Behavior of White Sturgeon Near Hydroprojects and Fishways

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Executive Summary

During March 2004 through November 2005, white sturgeon movements were monitored at The Dalles Dam to characterize their distribution and movements in the immediate vicinity of the dam and to determine timing and routes of passage. A combination of radio and acoustic telemetry technologies were used to detect tagged fish within fishways and at strategic locations along the dam, the shorelines, and in the forebay. White sturgeon > 95 cm total length (TL) that were captured on baited setlines fished in the forebay and in the tailrace cul-de-sac received a surgically implanted transmitter that emitted radio and acoustic signals. During the course of this study, a total of 148 fish were tagged; 58 were captured and released in the forebay and 90 in the tailrace.

We documented 26 passage events at The Dalles Dam by 19 tagged fish; 8 upstream and 18 downstream. Interestingly, 11 of these passage events (42% of the total) were made by only four fish. Seven of the upstream passage events were conclusively made through the east fish ladder; one fish passed upstream undetected in either ladder. The limited monitoring infrastructure in place during 2004 precluded determination of routes of downstream passage. In 2005 we increased coverage of the tailrace with hydrophones and determined that at least 10 of 12 downstream passage events occurred through the open spillway gates.

During the study 17 individual fish entered the ladders one or more times. Eleven individuals entered only the east ladder, 3 entered only the north ladder, and 3 individual fish entered both ladders at some time. Residence time within the ladders by individual fish was quite variable, ranging from about 1 min to nearly six months (mean = 7.1 days; SD = 24.8 days). Ladder residence times were considerably shorter in 2005 (mean = 0.9 days) compared to 2004 (mean = 8.63 days) after excluding one fish (ID 47) that appeared to have an affinity for the north fish ladder. Counts of white sturgeon passing the viewing windows declined substantially in each ladder between 2004 and 2005. In 2004 the number of white sturgeon counted was 106 in the east fish ladder and 29 in the north fish ladder. In 2005 these numbers dropped to 2 fish counted in the east fish ladder and 0 fish counted in the north fish ladder. In 2004 we noted 6 upstream passage events. In 2005, despite a substantial increase in the number of fish with transmitters in the tailrace, we noted only 2 upstream passage events.

Construction differences between the north and east fish ladders may account for the differences in numbers of white sturgeon that successfully ascend the ladders. The north ladder is narrower and the weir orifices are substantially smaller than those in the east ladder weirs. Also, the eight uppermost weirs in the north ladder are vertical slot weirs with a single orifice. Although the weir orifice openings are identical in size to other north ladder orifices, the vertical slot opening is only 0.3 m wide. The east ladder does not have vertical slot weirs.

Individual sturgeon tagged at The Dalles Dam dispersed as far as 254 km downstream into the estuary and 38 km upstream to John Day Dam. Seasonal patterns of aggregation and dispersal in the tailrace were evident. White sturgeon aggregated in the cul-de-sac during winter months, dispersed downstream during spring and summer months, and returned to the cul-de-sac

during the fall. Patterns of aggregation and dispersal in the forebay were less pronounced but detections of individual fish near the spillway were greater in winter than in late summer or early fall and detections further upstream in the forebay were greater in late summer and early fall than during the winter.

Changes to operations at hydroelectric dams to benefit migrating anadromous salmonids may influence upstream or downstream passage by white sturgeon. Altering spill patterns and timing, installation of removable spillway weirs, and adjusting attraction flows to fishway entrances will likely influence passage by white sturgeon. However, it is also important to understand the metapopulation dynamics of white sturgeon within and among river reaches since the consequences of increasing or precluding upstream or downstream passage are currently unclear. That is, improving passage into areas unfavorable for growth or reproduction could have a negative demographic benefit to the metapopulation. Likewise, allowing fish to disperse from unproductive river reaches could increase benefits to the metapopulation. Smaller white sturgeon that may more readily pass downstream through turbines were not monitored in this study. Knowledge of the degree of downstream passage of small sturgeon via turbines and survival of fish that pass through turbines is needed to better understand the consequences of downstream passage to the metapopulation.

Introduction

White sturgeon *Acipenser transmontanus* are an important cultural, recreational, and commercial resource in the Columbia River Basin. The construction of hydroelectric dams is believed to have created 24 functionally discreet populations of white sturgeon within the basin (North et al. 1993) in addition to the geologically isolated Kootenai River population. The populations vary considerably in abundance and age structure among river reaches (Beamesderfer et al. 1995), with the greatest abundance and density occurring in the unimpounded river downstream from Bonneville Dam, which is considered one of the largest and most productive sturgeon populations in the world (Devore et al. 1995). Conversely, the white sturgeon population from the Kootenai River in northern Idaho has been listed as endangered since 1994. Populations in the Snake River downstream from Hells Canyon Dam appear to be persisting but at a lower abundance than prior to impoundment.

This variation in population status can be attributed to a number of factors including differences in exploitation rates and recruitment success, access to marine food resources, and suitability of hydrologic conditions and available habitats (Beamesderfer et al. 1995; DeVore et al. 1995). In particular, construction and operation of hydroelectric dams on the Columbia and Snake rivers has directly affected white sturgeon populations in several ways. Spawning habitats have been reduced (Parsley and Beckman 1994), upstream and downstream passage is limited (Warren and Beckman 1993) and impoundment of the free flowing river has impacted primary and secondary production in ways that may reduce the fitness of the river environment for white sturgeon (Coutant 2004).

White sturgeon seldom ascend the existing fishways at the hydroelectric projects probably because the fish passage facilities for upstream migrating fish at Columbia River Basin dams were designed primarily for anadromous salmonids. Although little is known about white sturgeon swimming performance, research conducted with lake sturgeon (Peake et al. 1997) demonstrated that the swimming abilities of sturgeons are substantially different from those of salmonids. In particular, Peake et al. (1997) found that lake sturgeon are poor swimmers compared with salmonids, particularly at burst swimming speeds. Sturgeons also generate greater drag than salmonids while swimming (Webb 1986) and have a less efficient tail, resulting in greater energy expenditure while swimming in higher velocity areas. Wilga and Lauder (1999) showed that small white sturgeon (<32 cm TL) exhibited undulatory swimming in current velocities of 0.5 – 2.0 body lengths/sec, and that the transition to burst-and-glide swimming occurred when velocities reached 2.5 body lengths/sec. The large body size of sturgeon may also impede progress through submerged orifices designed for salmonids. Unlike teleosts, sturgeons generate rapid swim speeds via increased body curvature (Long 1995) and thus may be hindered by submerged orifices that were dimensioned to accommodate salmonids.

An exception to limited upstream movement is the east fishway at The Dalles Dam. Warren and Beckman (1993) reported that during 1986 through 1991, 3,181 white sturgeon (range = 187-791 fish per year) were counted at the two fishways at The Dalles Dam. The majority of these fish were counted in the east fishway. In comparison, during the same period only 215 fish (annual range 19-60) were counted at Bonneville Dam fishways with even fewer (N = 68, annual range 4-29) observed at John Day Dam. Upstream passage of white sturgeon at all of the dams was generally highest during the months of July and August. Similar late summer and early fall upstream movement patterns have been identified in reservoirs and unimpounded river reaches (Haynes et al. 1978; North et al. 1993). Navigation locks at dams provide another possible passage route (upstream and downstream) for fish, but use of navigation locks by white sturgeon has not been confirmed (Warren and Beckman 1992). Historically, the original fish lock at Bonneville Dam was operated to pass white sturgeon upstream. Though numbers passed upstream were typically low during each lift, 119 white sturgeon were once passed upstream during a single day in 1951 (Warren and Beckman 1992). The lock, though still in place, has not been used since 1971.

Some white sturgeon pass downstream through dams, but the route of passage is unknown. Fisheries sampling done by the Oregon and Washington Departments of Fish and Wildlife and angler returns of tagged fish have documented many fish that had moved downstream past one or more dams. North et al. (1995) reports that since 1987, the Oregon Department of Fish and Wildlife has recovered four tagged white sturgeon that passed upstream and 74 fish that passed downstream through one or more dams. The spacing on trash racks at the entrances to turbines will preclude entrainment of large white sturgeon but smaller fish can be entrained (Coutant and Whitney 2000). Age-0 white sturgeon have been recovered in the juvenile salmonid bypass collection system at Lower Granite Dam, which suggests that some fish do pass through turbines. While downstream passage through spill gates can only occur during the brief periods when they are open, downstream passage through turbines could conceivably happen throughout the year.

Thus, construction of hydroelectric dams on the Columbia and Snake rivers has largely restricted movements of white sturgeon to within impounded reaches, effectively resulting in a series of individual landlocked populations (North et al. 1993). Prior to dam construction in the Columbia River Basin, white sturgeon likely responded to seasonal changes in food and habitat availability by ranging extensively between freshwater, estuarine, and marine environments. Because the physiochemical and biotic characteristics of reservoirs vary greatly within the basin, individual impoundments may not contain optimal conditions for all life stages of white sturgeon (Parsley and Beckman 1994; Beamesderfer et al. 1995). Providing passage at dams could enhance the productivity of white sturgeon populations.

Isolation by dams has also possibly reduced the genetic diversity of the populations within the impoundments. Consistent with this possibility, Brown et al. (1992) found that mitochondrial DNA diversity was greater in white sturgeon downstream from Bonneville Dam than in upstream populations. These findings were questioned by North et al. (1993), however, who theorized that existing white sturgeon passage, though very limited, could maintain adequate gene flow between reservoirs and prevent divergence of populations. Geneticists at the University of California – Davis and the University of Idaho are investigating the genetic structure of white sturgeon throughout the Columbia River Basin, which should provide information on the degree of passage needed to maintain the genetic integrity of this species.

In addition to possible genetic differences, white sturgeon condition, growth, and size at maturity vary among the lower Columbia River reservoirs (Beamesderfer et al. 1995), presumably due to variations in resource availability among areas. Dams, as barriers to movements, prevent fish from finding more productive habitats. In some impoundments, suitable rearing habitat exists, but spawning habitat is lacking and recruitment of fish is poor (Parsley and Beckman 1994). Conversely, research conducted in the Bonneville Reservoir suggests that spawning conditions are favorable for good recruitment of young-of-the-year white sturgeon in most years, but growth of young fish may be density limited (Beamesderfer et al. 1995). Improving upstream passage for fish would facilitate movement of sub-adult white sturgeon into under-seeded areas.

To better understand how to improve passage opportunities for white sturgeon we monitored their movements near The Dalles Dam and fishways by using biotelemetry. We conducted this work at The Dalles Dam because this is where most white sturgeon passage presently occurs (Warren and Beckman 1992). Our objectives were to characterize the distribution and movements of white sturgeon in the immediate vicinity of the dam and to determine timing and routes of passage.

Methods

Study Area

This study was conducted from March 2004 through November 2005 at The Dalles Dam, located 309 river kilometers (rkm) from the mouth of the Columbia River. The Dalles Dam is the second dam from the river mouth on the mainstem Columbia River. Construction began in 1952 and the dam was closed in 1957. The dam extends about 2.4 km from the Oregon shore to the navigation lock on the Washington shore and has a head of 24.4 m. Turbine units 1-14 were installed by 1960, and units 15-22 were added in 1973. The navigation lock at The Dalles Dam is 198 m long and 26.2 m wide, with a maximum lift of 27.4 m. The reservoir upstream of the dam is 36 km in length while the reservoir downstream is 74.4 km long.

The river bottom near the dam is comprised of relatively flat excavated regions upstream of the dam, as well as deep holes and gorges upstream and downstream formed by the basalt flows that constrained the original river channel (Figure 1). The total river discharge, spill, and water temperatures that occurred during the study period are show in Figure 2. The Dalles Dam has two fish ladders; both are overflow weir ladders with orifices. The North ladder has one entrance while the East ladder has three separate entrances (Table 1, Figure 3).

Table 1. General characteristics of adult fish ladders at The Dalles Dam obtained from construction drawings. The U.S. Army Corps of Engineers operates the fish ladders to maintain entrance depths at approximately 2.4 m or greater below tailwater elevation, a hydraulic head of 0.3-0.6 m at the entrances, and a water velocity of 0.5-1.2 m/sec in the collection channels and lower portions of the ladders. The head between the forebay elevation and tailwater elevation is approximately 24.4 m. The ladders are typically in operation throughout the year except for several weeks during December, January, or February when they are dewatered for annual maintenance.

