US Army Corps
of Engineers
Walla Walla District

Surveys of Fall Chinook Salmon Spawning Downstream of Lower Snake River Hydroelectric Projects

Summary Report for 1993-1998

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U.S. Army Corps of Engineers
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Executive Summary

Pacific Northwest National Laboratory conducted studies from 1993-1998 to search for and to characterize fall chinook salmon spawning sites in areas immediately downstream of the four lower Snake River dams. The data were needed as input to decisions on the potential impacts of localized construction activities on adult fall chinook salmon and to provide guidelines for future operation of the hydroelectric system, including assessment of reservoir drawdown. Specific study objectives were to 1) determine if fall chinook salmon spawned in the tailrace or other locations where construction activities or dam operations could adversely impact their reproductive success, 2) document the distribution and abundance of redds, and 3) obtain detailed information on habitat characteristics.

Initial efforts to locate tailrace spawning areas using aerial surveys with fixed-wing aircraft and reviewing data from adult radiotracking studies were unsuccessful. Subsequently, Geographic Information System (GIS) technology was used to create maps of potential spawning habitat (primary search areas) at each of the four lower Snake River dams. A boat-deployed underwater video system was then used to survey for salmon redds in primary search areas and in other areas identified as potential spawning sites. The camera's position was tracked using a Global Positioning System (GPS) linked to a field computer equipped with GPS visualization software. Individual redd locations were marked, and a laser transit was used to map the distribution of redds during the first year of the study. GIS also was used to produce maps of redd locations and to conduct spatial analyses of key habitat variables. Water quality, current velocity profiles, and substrate were characterized also as part of the spawning habitat studies.

Fall chinook salmon redds were located downstream of three of the four lower Snake River dams during the 5-year project. Only limited surveys were conducted in 1995 because flooding resulted in high spill and low visibility during the spawning season. Frequency of use was variable among tailrace spawning areas, but site fidelity was high. The Lower Granite Dam tailrace had the highest number of redds during the 4 years (14 redds in 1993). However, the Little Goose Dam tailrace had the highest frequency of use (all 4 years). At both dams, redds were located on the powerhouse side of the tailrace and downstream of the high-volume discharge from the original juvenile bypass outfall. Only one redd was found at Ice Harbor Dam in 1996. No evidence of spawning was observed in the tailrace downstream of Lower Monumental Dam during 3 years of surveys.

No redds were found in proposed dredging areas. Although some portion of each area had substrate of suitable size for spawning, velocities were generally too low. Juvenile bypass systems were modified at Lower Granite, Little Goose and Ice Harbor from 1995-1996. While there was no evidence that in-channel construction activities affected spawning habitat, the number of redds relative to adult passage declined significantly in 1996 and 1997.

These studies and others demonstrate that physical habitat conditions suitable for spawning by fall chinook salmon exist for a short distance downstream of each of the four lower Snake River dams. These conditions are highly regulated by project operations. Thus, any proposed changes in operations, including reservoir drawdown, spilling, and altered outfall flows need to be evaluated to minimize potential impacts to fall chinook salmon populations.

Acknowledgments

We thank Joanne Duncan and Jeff Marco (Pacific Northwest National Laboratory) for technical support with site surveys, Geographic Information System (GIS) analysis, and image analysis. Aaron Garcia (U.S. Fish and Wildlife Service) provided valuable assistance related to methodology development and peer review of reporting over the course of the 5-year project. Dan Kenney and Rick Jones (U.S. Army Corps of Engineers, Walla Walla District) directed our efforts.

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Introduction

Snake River fall chinook salmon populations were recently listed as "endangered" under the Endangered Species Act of 1973 (NMFS 1992), resulting in focused studies on their habitat requirements in the Hells Canyon Reach (Connor et al. 1993). This listing also required the U.S. Army Corps of Engineers to evaluate potential impacts of their mainstem dam operations on Snake River salmon populations. There was limited information to determine spawner use near lower Snake River dams because no surveys of fall chinook salmon spawning had been conducted in the lower Snake River since the late 1940s (Parkhurst 1950). Some anecdotal evidence suggested that fall chinook salmon spawned in the tailrace area downstream of two lower Snake River dams. For example, Bennett et al. (1983, 1993) captured subyearling chinook salmon in Little Goose reservoir before the arrival of downstream migrants in the juvenile collection facility at Lower Granite Dam. Additionally, salmon embryos, believed to be fall chinook salmon, were discovered downstream of Lower Monumental Dam during dredging operations in February 1992 (Kenney 1992). High fallback rates and holding patterns of adults during the spawning season (Mendel et al. 1992, 1994) also provided evidence that some fall chinook salmon may spawn downstream of some lower Snake River hydroelectric facilities. Because of the lack of definitive data, the U.S. Army Corps of Engineers contracted with Pacific Northwest National Laboratory to determine if fall chinook salmon spawned in the tailrace, or free-flowing area, immediately downstream of four lower Snake River hydroelectric projects (i.e., Lower Granite, Little Goose, Lower Monumental and Ice Harbor Dams; Figure 1). The overall study objective was to search for and characterize spawning sites and to assess the potential impacts of in-channel construction activities and dam operations on fall chinook salmon populations. Thus, the assessment was coordinated with recovery planning efforts developed by resource management agencies for fall chinook salmon in the Snake River basin (Garcia et al. 1994a, 1994b).

The initial approach to locating redds involved aerial surveys with fixed-wing aircraft, review of data from adult radiotracking studies, and underwater video surveys (Dauble et al. 1994, 1995). However, no redds were observed during 2 years of aerial surveys, and the spatial resolution of radiotracking data was inadequate to verify spawning. This report summarizes data for redd surveys conducted from 1993 to 1997 using an underwater video system. Included are results of redd distribution and abundance in the dam tailraces, habitat characterization studies, construction assessments, and technology evaluations. Results from the 1993 to 1995 surveys are described in more detail in Dauble et al. (1994, 1995, 1996). Results of the 1996 and 1997 surveys are included here for the first time.

