# UPSTREAM MIGRATION OF PACIFIC LAMPREYS IN THE JOHN DAY RIVER: BEHAVIOR, TIMING, AND HABITAT USE

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## EXECUTIVE SUMMARY

Historic accounts and recent observations of Pacific lampreys (*Lampetra tridentata*) at mainstem Columbia River dams indicate the number of Pacific lampreys migrating upriver has decreased dramatically over the last 60 years. Consequently, state, federal, and tribal governments have recently expressed concern for this species. Little is known about the biological and ecological characteristics of habitats suitable for upstream migrating Pacific lampreys. If rehabilitation efforts are to be done effectively and efficiently, we must gain knowledge of factors limiting survival and reproduction of Pacific lampreys. From data gathered in the first year of this project, we can for the first time, describe the timing, extent, and patterns of movements for Pacific lampreys. We have tested methods and gained information that will allow us to refine our objectives and approach in future work. Knowledge of behavior, timing, and the resulting quantification of habitat use will provide a means to assess the suitability of overwintering and spawning habitats and allow the establishment of goals for recovery projects. Further research is necessary, including multiple years of data collection, tracking of movement patterns through the spawning season, and more rigorously examining habitat use.

## ACKNOWLEDGEMENTS

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# INTRODUCTION

Pacific lamprey (Lampetra tridentata) populations in the Columbia River Basin (CRB) have declined dramatically compared to their populations prior to hydropower development (Close et al. 1995). Consequently, state, federal, and tribal organizations have recently expressed concern for this species. For example, in 1993 the Oregon Department of Fish and Wildlife designated the Pacific lamprey at risk of being listed as threatened or endangered, should its status continue to deteriorate. Columbia River treaty tribes have also voiced concern about the decline of this culturally significant species (Close et al. 1995, Jackson et al. 2000). The Northwest Power Planning Council's Fish and Wildlife Program (1994) noted the apparent decline of Pacific lampreys and requested a status report to identify research needs. The resulting report (Close et al. 1995) called for studies on lamprey abundance, evaluation of their current distribution, and determination of habitat limiting factors. Rehabilitation is now being planned in some areas where lampreys are believed to have been extirpated (Close et al. 1995, Jackson et al. 2000).

Participants in the Columbia Basin Pacific Lamprey Technical Workgroup (Pendleton, OR 1998 and 2000) concluded that in addition to evaluating the population status of lampreys, fundamental biological questions must be answered, including identification of biological and ecological factors limiting lamprey production in the CRB. Some biological and ecological information for this and sympatric species (western brook lamprey *L. richardsoni* and river lamprey *L. ayresi*) is available from studies conducted in Canada (Pletcher 1963, Beamish 1980, Richards 1980, Beamish and Levings 1991). However, little is known of the biology and ecology of lampreys in the

CRB (Kan 1975, Hammond 1979). Along the Pacific coast of Canada, Pacific lampreys are believed to migrate into freshwater and move upstream to spawn from May to September, overwinter, and spawn in early spring the following year (Beamish 1980, Beamish and Levings 1991). Data from trapping efforts by the National Marine Fisheries Service (NMFS) at Bonneville Dam also suggest Pacific lampreys move upstream to spawn from May to September in the Columbia River Basin, with the run peaking in mid-July (NMFS pers. comm). Further, studies by the NMFS have shown that hydroelectric projects can pose significant passage constraints for Pacific lampreys (NMFS pers. comm.). However, we presently have only a cursory understanding of the life history pattern of Pacific lampreys and information regarding the migration behavior (e.g., timing of movement into tributaries, rate of movement in tributaries) and habitat preferences (e.g., over-wintering, spawning, and rearing) of Pacific lamprey in the tributaries in which they spawn is lacking.

Documentation of the life history strategy and habitat preferences of Pacific lampreys in streams and rivers tributary to the Columbia River will help identify factors limiting lamprey populations, identify areas in need of rehabilitation, and help to assess the efficacy of management actions. Through the NWPPC funding process, we received funding as an “Innovative Project” in FY2000 to conduct a pilot study in the John Day River. We conducted this study in the John Day River Basin for several reasons. First, larval and adult stages of Pacific lampreys have been documented in the basin (Jackson et al. 2000; CTWSRO, pers. comm.; ODFW pers. comm.). Second, the John Day River is unimpounded and provides the opportunity to study migration behavior and timing of fish unimpeded by passage constraints. And third, since the John Day River Basin shares certain characteristics with the Umatilla River Basin, data collected during this study may be useful in the implementation and evaluation of the proposed restoration of Pacific lampreys in the Umatilla River. Migration behavior, timing, and the quantification of habitat preferences will provide a means to assess the suitability of overwintering and spawning habitat and help to establish goals for recovery projects.

During 2000, our objectives were to 1) Assess the logistics associated with conducting a radio telemetry study of Pacific lamprey in the John Day River including developing capturing, tagging, holding, and tracking (i.e., fixed station and mobile tracking) protocols. 2) Collect preliminary information on the migration behavior in the John Day River. 3) Collect preliminary information on the over-wintering and spawning habitats used by Pacific lamprey in the John Day River. In this report we present the results of our pilot study. Unfortunately, given the timing and one-year duration of the "Innovative Project" funding contract, we were only able to collect preliminary information on the migration behavior and over-wintering habitats because our contract terminated before the lamprey spawning season.

## METHODS

### *Study Area*[1]

The John Day River Basin (Figure 1) is located in the southern portion of the Columbia Plateau Ecological Province, covering nearly 21,000 $km^2$ in north-central and northeastern Oregon. This system is the fourth largest watershed in Oregon and contains over 800 kilometers of river between the mainstem and its three major tributaries: the North Fork John Day, the Middle Fork John Day, and the South Fork John Day. The Basin is bounded by the Columbia River to the north, the Blue Mountains to the east, the

[1] Subbasin description taken from Knapp, 2001.

Aldrich Mountains and the Strawberry Range to the south, and the Ochoco Mountains to the west. Topography, climate, and vegetation of the John Day Basin are extremely varied, ranging from glaciated alpine peaks over 2,700 m at the headwaters to semi-arid, shrub-steppe at 60 m elevation near the mouth. Annual precipitation ranges from 130 cm in the upper elevations to 30 cm or less in the lower elevations. Throughout the basin, air temperatures can range from less than -20° C in the winter to over 38° C in the summer. Average annual discharge of the John Day River into the Columbia River is 59.6 $m^3/s$. The North Fork John Day watershed is the largest within the John Day Basin, draining approximately 4,600 $km^2$ and supplying approximately 60% (average 35.9 $m^3/s$) of the basin's discharge.

*Animal Collection and Transmitter Implantation*

Between July 26 and September 1, 2000, adult Pacific lampreys were captured after sunset in the John Day River, OR at Tumwater Falls (river kilometer (RKM) 16.9) using dip nets (Figure 2). Lampreys were held in 68 L containers for 2 to 6 h until transmitters were surgically implanted. During their confinement lampreys were provided with aerated river water, which was periodically exchanged for fresh river water. Radio transmitters were surgically implanted into lampreys at the capture site, using methods as used by NMFS (pers. comm.). The transmitter was 29 mm x 8 mm and weighed 4.5 g in air (Lotek Engineering, Inc., Ontario, Canada[2]). Animals were anesthetized by immersion in 70 mg/L buffered tricaine methanesulfonate (MS-222) for 5-7 min. Length, weight, anterior girth (body circumference posterior to seventh gill pore), mid girth (body circumference anterior to first dorsal fin), and posterior girth (body

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2 Mention of trade names does not imply endorsement by the U.S. Geological Survey.

circumference between first and second dorsal fins) of lampreys were measured prior to surgery.  A mid girth of 100 mm was determined to be the minimum criterion for surgery due to tag size and limited space within the body cavity.  Sedated lampreys were placed ventral side up on a padded, U-shaped trough.  Anesthesia was maintained during surgery by immersion of the head and gill pores in 50 mg/L buffered MS-222.  A 2.5 cm incision was made along the longitudinal axis of the abdomen beginning 3 to 4 cm anterior to the dorsal fin and just off the midline.  A Teflon-sheathed catheter needle was inserted through the incision along the peritoneal wall and pierced through the musculature 1 to 3 cm anterior to the incision.  The needle was withdrawn, leaving the Teflon sheath in the exit wound.  A tag was inserted antenna-first into the body cavity and through the Teflon sheath.  The body of the transmitter was then inserted into the peritoneal cavity starting at the anterior end of the incision.  Once the transmitter had entered the peritoneal cavity, the Teflon sheath was slid off the end of the antenna.  The incision was closed with 4 to 5 evenly spaced, simple interrupted sutures using 4/0 absorbable material.  A 0.4 mL dose of oxytetracycline (100 mg/mL) was injected into the closed incision underneath the sutures using a syringe with a blunt-tipped needle, and the incision was swabbed with antibiotic ointment.  The entire procedure averaged 8 min (range = 6 to 15 min). Lampreys were transferred to a tank with a flow-through water supply and allowed to recover for 15 to 20 h.  All lampreys were released after sunset.

*Tracking*

Movements of radio-tagged lampreys were followed in the John Day River using three methods.  Fixed-site, data-logging receivers were used to continuously record timing of movements.  Data from fixed-site receivers were used to limit the extent of the aerial search area. Aerial telemetry was used to find general positions of tagged lampreys over large portions of the basin. Terrestrial telemetry was used to find precise locations of lampreys.

Five stations in the John Day River basin were equipped with data-logging receivers and water temperature recorders. Receivers continuously monitored assigned channels for passage of radio-tagged lampreys by key points. Two stations were established on the lower mainstem John Day River and one station each was positioned on the North Fork John Day River, the Middle Fork John Day River, and the South Fork John Day River (Figure 2). Each station consisted of a telemetry receiver equipped with data-logging firmware (Lotek Engineering, Inc., Ontario, Canada[3]), a 4-element Yagi antenna, and a power source, and a data-logging temperature recorder (Onset Computer Corporation, Bourne, MA). Antennas faced downriver approximately 45° offshore and down toward the thalweg. The North Fork station antenna was initially faced upriver due to physical constraints of the station, but was later pointed downstream like the other stations due to excessive noise events in the upstream direction. Receiver sensitivities were maximized based on reception of test transmitters and limits imposed by background noise. Data from fixed receivers were downloaded as needed to determine flight plans for aerial tracking. Temperature recorders were placed in-river near the receiver station and logged water temperature hourly. Data from temperature recorders were downloaded periodically.

Aerial telemetry was used to monitor basin-wide movements of lampreys. We attempted to detect lampreys by aerial surveys at 14 d intervals, weather permitting. A

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[3] Mention of trade names does not imply endorsement by the U.S. Geological Survey.

small, fixed-wing aircraft (Cessna 185[4]) was outfitted with two four-element Yagi antennas, one mounted to the strut under each wing, facing forward and down approximately 45 degrees from the bottom of the wing. Co-axial cables from these antennas were spliced together into a common line, allowing them to be monitored as one antenna. A telemetry receiver monitored incoming signals and incorporated global positioning system (GPS) locations into the data stream. Upon acquisition of a transmitter signal, multiple passes were made in order to collect multiple data points. One crewmember varied the gain of the receiver to maximize signal reception while the receiver recorded the date, time, channel, code, and strength of received signals. The telemetry receiver incorporated latitude and longitude of data points into the data stream using output from a GPS receiver. A second crewmember recorded a paper copy of the data and estimated fish locations on a paper map as a backup to digitally logged data. The accuracy and precision of aerial tracking were determined by comparing the known coordinates of two test tags placed in the river basin to the locations predicted by flight data. Additionally, lamprey locations determined by terrestrial tracking were used to validate aerial locations.

Terrestrial telemetry was used to precisely locate lampreys. Because terrestrial tracking was more labor intensive than aerial tracking, a subset of radio-tagged individuals was chosen to be precisely located based on their "holding" behavior and ease of access via roads or by boat (since much of the river is not accessible by road). A lamprey was considered to be holding if it remained in one location for a minimum of one month. Lampreys located near roads were approached by vehicle, while more

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remotely located lampreys were approached by raft. Either a four-element or three-element antenna connected to a telemetry receiver was used to locate tagged lampreys. The operator of the receiver incrementally reduced the gain as proximity to the transmitter increased, thereby decreasing the range and increasing the directionality of the antenna. Once a transmitter's signal strength was greater than –79.2 decibels (power of 100 at a gain of 30), the transmitter was considered to have been accurately located. A GPS receiver was used to record latitude and longitude at the location.

*Habitat Assessment*

For each precisely located lamprey, habitat data were recorded at the time of location. Water depth, flow, and temperature were measured where each lamprey was found. Substrate characteristics of the immediate area surrounding the location were qualitatively described. Water depth was measured using a wading rod. Water flow was measured using an electromagnetic flow meter (Marsh-McBirney, Frederick, MD[5]). Flow measurements were made as in Gallagher and Stevenson, 1999. Water temperature was measured using a digital thermometer, which had been calibrated against a mercury thermometer before use in the field. Photographs of the immediate reach were taken.

*Data Analysis*

Fixed, aerial, and terrestrial telemetry data were entered into and processed in a geographic information system. Fixed telemetry data were mapped using the coordinates of the station from which the data originated. Aerial telemetry data were mapped by estimating the transmitter location through interpretation of the locations and received signal strengths of data points collected by the receiver. Data from test transmitters

[5] Mention of trade names does not imply endorsement by the U.S. Geological Survey.

revealed that received signal strength increased with increased proximity to the transmitter. Thus, aerial locations of lampreys were mapped where received signal strength was greatest. Terrestrial telemetry data was mapped using either the coordinates recorded by a GPS or the position estimated on a paper map (when the GPS was not functional). Each telemetry location was assigned a river mile as determined from digital USGS 7.5' quadrangles. Fixed telemetry locations were assigned the river mile of the station that recorded the data. Aerial telemetry locations were assigned the closest 0.5 river mile to the mapped location. Terrestrial telemetry locations were assigned the closest 0.1 river mile as determined by measurement from the closest whole river mile along the thalweg. River miles were converted to river kilometers. River kilometer assignments were used to reference lamprey locations on a basin-wide scale, and thus were conservative estimates of position reflective of the differences in precision between aerial and terrestrial telemetry data.