	Fishway	
	East	North
Number of entrances	3	1
Ladder length	540 m[a]	540 m
Ladder width (typical)	9.14 m	7.32 m
Mean slope	4.4%	4.4%
Number of weirs	89	90
Weir spacing	4.67 – 4.88 m	4.27 – 4.88 m
Weir configuration	Weirs 1 through 89 - Overflow with 2 orifices	Weirs 1 through 82 – Overflow with 2 orifices Weirs 83 through 90 – non-overflow with 1 orifice and 1 vertical slot
Weir overflow slot width	1.83 m	1.68 m
Weir orifice size	0.64 m W x 0.66 m H	0.46 m W x 0.46 m H[b]
Weir vertical slot width	none	0.30 m

[a]Shortest length measured from the east entrance. Length does not include fishway channels leading from the west and south entrances to the east ladder.
[b]Orifice sizes in the upper weirs (weirs 83 through 90) are slightly larger at 0.46 m W x 0.61 m H.

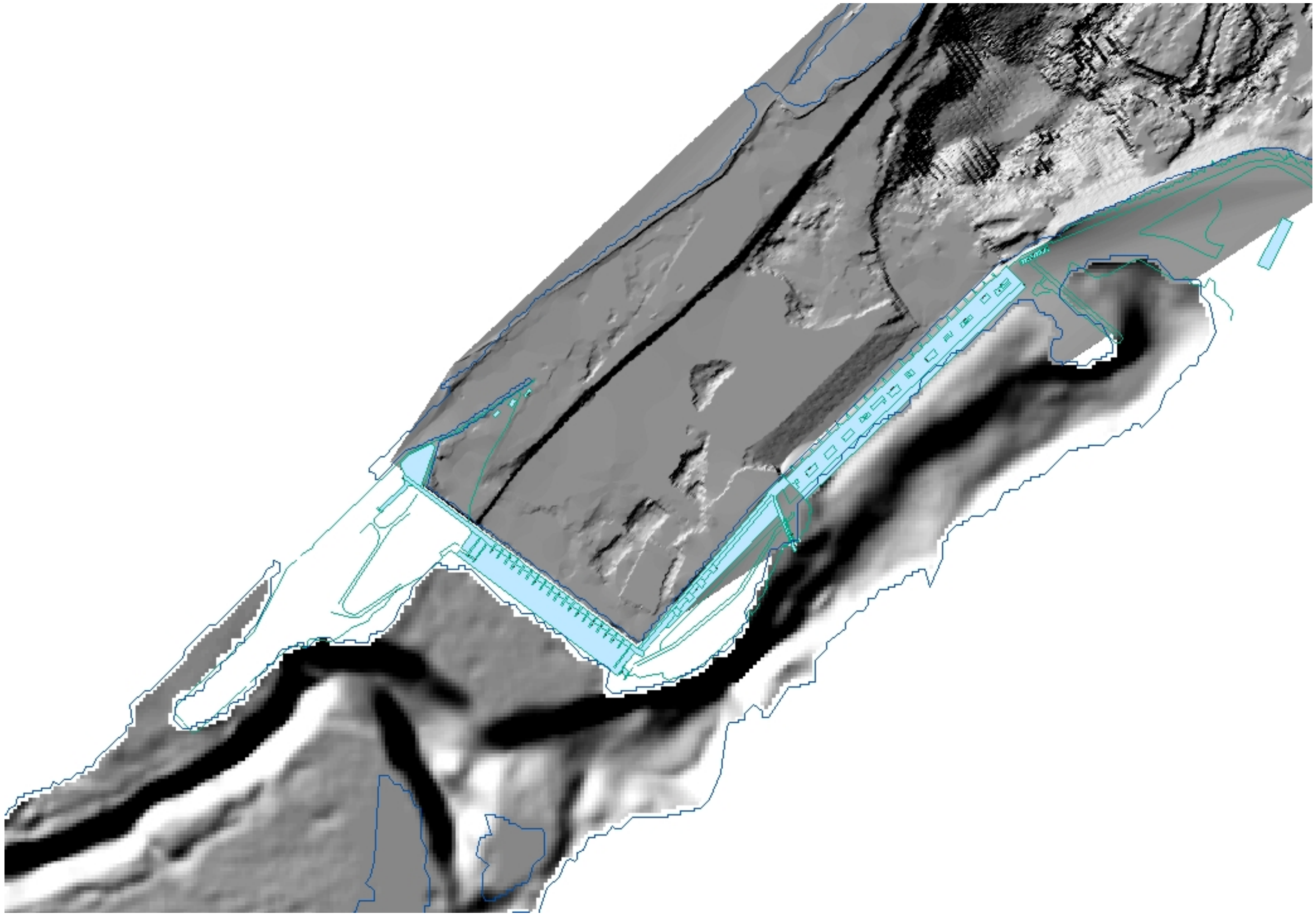

Figure 1. Shaded relief of river bathymetry near The Dalles Dam. River flow is from right to left. Note the excavated forebay and depression immediately in front of the turbines created during construction. The original river thalweg followed the channel to the lower right of the image, which was plugged with rock during construction and created the area called the cul-de-sac.

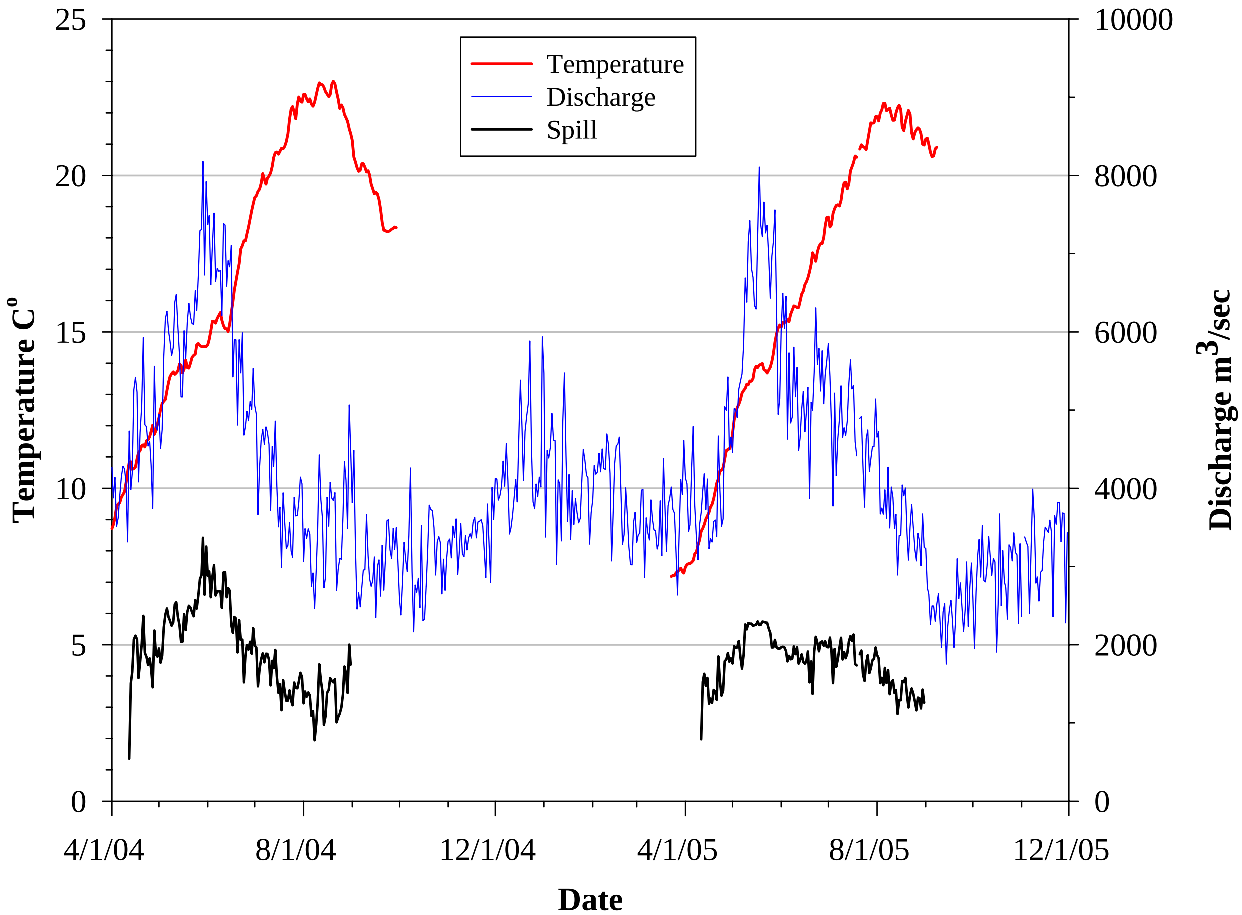

Figure 2. Mean daily water temperatures (red; upper line), total river discharge (blue; middle line), and spill discharge (black; lower line) that occurred during the study period. Data were obtained from the Columbia River DART website (http://www.cqs.washington.edu/dart/). Temperature data were not available for the late fall, winter, and early spring.

Telemetry Equipment

A combination of acoustic and radio telemetry technologies were used to obtain information on white sturgeon as they resided and moved within the study area. We deployed Lotek SRX_400 radio receivers (Lotek Wireless, Inc., Newmarket, Ontario, Canada) and Lotek MAP acoustic receivers and hydrophones at strategic locations within the fish ladders and along the upstream and downstream faces of the dam. Each receiver was capable of receiving signals from one or more antenna or hydrophone ports. Each port provided information on tagged sturgeon presence within the range of detection. That is, when a tagged sturgeon was present within the detection range of either a radio antenna or hydrophone, the receiver logged the date and time of each transmitter signal detection for each port. Thus, the general location of individual transmitters was inferred by carefully scrutinizing time of detection and signal strength among locations.

Transmitters used were made by Lotek Wireless, Inc. The model CH-16-25 transmitter was a hybrid that housed radio and acoustic components in one casing. The radio antenna was coiled internally and the entire transmitter was encased in biologically inert material. The tag transmitted an acoustic signal at 76.8 kHz and a radio signal at 149.460 MHz. The cylindrical transmitters were 16 mm in diameter and 80 mm in length and weighed 29 g in air and 15.5 g in water. The tags used in this study serially transmitted individually coded acoustic and radio pulses. Pulses occurred at 20 s intervals, with each radio pulse followed by 2 acoustic pulses (R-A-A-R-A-A-R; hyphens represent 20 s intervals). Thus, each transmitter emitted one radio pulse each minute separated by 2 acoustic pulses. The delay between signals was selected to reduce the potential to fill the storage capacity of the data logging receivers since sturgeon were expected to reside for considerable periods of time in some areas. Each transmitter was programmed to have a two-year operating life. All transmitters were tested to verify functionality prior to use.

Radio antennas and hydrophones were dispersed to provide coverage of key areas (Figures 4 and 5). Radio antennas provided coverage primarily of the fish ladders while hydrophones were used to provide coverage of areas where water depths would attenuate radio signals. During 2004, four acoustic receivers with seven hydrophones were installed in the forebay of the dam and one acoustic receiver with a single hydrophone was installed approximately 4 km downstream of the dam at the existing USGS gauging station (Station 14105700). Thus in 2004 the hydrophones and receivers provided forbay use information and dispersion to the downstream gate, while radio antennas and receivers provided information primarily on fish ladder use with limited coverage of the immediate tailrace. Radio receiver sites remained fixed throughout the study period but additional acoustic receivers and hydrophones were added in 2005. In addition to the radio sites at The Dalles Dam, radio receivers throughout the Bonneville and Dalles reservoirs operated by the University of Idaho were also set to monitor for these sturgeon. Periodic mobile surveys with portable radio and acoustic receivers operated from a vessel were also conducted to document sturgeon presence as far downstream as the estuary.