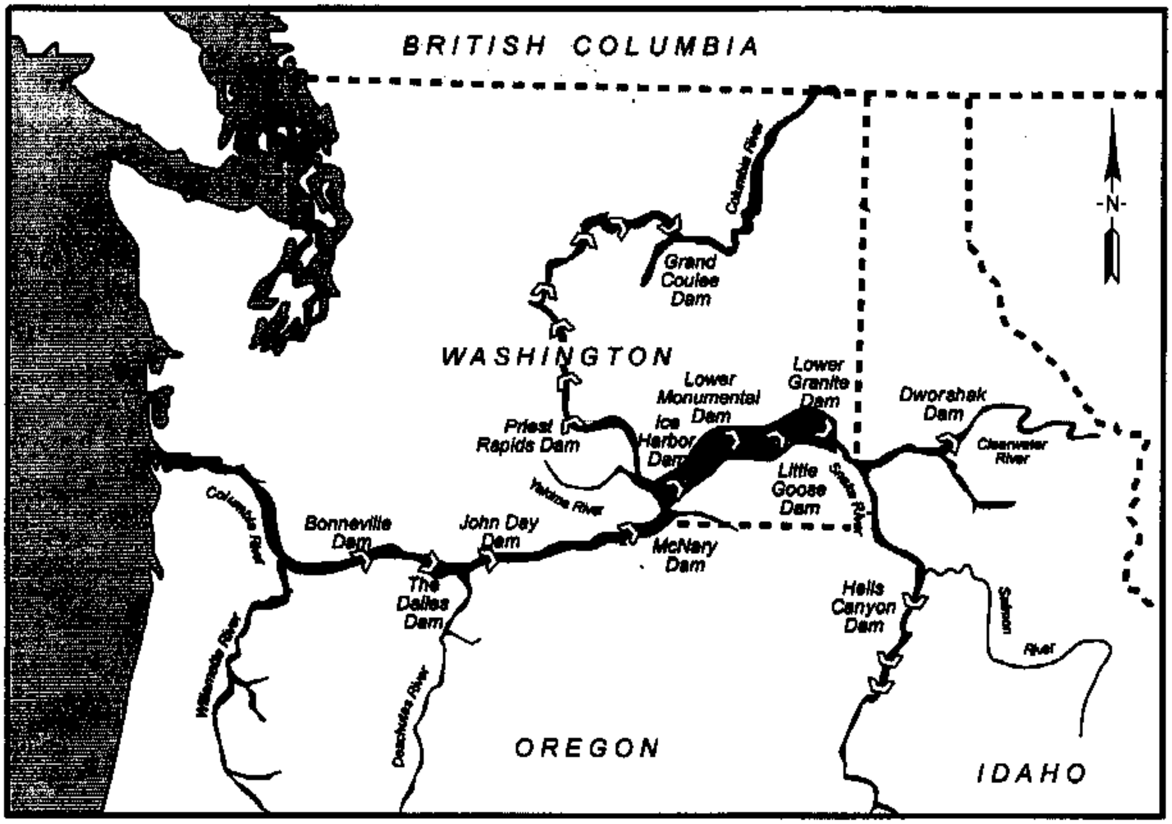

Figure 1. Location of the Four Lower Snake River Dams (shaded) in the Columbia River Basin

Methods

This section contains a review of the Geographic Information System (GIS)-based approach for establishing initial search areas, redd survey techniques, and methods used to characterize spawning habitat.

Definition of Primary Search Areas

Existing databases of physical habitat downstream of the four lower Snake River dams included bathymetric profiles of the river channel (2-ft contours), near-bed velocity profiles, and substrate maps. Electronic maps of these habitat attributes were provided to Pacific Northwest National Laboratory by the U.S. Army Corps of Engineers and transferred to an intergraph-based GIS. The U.S. Fish and Wildlife Service provided additional preliminary substrate maps. These databases were queried to determine suitable substrate, velocity, and depth characteristics at each tailrace site, using the criteria summarized in Table 1. Maps of potential spawning areas or spawning habitat polygons were then created, based on the area of common overlap, using GIS mapping software. At Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams, primary search areas were then created that encompassed the spawning habitat polygons (Figure 2). The primary search area downstream of Ice Harbor Dam was estimated to be 1,310,670 ft^2 in 1993 and revised to 1,705,670 ft^2 in 1994 based on additional substrate data. The primary search areas downstream of Lower Monumental, Little Goose, and Lower Granite Dams were 197,840 ft^2, 166,030 ft^2, and 476,040 ft^2, respectively.

Table 1. Spawning Habitat Criteria Used to Develop Primary Search Areas Downstream of the Four Lower Snake River Dams

Attribute	Description
Substrate	Gravel/cobble (0.1 to 12 in. dia.)
Depth	30 ft below base water-surface elevation
Velocity	0.5 to 6.0 ft/s
Slope	$<20\%$

Construction Impact Evaluations

Prior to proposed in-channel activities (i.e., navigation channel dredging and juvenile outfall modification), the Corps provided detailed survey maps. We used this information to develop geo-referenced regular shaped search zones. All areas were then surveyed to assess their potential for use by fall chinook salmon.

Redd Surveys

All redd surveys were conducted after the peak spawning period for fall chinook salmon in the Snake River (i.e., mid-November; Garcia et al. 1994a). The primary search area or spawning habitat polygon was typically surveyed two to three times each year.