## RESULTS

### *Tagging*

Between July 26 and September 1, 2000, 55 lampreys were caught at Tumwater Falls. Of these, 42 were surgically implanted with radio transmitters (Table 1). For tagged lampreys, the mean fork length was 662 mm (range 610 to 725 mm), mean weight was 446 g (range 305 to 565 g), mean anterior girth was 114 mm (range 102 to 126 mm), mean mid girth was 108 mm (range 98 to 124 mm), and mean posterior girth was 87 mm (range 79 to 99 mm). Fifty percent of tagged lampreys were male and fifty percent were female, however sex was not a factor in deciding which lampreys to tag. The duration of the surgical procedure averaged 8 minutes (range 6 to 15 minutes) and the recovery time before release averaged 18 hours (range 15 to 20 hours). Of the 13 lampreys not used in this study, 3 were killed because of surgical error, and 10 were released because they did not meet minimum size criteria for surgery.

*Tracking*

<u>Summary</u>

- Movement past fixed receivers was exclusively between sunset and sunrise, with one lamprey holding position in front of a receiver during daylight hours.
- Lampreys were observed to travel from 0 to 20.9 km/days.
- Median distance traveled from tagging site before overwinter holding was 57.8 km (range –2.9 to 285.0 km, n=36)
- Most over-winter holding was initiated by mid-September, 2000, and continued until mid-March, 2001.
- Lampreys held position exclusively in the lower John Day River (below 297 RKM) except for one individual that held in the North Fork John Day River.
- Five lampreys of over 300 tagged by National Marine Fisheries Service (NMFS) at Bonneville Dam in summer (May – September) 2000 were found in proximity to USGS-tagged lampreys and have behaved similarly to the lampreys we tagged.
- Holding behavior initiation appears to have coincided with decreasing temperature, day length, and discharge.
- Thirty-five of 41 lampreys actively tracked by air were chosen for more precise locations from the ground or by boat.
- Lampreys over-wintered under boulders in riffle/glide type habitats.
- Resumption of upstream movement has been documented as of March 2001

## Fixed Receiver Stations

Continuous monitoring of transmitters at fixed receiver stations revealed that lampreys moved exclusively between sunset and sunrise (Figures 3 to 6), with one lamprey holding during daylight hours in close proximity to the receiver. Movements were only detected past the two Lower John Day receivers before upstream movement ceased. Twenty-three lampreys (20 USGS and 3 NMFS) passed the Cottonwood Bridge fixed receiver station (RKM 63.6) before holding (Figure 3). Two lampreys (both USGS) passed the Service Creek fixed receiver station (RKM 252.0) before holding (Figure 4). All lampreys detected by fixed receiver stations were subsequently detected upriver of those stations. All lampreys detected upriver of fixed receiver sites had been previously detected by those fixed receiver sites.

Lamprey passage at Cottonwood Bridge before holding was used as an indicator of maximal travel times and rates of travel. Median travel time for twenty USGS lampreys to move 46.7 km from release to detection at Cottonwood Bridge was 4.2 days (range 2.2 to 48.2 days), resulting in a median rate of travel of 11.0 km/day with a maximum rate of 20.9 km/day observed. Median rate of travel for females (11.4 km/day, n=9) was slightly higher than for males (9.1 km/day, n=11) but maximum rates were very similar between the sexes (20.5 km/day for females vs. 20.9 km/day for males). When compared by release date, lampreys released in late-August/early-September, 2000 exhibited greater maximum and median rates of travel than earlier releases (Table 2).

Lampreys resumed migration in mid-March, 2001 as evidenced by resumption in passage by fixed receiver stations. To date, 7 lampreys (6 USGS and 1 NMFS) have passed the Cottonwood Bridge fixed receiver station (RKM 63.6) after holding over the winter (Figure 5). Three lampreys (all USGS) have passed the Service Creek fixed receiver station (RKM 252.0) after holding in one location through the winter (Figure 6).

Aerial Telemetry

Fourteen aerial surveys of the John Day River Basin were conducted between August 8, 2000 and March 29, 2001. The median interval between flights was 15 days, ranging between 12 and 28 days. Test tags were detectable from 0.8 to 1.6 km. Predicted aerial locations of test tags differed from known locations by a median of 140 m (range 38 to 311 m, n=4). The median number of aerial locations per lamprey was 11 (range 1 to 14, n=41).

Aerial surveys revealed that most lampreys stopped upstream movement by mid-September, 2000 (Figures 7 to 13). The median date of last observed movement was September 12, 2000 (n=37, range August 8 to November 14). Initiation of holding behavior appears to have coincided with decreasing temperature, day length, and discharge (Figures 14 to 20). There were no substantial differences in median observed holding date by sex (Table 3), but median holding date showed an increasing trend by release date (Table 4).

Lampreys tagged by USGS held position through the winter almost exclusively in the lower John Day River Basin (Figure 21). Twenty-eight lampreys (66.7%) held evenly-distributed positions between the release site and Clarno (RKM 176.3); 6 (14.3%) held below the release site; 3 (7.1%) held upriver of Clarno, with one individual holding in the North Fork John Day River; and 5 (11.9%) have not been located since September, 2000. Lampreys tagged by NMFS showed a similar distribution (Figure 21). The median distance traveled by USGS lampreys from the release site to holding location was

57.8 km (range –2.9 to 285.0 km, n=36). There were no great differences between sexes in median distance traveled (Table 5). However, there were large differences in median distance traveled among release dates (Table 6).

Aerial surveys, like fixed receiver monitoring, revealed resumption in migration in mid-March, 2001. Figures 7 through 13 show lampreys from all releases, except Release 7/26/2000, beginning migratory movements up-river after holding over the winter. Periodic checks of temperature and discharge indicate an increasing trend during this period; day length is increasing as well.

Terrestrial Tracking

Thirty-five of 41 actively tracked lampreys were more precisely located by ground or boat. In November 2000, 14.5 km of the John Day River between Hay Creek (RKM 47.5) and McDonald Ferry (RKM 33.0), and 112.7 km between Clarno and Cottonwood Bridge, were rafted in order to locate 23 lampreys detected by aerial tracking. Of those 23 lampreys, 18 were located, and 5 were missed due to equipment difficulties. In addition, 1 lamprey was located that had not been detected by aerial tracking due to weak signal strength. Ten lamprey locations were accessed by road on separate trips in November 2000 and January 2001. The locations of 6 lampreys were determined by boat in 16 km of the John Day River impounded by the John Day Dam. Predicted aerial locations of holding lampreys differed from determined ground locations by a median of 125 m (range 3 to 2738 m, n=295).

*Habitat Assessment*

Terrestrial locations revealed that individuals were over-wintering under boulders in riffles/glides. Substrate was dominantly boulders (>25.4 cm) at 30 locations and dominantly cobbles (5.1 to 25.4 cm) at 1 location. Four locations were too deep to observe substrate. Median depth at location was 0.9 m (range 0.5 to 10.4 m, n=35). Median velocity at location was 0.37 m/s (range 0.02 to 1.22 m/s, n=29).

## DISCUSSION

Most Pacific lampreys released with radio transmitters remained in the John Day River Basin and moved upstream from the point of release. Upstream movement ceased in the fall, lampreys remained in the same location through the winter, and upstream movement resumed in early spring. A similar pattern of movement has been reported for *Geotria australis*, a southern hemisphere lamprey species, in which the rate of upstream movement in *G. australis* was shown to decline from 88 m/day to 0 over several months (Kelso and Glova 1993). *G. australis* has a protracted non-feeding upstream migration phase which lasts 15-16 months (Potter and Robinson 1991). Results from our study and suggest the Pacific lamprey may have a similar life history. This has been suggested by research conducted in Canada as well (Pletcher 1963, Beamish 1980). Other species of lamprey have an abbreviated freshwater upstream migrating phase, such as the sea lamprey (*Petromyzon marinus*) in which the duration of the spawning migration is as short as two to three months (Potter and Beamish 1977).

Upstream rate of progress in sea lamprey, another anadromous species of lamprey, (*Petromyzon marinus*), has been reported to range from 0.1-1.3 km/day (Kelso and Gardner 2000) and up to 1.0 km/hour (Stier and Kynard 1986). Upstream travel rates in our study ranged from 0 to 20.9 km/day and movements were often a series of bursts of swimming followed by periods of rest that lasted days or more. Rate of upstream movement has been reported to vary by sex (6.5 km/day for males and 6.2 km/day for females; Beamish 1979) in sea lampreys. In our study, we did not detect a difference in upstream migration rates between male and female Pacific lampreys.

Travel by sea lampreys has been reported to be primarily at night, with the greatest upstream movement occurring between 2200 and 0300 hours (Kelso and Gardner 2000). Similar patterns of nocturnal behavior were observed in landlocked sea lampreys in the Ocqueoc River, Michigan, and anadromous sea lampreys in the Connecticut River (Stier and Kynard 1986). Results of our study show that Pacific lampreys in the John Day River moved past stationary telemetry receivers exclusively at night. One receiver recorded a Pacific lamprey approaching the receiver near dawn, holding in position near the receiver through the day, and resuming upstream movement at dusk.

Cryptic behavior has been described for other species of lampreys (Kelso and Glova 1993; Kelso and Gardner 2000). Upstream migrating sea lampreys were almost always located under cover or in areas of reduced light, commonly within debris piles, under boulders and under undercut banks (Kelso and Gardner 2000). In the John Day River Basin, locations of Pacific lampreys considered to be holding through the winter were nearly always in substrate comprised mostly of boulders.

Based on our results from the first year of "Innovative Project" funding, we have confidence further research will be successful in describing a previously unknown component of this anadromous fishes' life history. Our opportunity to test techniques and methodologies in FY2000 will increase the efficiency and likelihood of success of future work. If allowed to be continued in the future, this study will answer questions about Pacific lampreys posed by regional fishery managers. Specifically, the quantification of habitat needs will help managers to develop strategies that assure long-term population viability of Pacific lampreys. Data from this project will provide information necessary to examine other aspects of lamprey biology and ecology, such as quantification of rearing habitat and determination of relative abundance of sympatric species of lamprey present in the CRB. Knowledge of behavior of Pacific lampreys in tributaries to the CRB will provide baseline information to facilitate future studies to examine possible effects of delays to migration, such as might be caused by mainstem passage constraints.

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# TABLES

**Table 1.** Summary of tagging and morphometric data from Pacific lampreys radio-tagged in the John Day River Basin, 2000.

| Tagging Date | Channel | Code | Fork Length (mm) | Weight (g) | Anterior Girth (mm) | Mid Girth (mm) | Posterior Girth (mm) | Sex |
|---|---|---|---|---|---|---|---|---|
| 07/26/2000 | 8 | 100 | 687 | 495 | 115 | 110 | 90 | male |
| 07/26/2000 | 8 | 101 | 700 | 530 | 121 | 118 | 95 | male |
| 07/26/2000 | 8 | 102 | 667 | 465 | 115 | 110 | 86 | female |
| 07/26/2000 | 8 | 103 | 705 | 520 | 123 | 114 | 90 | male |
| 07/26/2000 | 8 | 104 | 710 | 505 | 119 | 112 | 89 | female |
| 07/26/2000 | 8 | 105 | 633 | 390 | 109 | 101 | 82 | male |
| 07/26/2000 | 8 | 106 | 637 | 370 | 105 | 104 | 80 | male |
| | | | | | | | | |
| 08/01/2000 | 6 | 1 | 634 | 420 | 112 | 105 | 85 | female |
| 08/01/2000 | 6 | 2 | 639 | 456 | 103 | 98 | 79 | male |
| 08/01/2000 | 6 | 3 | 645 | 435 | 116 | 114 | 92 | female |
| 08/01/2000 | 6 | 4 | 683 | 500 | 120 | 115 | 94 | female |
| 08/01/2000 | 6 | 5 | 662 | 505 | 126 | 117 | 93 | female |
| 08/01/2000 | 6 | 6 | 665 | 495 | 114 | 109 | 89 | male |
| 08/01/2000 | 6 | 7 | 634 | 465 | 114 | 113 | 92 | female |
| 08/01/2000 | 6 | 8 | 720 | 565 | 123 | 117 | 94 | female |
| | | | | | | | | |
| 08/02/2000 | 7 | 15 | 617 | 355 | 106 | 101 | 80 | male |
| 08/02/2000 | 7 | 16 | 676 | 565 | 126 | 124 | 99 | female |
| 08/02/2000 | 7 | 17 | 661 | 395 | 109 | 98 | 80 | male |
| 08/02/2000 | 7 | 19 | 616 | 385 | 107 | 103 | 86 | female |
| 08/02/2000 | 7 | 20 | 633 | 485 | 121 | 114 | 90 | female |
| 08/02/2000 | 7 | 21 | 668 | 450 | 117 | 110 | 88 | female |
| 08/02/2000 | 7 | 22 | 681 | 400 | 108 | 100 | 81 | female |
| 08/02/2000 | 8 | 107 | 649 | 365 | 104 | 99 | 83 | female |
| | | | | | | | | |
| 08/17/2000 | 8 | 108 | 663 | 440 | 117 | 111 | 84 | male |
| 08/17/2000 | 8 | 109 | 663 | 425 | 111 | 106 | 90 | female |
| 08/17/2000 | 7 | 23 | 636 | 415 | 116 | 106 | 84 | male |
| 08/17/2000 | 7 | 24 | 725 | 520 | 120 | 113 | 90 | male |
| 08/17/2000 | 7 | 26 | 635 | 375 | 112 | 101 | 83 | male |
| 08/17/2000 | 7 | 27 | 641 | 385 | 108 | 100 | 84 | male |
| 08/17/2000 | 8 | 110 | 674 | 485 | 117 | 109 | 87 | male |
| 08/17/2000 | 6 | 10 | 657 | 405 | 107 | 102 | 81 | male |
| 08/17/2000 | 6 | 12 | 665 | 470 | 115 | 111 | 89 | female |
| 08/17/2000 | 6 | 13 | 637 | 405 | 104 | 101 | 84 | female |

**Table 1 (continued).**

| Tagging Date | Channel | Code | Fork Length (mm) | Weight (g) | Anterior Girth (mm) | Mid Girth (mm) | Posterior Girth (mm) | Sex |
|---|---|---|---|---|---|---|---|---|
| 08/31/2000 | 6 | 9 | 705 | 305 | 119 | 111 | 93 | female |
| 08/31/2000 | 6 | 11 | 666 | 375 | 102 | 100 | 84 | female |
| 08/31/2000 | 6 | 14 | 634 | 370 | 109 | 100 | 80 | male |
| 08/31/2000 | 6 | 18 | 684 | 495 | 114 | 111 | 90 | female |
| 08/31/2000 | 6 | 25 | 663 | 475 | 114 | 113 | 91 | male |
| 09/01/2000 | 7 | 28 | 693 | 550 | 125 | 116 | 95 | male |
| 09/01/2000 | 8 | 111 | 680 | 515 | 115 | 114 | 94 | female |
| 09/01/2000 | 8 | 113 | 657 | 395 | 112 | 102 | 85 | male |
| 09/01/2000 | 8 | 114 | 610 | 395 | 104 | 103 | 87 | male |