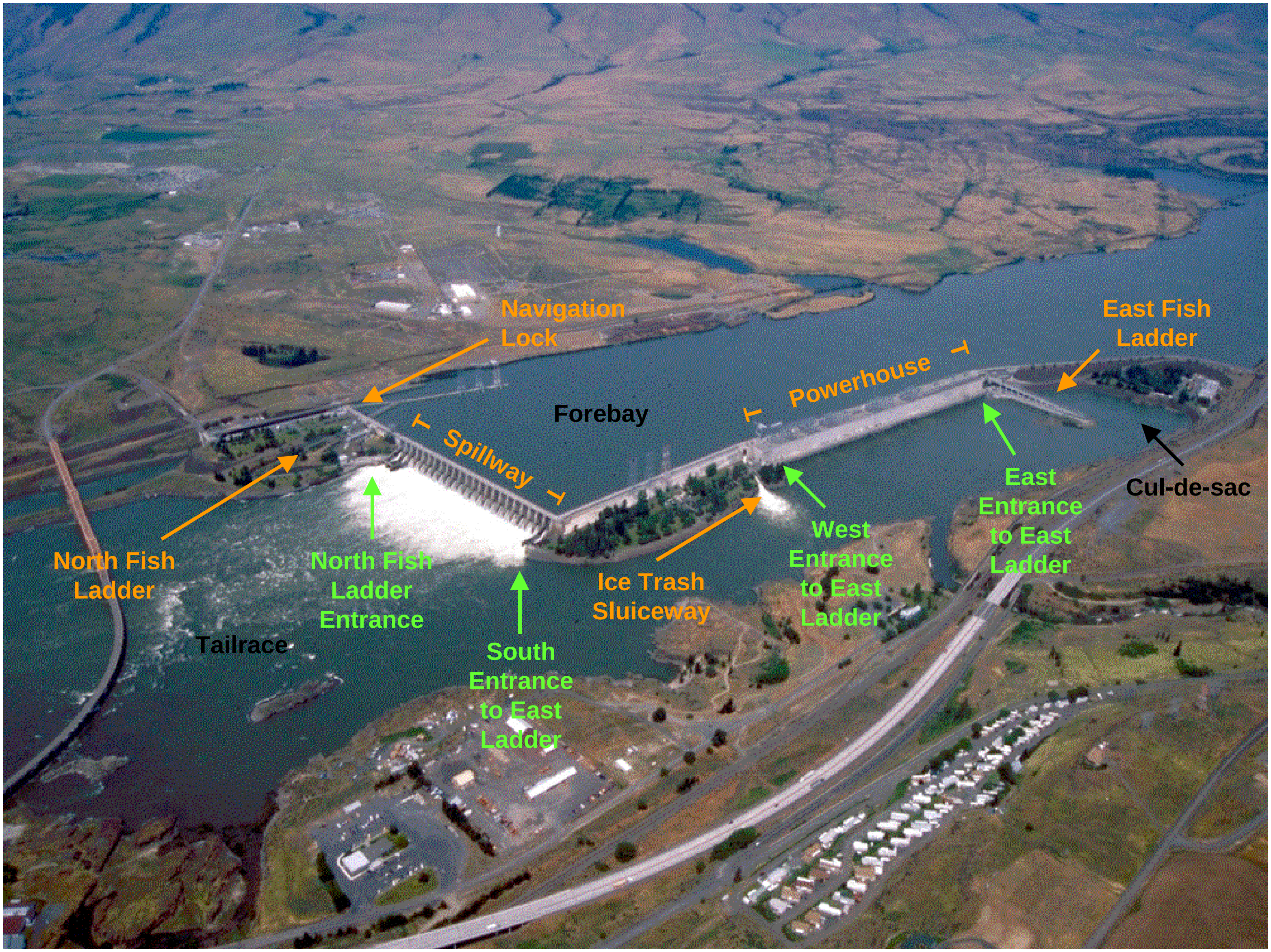

Figure 3. Aerial photograph of The Dalles Dam with key fish passage features noted.

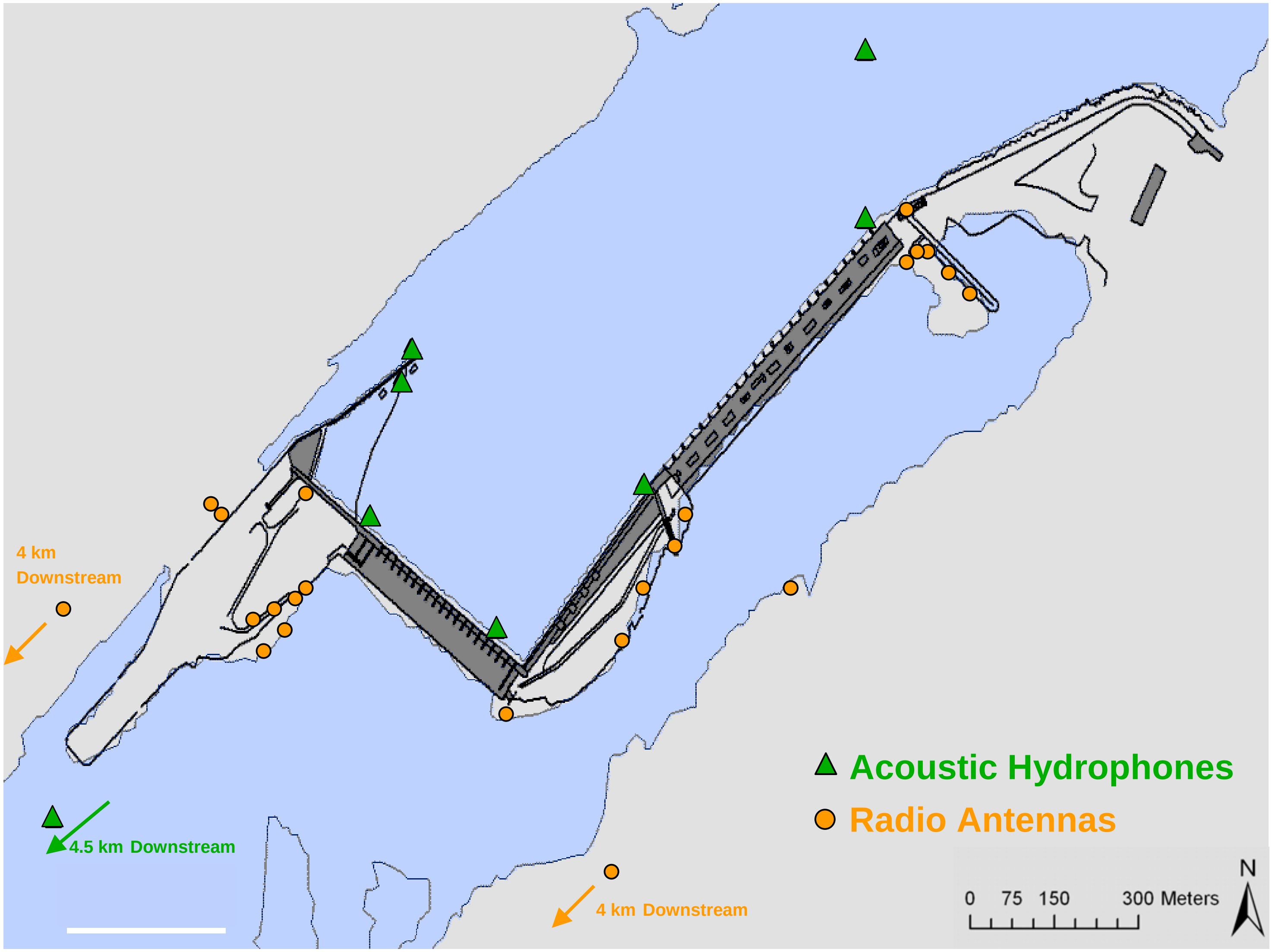

Figure 4. Locations of acoustic hydrophones and radio antennas around The Dalles Dam during 2004. Two radio antennas and one hydrophone were located 4 and 4.5 km downstream of the dam and are not illustrated in their proper location in this graphic.

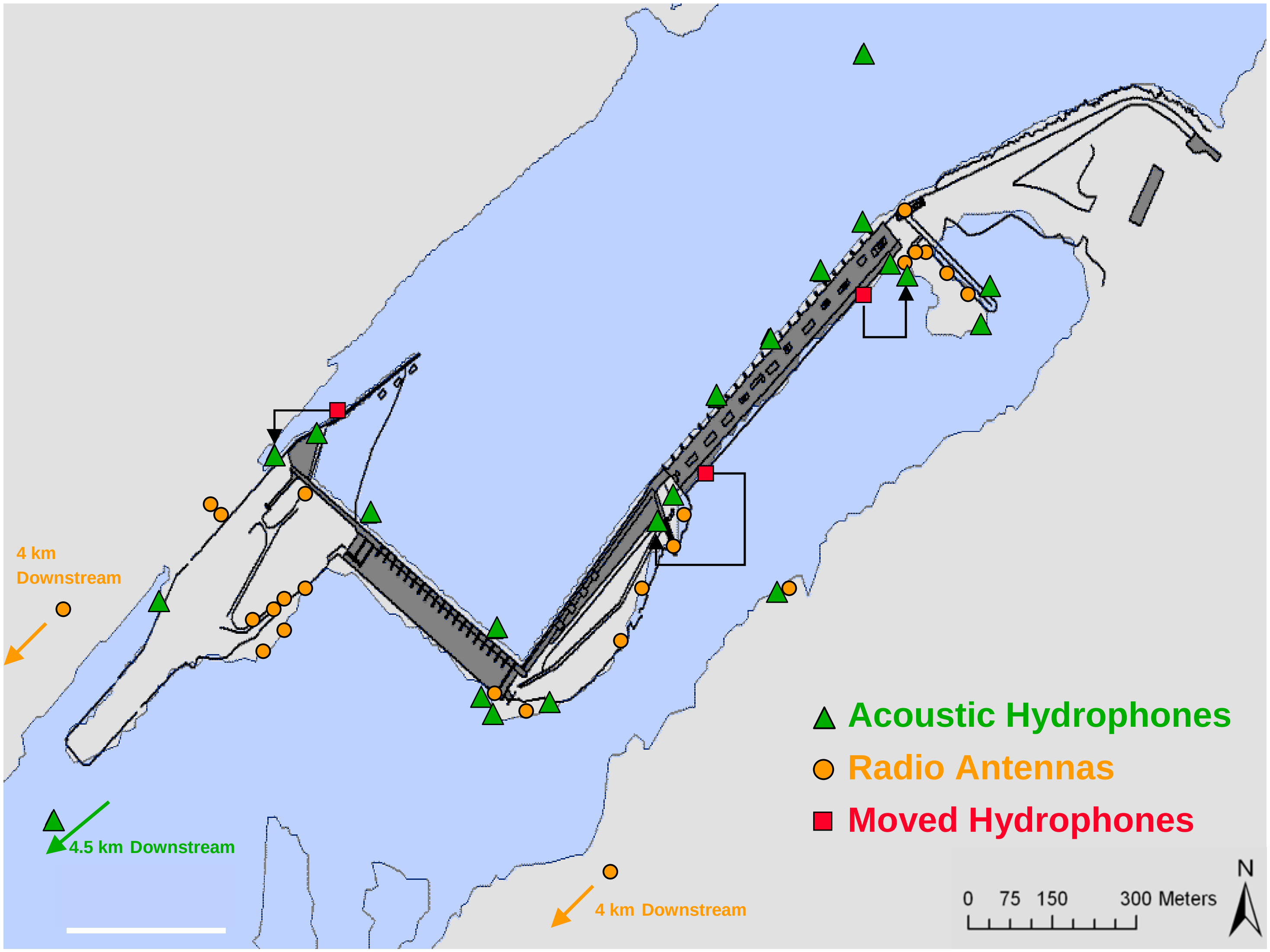

Figure 5. Locations of acoustic hydrophones and radio antennas around The Dalles Dam during 2005. Thirteen additional hydrophones were added and three existing hydrophones moved in 2005 to provide better coverage.