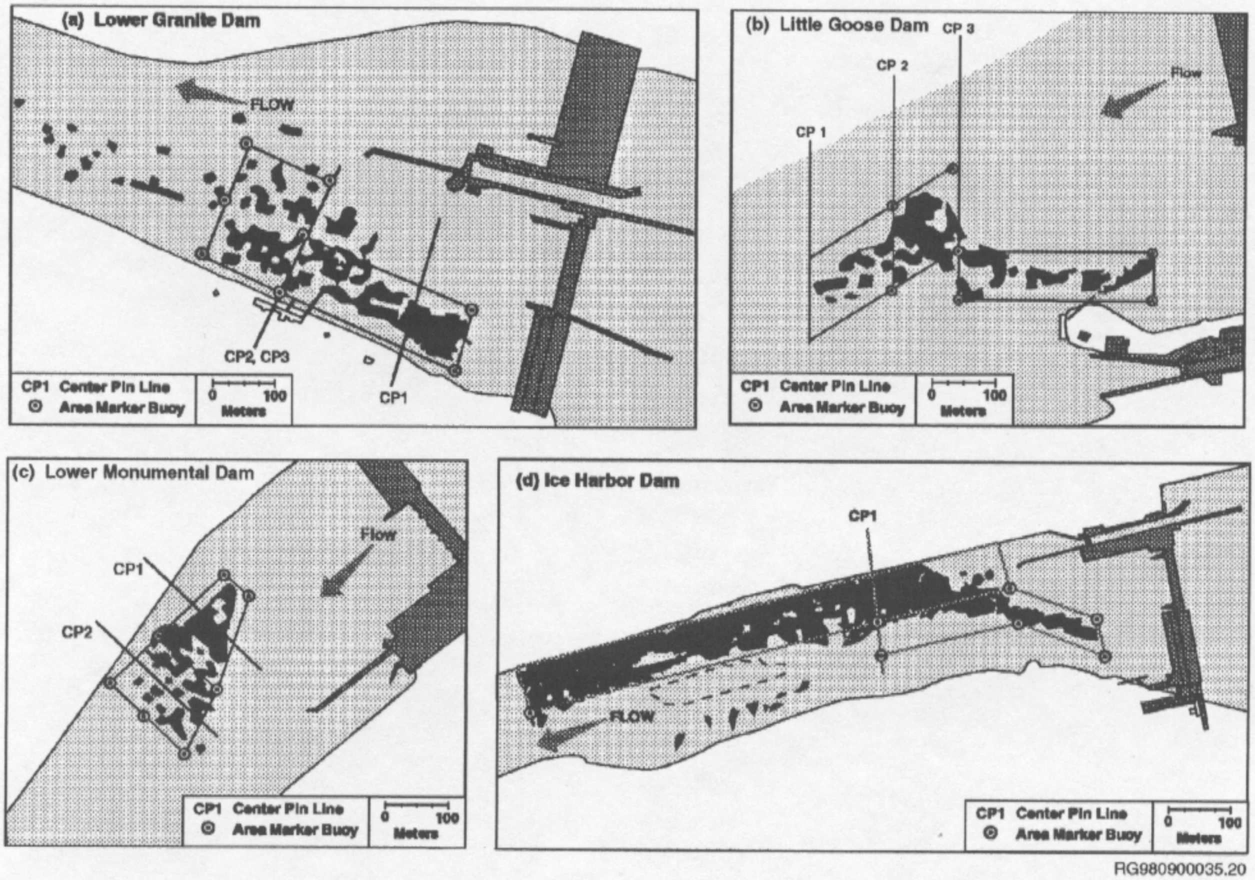

Figure 2. Location of Primary Search Areas in the Tailraces of the Four Lower Snake River Projects. (Irregular dark areas signify where physical habitat ranges suitable for spawning overlap based on GIS analysis)

All four dam tailraces were surveyed in 1993 and 1994. Only one spawning survey was completed during 1995 at Lower Granite Dam because of flooding and high turbidity that occurred during the spawning period. Emphasis in 1996 was placed on surveying previously known spawning sites at Lower Granite and Little Goose Dams, and only one survey was conducted at Ice Harbor and Lower Monumental Dams. In 1997, surveys were confined to Lower Granite and Little Goose Dams.

For each search area, line transects were established at 25- to 100-ft intervals, depending on the size of the search area to be surveyed. A diving sled with attached video camera (Garcia and Groves in press) deployed from a boat was used to search for redds, and the camera's position was tracked using a GPS (Figure 3). The mobile underwater video system comprised a high-sensitivity remote camera mounted on a weighted sled (Figure 4). The video camera was passed through each search area, perpendicular to the current, using shore markers and mid-river floats as navigational aids. The video recording system consisted of a high-resolution monochrome camera (Sony, model HVM-352) with a wide-angle lens (110 degrees) connected to an 8-mm camcorder (Sony model CCD-FX710 Handycam Hi 8). Recordings were made with Sony Hi8 tapes. Two high-resolution monitors were used for viewing the bottom images during each survey.

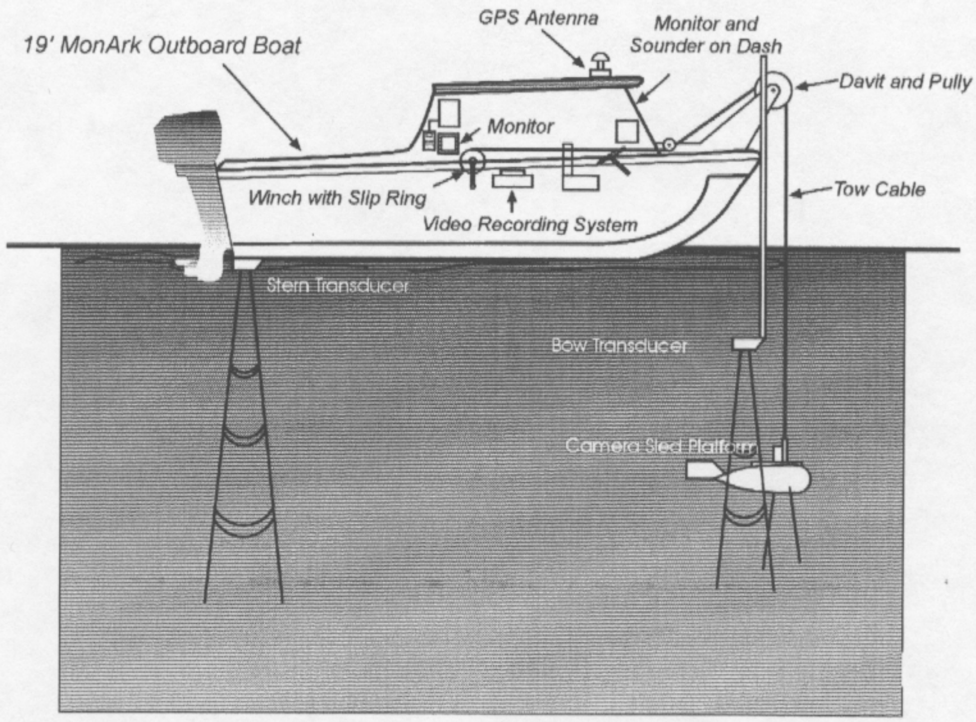

Figure 3. Schematic of Boat and Equipment Used to Search for Redds

Figure 4. Underwater Video System Used for Redd Surveys

A new tow cable, consisting of a 75-ohm coaxial with 5-wire leads surrounded by a Kevlar braid and polyurethane jacket, was employed in 1997. The tow cable was lowered to the desired depth using a large handwinch with a slip-ring mechanism that provided distortion-free video recording. Turbidity measurements were taken prior to and during each survey using a LaMotte Model 2008 portable turbidimeter. Values of <4 nephelometric turbidity units (NTUs) were required to obtain good images of substrate and to document contrast of the substrate. Water temperature and project discharge were also recorded for each survey date.