**Table 2.** Rates of travel by radio-tagged upstream migrating Pacific lampreys in the John Day River Basin between the release site and Cottonwood Bridge fixed receiver station, including maximum, minimum, and median rate of travel (km/day).

| Release Date | Number Tagged | Maximum Rate of Travel (km/day) | Median Rate of Travel (km/day) | Minimum Rate of Travel (km/day) |
|---|---|---|---|---|
| 7/26/2000 | 1 | 4.2 | 4.2 | 4.2 |
| 8/01/2000 | 3 | 14.4 | 11.3 | 10.8 |
| 8/02/2000 | 5 | 15.1 | 14.4 | 1.0 |
| 8/17/2000 | 7 | 9.1 | 5.8 | 2.6 |
| 8/31/2000 | 1 | 20.5 | 20.5 | 20.5 |
| 9/01/2000 | 3 | 20.9 | 20.6 | 19.6 |

**Table 3.** Maximum, minimum, and median date of last observed movement ("holding date") of radio-tagged Pacific lampreys in the John Day River Basin by sex.

| Sex | Number | Maximum Holding Date | Median Holding Date | Minimum Holding Date |
|---|---|---|---|---|
| Female | 16 | 10/25/2000 | 9/05/2000 | 8/08/2000 |
| Male | 16 | 11/14/2000 | 9/12/2000 | 8/08/2000 |

**Table 4.** Maximum, minimum, and median date of last observed movement ("holding date") of radio-tagged Pacific lampreys in the John Day River Basin by release date.

| Release Date | Number | Maximum Holding Date | Median Holding Date | Minimum Holding Date |
|---|---|---|---|---|
| 7/26/2000 | 2 | 9/27/2000 | 9/12/2000 | 8/29/2000 |
| 8/01/2000 | 7 | 10/25/2000 | 8/29/2000 | 8/08/2000 |
| 8/02/2000 | 7 | 10/12/2000 | 8/29/2000 | 8/08/2000 |
| 8/17/2000 | 9 | 9/27/2000 | 9/12/2000 | 8/29/2000 |
| 8/31/2000 | 4 | 10/12/2000 | 9/27/2000 | 9/12/2000 |
| 9/01/2000 | 3 | 11/14/2000 | 10/12/2000 | 9/12/2000 |
| NMFS | 5 | 9/27/2000 | 8/29/2000 | 8/8/2000 |

**Table 5.** Maximum, minimum, and median distance traveled by radio-tagged Pacific lampreys in the John Day River Basin by sex.

| Sex | Number | Maximum Distance Traveled | Median Distance Traveled | Minimum Distance Traveled |
|---|---|---|---|---|
| Female | 18 | 285.0 | 53.1 | -1.9 |
| Male | 18 | 254.9 | 57.8 | -2.9 |

**Table 6.** Maximum, minimum, and median distance traveled by radio-tagged Pacific lampreys in the John Day River Basin by release date.

| Release Date | Number | Maximum Distance Traveled | Median Distance Traveled | Minimum Distance Traveled |
|---|---|---|---|---|
| 7/26/2000 | 3 | 100.9 | -1.1 | -2.9 |
| 8/01/2000 | 7 | 117.5 | 29.8 | -1.8 |
| 8/02/2000 | 7 | 285.0 | 102.9 | -2.9 |
| 8/17/2000 | 10 | 254.9 | 90.5 | 0.0 |
| 8/31/2000 | 5 | 104.7 | 12.6 | -1.9 |
| 9/01/2000 | 4 | 150.2 | 95.7 | 0.5 |

## FIGURES

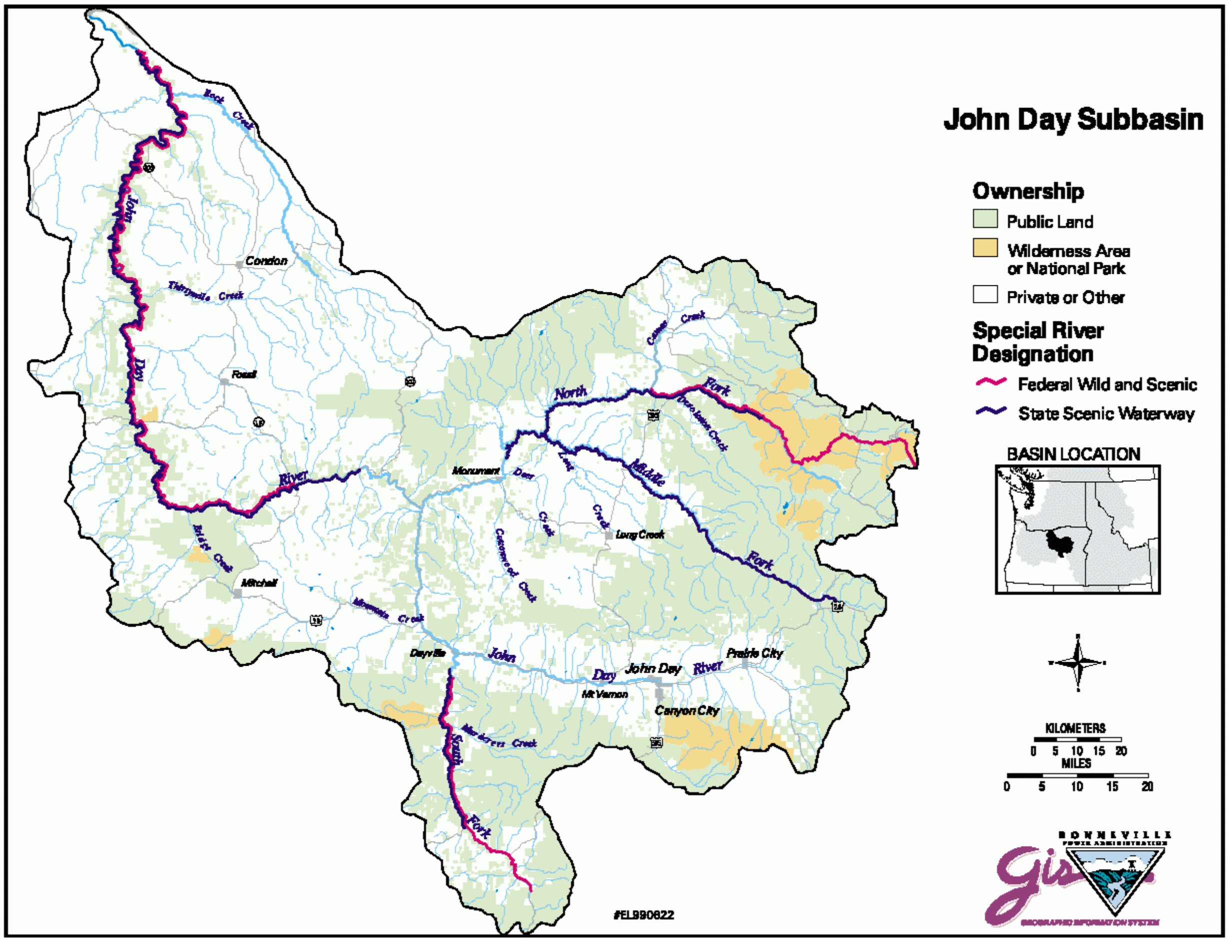


**Figure 1**. The location of the John Day River Basin (taken from the John Day River Subbasin Summary 2001).

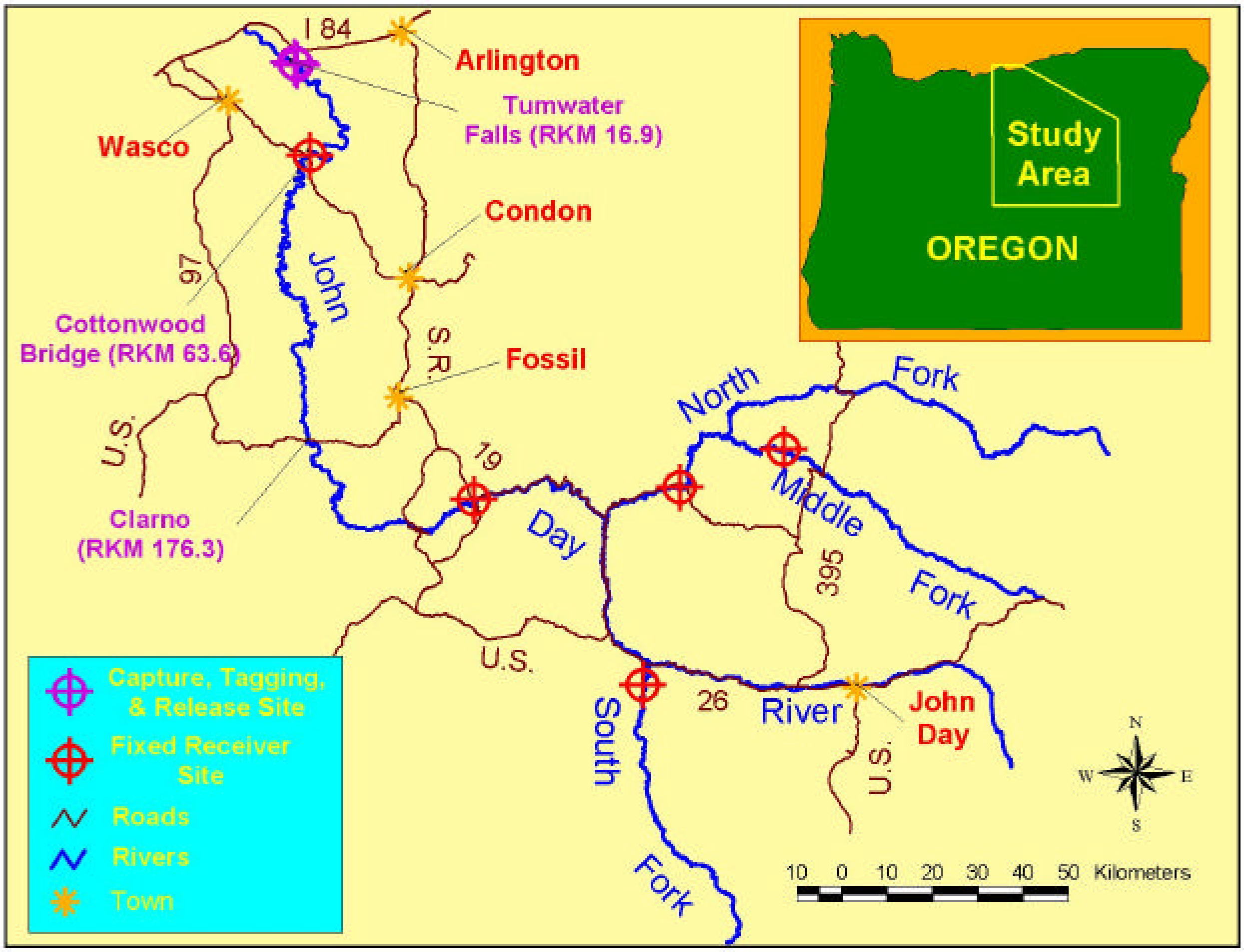


**Figure 2.** Locations of Pacific lamprey capture and tagging site (**A**) and fixed receiver stations (**A**) in 2000-2001 in the John Day River Basin, OR.

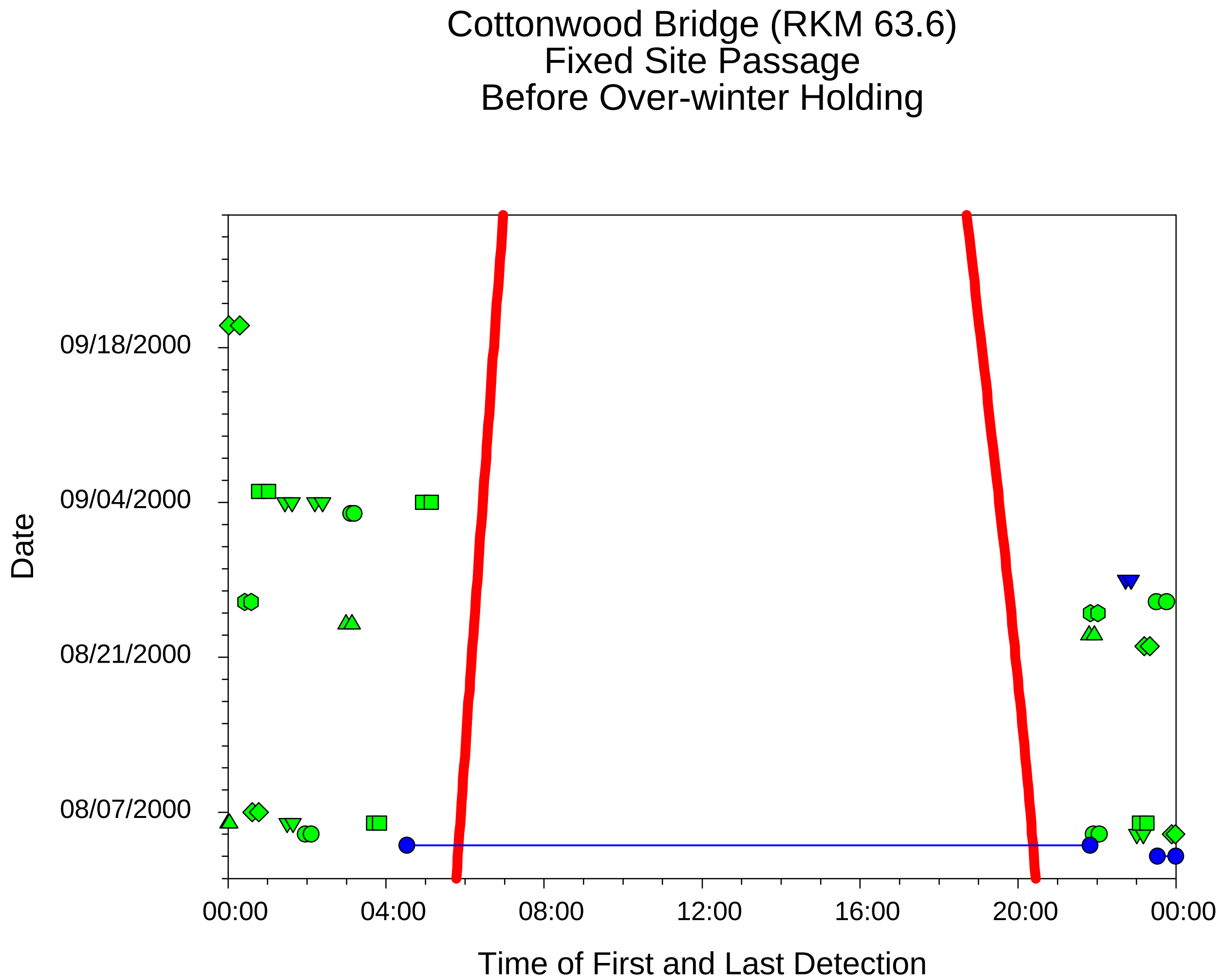


**Figure 3.** Passage of Pacific lampreys by Cottonwood Bridge fixed receiver station before holding behavior was initiated. Red lines represent time of sunrise and sunset. Green symbols represent USGS-tagged lampreys. Blue symbols represent NMFS-tagged lampreys.