During 2005 an increased emphasis was placed on determining routes of downstream passage and eight additional acoustic receivers with 13 hydrophones were added to the existing array (Figure 5). These were positioned to increase the acoustic coverage of the tailrace, the forebay side of the powerhouse, and navigation lock. Figure 6 shows the approximate detection ranges of all acoustic hydrophones used during the study. Recognizing that maintaining hydrophones within the zone of spill downstream of the dam would be problematic, an approach was taken to maximize the probability of detecting fish that passed downstream through the turbines, ice/trash sluiceway, and navigation lock, leaving the tailrace side of the spillway as the only unmonitored passage route. With this approach, we assumed that any fish that passed downstream and was not noted as passing via these monitored routes must have passed through the open spill gates. Additional hydrophones were deployed to determine the direction of fish movement between the powerhouse and spillway areas, giving further information on their routes of downstream passage.

Fish Capture and Handling

Baited setlines were fished to capture sturgeon in the vicinity of The Dalles Dam. Fishing was done in the forebay directly upstream of the dam and in the area referred to as the cul-de-sac on the downstream side of the dam. The cul-de-sac, a pool-like area east of the powerhouse that is part of the historic river thalweg, has depths ranging to 38 m. Each setline consisted of a 91.5 m long mainline with an anchor at each end and float lines with inflatable buoys adjusted to depth. A variable number (10-25) of circle hooks were attached to each line as part of a gangion that could be easily clipped and unclipped from the mainline. Circle hooks of size 12/0, 14/0, and 16/0 were used although size 14/0 and 16/0 hooks were fished almost exclusively since we were targeting white sturgeon approximately 1 m in length and larger. Pickled squid (*Loliga* sp.) was used as bait on all setlines. Fishing effort (i.e., number of lines set and the number of hooks per line) varied depending on site conditions, the target number of fish to be caught, and catch rates.

Only sturgeon that were $\geq$ 95 cm TL and in good physical condition were retained for transmitter implantation. Sturgeon that were too large to be placed in the 50-gal livewell on the boat were held by passing a loop of line around the caudal peduncle and tying the tag end to the boat. These fish remained attached to the boat and suspended in the water column until they were tagged. Fish that were less than 95 cm TL were considered too small for the size of the transmitters we used and were released.

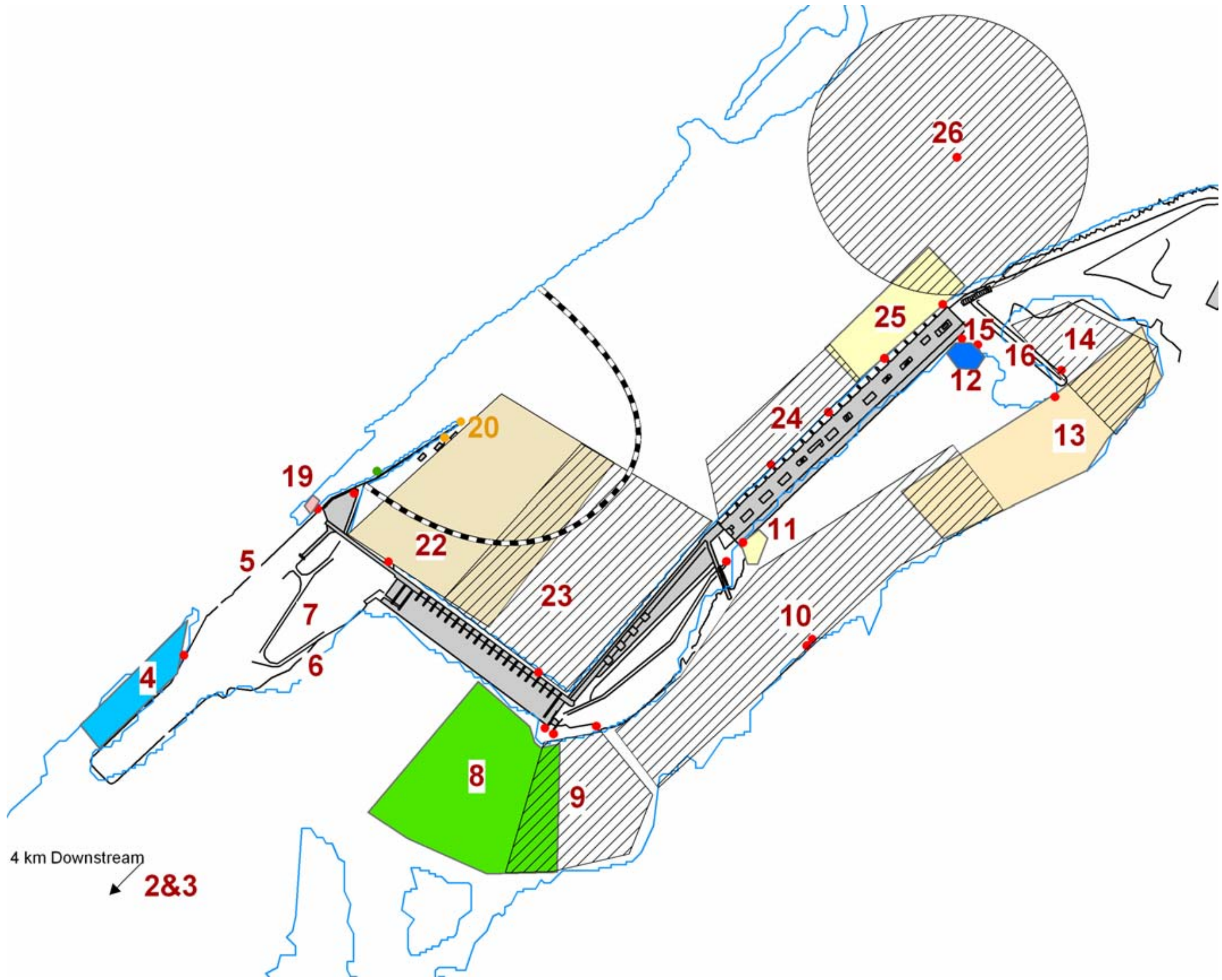

Figure 6. A generalization of the zones of detection of hydrophones deployed during this study. Daily ambient acoustic conditions, riverbed morphometry, and seasonal changes in river discharge and dam operations influence detection ranges. Location 20 was removed after 2004; the dashed line around it indicates its estimated zone for the time it was operational.

Surgical Procedures to Implant Transmitters

Surgical techniques to implant the transmitters followed the same basic procedure regardless of capture method. Surgical instruments and transmitters were sanitized and stored in Benzall solution (Xttrium Laboratories, Inc., Chicago). Large fish were held ventral side up in a stretcher and braced with sand bags during the surgery. Smaller fish were held ventral side up in a padded cradle. An external health assessment of the fish was conducted and then measurements of fork length, total length, and girth were measured to the nearest centimeter. A small pump and hose was used to irrigate the gills with river water during surgery. An incision approximately 35 mm long was made off the centerline, 50-160 mm anterior to the urogenital pore with a #12 scalpel blade. Exact placement of the incision varied somewhat depending on the size of the fish. A transmitter was then inserted into the body cavity of the fish and a sterile absorbable suture of either coated Vicryl (Ethicon, Inc., Piscataway, New Jersey) or PDS II was used to close the incision. Both types of sutures were 2-0 diameter size with a CP-1 cutting edge needle. Four or five individual knots in a simple interrupted pattern were tied and a drop of Vetbond (3M, St. Paul, Minnesota) tissue adhesive was placed on each knot. The sturgeon were then released near the location of capture and time of release was noted.

Data Processing

Data were periodically downloaded from the radio and acoustic receivers throughout the study period. At the end of the study period the complete set of raw data files for each acoustic receiver was decompressed with Lotek BioMap software. All acoustic data was then combined into one large dataset. The data was then filtered with an algorithm that removed spurious detections likely caused by background noise. The algorithm also added passage event indicators. Data downloaded from radio receivers were electronically transferred to the NOAA Fisheries office in Seattle, WA for initial processing. Each file was loaded into an Oracle database and run through initial filters that removed spurious records likely caused by electronic background noise. The filtered data were then transferred to the University of Idaho for coding. Coding involved inspecting all radio records for each fish and assigning a code to appropriate records that defined a specific behavior for that fish (e.g., entrance or exit from a fishway). Mobile tracking records and records of fish that were recaptured in subsequent fisheries were integrated into the datasets.

The acoustic and radio datasets were then combined into a summary dataset. Data were condensed by noting first and last detections of a fish at a specific site, then eliminating the redundant data between the two events. Daily individual fish histories over time were created by aggregating radio and acoustic data among antenna and hydrophone sites. Fish that were detected at more than one site during a given day were assigned to the location with the most detections. This enabled the display and examination of individual long-term movement patterns and passage events. Broader scale population movements were assessed by aggregating data from specific hydrophones and radio antennas located in close proximity to each other into single sites (Figure 7).

At times it was necessary to carefully scrutinize the raw data to investigate individual fish passage events or to clarify locations of individual transmitters. Identifying downstream routes of passage was problematic since we did not have complete radio or acoustic coverage of the spillway. Therefore, if a fish that was residing in the forebay passed downstream through the dam and had a last forebay detection at a hydrophone mounted along the spillway and had a subsequent first detection at location 2, 6, 8, or 9 (Figure 7), it was designated as having passed downstream through the spillway. Forebay resident fish that passed downstream and were first detected at sites 10-14 were designated as passing downstream via an unknown route since they could have passed either through the spillway or turbine units. However, trashrack spacing on the turbine units is narrow enough to preclude large white sturgeon from passing through turbines, therefore, if a fish was larger than 1.2 m TL and was assigned an unknown downstream passage route and spillway gates were open, the fish was categorized as having passed downstream through the spillway rather than through a turbine unit.

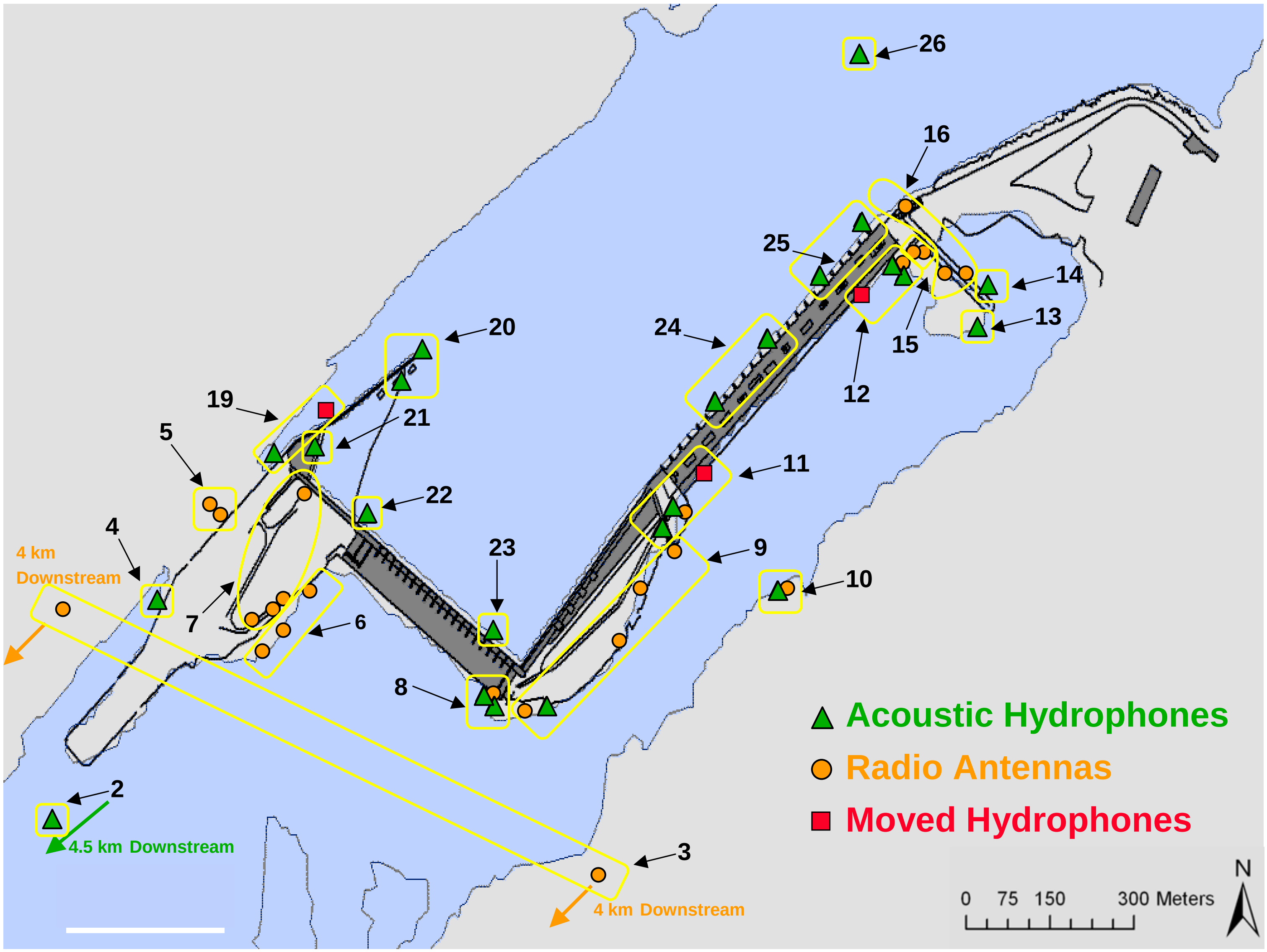

Figure 7. Aggregations of hydrophones and radio antennas and associated site locations used in analyses. Hydrophones and antennas bounded by lines were aggregated into a single site, indicated by a numeral, for analysis.