Most surveys were conducted between 1000 and 1500 h to take advantage of optimal ambient light conditions. Changes in background contrast, bed elevation, or substrate composition were the primary criteria used to determine spawning activity. Video images were also reviewed in the laboratory and areas of clean gravel, or potential redd sites, were identified and mapped. Located redds were marked with painted rebar and flagging to facilitate their relocation and to track timing. On subsequent surveys, the "marked" sites were revisited and more focused searches conducted to verify and pinpoint redd locations using the GPS. The depth of the camera relative to the bottom substrate, the number of transects, and the distance covered during each transect were recorded at each site so that the total bottom area covered during each survey could be estimated. The distance from the camera to the substrate was typically ~2 to 4 ft. This provided a path that ranged from 5 to 17 ft^2. Two lasers, pointed downward 7.2 in. apart, were used to provide a reference scale within the camera image (Figure 5). Some surveys included the use of infrared light-emitting diode light bars to enhance visibility in deep-water areas and to reduce the potential for disturbance to adult salmon.

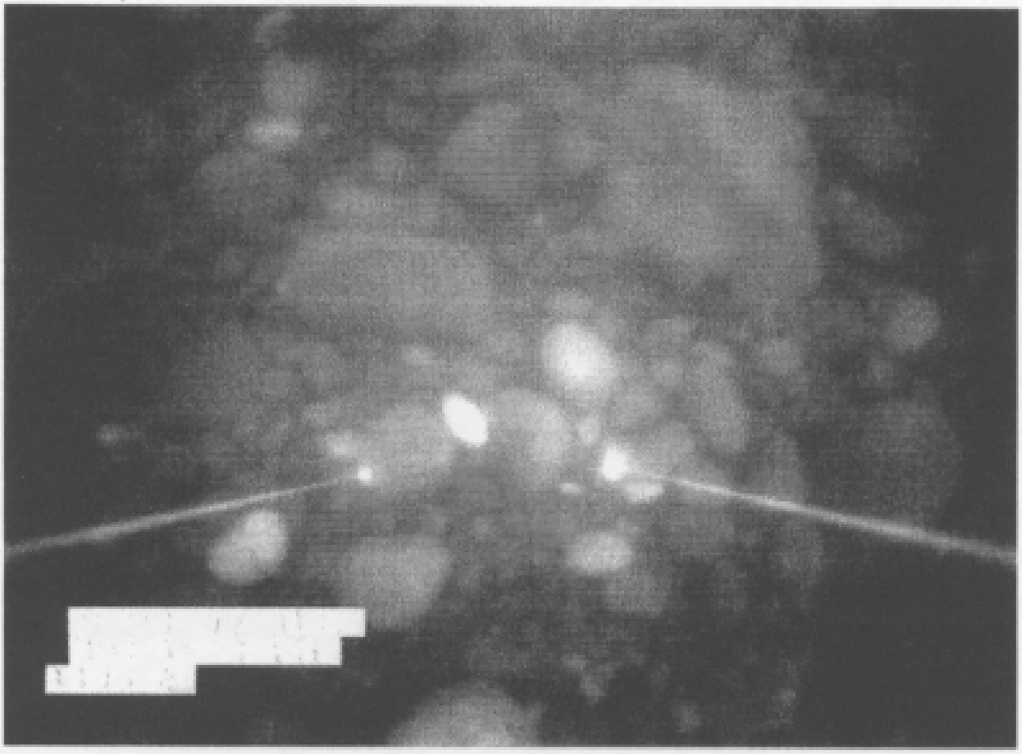

Figure 5. Substrate Image Showing Laser Calibration Points

Prior to the 1997 field season, a Trimble Pro XL GPS data logger was used to collect boat track data. The files were post-processed and differentially corrected after the surveys. A real-time Trimble GPS Pro XR with ASPEN software was used to collect positional data, as well as to navigate a pre-set transect grid during subsequent surveys. The ASPEN system included an integrated beacon receiver and antenna and was accurate to ±1.6 ft (tested on geo-referenced points at Lower Granite Dam) and eliminated the need for a surveyor and shoreline markers to determine boat position. A notebook computer was used in the field to display a background map, so that navigation on a predetermined transect line could be visually verified. The location for each image (UTM X and UTM Y) was correlated to the GPS via a synchronized time stamp.

Habitat Characterization

Redd Measurements

Specific data collected to characterize habitat at the site scale included near-bed velocity and depth. Water velocities at individual redd locations were measured using a Marsh McBirney

Flow-Mate Model 2000 portable flow meter. The sensor was attached to the camera sled platform and obtained a near-bed velocity measurement ~14 to 16 in. above the substrate. Water depths were measured using a digital echo sounder. The depth and velocity measurements represented a "point-in-time" measurement and changed according to operating conditions (e.g., discharge and spill) at the dam. For example, tailwater elevation differed by as much as ±3 ft during the spawning period.

Spawning Area Characterization

In September 1997, baseline descriptions of substrate were made at known spawning areas downstream of Lower Granite and Little Goose Dams. The purpose was to document substrate conditions at the channel scale. The total area used for spawning was first delineated and mapped using GIS techniques. At Lower Granite Dam, a 200- by 500-ft area near the loading dock was mapped and 116 points were videotaped for substrate measurements. The taped images represented ~7% of the survey area. A 100- by 150-ft area was mapped at Little Goose Dam and 42 points were videotaped. The boat driver guided the boat to the survey points via the visual real-time GPS display, with the predetermined sampling points displayed on the computer screen. Time and location of each transect were documented on a data sheet.

