1%
16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	0.0%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5. Mean temperature, standard deviation, maximum and minimum temperatures, and percent of time in 1°C categories for temperature data from a steelhead trout tagged with temperature data tag no. 198 in the Gulf of Alaska 7/9/98 and recovered in the Copper River Delta, Alaska on 8/14/98. Data were recorded at 7.5 minute intervals. Periods based on examination of graph of temperature by day (see text).
* = significant differences between day and night values, p>0.05; *** p>0.001.

Temperature (°C)	Initial phase			Extended phase									All Data		
	7/9-13			Period 1: 7/13-28			Period 2: 7/28-8/9			Period 3: 8/9-14					
	Day n=504	Night n=256	All n=760	Day n=1,913	Night n=960	All n=2,873	Day n=1,655	Night n=781	All n=2,436	Day n=533	Night n=307	All n=840	Day n=4,605	Night n=2,304	All n=6,909
Mean	10.68	10.46 ***	10.60	10.39	11.01 ***	10.60	13.28	13.37 *	13.31	12.85	12.80	12.83	11.75	11.98	11.83
Std. Dev.	0.53	0.11 ***	0.45	1.49	0.35 ***	1.27	1.47	0.60 ***	1.26	1.59	0.91 ***	1.38	1.97	1.30	1.78
Maximum	11.82	10.56	11.82	12.71	11.82	12.71	15.64	14.36	15.64	15.77	14.23	15.77	15.77	14.36	15.77
Minimum	8.41	10.3	8.41	6.38	8.54	6.38	6.51	10.18	6.51	7.14	10.93	7.14	6.38	8.54	6.38
Temperature interval															
6	0.0%	0.0%	0.0%	2.6%	0.0%	1.7%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	1.1%	0.0%	0.7%
7	0.0%	0.0%	0.0%	6.0%	0.0%	4.0%	1.5%	0.0%	1.0%	0.4%	0.0%	0.2%	3.1%	0.0%	2.0%
8	2.4%	0.0%	1.6%	15.1%	0.3%	10.2%	1.0%	0.0%	0.7%	1.9%	0.0%	1.2%	7.1%	0.1%	4.8%
9	3.8%	0.0%	2.5%	7.5%	0.6%	5.2%	1.1%	0.0%	0.8%	3.4%	0.0%	2.1%	4.3%	0.3%	3.0%
10	68.8%	100.0%	79.3%	23.5%	50.1%	32.4%	3.8%	0.4%	2.7%	4.7%	0.3%	3.1%	19.2%	32.2%	23.5%
11	25.0%	0.0%	16.6%	36.5%	49.0%	40.7%	8.9%	5.9%	8.0%	17.4%	28.0%	21.3%	23.1%	26.1%	24.1%
12	0.0%	0.0%	0.0%	8.8%	0.0%	5.9%	12.9%	9.0%	11.6%	23.3%	24.8%	23.8%	11.0%	6.3%	9.4%
13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	36.4%	77.1%	49.5%	23.3%	39.1%	29.0%	15.8%	31.3%	21.0%
14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	31.6%	7.7%	23.9%	16.7%	7.8%	13.5%	13.3%	3.6%	10.1%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.7%	0.0%	1.8%	9.0%	0.0%	5.7%	2.0%	0.0%	1.3%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 6. Mean temperature, standard deviation, maximum and minimum temperatures, and percent of time in 1°C categories for temperature data from a chum salmon tagged with temperature data tag no. 259 in the southern Bering Sea 7/3/98 and recovered on the Pacific coast of Hokkaido, Japan on 9/4/98. Data were recorded at 15 minute intervals. Periods based on examination of graph of temperature by day (see text).
* = significant differences between day and night values, p>0.05; ** p>0.01; *** p>0.001.