Results

Setlining occurred between March 2004 and April 2005 during six distinct periods (Table 1). Soak times varied between 18 and 26 hours in duration. An individual line fished overnight comprised a single effort. We made a total of 130 overnight setline efforts during the study; 99 efforts were made in the cul-de-sac and 31 efforts were made in the forebay.

A total of 148 white sturgeon were tagged with transmitters during the course of this study; 90 fish were released into the tailrace and 58 into the forebay. More than 350 sturgeon were captured during two fishing periods in the cul-de-sac and four fishing periods in the forebay, and 146 of these received surgically implanted transmitters (Table 2). A total of 89 fish captured on setlines were tagged and released in the tailrace, and 57 setline-caught fish were tagged and released in the forebay. Sturgeon were also obtained opportunistically during maintenance operations at the dam. A single sturgeon obtained during a turbine dewatering operation was tagged and released into the tailrace and another sturgeon obtained during dewatering and maintenance of the east ladder was tagged and released into the forebay. All tagged sturgeon ranged in size from 95 to 280 cm TL (Figure 8). The average size of the sturgeon tagged in the cul-de-sac (mean = 167 cm TL) was greater than the average size of fish tagged in the forebay (mean = 123 cm TL).

Table 2. Setlining and tagging efforts in the vicinity of the Dalles Dam between March 2004 and April 2005.

		Effort		Sturgeon	
Dates	Location	Setlines	Hooks	Captured	Tagged
04 Mar–19 Mar 2004	Cul-de-sac	26	339	a	50
23 Mar–02 Apr 2004	Forebay	39	582	12	7
09 Aug–12 Aug 2004	Forebay	12	262	69	20
24 Jan–28 Jan 2005	Forebay	24	480	18	9
31 Jan–02 Feb 2005	Cul-de-sac	5	100	51	39
18 Apr–22 Apr 2005	Forebay	24	480	48	21

[a]Due to high catches of small sturgeon, all fish captured were not counted.

All 58 of the fish released in the forebay were detected at some point during the study. Of the 90 fish released in the tailrace, 88 were subsequently detected (97.7%). During the study period at least 11 fish with transmitters (7.4% of all tagged fish) were harvested by sport anglers or Native American fishers. It is likely that more fish were actually harvested since there were no external marks identifying fish with transmitters. Persons reporting transmitters often stated that they only noticed the transmitter when the fish was being gutted. Persons that filleted fish rather than gutted them would not have opened the body cavity and thus may not have known that the fish was carrying a transmitter.

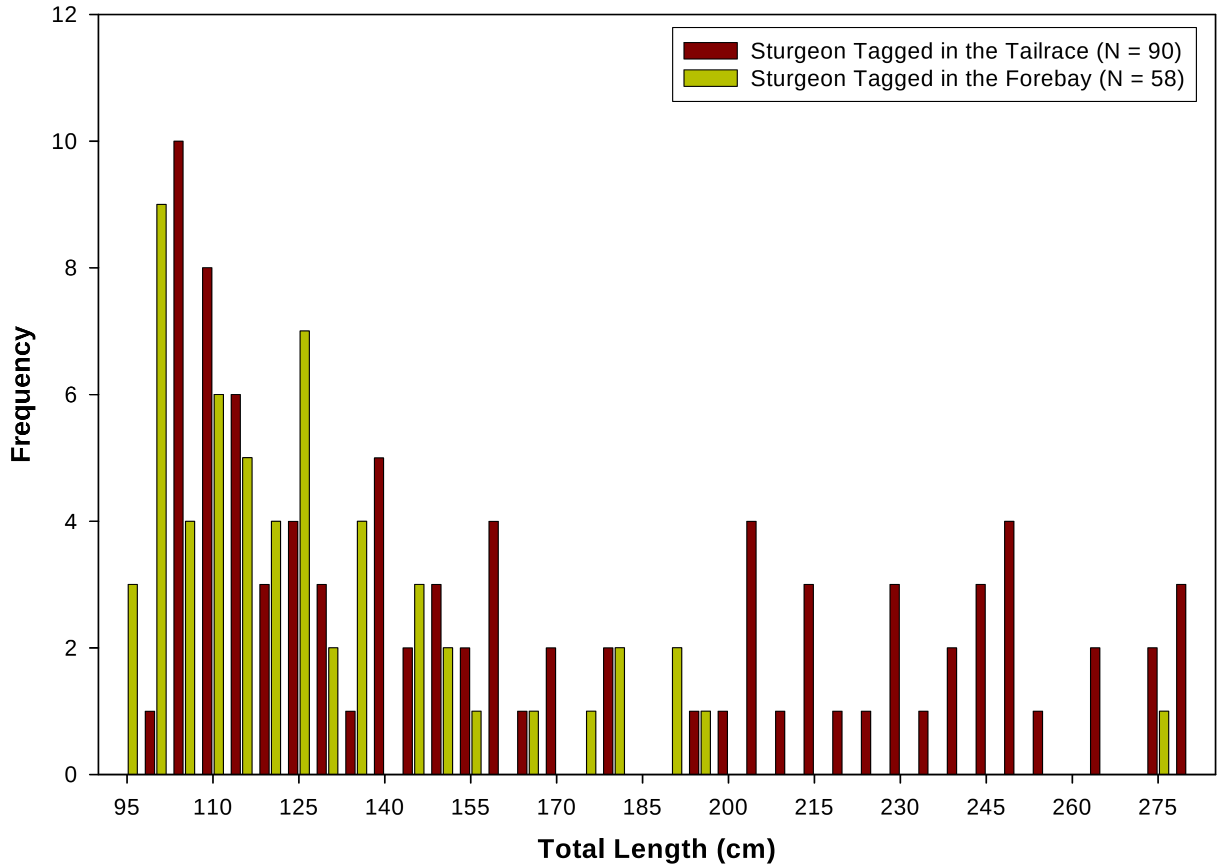

Figure 8. Length frequency of fish tagged in the forebay and tailrace.

Dam Passage

We documented 26 passage events at The Dalles Dam by 19 tagged fish; 8 upstream and 18 downstream (Table 3). Interestingly, 11 of these passage events (42% of the total) were made by only four fish. The 19 fish ranged in size from 97 cm to 207 cm TL. Seven of the upstream passage events were conclusively made through the east fish ladder; one fish passed upstream undetected in either ladder. No fish were conclusively known to have used the north ladder to pass upstream. Two fish were detected in the vicinity of the navigation lock but did not subsequently pass the dam. The limited monitoring infrastructure in place during 2004 precluded determination of routes of downstream passage. However, in 2005 after substantially increasing coverage of the tailrace with hydrophones, 10 of 12 recorded downstream passage events occurred through the open spillway gates. Combining both years, 25 of the 26 passage events occurred between the months of April and September (Figure 9). One downstream passage event occurred in October 2005 (ID 133). Since the spill gates were closed at this time, it is probable that this fish passed downstream via either the ice/trash sluiceway, which was operating at the time, or via a turbine unit, since this fish was small enough to fit through the trash racks.

Mobile tracking via boat conducted by the University of Idaho (Table 4) revealed that two fish that had been tagged in the cul-de-sac had moved downstream and passed through Bonneville Dam into the lower Columbia River. One of these fish was subsequently harvested near Cathlamet, WA during a commercial fishing season. We do not know when or how these fish passed Bonneville Dam.

Table 3. Passage events at The Dalles Dam between March 2004 and November 2005.

Individual fish ID	Fish total length (cm)	Passage direction	Probable route of passage	Date of passage or of last detection
19	141	Up	East ladder	7-Jul-04
21	207	Up	East ladder	10-Jun-04
44	117	Up	East ladder	10-Aug-04
51	129	Down	Spillway	16-May-05
52	97	Down	Unknown	25-Jul-04
52	97	Up	Unknown	23-Aug-04
52	97	Down	Spillway	3-Jul-05
53	112	Down	Spillway	8-Jul-05
55	106	Down	Unknown	30-Mar-04
56	180	Down	Unknown	31-Mar-04
56	180	Up	East ladder	2-Jul-04
56	180	Down	Unknown	9-Aug-04
56	180	Up	East ladder	19-Sep-04
72	152	Down	Unknown	12-Aug-04
74	192	Down	Spillway	15-May-05
75	116	Down	Spillway	6-May-05
78	106	Down	Unknown	1-Sep-04
91	98	Down	Unknown	19-Jun-05
130	134	Down	Spillway	29-Apr-05
130	134	Up	East ladder	14-Jul-05
133	108	Down	Unknown	26-Oct-05
134	187	Down	Spillway	6-Aug-05
141	143	Down	Spillway	29-Apr-05
143	101	Down	Unknown	22-Apr-05
144	125	Down	Spillway	28-Apr-05
144	125	Up	East ladder	15-Jun-05

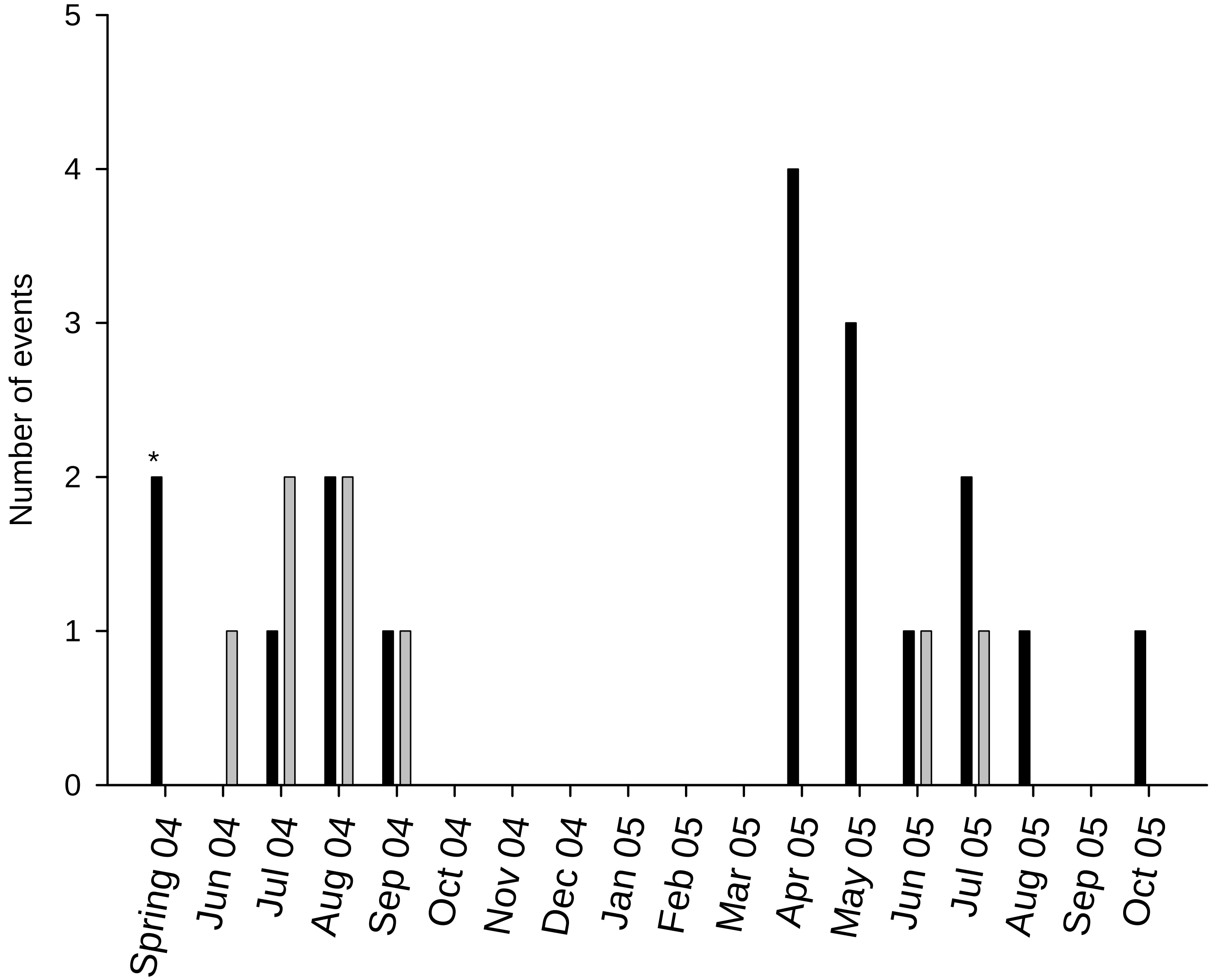

Figure 9. Passage events by month. Black bars indicate downstream passage, and gray bars indicate upstream passage.