Recorded tapes were processed using the Optimas™ imaging program to measure dominant substrate size, based on surface area, and percent fines. Each survey point was given a substrate code, based on percent dominant substrate, and measurements were grouped into three categories for mapping: 1) gravel 0.25 to 3 in., 2) cobble 3 to 12 in., and 3) boulder >12 in. Image analysis involved time-tagging data by comparing the recorded tape time to the GPS time, which determined the location of each transect. Only video images of good quality, closest to the transect points, were used.

Low-Visibility Detection Studies

Studies were conducted in 1996 to determine the feasibility of scanning sonar to increase the efficiency of redd surveys where visibility was limited during periods of high turbidity (e.g., >4 NTUs). This technology was previously used to map substrate and bottom features of lake trout (*Salvelinus namaycush*) spawning habitat, but at a much larger (i.e., 1:1,000) measurement scale (Edsall et al. 1989). The goal was to differentiate between bottom profiles of 1 to 2 ft or the approximate vertical distance between a redd pot and tailspill. Because well-defined redds were not present when the scanning sonar was available for testing, two different-shaped objects of a known size (i.e., 50-lb sack of potatoes and an 8-ft-long, 15 in.-dia. polyvinyl chloride pipe) were deployed.

The scanning sonar (Simrad/Mesotech Model 971), operating at a frequency of 675 kHz, was deployed ~1 ft below the surface of the water. An antenna-type rotator was used to rotate the scanhead on the horizontal axis. The scan sector was set at 240 degrees to provide good definition of the surface, in addition to providing an entire sweep of the river bottom. Periodically, the head was rotated to look across the river bottom in a side-to-side fashion. The synchronized images were then evaluated using OPTIMAS™ software to determine if sufficient spatial resolution could be achieved to differentiate test objects from other bottom features.

While the quality of the sonar image was not optimal for either of the two test objects, the diameter of the 15-in. polyvinyl chloride pipe could be measured to within ±0.6 in. (Figure 6). Thus, image resolution was adequate for distinguishing between gravel and large cobble substrate. Improved display output would be needed to accurately distinguish locations where fall chinook salmon spawned from adjacent bottom profiles. These studies were not applied to the field in 1997 because of reduced project scope.

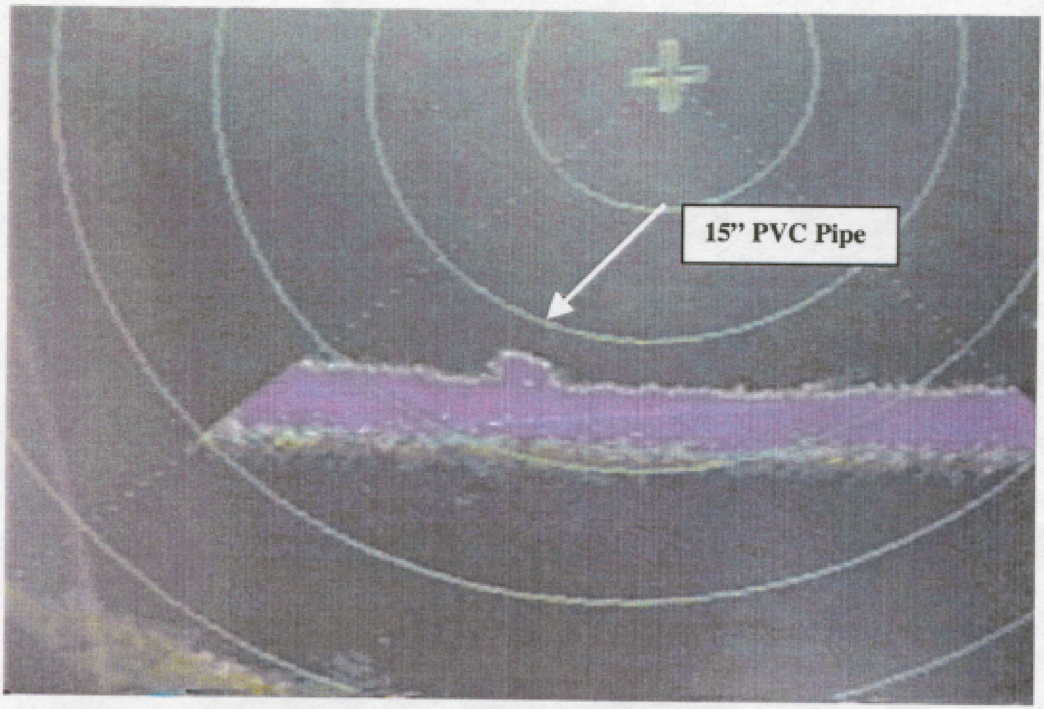

Figure 6. Scanning Sonar Visualization of a 15" PVC Pipe Located at a Depth of 5 m on the Bottom of the Hanford Reach of the Columbia River. (Concentric circles represent 2 m range increments from the transducer location on the side of the boat).

Results

This section summarizes the results of fall chinook spawning surveys conducted in the tailraces immediately downstream of the four lower Snake River dams from 1993 to 1997. The total area surveyed varied at each dam, depending on the year and environmental conditions encountered (Table 2). In addition, primary search areas were modified slightly over the course of the evaluation depending on previous results, planned construction activities, and budget. For example, the coverage of marginal habitat was reduced and/or coverage for new areas was added based on analysis of video images collected during initial surveys.