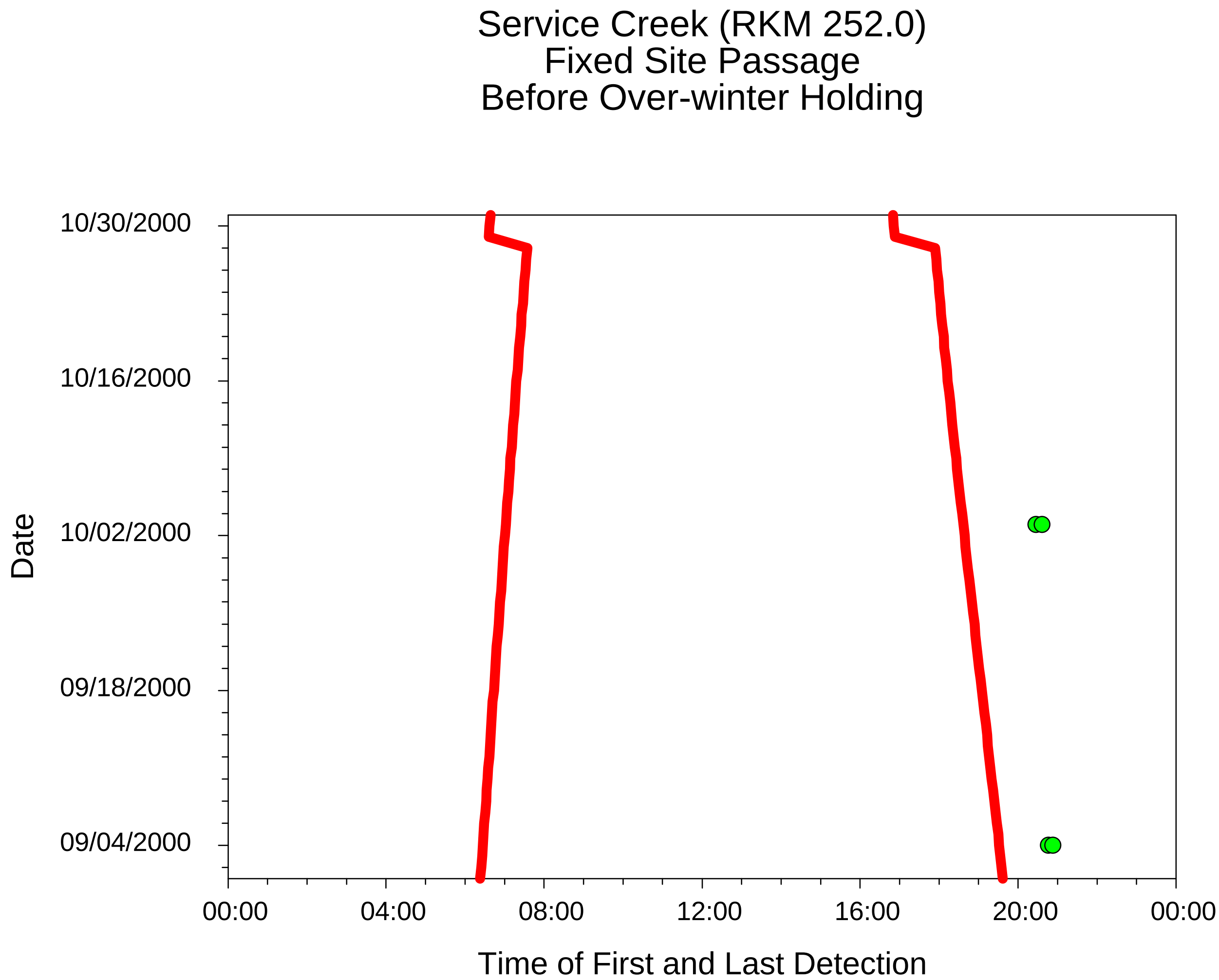


**Figure 4.** Passage of Pacific lampreys by Service Creek fixed receiver station before holding behavior was initiated. Red lines represent time of sunrise and sunset. Green symbols represent USGS-tagged lampreys. Blue symbols represent NMFS-tagged lampreys.

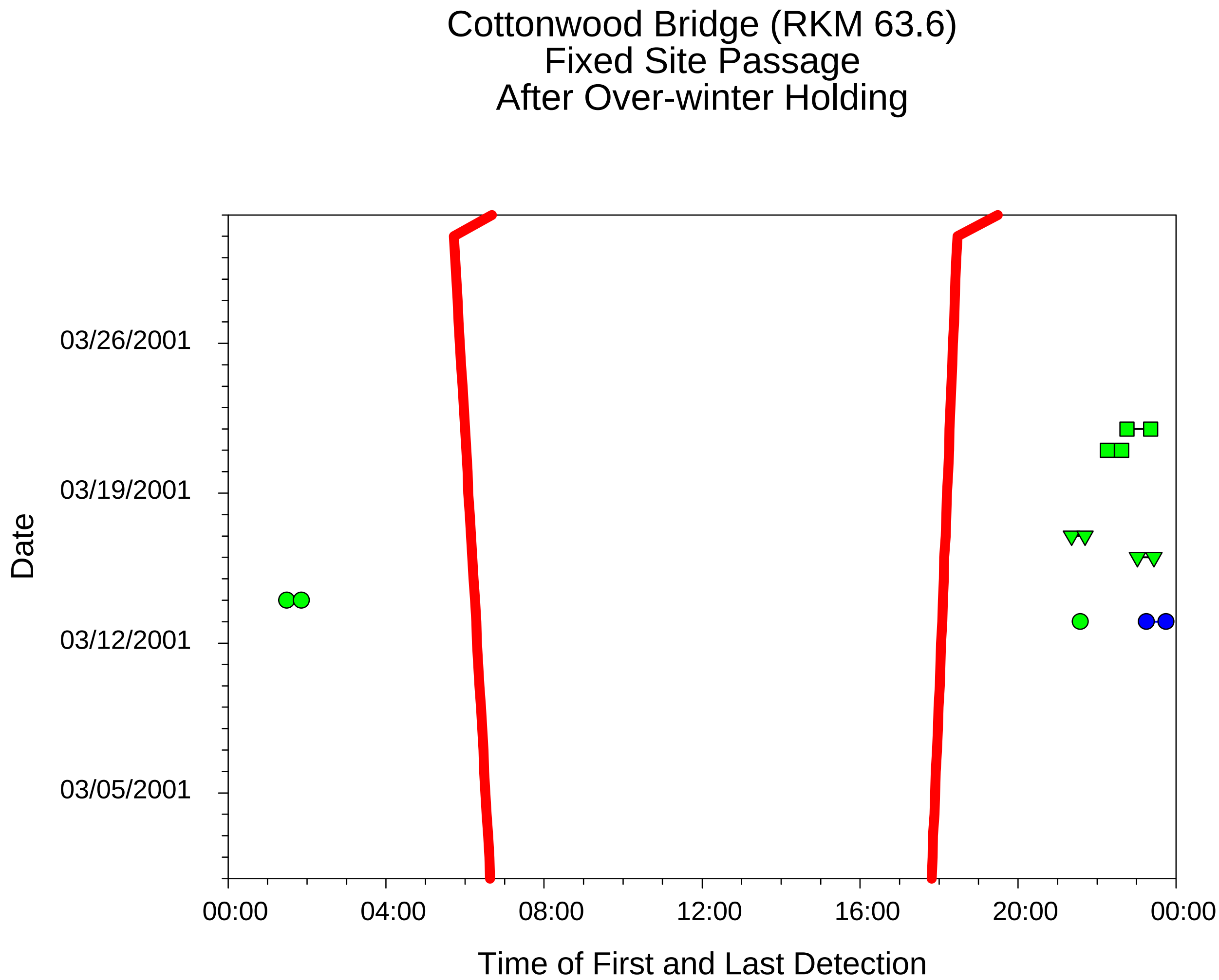


**Figure 5.** Passage of Pacific lampreys by Cottonwood Bridge fixed receiver station after holding behavior ceased. Red lines represent time of sunrise and sunset. Green symbols represent USGS-tagged lampreys. Blue symbols represent NMFS-tagged lampreys.

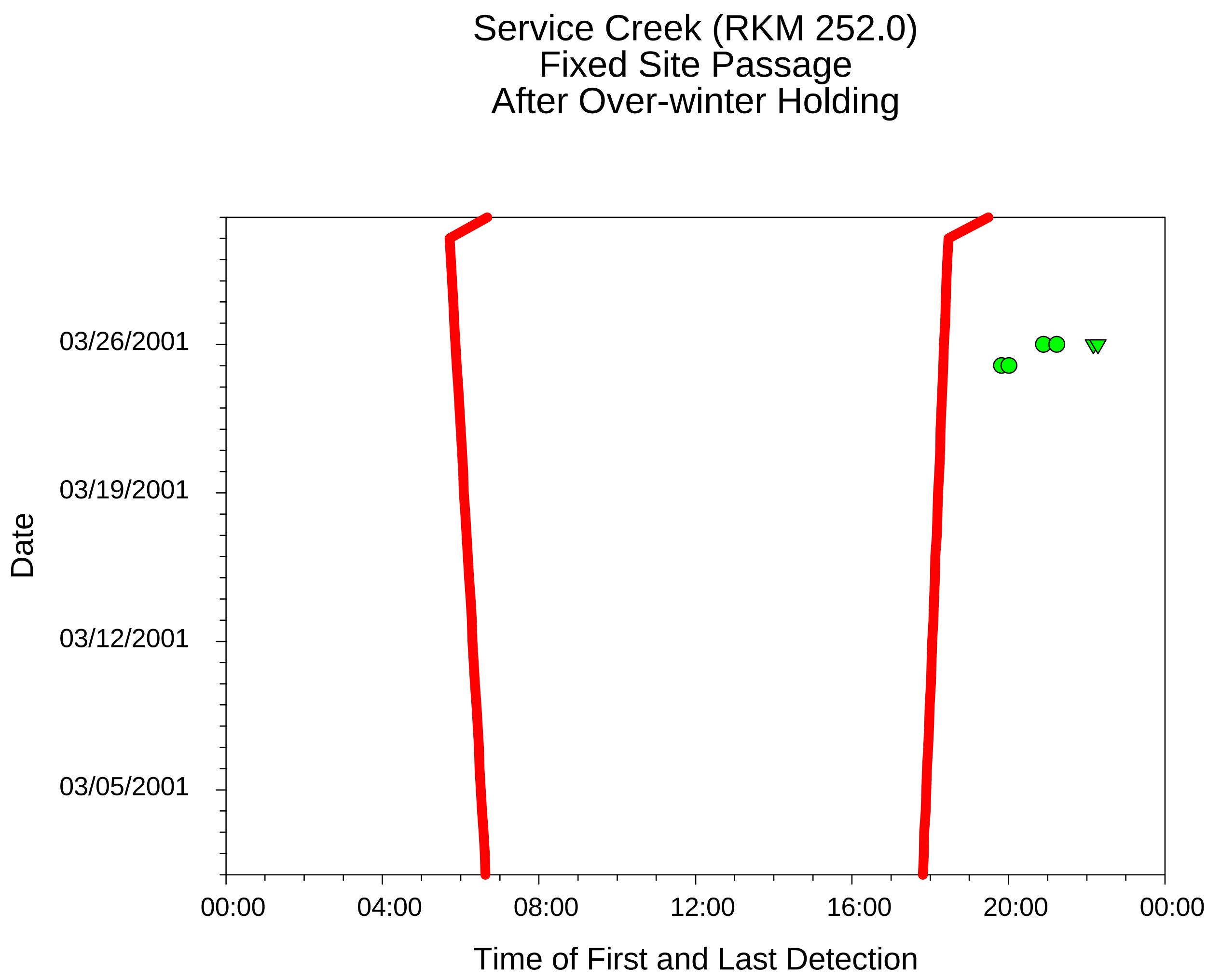


**Figure 6.** Passage of Pacific lampreys by Service Creek fixed receiver station after holding behavior ceased. Red lines represent time of sunrise and sunset. Green symbols represent USGS-tagged lampreys. Blue symbols represent NMFS-tagged lampreys.