Table 4. Mobile tracking detections of sturgeon. The Dalles Dam is located at river kilometer 309 and Bonneville Dam is at river kilometer 235.

Fish ID	Date	Time	River kilometer
6	7/17/2005	11:08:00	307
10	7/17/2005	11:05:00	307
19	7/18/2005	10:42:00	327
24	7/5/2005	09:32:00	256
24	7/6/2005	07:52:00	255
25	5/6/2004	10:09:00	308
28	7/14/2005	11:19:00	291
29	5/6/2004	11:16:00	305
32	5/6/2004	09:43:00	308
33	5/6/2004	11:28:00	305
33	5/6/2004	11:38:00	304
33	5/6/2004	12:15:00	305
35	10/12/2005	14:43:00	55
38	7/15/2005	12:02:00	306
40	7/15/2005	11:18:00	307
40	7/17/2005	11:03:00	307
45	7/15/2005	11:00:00	306
46	7/15/2005	12:05:00	306
46	7/17/2005	10:51:00	306
57	7/18/2005	09:01:00	310
63	7/18/2005	10:37:00	327
69	7/18/2005	08:54:00	309
70	7/18/2005	08:51:00	308
76	7/18/2005	08:47:00	309
79	7/18/2005	08:35:00	310
84	7/14/2005	07:05:00	263
84	7/14/2005	07:23:00	263
94	7/18/2005	08:35:00	310
98	7/17/2005	11:08:00	307
103	7/15/2005	11:15:00	307
103	7/17/2005	11:01:00	307
105	7/15/2005	07:19:00	305
105	7/17/2005	07:17:00	305
106	7/15/2005	07:25:00	305
106	7/17/2005	07:17:00	305
108	7/3/2005	10:56:00	250
108	7/3/2005	11:00:00	251
108	7/5/2005	09:04:00	252
109	7/15/2005	11:04:00	306
110	7/15/2005	10:57:00	306
110	7/17/2005	08:23:00	294
112	7/15/2005	11:18:00	307

Table 4. Mobile tracking detections of sturgeon. The Dalles Dam is located at river kilometer 309 and Bonneville Dam is at river kilometer 235.

Fish ID	Date	Time	River kilometer
117	7/15/2005	11:14:00	307
117	7/17/2005	10:51:00	306
117	7/17/2005	10:55:00	306
121	7/15/2005	11:00:00	306
121	7/15/2005	11:46:00	306
124	7/17/2005	11:05:00	307
130	7/18/2005	09:04:00	310
132	7/18/2005	08:54:00	309
136	7/18/2005	08:35:00	310
142	7/18/2005	07:54:00	320
145	7/18/2005	11:41:00	328
146	7/18/2005	08:47:00	309
148	7/18/2005	08:54:00	309

Ladder Use and Occupancy

During the study 17 individual fish entered the ladders one or more times. Eleven individuals entered the east ladder, 3 entered the north ladder, and 3 individual fish entered both ladders at some point (Figure 10). Residence time within in the ladders by individual fish was quite variable, ranging from about 1 min to nearly six months (mean = 7.1 days; SD = 24.8 days). Six fish occupied the north fish ladder for variable periods; one individual (ID 47) resided in the north ladder for a considerable period in 2004 and again in 2005 (Figure 10). No fish were detected exiting out the top of the north fish ladder. In the east ladder there were 16 separate periods of occupancy by 14 individuals. Seven of these periods lead to upstream passage events by six individuals (Figure 10). The east fish ladder has 3 entrances and although we were unable to determine which entrance was used for 7 of the periods of occupancy, we did determine that 7 entrances were made via the east entrance, one was made from the south entrance, and one fish entered through the west entrance. Two of the fish that spent time within the fish ladder but did not pass upstream and then returned to the tailrace did so via the east entrance and two departed out the south entrance. We were unable to determine which entrance was used as an exit when five fish returned to the tailrace.

White sturgeon may respond quickly to changes in local hydraulic conditions as dam operations change. One fish (ID 47) entered the north fish ladder on June 21, 2005 at approximately 1500 hours (Figure 10). Interestingly, spillway and north ladder attraction flow operations were suspended on this day for about three hours to inspect the spillway[1]. Spill was stopped at approximately 1200 hours and was restarted sometime between 1500 and 1600 hours

[1] Army Corps of Engineers Annual Fish Passage Report, April 2005 and historical operations data. Available online at http://www.nwp.usace.army.mil/op/fishdata/docs/afpr2005.pdf and http://www.nwd-wc.usace.army.mil/tmt/wcd/tdg/months.html.

(Figure 11). The fish was consistently detected at hydrophone group 8 (Figure 7) located at the south end of the spillway from May 9 through June 21. The last detection at hydrophone group 8 was at 1330 hours on June 21 and the first detection on a radio antenna within the north fish ladder at antenna group 7 (Figure 7) was at 1508 hours, suggesting the fish moved across the stilling basin towards the north fish ladder entrance during the period when spill was shut off. This fish had resided in the north fish ladder for an extended period of time during 2004 and was in the north ladder at the conclusion of this study (Figure 10).

Ladder use and occupancy times differed among years. In 2004, we released 50 fish into the tailrace and 9 fish entered the ladders. In 2005, we released an additional 39 fish into the tailrace yet only 9 fish from both release years entered the ladders. Ladder residence times were considerably shorter in 2005 (mean = 0.9 days) compared to 2004 (mean = 8.6 days) after excluding one fish (ID 47) that appeared to have an affinity for the north fish ladder. Interestingly, counts of white sturgeon passing the viewing windows declined substantially in each ladder between 2004 and 2005 (Figure 12). In 2004, the number of white sturgeon counted was 106 in the east fish ladder and 29 in the north fish ladder. In 2005, these numbers dropped to 2 fish counted in the east fish ladder and 0 fish counted in the north fish ladder (unpublished data, Portland District U.S. Army Corps of Engineers). In 2004, we noted 6 upstream passage events and in 2005, despite a substantial increase in the number of fish with transmitters in the tailrace, we noted only 2 upstream passage events.

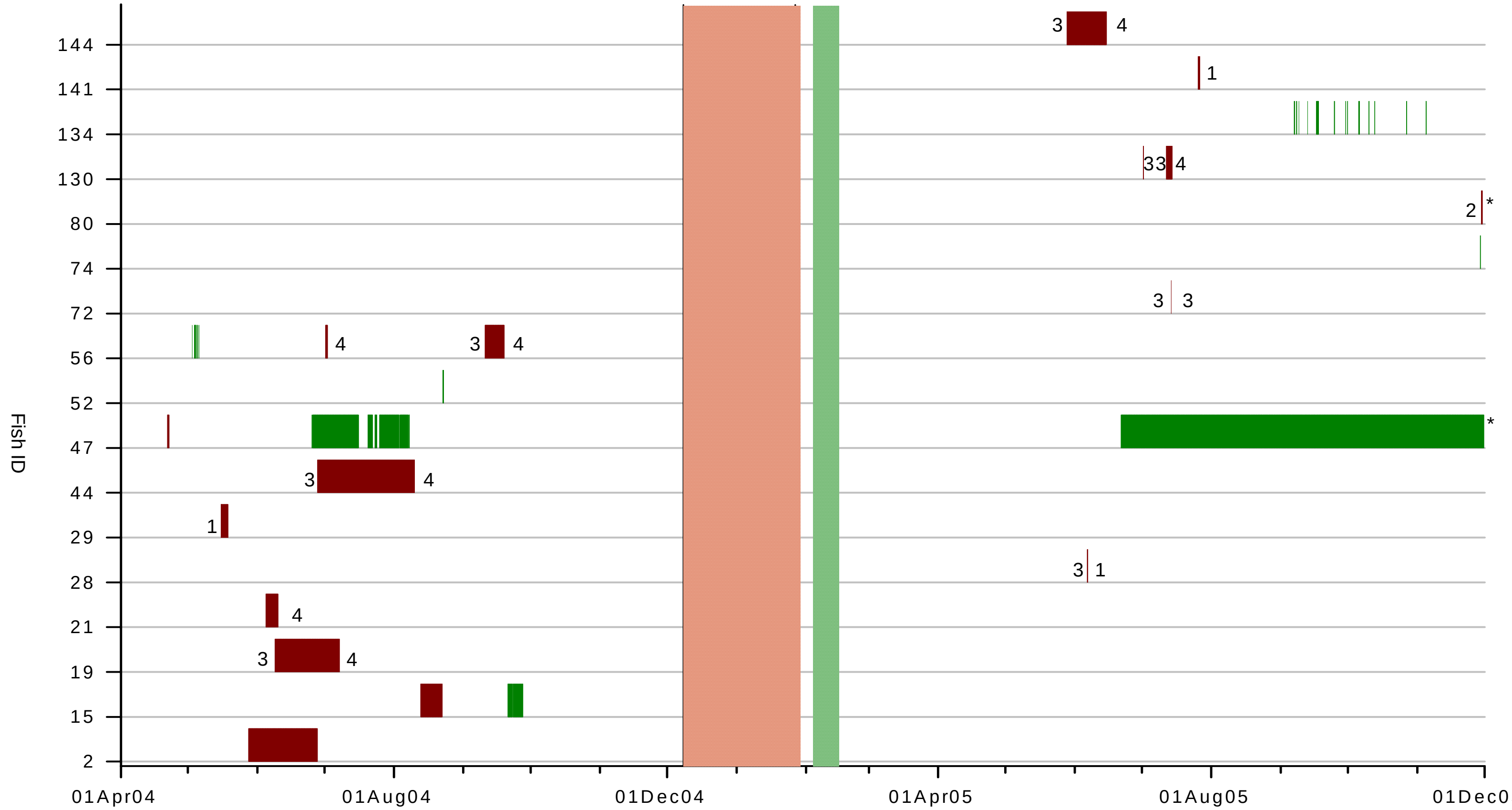

Figure 10. Ladder occupancy by individual fish during the study period and dates when the ladders were dewatered for maintenance. Horizontal green bars indicate residence times in the north ladder and horizontal red bars indicate residence times in the east ladder. Numbers indicate known entrance and exit locations at the east ladder, where 1 = south entrance, 2 = west entrance, 3 = east entrance, and 4 = top of east ladder. The north ladder has only one entrance that is located adjacent to the northernmost spillway. Two fish (ID 47 and 80) were in the ladders at the end of the study. Vertical bars indicate periods when the ladders (green = north, red = east) were dewatered for annual maintenance.