Table 2. Summary of Underwater Video Surveys Conducted in the Tailrace of Lower Snake River Dams (1993-1997) and Estimated Number of Fall Chinook Redds

Search Location	Year of Survey	Total Survey Area (ft^2)	Video Coverage (%)[a]	Number of Redds
Lower Granite Dam	1993	1,900,000	6.8	14
	1994	1,850,000	6.6	5
	1995	1,090,000	8.0	0
	1996	1,090,000	7.7	0
	1997	960,000	8.7	0
Little Goose Dam	1993	720,000	11.0	4
	1994	740,000	8.6	4
	1996	640,000	7.7	4
	1997	710,000	8.9	1
Lower Monumental Dam	1993	696,875	9.1	0
	1994	445,000	10.4	0
	1996	445,000	11.2	0
Ice Harbor Dam	1993	1,840,000	3.7	0
	1994	2,500,000	2.4	0
	1996	1,000,000	2.7	1

(a) Based on single pass through designated area

Lower Granite Dam

The redd surveys were concentrated along the shoreline immediately downstream of the Lower Granite Dam powerhouse and extended to the western end of the juvenile collection facility. An estimated 6.6% to 8.7% of each spawning habitat polygon was surveyed during the course of this 5-year project. Additional surveys were conducted near Schultz Bar (river mile 102) in 1994. In 1993, Dauble et al. (1994) estimated that 10 to 14 redds were present in the tailrace downstream of Lower Granite Dam. The U.S. Fish and Wildlife Service verified these redd observations using an underwater video system and by SCUBA. Six of the redds were marked and later mapped. A total of five redds were located and mapped in the same location in 1994. No redds were found in the dam tailrace during the 1995-1997 surveys.

The total spawning area (including inter-redd distance) downstream of Lower Granite Dam is estimated to be 27,500 ft^2 (Figure 7). The depth of water over the redds ranged from 15 to 27 ft (mean depth of 22 ft) and near-bed velocities ranged from 1.0 to 1.4 ft/s. Approximately 70% of the known spawning area downstream of Lower Granite Dam had dominant substrates between 1 and 6 in. in 1997 (Table 3). Five of the 10 redds mapped in 1993 and 1994 were associated with gravel (1 to 3 in.) and 5 were associated with cobble (3 to 10 in.) substrate (Figure 8).

Table 3. Substrate Composition and Area for the Fall Chinook Salmon Spawning Sites Downstream of Lower Granite Dam

Category	Size Range (in.)	Composition (%)	Estimated Area (ft^2)
Small gravel	< 1	12.6	2,180
Medium gravel	1-2	19.9	3,440
Large gravel	2-3	21.1	3,650
Small/med cobble	3-6	28.7	4,970
Large cobble	6-12	14.3	2,470
Boulder	>24	3.3	5,700

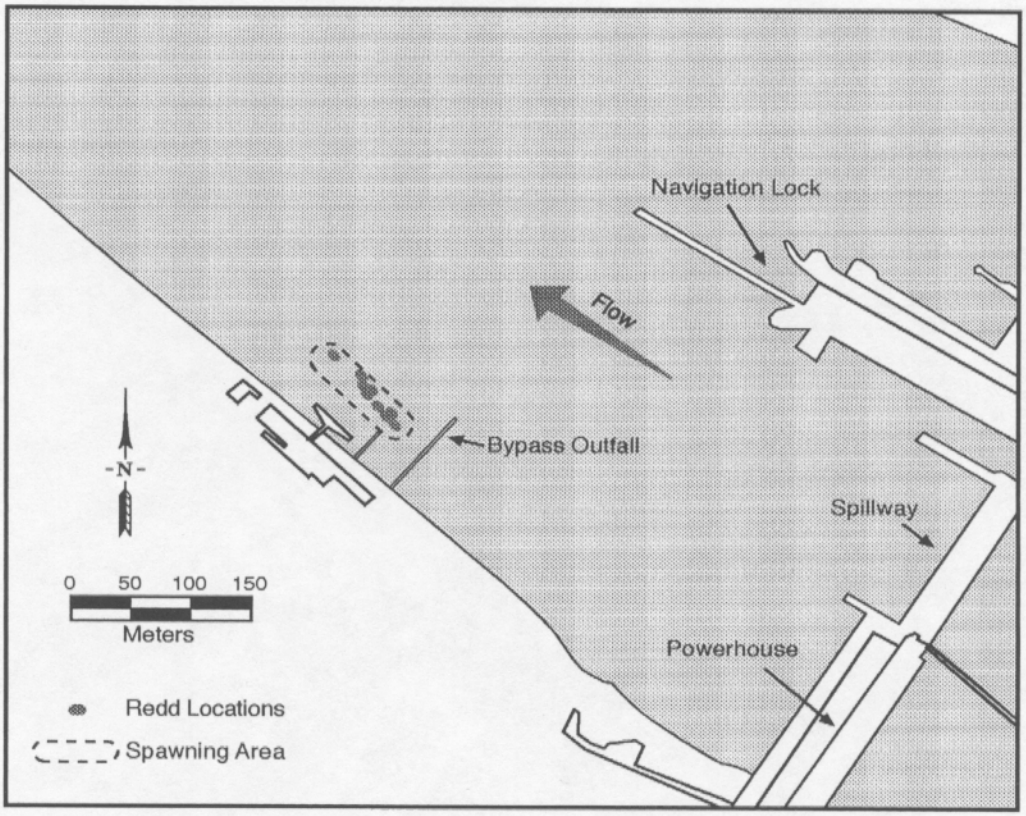

Figure 7. Fall Chinook Salmon Spawning Area and Principal Project Features in the Tailrace of Lower Granite Dam

Additional video surveys were conducted downstream of Lower Granite Dam in 1997 to evaluate potential impacts of in-channel dredging activities. A total of 30 transects were run within 2 survey areas (Figure 9). Also, several "zig-zag" passes were made through areas where extensive gravel/cobble substrate was found. It is estimated that ~6.2% of the total survey area was covered by the recorded video image during the transect surveys. There was no evidence that fall chinook salmon spawned in either of the two proposed construction areas. The predominant substrate within Area 1 was mostly large cobble and covered with periphyton. The river bottom in the upstream portion of Area 2 contained substrate with size characteristics suitable for spawning (i.e., gravel/cobble). This area occurred on a shallow-sloped shelf south of the main channel and appeared to have good potential for spawning based on substrate size. The closest known spawning area for fall chinook salmon was upstream and ~ 600 ft lateral (toward the juvenile collection facility) of the proposed dredging limits.