Temperature (°C)	Initial phase			Extended phase						All Data		
	7/3-25			Period 1: 7/25-8/4			Period 2: 8/24-9/4					
	Day n=1,376	Night n=699	All n=2,075	Day n=1,747	Night n=1,161	All n=2,908	Day n=571	Night n=457	All n=1,028	Day n=3,694	Night n=2,317	All n=6,011
Mean	7.33	7.24	7.30	8.13	9.96 ***	8.86	11.14	11.66 **	11.37	8.30	9.47	8.75
Std. Dev.	1.11	1.12	1.11	2.95	1.91 ***	2.74	2.78	3.03 *	2.90	2.72	2.57	2.72
Maximum	10.74	9.25	10.74	14.76	13.12	14.76	18.62	17.84	18.62	18.62	17.84	18.62
Minimum	3.3	3.82	3.3	1.61	1.61	1.61	4.21	4.85	4.21	1.61	1.61	1.61
Temperature interval												
1	0.0%	0.0%	0.0%	0.6%	0.1%	0.4%	0.0%	0.0%	0.0%	0.3%	0.0%	0.2%
2	0.0%	0.0%	0.0%	6.3%	1.0%	4.2%	0.0%	0.0%	0.0%	3.0%	0.5%	2.0%
3	0.4%	0.1%	0.3%	5.2%	0.9%	3.5%	0.0%	0.0%	0.0%	2.6%	0.5%	1.8%
4	3.0%	3.6%	3.2%	4.9%	1.3%	3.5%	0.5%	0.2%	0.4%	3.5%	1.8%	2.8%
5	3.9%	5.4%	4.4%	7.6%	1.3%	5.1%	1.2%	2.4%	1.8%	5.2%	2.8%	4.3%
6	35.2%	33.8%	34.7%	9.6%	1.3%	6.3%	4.2%	5.0%	4.6%	18.3%	11.8%	15.8%
7	31.7%	35.1%	32.8%	8.4%	3.5%	6.4%	5.1%	2.4%	3.9%	16.5%	12.8%	15.1%
8	13.1%	8.9%	11.7%	16.6%	11.1%	14.4%	11.4%	8.5%	10.1%	14.5%	9.9%	12.7%
9	12.4%	13.2%	12.6%	11.7%	23.4%	16.4%	17.5%	12.9%	15.5%	12.8%	18.3%	14.9%
10	0.4%	0.0%	0.3%	9.8%	28.4%	17.3%	13.5%	12.9%	13.2%	6.9%	16.8%	10.7%
11	0.0%	0.0%	0.0%	9.2%	12.6%	10.5%	9.3%	9.8%	9.5%	5.8%	8.2%	6.7%
12	0.0%	0.0%	0.0%	9.3%	14.8%	11.5%	9.3%	18.4%	13.3%	5.8%	11.0%	7.9%
13	0.0%	0.0%	0.0%	0.8%	0.2%	0.6%	9.6%	4.4%	7.3%	1.9%	0.9%	1.5%
14	0.0%	0.0%	0.0%	0.1%	0.0%	0.1%	9.5%	5.3%	7.6%	1.5%	1.0%	1.3%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.5%	7.4%	5.3%	0.5%	1.5%	0.9%
16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.9%	5.7%	4.7%	0.6%	1.1%	0.8%
17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.2%	4.6%	2.7%	0.2%	0.9%	0.5%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.0%	0.2%	0.1%	0.0%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 7. Mean temperature, standard deviation, maximum and minimum temperatures, and percent of time in 1°C categories for temperature data from a chum salmon tagged with temperature data tag no. 274 in the central Bering Sea 7/7/98 and recovered on the Okhotsk Sea coast of Hokkaido, Japan on 9/24/98. Data were recorded at 30 minute intervals. Periods based on examination of graph of temperature by day (see text).
* = significant differences between day and night values, p>0.05; *** p>0.001.