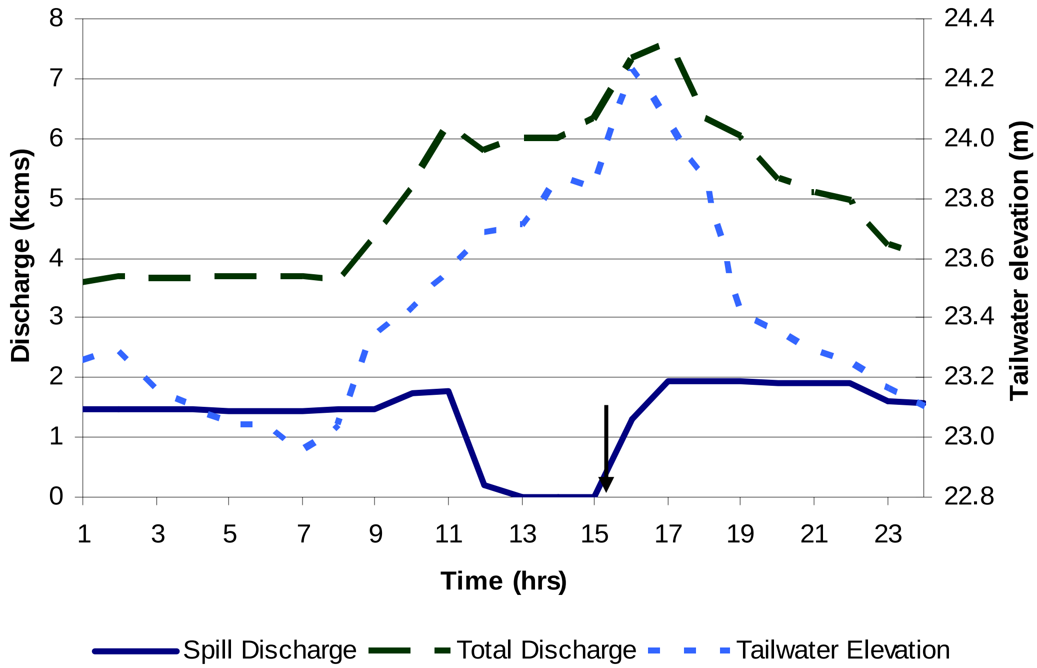

Figure 11. Hourly river discharge and tailwater elevation at The Dalles Dam on June 21, 2005. On this day spill discharge and north fish ladder attraction flows were temporally suspended for while inspections of the spillway were made. One tagged white sturgeon (ID 47) entered the north fish ladder at 1508 hours (vertical arrow). This fish was last detected at hydrophones located on the southern end of the spillway at 1330 hrs.

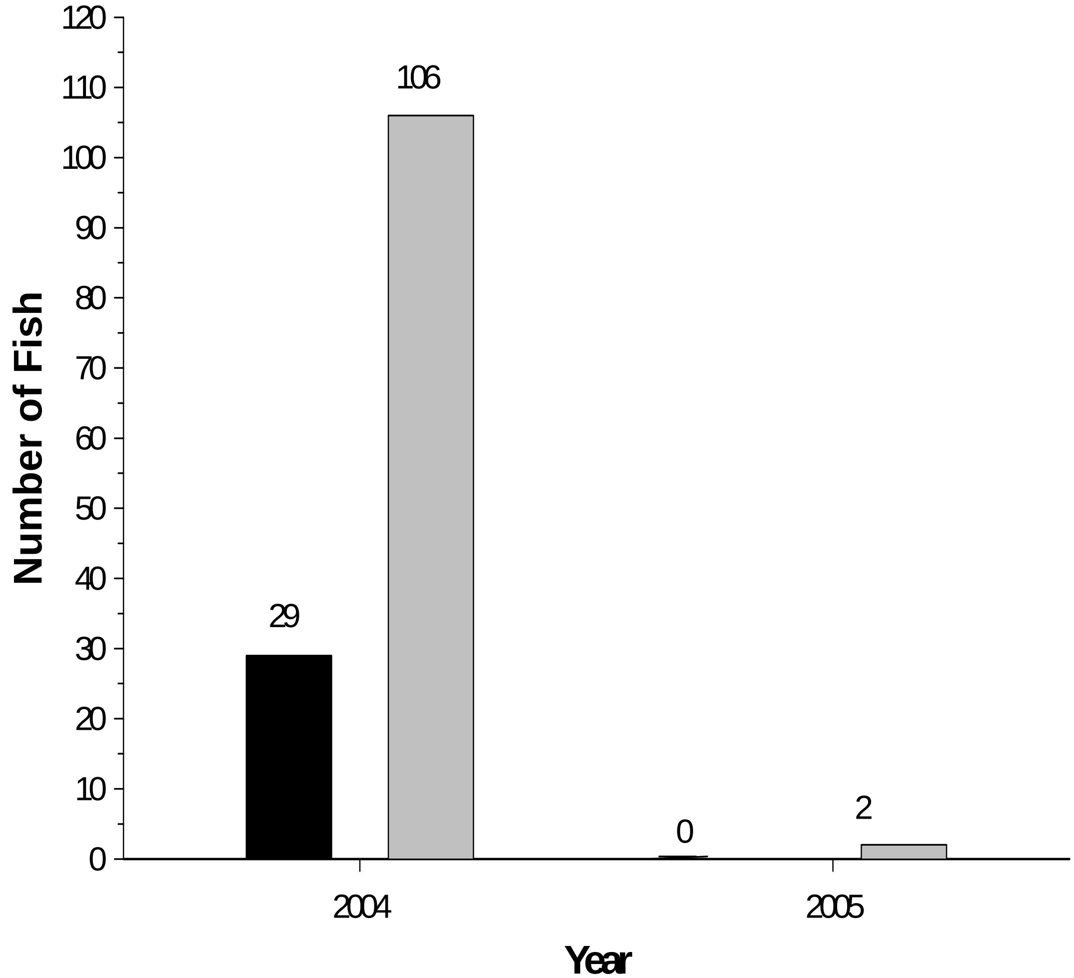

Figure 12. Ladder counts of white sturgeon during 2004 and 2005 (U.S. Army Corps of Engineers unpublished data). Black bars indicate north ladder counts, and gray bars indicate east ladder counts. Counting stations are located in the upper reaches of each ladder, and therefore do not include fish that entered ladders but did not ascend to the counting stations.

Individual and Population Movements

Individual sturgeon tagged at The Dalles Dam dispersed as far as 254 km downstream into the estuary and 38 km upstream to John Day Dam. Mobile telemetry surveys conducted by the University of Idaho detected 20 fish downstream beyond our immediate study area at The Dalles Dam and 1 fish was detected on a stationary radio receiver at John Day Dam (Table 3).

Seasonal patterns of aggregation and dispersal in the forebay and tailrace are evident when plots of the number of individual sturgeon detected each day at distinct hydrophones are examined (Figures 13 and 14). Since there were no hydrophones located in the tailrace near the dam in 2004, only data collected during 2005 can be used to show population movements downstream of the dam. However, the plots show an apparent abundance of fish in the cul-de-sac during winter months, dispersal downstream during spring and summer months, and a reformation of an aggregation in the cul-de-sac during the fall (Figure 13). Detections at other locations around the dam, including the hydrophone located furthest downstream at the gauging station (Location 2), indicate that fish aggregate in the cul-de-sac during winter. Lower numbers of individuals occurred at this downstream area during winter months and numbers increased during spring and summer (Figure 13), supporting a pattern of dispersal from an upstream wintering area in the cul-de-sac.

The tagged white sturgeon in the forebay showed a less distinct pattern of seasonal aggregation. During winter of early 2005 more white sturgeon were detected at hydrophones near the spillway when compared to detections at the forebay barge (Location 26; Figure 14). Conversely, during the late summer and fall of 2005 a slightly greater number of white sturgeon were detected at the forebay barge (Location 26) than at hydrophones near the spillway.

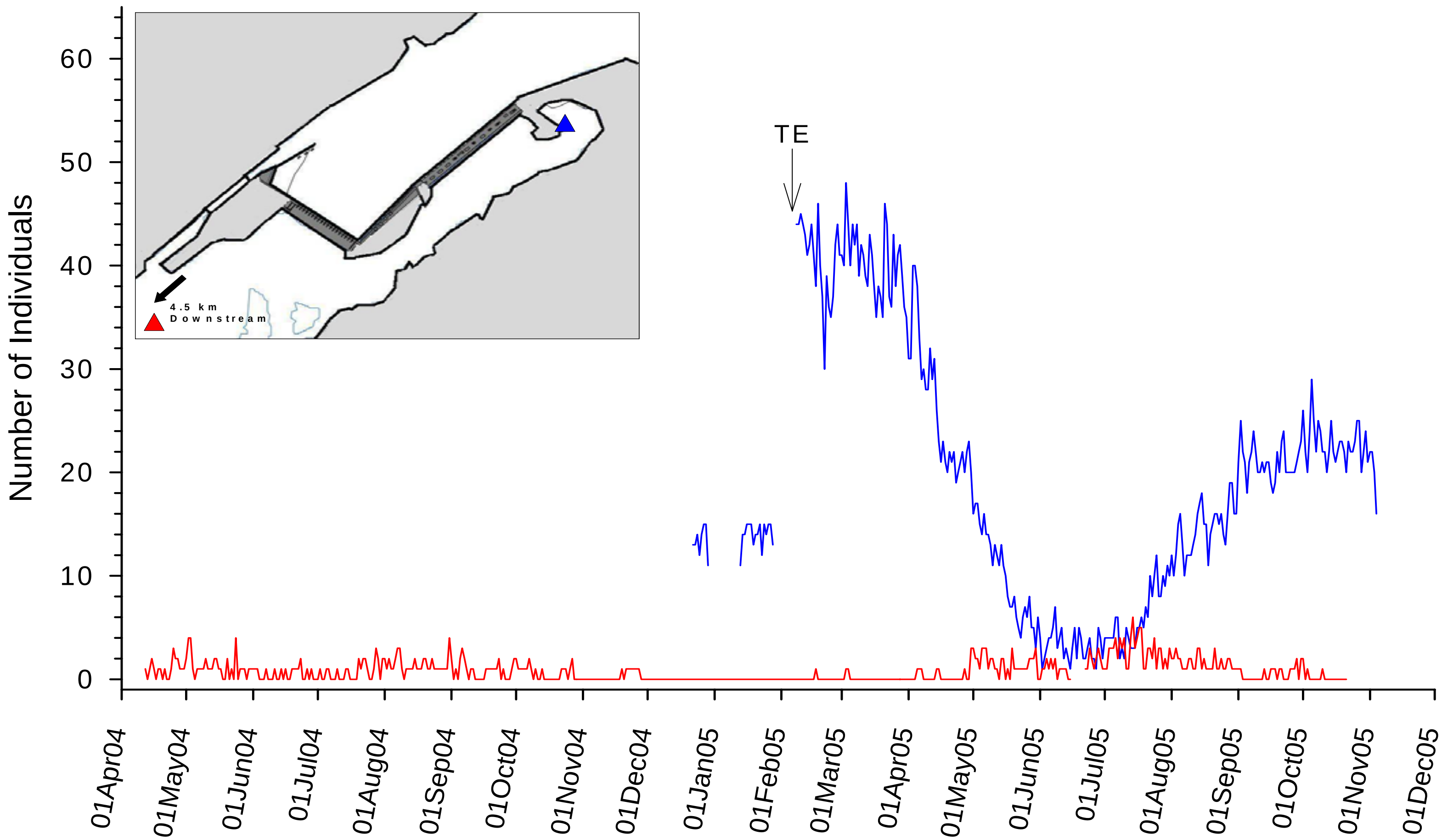

Figure 13. Evidence of a winter aggregation of white sturgeon in the cul-de-sac and a summer dispersal downstream as indicated by the number of individual fish detected at two key hydrophones (see inset); one located in the cul-de-sac (blue line) and one downstream at the gauging station (red line). The solar powered hydrophone in the cul-de-sac was installed in December 2004 and experienced brief power outages due to low daylight conditions. Thirty-nine fish were released into the cul-de-sac during a tagging event (TE) from 31 January – 2 February 2005.