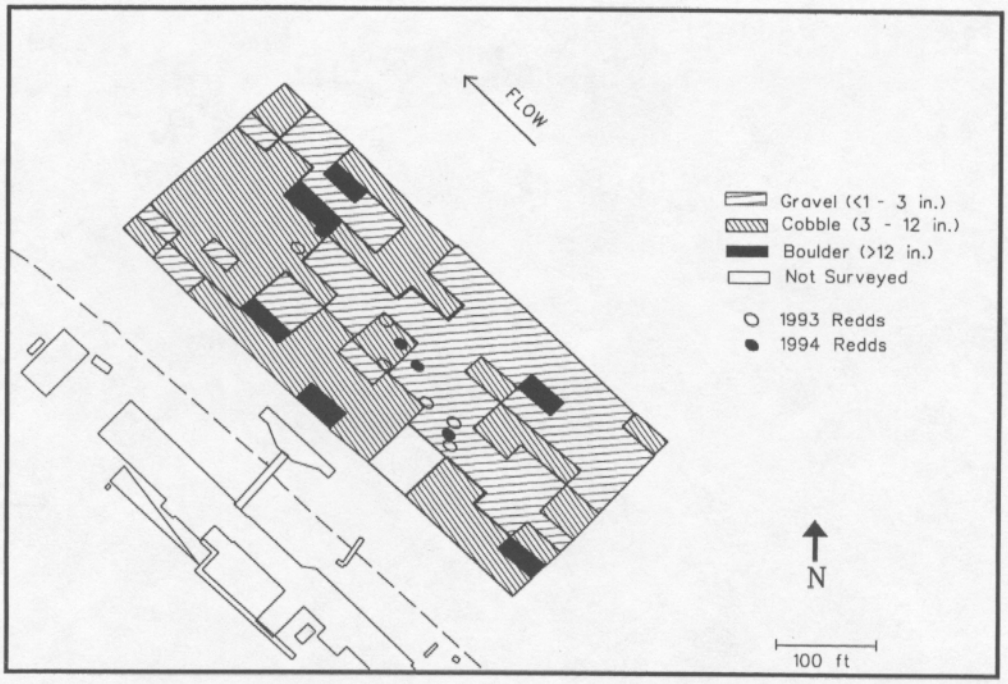

Figure 8. General Substrate Characteristics of the Lower Granite Dam Spawning Area

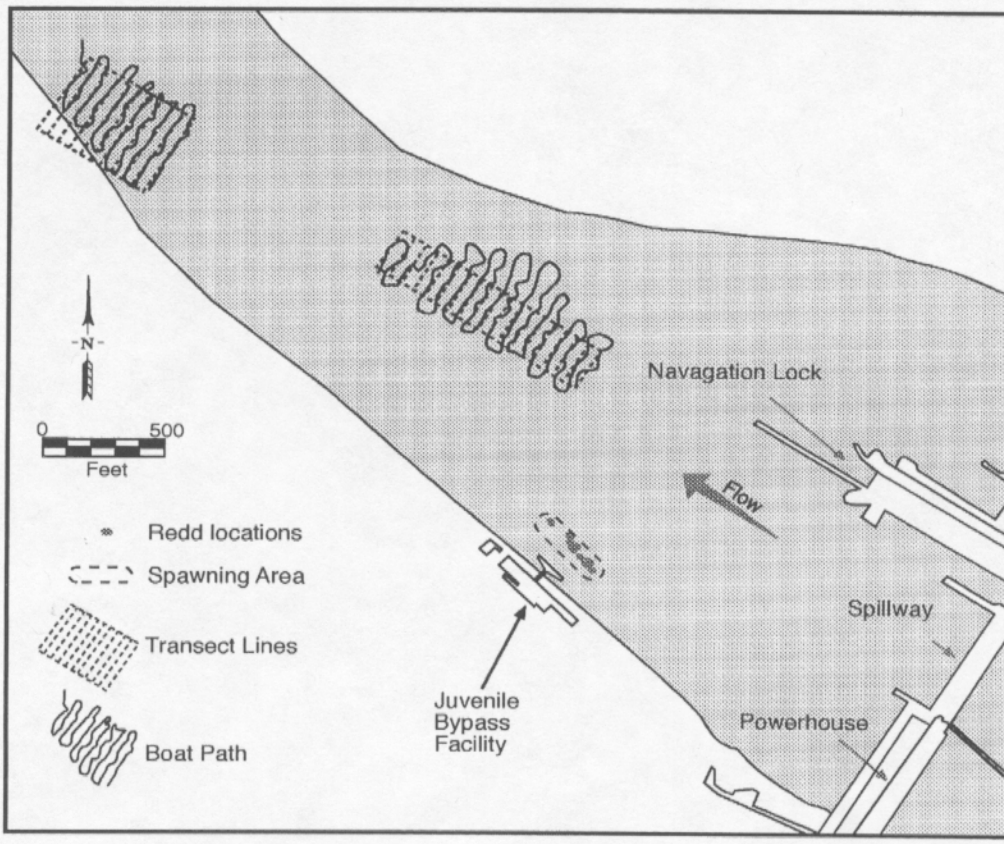

Figure 9. Location of Proposed Dredging Area Downstream of Lower Granite Dam Relative to the Known Spawning Area

Little Goose Dam

Spawning by fall chinook salmon in the Little Goose Dam tailrace was documented during all four of the survey years. Four redds were found in each of 1993, 1994, and 1996; one redd was found in 1997. All redds were found adjacent to the juvenile bypass outfall and immediately downstream of the south side of the powerhouse. The total area used for spawning during 1993 to 1997, including the inter-redd space, was ~ 5,230 ft^2 (Figure 10). The depth of water over redds was fairly uniform at this spawning site and ranged from 15 to 18 ft. Near-bed water velocity over the redds ranged from 1.4 to 2.3 ft/s.

The overall composition of the substrate within the known spawning area downstream of Little Goose Dam was smaller than that found in the spawning area downstream of Lower Granite Dam in 1997. Dominant substrates between 1 and 6 in. comprised ~60% of the total and those <1 in. ~31% of the total substrate available (Table 4). Of the 12 redds found in the survey area from 1993-1996, 10 were found in gravel (1 to 3 in.), one in cobble (3 to 12 in.), and one in boulder substrate (>12 in.) (Figure 11).