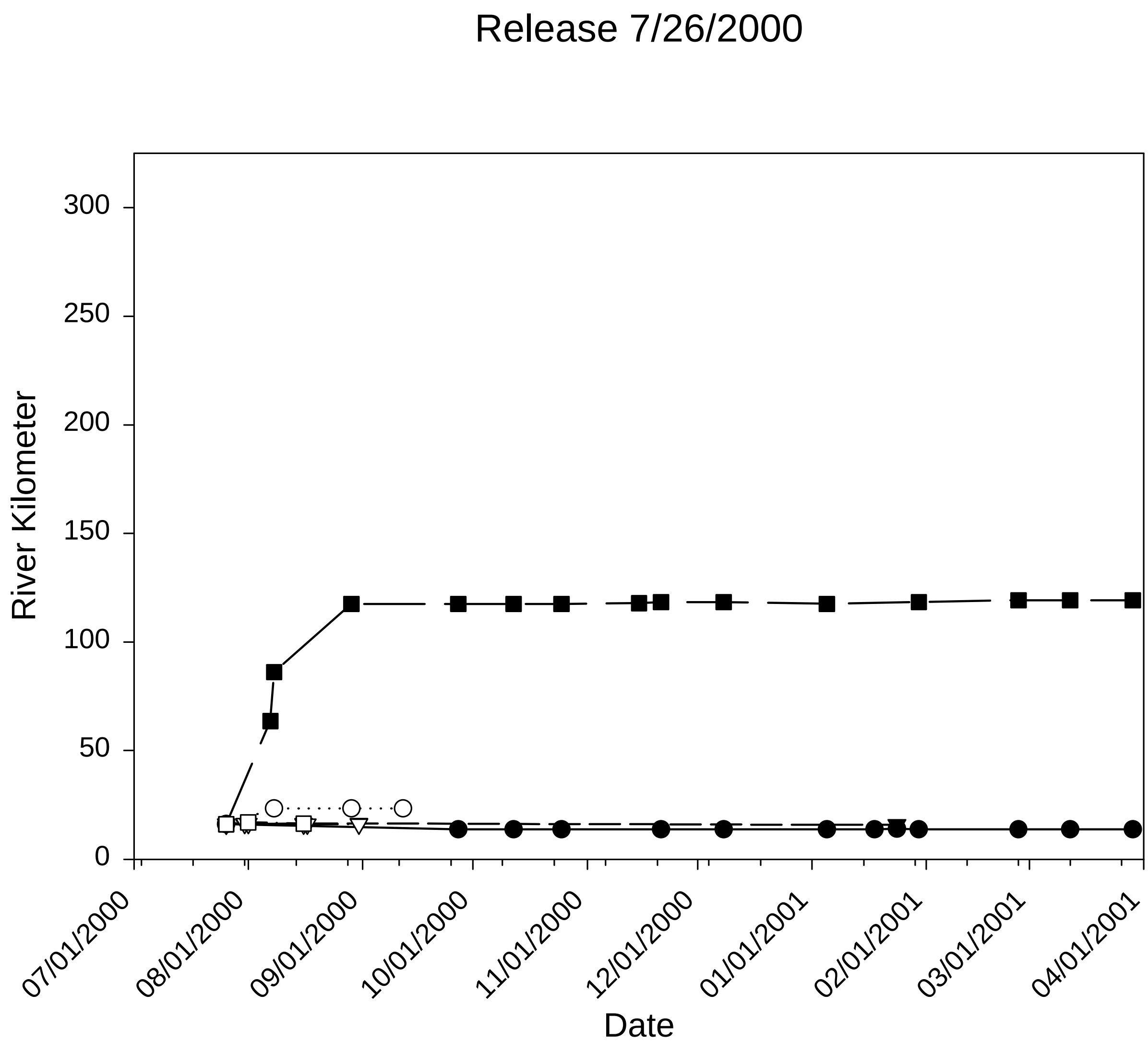


**Figure 7.** Lamprey locations by date from a group released on 7/26/2000. Each unique symbol represents an individual lamprey.

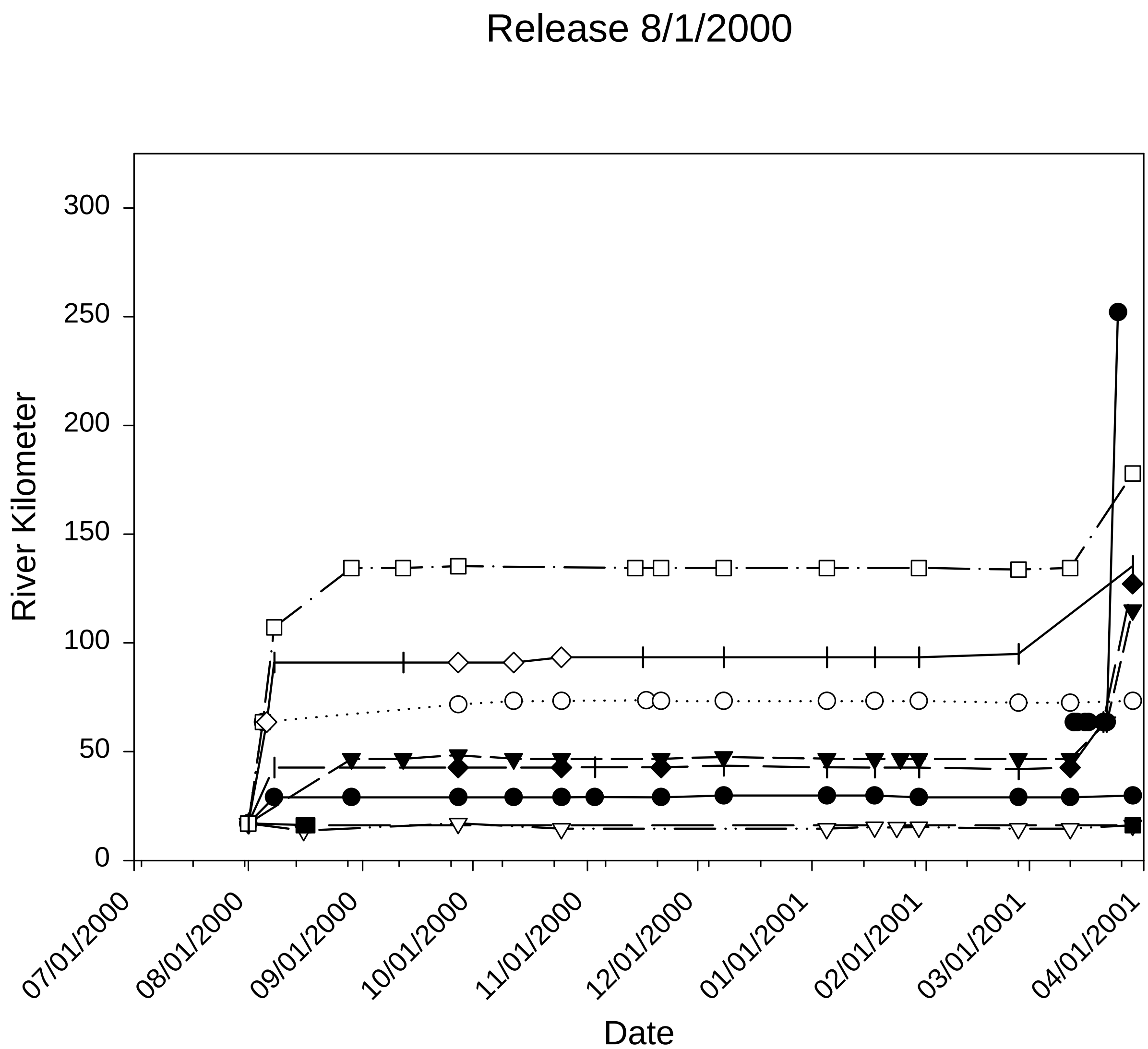


**Figure 8.** Lamprey locations by date from a group released on 8/01/2000. Each unique symbol represents an individual lamprey.

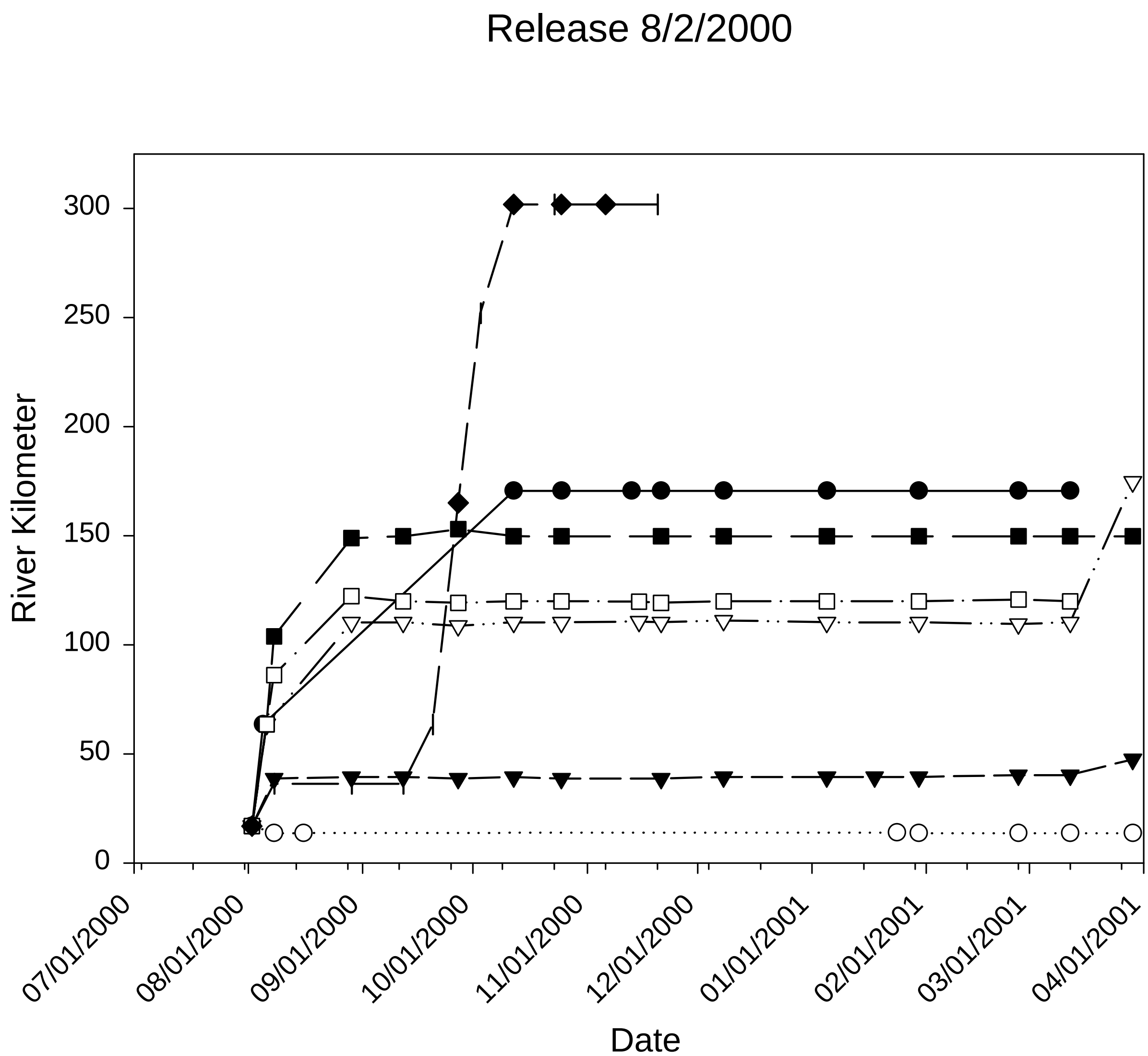


**Figure 9.** Lamprey locations by date from a group released on 8/02/2000. Each unique symbol represents an individual lamprey.

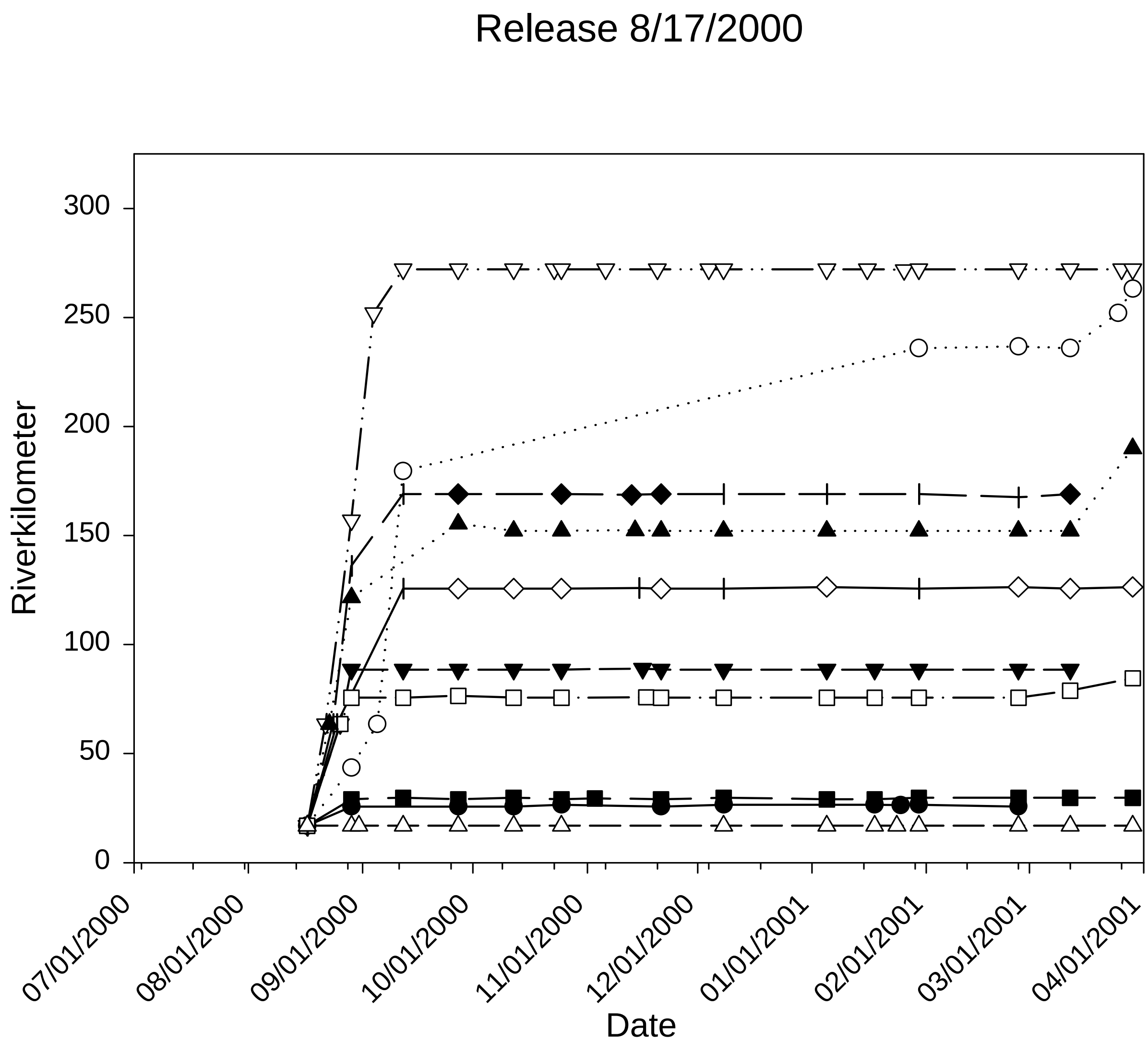


**Figure 10.** Lamprey locations by date from a group released on 8/17/2000. Each unique symbol represents an individual lamprey.