Temperature (°C)	Initial phase			Extended phase									All Data		
	7/7-15			Period 1: 7/15-8/31			Period 2: 8/31-9/12			Period 3: 9/12-24					
	Day n=253	Night n=100	All n=353	Day n=1,454	Night n=826	All n=2,280	Day n=324	Night n=251	All n=575	Day n=300	Night n=274	All n=574	Day n=2,331	Night n=1,451	All n=3,782
Mean	7.27	6.85 *	7.15	6.56	8.71 ***	7.34	10.90	11.34 *	11.09	11.68	11.95	11.81	7.90	9.65	8.57
Std. Dev.	0.97	1.50 ***	1.16	3.14	1.98 ***	2.96	2.66	1.92 ***	2.38	2.09	3.28 ***	2.72	3.47	2.75	3.32
Maximum	8.16	7.78	8.16	12.68	12.16	12.68	14.24	14.24	14.24	17.41	18.08	18.08	17.41	18.08	18.08
Minimum	2.51	1.83	1.83	0.04	1.01	0.04	1.56	5.69	1.56	-0.38	-0.67	-0.67	-0.38	-0.67	-0.67
Temperature interval															
-1	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	0.7%	0.5%	0.0%	0.1%	0.1%
0	0.0%	0.0%	0.0%	0.9%	0.0%	0.6%	0.0%	0.0%	0.0%	0.0%	1.1%	0.5%	0.6%	0.2%	0.4%
1	0.0%	1.0%	0.3%	5.8%	0.4%	3.9%	0.3%	0.0%	0.2%	0.3%	0.4%	0.3%	3.7%	0.3%	2.4%
2	0.8%	5.0%	2.0%	13.9%	0.7%	9.1%	1.2%	0.0%	0.7%	0.3%	2.2%	1.2%	9.0%	1.2%	6.0%
3	3.2%	3.0%	3.1%	8.9%	1.9%	6.4%	1.2%	0.0%	0.7%	1.3%	2.6%	1.9%	6.2%	1.8%	4.5%
4	0.0%	1.0%	0.3%	4.3%	1.9%	3.4%	1.5%	0.0%	0.9%	0.0%	0.0%	0.0%	2.9%	1.2%	2.2%
5	3.2%	9.0%	4.8%	6.5%	1.7%	4.8%	2.8%	0.8%	1.9%	0.0%	0.0%	0.0%	4.8%	1.7%	3.6%
6	11.9%	3.0%	9.3%	8.8%	8.0%	8.5%	2.5%	0.0%	1.4%	0.0%	0.0%	0.0%	7.1%	4.8%	6.2%
7	75.1%	78.0%	75.9%	13.8%	23.0%	17.1%	3.4%	1.6%	2.6%	0.0%	0.4%	0.2%	17.2%	18.8%	17.8%
8	5.9%	0.0%	4.2%	12.4%	16.1%	13.7%	4.6%	5.2%	4.9%	1.0%	1.5%	1.2%	9.1%	10.3%	9.6%
9	0.0%	0.0%	0.0%	9.2%	19.2%	12.9%	12.3%	19.9%	15.7%	6.3%	1.8%	4.2%	8.3%	14.7%	10.8%
10	0.0%	0.0%	0.0%	7.2%	11.7%	8.9%	11.7%	18.3%	14.6%	23.7%	10.6%	17.4%	9.2%	11.9%	10.2%
11	0.0%	0.0%	0.0%	6.3%	12.7%	8.6%	15.1%	15.5%	15.3%	20.0%	21.5%	20.7%	8.6%	14.0%	10.7%
12	0.0%	0.0%	0.0%	2.0%	2.5%	2.2%	22.2%	11.6%	17.6%	27.3%	27.4%	27.4%	7.9%	8.6%	8.1%
13	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	18.5%	22.3%	20.2%	11.3%	14.6%	12.9%	4.0%	6.6%	5.0%
14	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%	4.8%	3.5%	5.0%	2.6%	3.8%	1.0%	1.3%	1.1%
15	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.7%	4.4%	3.0%	0.2%	0.8%	0.4%
16	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.3%	4.7%	2.4%	0.0%	0.9%	0.4%
17	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	3.3%	2.1%	0.1%	0.6%	0.3%
18	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%	0.2%	0.0%	0.1%	0.0%
Total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%