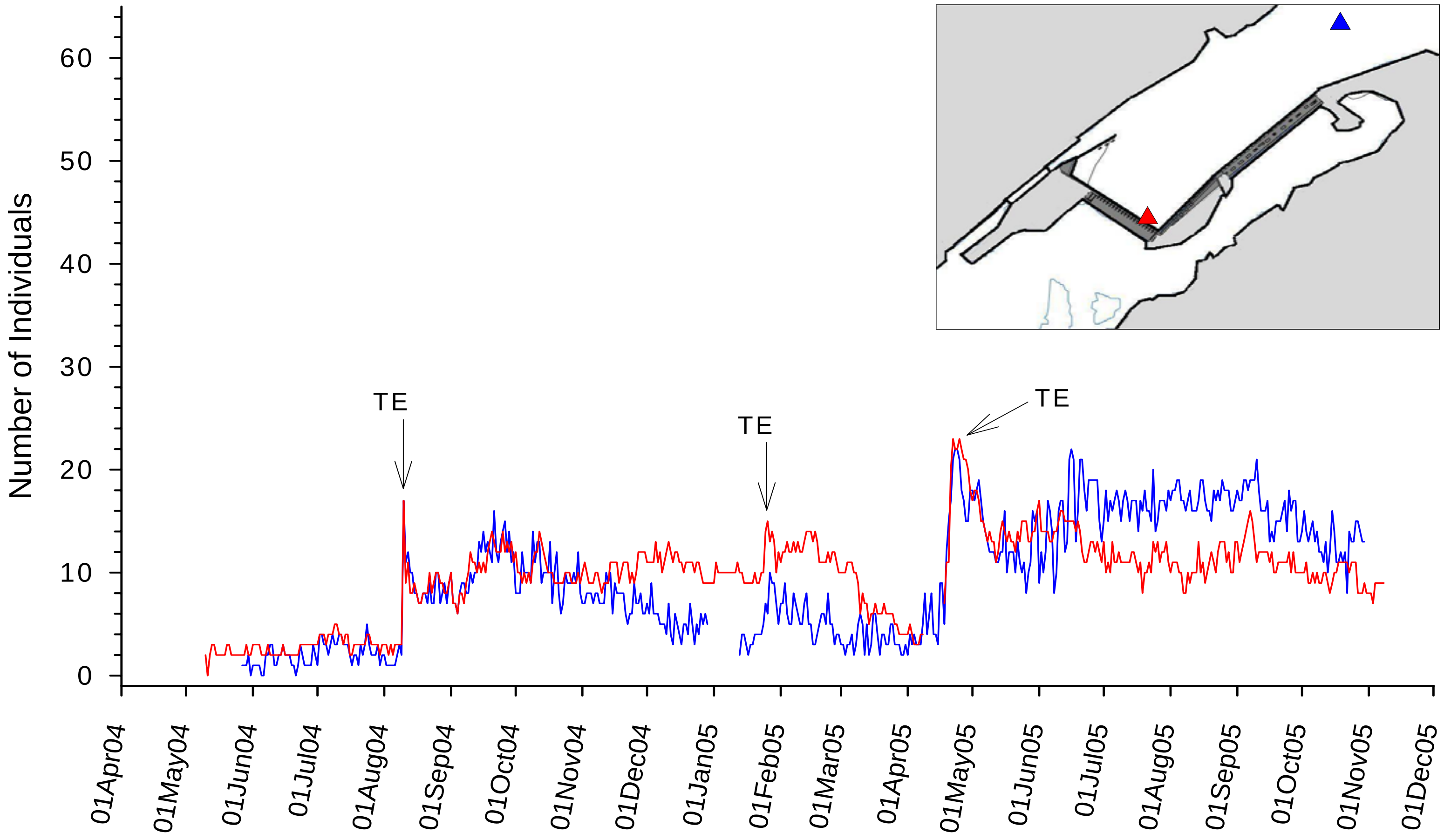

Figure 14. Evidence of a seasonal aggregation of white sturgeon in the forebay as indicated by the number of individual fish detected at two key hydrophones (see inset); one located on a barge moored in the forebay (blue line) and one deployed along the spillway proximal to the non-overflow wall (red line). The solar powered hydrophone on the barge experienced a brief power outage during late December 2004 and early January 2005 due to low daylight conditions. Additional fish were released into the forebay during three tagging events (TE); 20 fish were released during 9-12 August 2004, 9 fish during 24-28 January 2005, and 21 fish were released during 18-22 April 2005.

Discussion

Compared to the collective knowledge of juvenile and adult salmonid passage at dams, knowledge of sturgeon passage and its effect on population dynamics is in its infancy. It has been assumed that construction of hydroelectric dams on the Columbia and Snake rivers has restricted movements of white sturgeon to within impounded reaches, effectively resulting in a series of individual landlocked populations (North et al. 1993). Evidence now suggests that there is a net downstream movement of white sturgeon among reservoirs. The overall effect of this on population dynamics within individual reservoirs has not been investigated, although Jager (2005) used population viability analysis modeling to examine potential effects. Prior to dam construction in the Columbia River Basin, white sturgeon likely responded to seasonal changes in food and habitat availability by ranging extensively between freshwater, estuarine, and marine environments. Because the physiochemical and biotic characteristics of reservoirs vary greatly within the basin, individual impoundments may not contain optimal conditions for all life stages of white sturgeon (Parsley and Beckman 1994; Beamesderfer et al. 1995).

One of the more interesting findings of this study was that some sturgeon made multiple transits of the dam during a year. That is, several individual fish made both upstream and downstream passages in a year. This has important ramifications for the use of visual counts made at ladder count stations as estimates of sturgeon passing upstream since fish did not permanently reside in the upstream reservoir. It is important for fishery resource managers to know that the number of sturgeon counted at ladder count stations is likely greater than the increase to the population residing in the upstream reservoir. Why fish made multiple transits of the dam within a year is unclear.

The east ladder was used almost exclusively for upstream passage even for fish that occupied the north ladder for a period of time. Historical counts of white sturgeon in the fish ladders at The Dalles Dam always show more fish counted in the east ladder than the north ladder. Our study showed that fish do enter and reside within the north ladder, but evidently few ascend to the counting station and even fewer exit out the top into the upstream reservoir. Our monitoring infrastructure was not designed to provide detailed information on fish behavior within the fish ladders. However, construction drawings for the fish ladders indicate that there are physical differences between the north and east ladders. The north ladder is narrower than the east ladder and the orifices in the weirs in the north fish ladder are substantially smaller than the orifices in the weirs in the east fish ladder (Table 1). The cross-sectional areas of individual orifices in the north ladder are 0.21 m^2 while the cross-sectional areas of orifices in the east fish ladder are twice as large at 0.42 m^2. Also, the north ladder has eight weirs near the upper exit that have only 1 orifice and a vertical slot, while the east ladder has no vertical slot weirs. The vertical slots are only 0.3 m wide. It is conceivable that the larger orifices or lack of vertical slot weirs facilitated upstream passage of white sturgeon in the east ladder. Higher counts in the east ladder could also be expected simply because there are three entrances to this ladder compared to only one entrance to the north ladder, thus white sturgeon would potentially have a greater opportunity to locate an entrance to the east ladder.

Our data suggest that larger white sturgeon (we tagged only white sturgeon ≥ 95 cm TL) successfully pass downstream at The Dalles Dam through open spill gates. It is important to understand the magnitude of downstream movements of white sturgeon passage since some reservoirs may act as source populations and others as sinks. We are unaware of any published studies of turbine or spillway passage survival for sturgeons. Based on our work, the survival of fish ≥ 95 cm TL that pass downstream is relatively high, since none of the fish we noted passing downstream appeared to die. However, we did not tag smaller juvenile white sturgeon that may more readily pass through turbines. If the magnitude and mortality of young white sturgeon passing downstream is high, there is no benefit to the downstream population but there is a net loss from the upstream population. If mortality is low, downstream passage can provide benefits to the recipient population only if there are adequate food resources to support the additional fish. However, this downstream movement still represents a loss to the upstream population since there are limited opportunities for fish to return upstream to the source population. White sturgeon are resident to the reservoirs, and, unlike juvenile salmonids which actively migrate downstream only during a portion of the year, small white sturgeon could conceivably pass downstream through turbines at any time of the year. Thus, it's important to determine if smaller white sturgeon are passing downstream through turbines and if so, what the survival rates are.

Even if downstream passage survival is high, there could be a negative effect on the sturgeon metapopulation. White sturgeon condition, growth, and size at maturity vary among the lower Columbia River reservoirs (Beamesderfer et al. 1995), presumably due to variations in resource availability among areas. In some impoundments, suitable rearing habitat exists, but spawning habitat is lacking and recruitment of fish is poor (Parsley and Beckman 1994). Conversely, research conducted in the Bonneville Reservoir suggests that spawning conditions are favorable for good recruitment of young-of-the-year white sturgeon in most years, but growth of young fish may be density limited (Beamesderfer et al. 1995). Thus, the input of additional white sturgeon from upriver impoundments could exacerbate density limitations to growth.

It is important to consider how changes to operations at hydroelectric dams to benefit migrating anadromous salmonids may influence upstream or downstream passage by white sturgeon. Hydraulic conditions at all fish ladder entrances vary with flow and tailwater elevation, and the current practice of operating the northernmost spill gates at The Dalles Dam to pass juvenile salmonids may reduce sturgeon use of the single entrance to the north fish ladder during periods of spill. The fact that one tagged fish entered the north fish ladder during a brief period when spill and north fishway attraction flow operations were halted on June 21, 2005 provides evidence that sturgeon may not readily use the north entrance during periods of spill and may be attracted to areas with lower velocities as opposed to adult anadromous salmonids. Operators of the hydroelectric dams in the Columbia River basin are also currently on an ambitious path to reduce the volume of spill now required to pass juvenile salmonids by implementing a suite of technological fixes including removable spillway weirs. Removable spillway weirs use less flow volume to pass equivalent numbers of juvenile salmonids and don't require juvenile salmonids to sound to deeper depths to pass. However, installation of removable spillway weirs will likely reduce downstream passage by adult white sturgeon since benthic oriented sturgeon will now have to ascend nearly to the river surface instead of only to the top of a spillway crest to pass downstream. In addition, since more water will be diverted to turbines instead of spilled, installation of removable spillway weirs may result in an increase in passage of sturgeon through turbines or in a greater retention of larger fish within the upstream reservoir. The consequences of greater downstream passage through turbines or retention of larger fish in reservoirs to the sturgeon metapopulation is not obvious and may oppose the commonly held belief that passage would benefit white sturgeon populations, as Jager (2005) pointed out. Other actions aimed at improving passage for salmonids that potentially influence passage by sturgeon include the installation of grates to prevent sea lions from entering fish ladders at Bonneville Dam, spill patterns or tailwater elevations that may preclude sturgeon from entering fish ladders, installation of behavioral guidance structures (steel curtains) in dam forebays to route juvenile salmonids away from turbines, and the experimental use of sound, light, or other means to enhance passage or repel predators of fish.

This study was a logical step in increasing understanding of sturgeon behavior near dams. Future studies will be able to build upon these results as many questions remain unanswered. We showed that it is feasible to use radio and acoustic telemetry technologies to monitor general movement patterns of sturgeon near dams and in fishways for extended periods of time. The combination radio and acoustic transmitter allowed us to monitor fish in deeper areas as well as within the fishways. The pulse pattern with a 20 sec interval for the transmitters (R-A-A-R-A-A) was adequate for the acoustic monitoring but we would recommend a more frequent pulse rate for radio transmitters. It is likely that some fish within the fish ladders passed by radio antennas undetected during the 1-min interval between radio pulses. Our study monitored only fish entrances and exits and provided residence time within the fish ladders. Additional radio antennas mounted longitudinally along fish ladders would provide greater detail on what fish do within the ladders. Since few fish that enter the fish ladders actually pass upstream, additional monitoring within the ladders may provide insight on why they cannot pass. Expansion of the population viability analysis modeling done by Jager (2005) would provide a better understanding of the role that passage can play in maintaining or increasing white sturgeon populations.

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Reference to trade names does not imply endorsement by the U.S. Government.

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