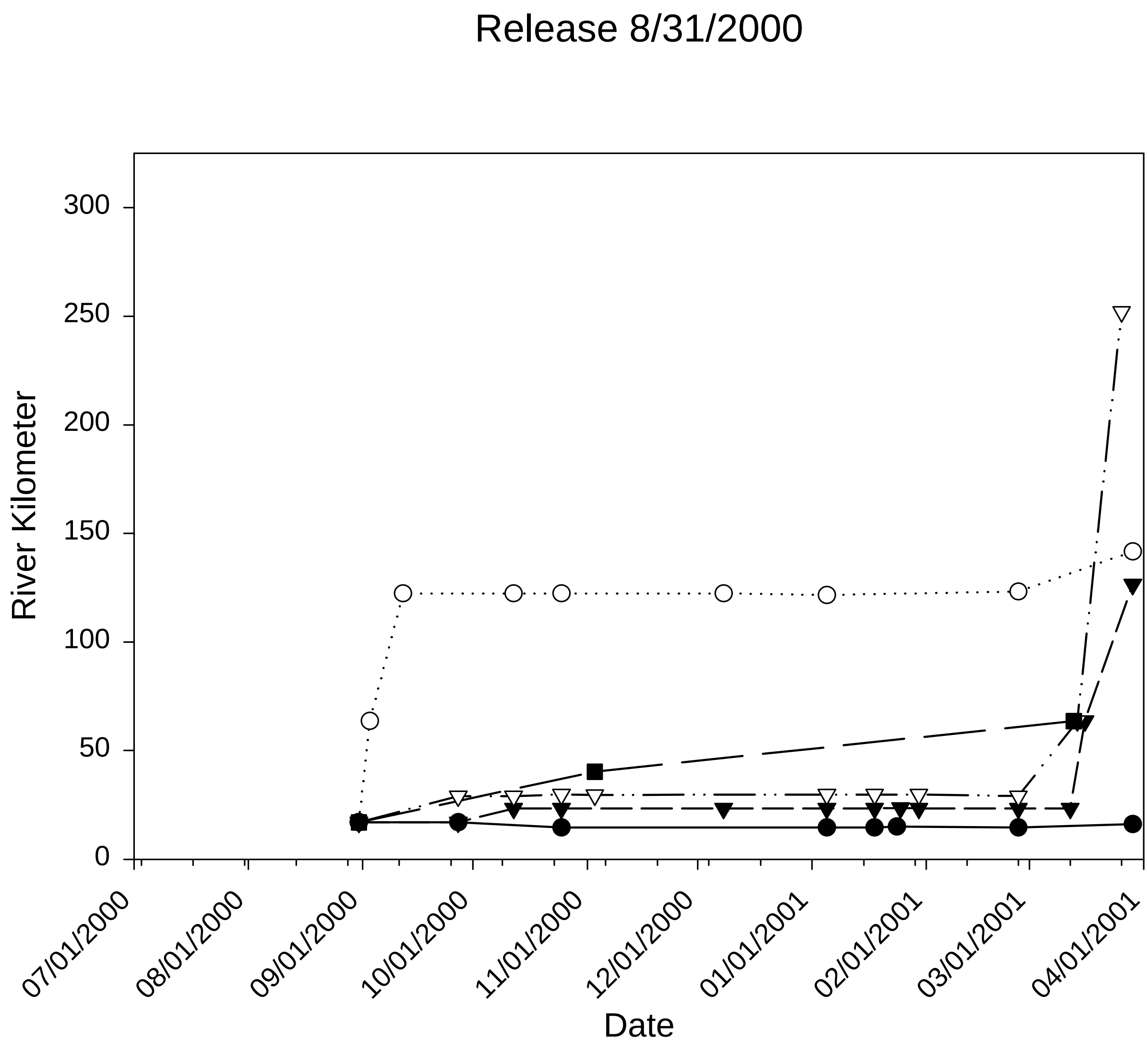


**Figure 11.** Lamprey locations by date from a group released on 8/31/2000. Each unique symbol represents an individual lamprey.

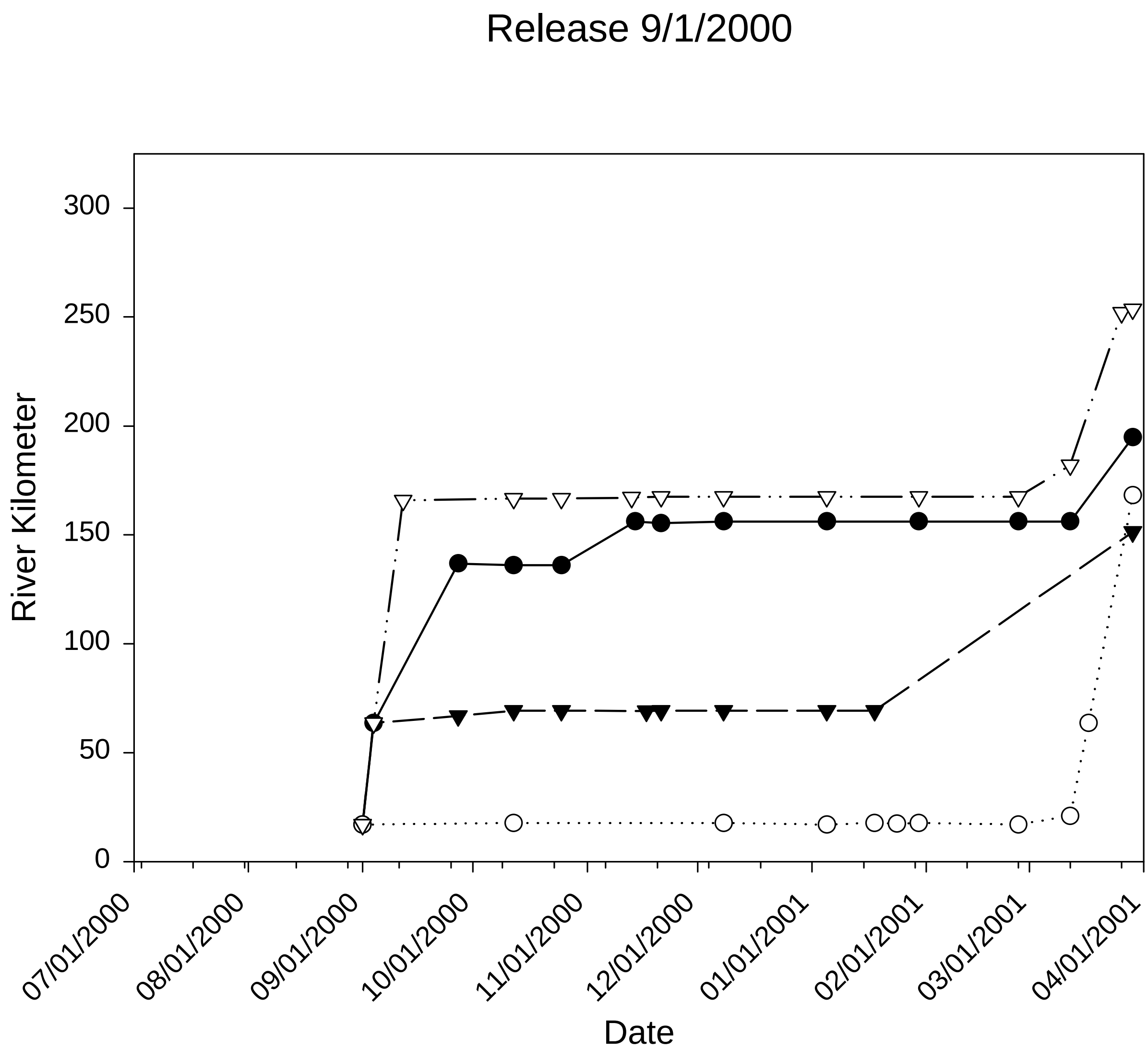


**Figure 12.** Lamprey locations by date from a group released on 9/01/2000. Each unique symbol represents an individual lamprey.

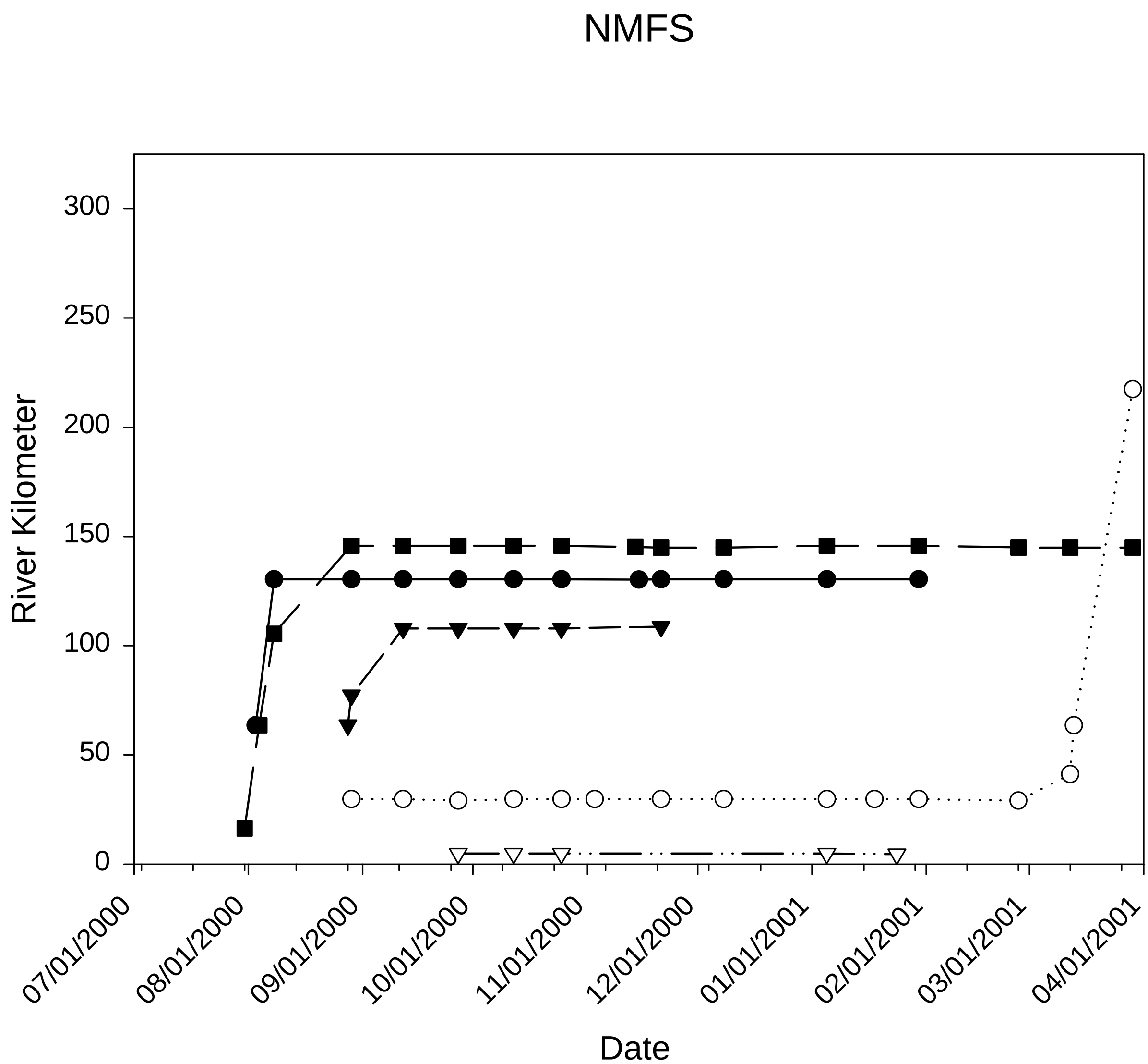


**Figure 13.** Lamprey locations by date from NMFS releases. Each unique symbol represents an individual lamprey.

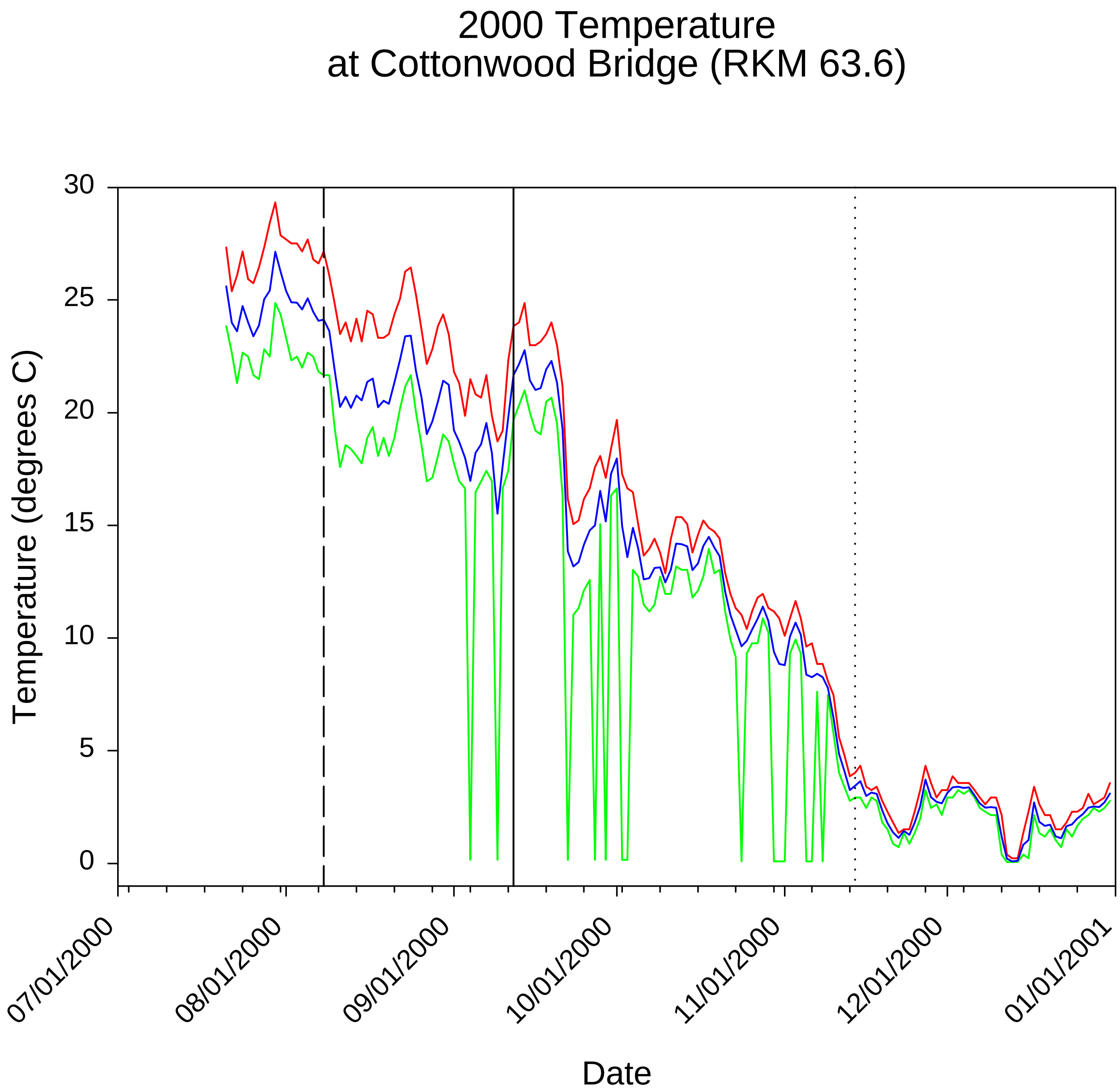


**Figure 14.** Temperature data collected at Cottonwood Bridge fixed receiver station in 2000. Red line represents daily maximum temperature. Blue line represents daily median temperature. Green line represents daily minimum temperature. Dashed line represents minimum holding date. Solid line represents median holding date. Dotted line represents maximum holding date.

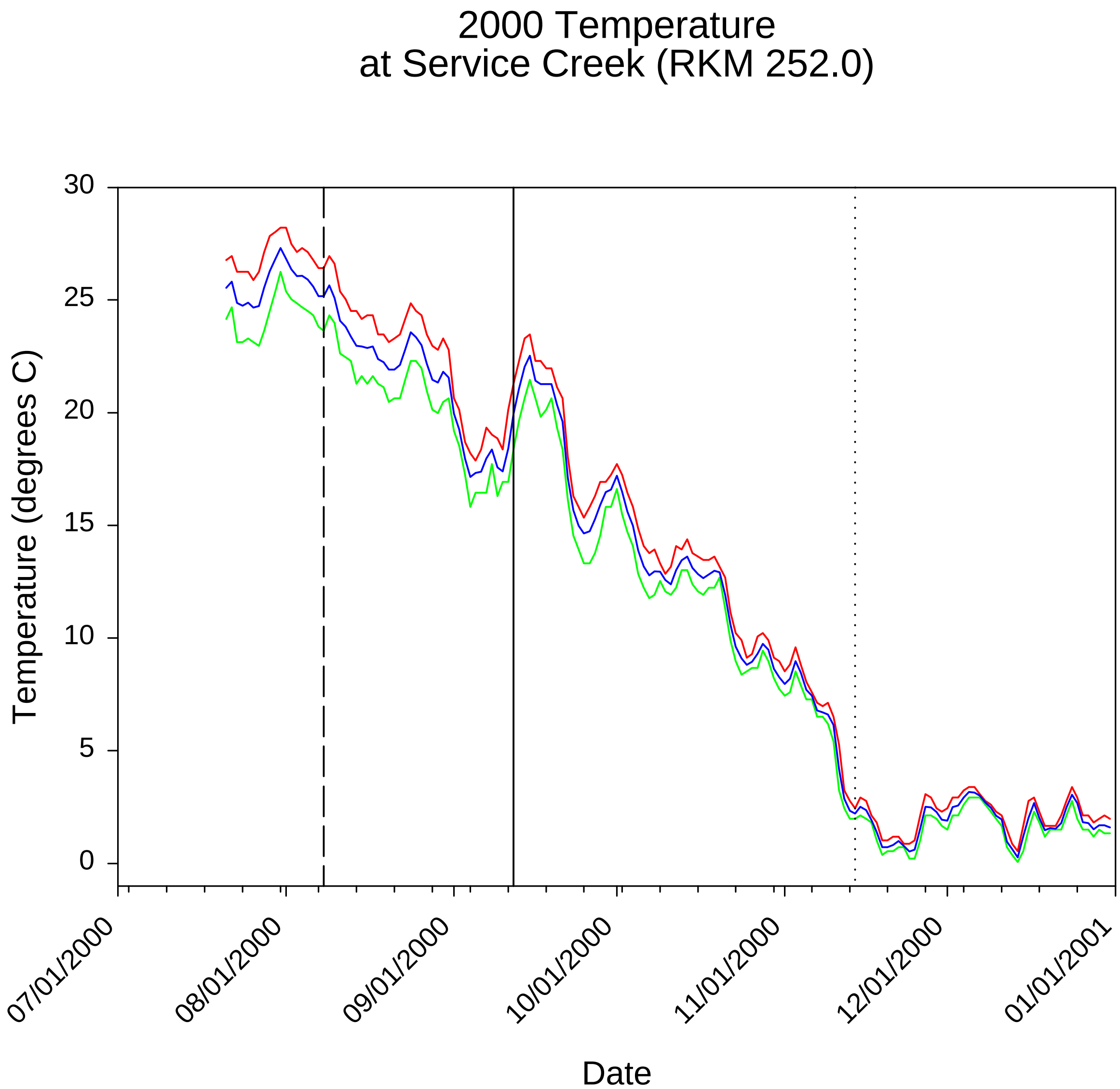


**Figure 15.** Temperature data collected at Service Creek fixed receiver station in 2000. Red line represents daily maximum temperature. Blue line represents daily median temperature. Green line represents daily minimum temperature. Dashed line represents minimum holding date. Solid line represents median holding date. Dotted line represents maximum holding date.

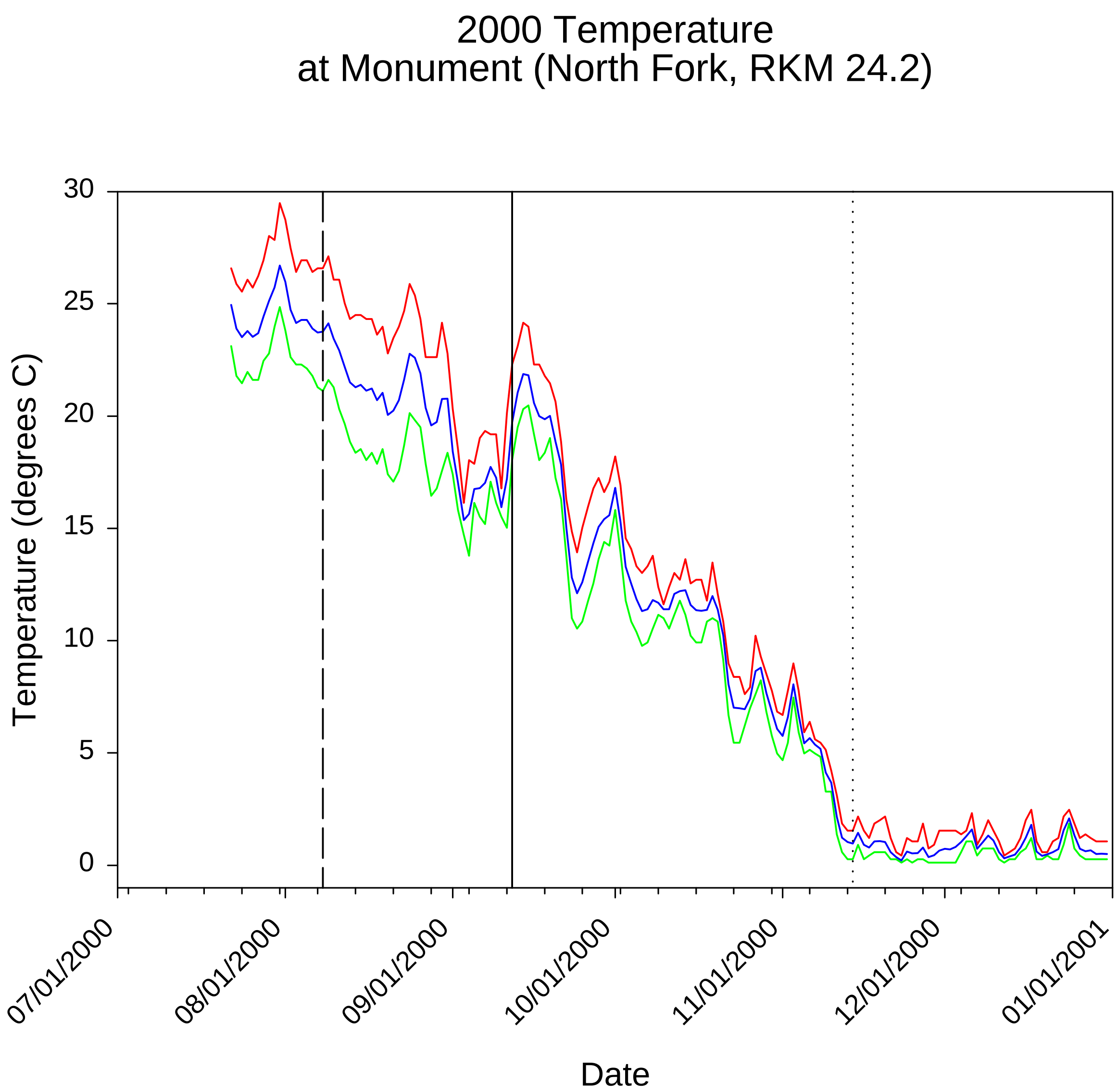


**Figure 16.** Temperature data collected at Monument (North Fork) fixed receiver station in 2000. Red line represents daily maximum temperature. Blue line represents daily median temperature. Green line represents daily minimum temperature. Dashed line represents minimum holding date. Solid line represents median holding date. Dotted line represents maximum holding date.

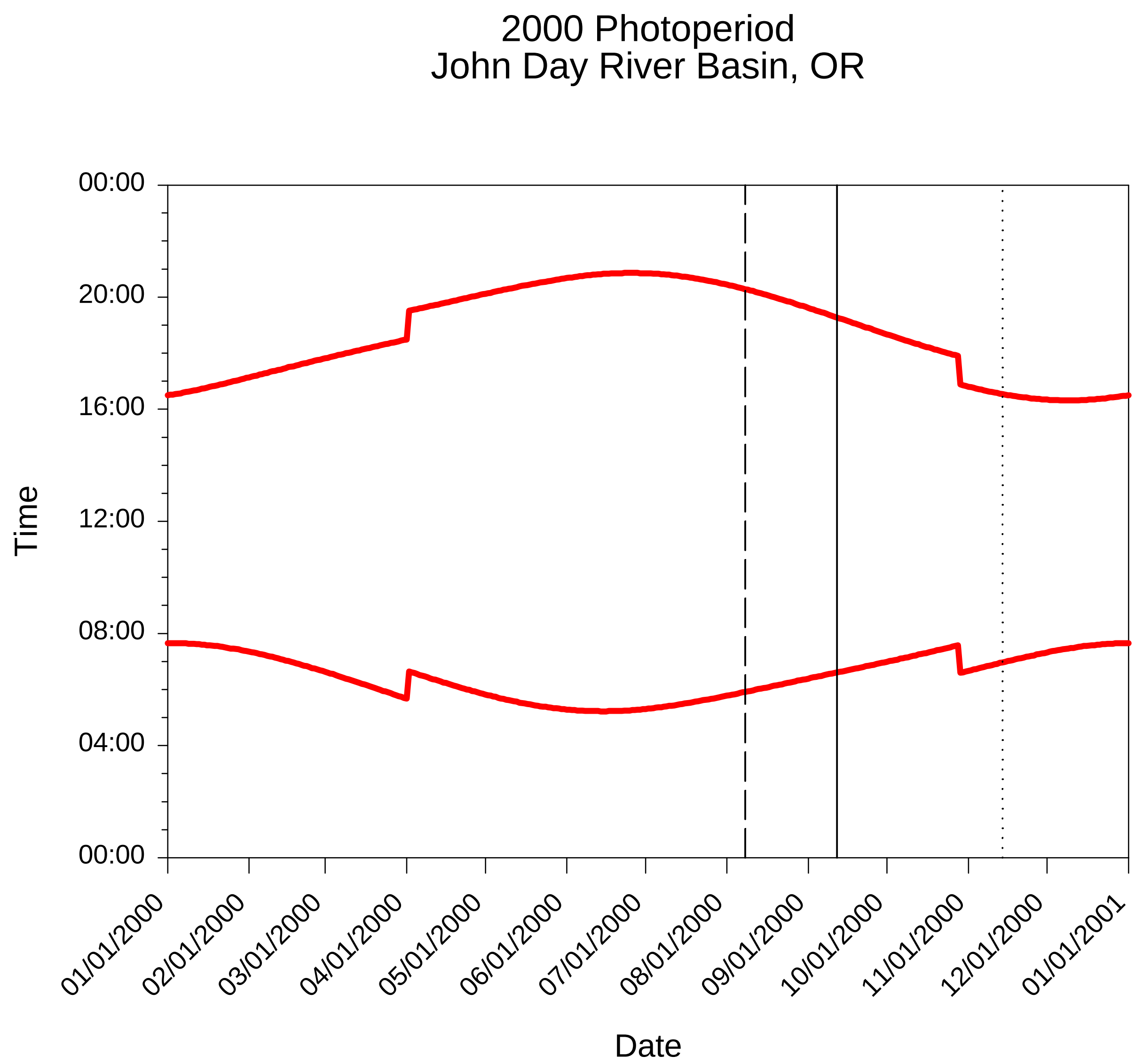


**Figure 17.** 2000 Photoperiod for the John Day River Basin, OR (data from U.S. Naval Observatory web site at: http://aa.usno.navy.mil/data/docs/RS_OneYear.html). Red lines represent time of sunrise and sunset. Dashed line represents minimum holding date. Solid line represents median holding date. Dotted line represents maximum holding date.

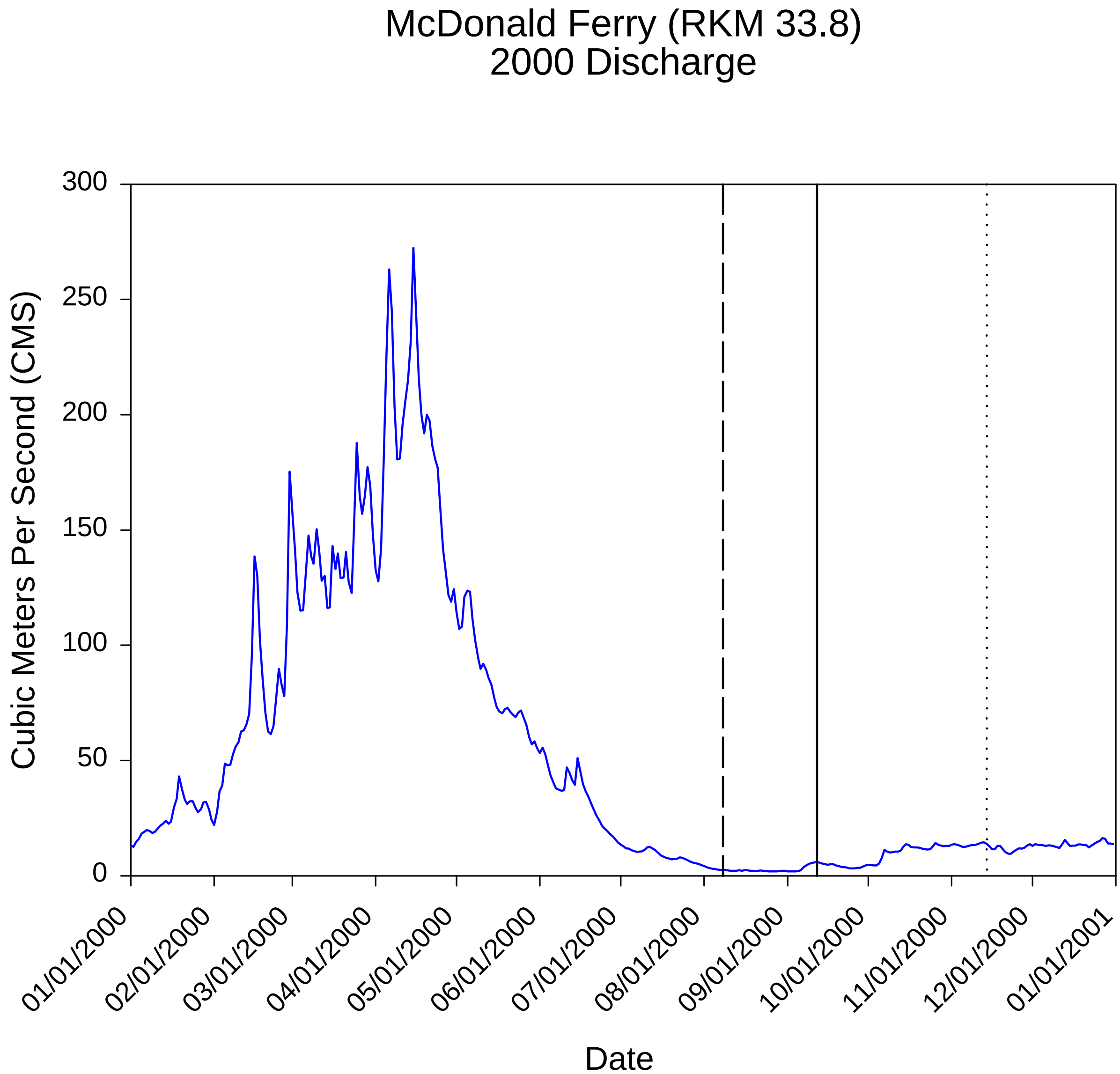


**Figure 18.** Discharge data from McDonald Ferry Gaging Station in 2000 (USGS, Water Resources Division). Blue line represents daily discharge. Dashed line represents minimum holding date. Solid line represents median holding date. Dotted line represents maximum holding date.

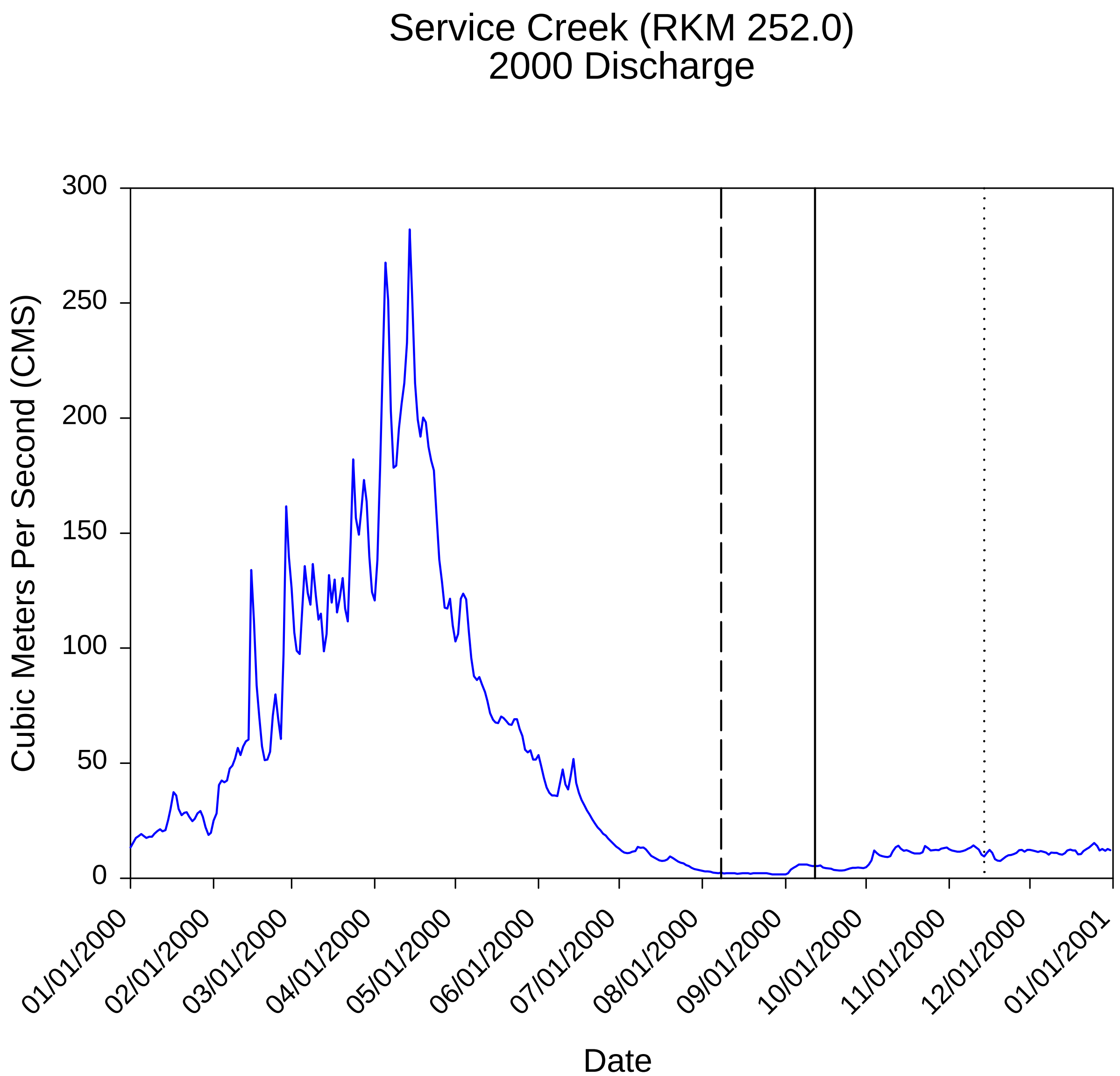


**Figure 19.** Discharge data from Service Creek Gaging Station in 2000 (USGS, Water Resources Division). Blue line represents daily discharge. Dashed line represents minimum holding date. Solid line represents median holding date. Dotted line represents maximum holding date.

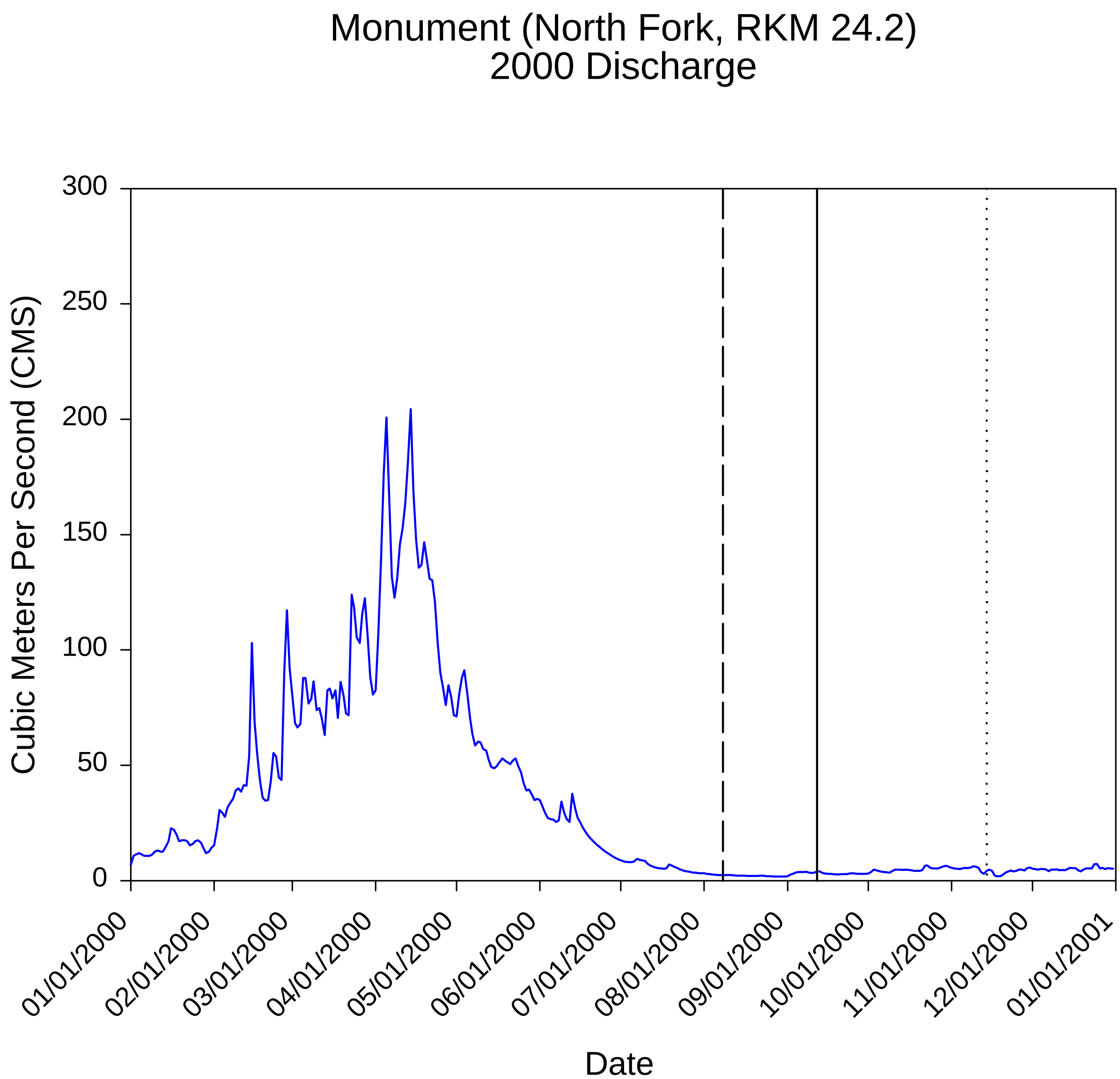


**Figure 20.** Discharge data from Monument (North Fork) Gaging Station in 2000 (USGS, Water Resources Division). Blue line represents daily discharge. Dashed line represents minimum holding date. Solid line represents median holding date. Dotted line represents maximum holding date.

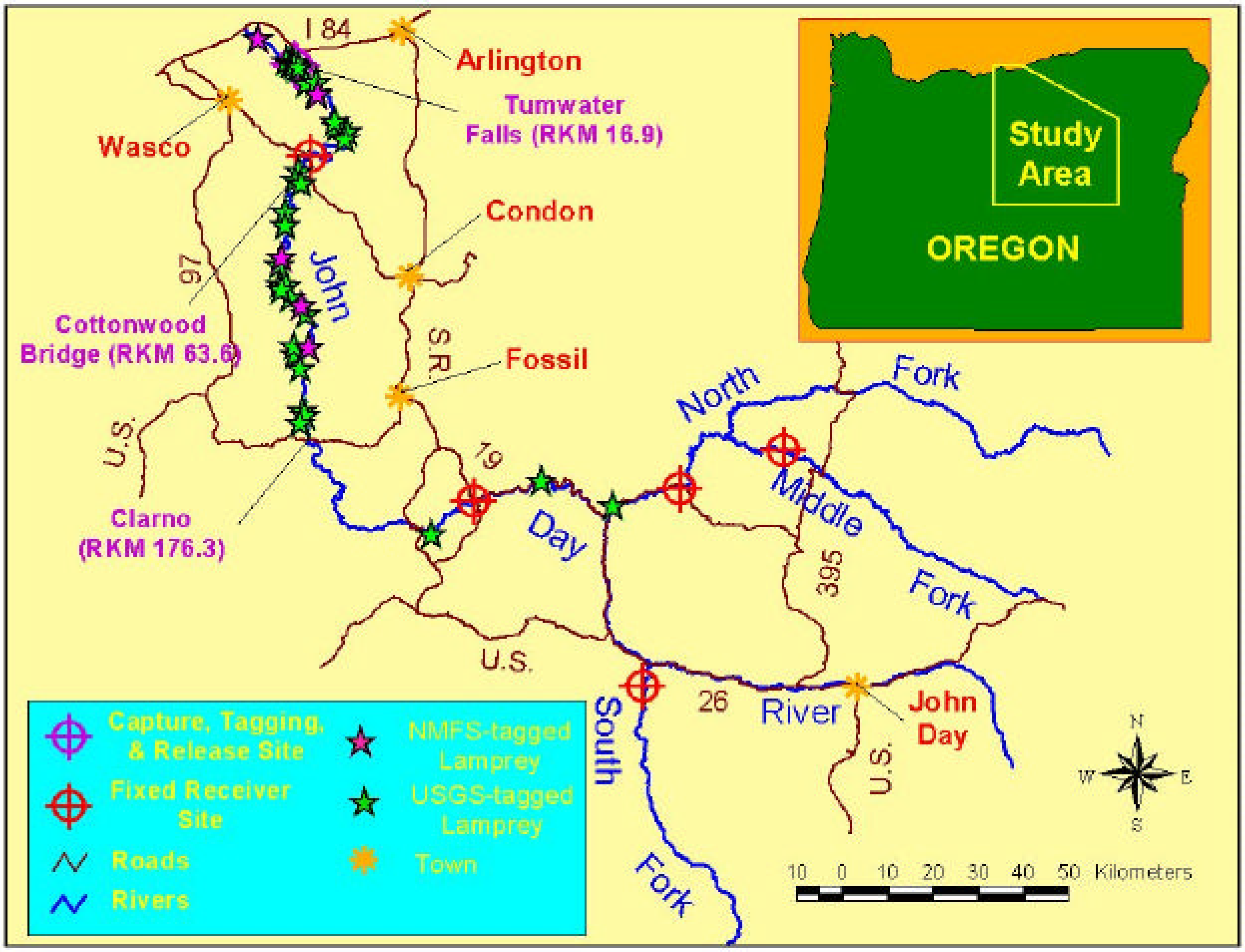


**Figure 21.** Locations of lampreys holding over winter in the John Day River Basin, OR.