In 1996, an assessment was made of the potential for construction activities associated with placement of a new juvenile fish bypass pipe to impact available spawning habitat (Dauble et al. 1996). This assessment was needed because the upstream boundary of the construction area and the associated support structures for the bypass pipe were 50 and 200 ft, respectively, downstream of a previously identified spawning area. Based on a qualitative review of video images acquired from the 1994 spawning surveys, 10% of the proposed construction area was estimated to have a high potential for spawning (gravel/cobble substrate) and 26% had a medium potential for spawning (cobble substrate). It was not likely that the remaining portion of the proposed construction site (64%) would be used by fall chinook salmon for spawning based on substrate and flow characteristics present in this location (Dauble et al. 1996).

Table 4. Substrate Composition and Area for the Fall Chinook Salmon Spawning Sites Downstream of Little Goose Dam in 1997

Category	Size Range (in.)	Composition (%)	Estimated Area (ft^2)
Small gravel	<1	31.4	2,400
Medium gravel	1-2	27.3	2,080
Large gravel	2-3	17.1	1,300
Small/med cobble	3-6	16.4	1,260
Large cobble	6-12	4.0	300
Boulder	>24	3.8	280

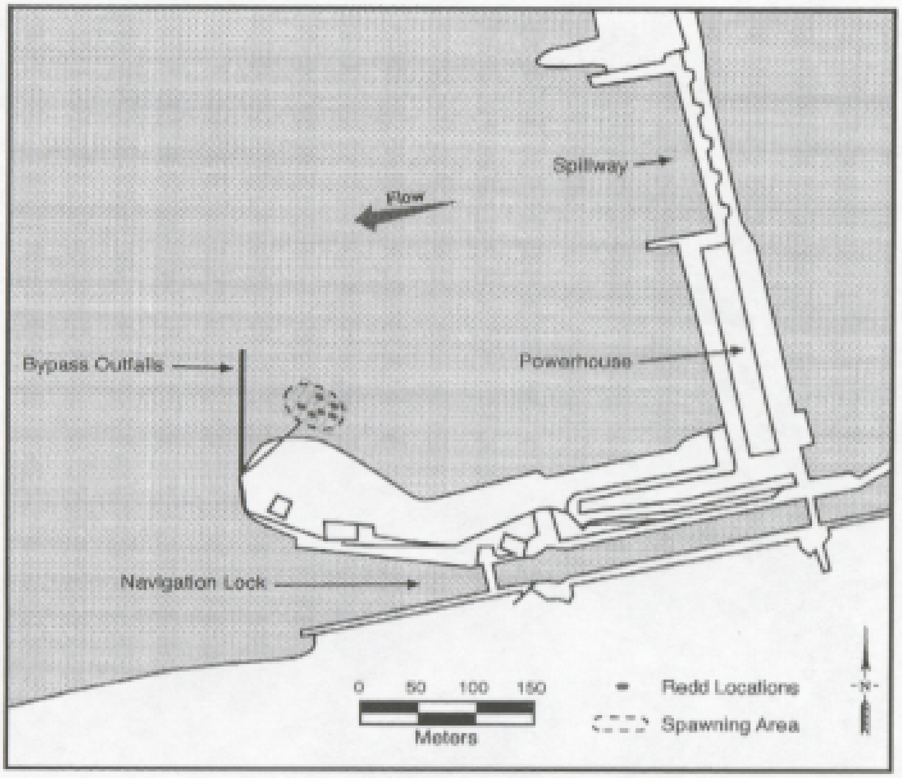

Figure 10. Fall Chinook Salmon Spawning Area and Principal Project Features in the Tailrace of Little Goose Dam

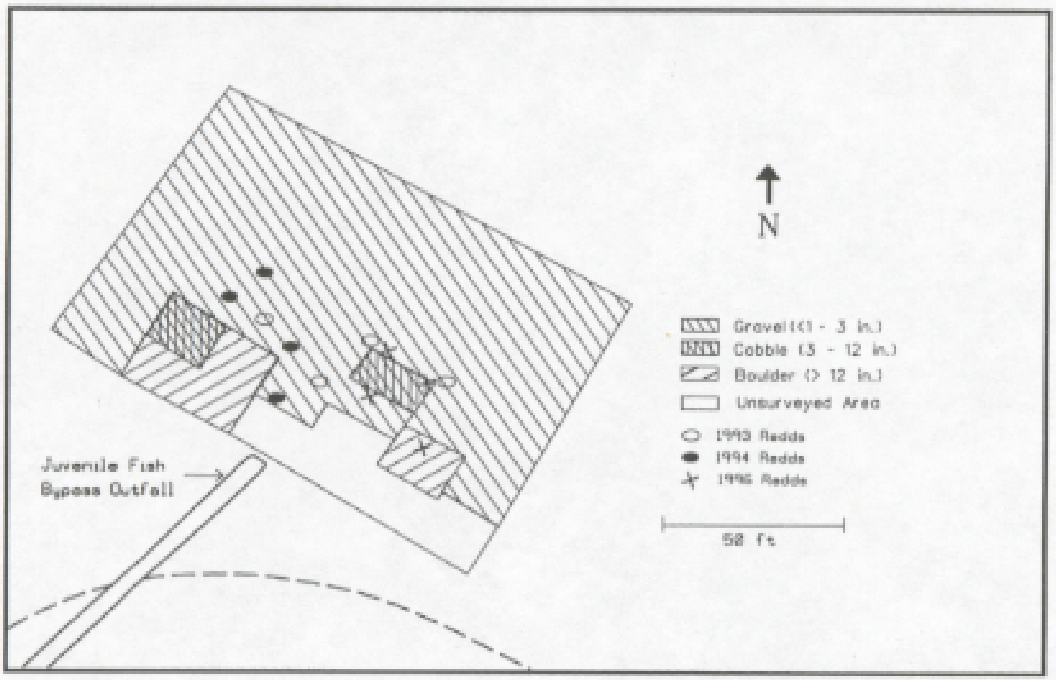

Figure 11. General Substrate Characteristics of the Little Goose Dam Spawning Area

Lower Monumental Dam

During 1993 to 1996, no major construction activities were planned downstream of Lower Monumental Dam and outside of the primary search areas. Thus, all redd searches were limited to the upper tailrace immediately downstream of the powerhouse. No redds were found during the 3 years that this area was surveyed (i.e., 1993, 1994, and 1996). Video analyses indicated that the majority of the substrate in the tailrace search area was a mixture of large cobble and boulders. Both the channel morphology and substrate composition at this site have been altered by past dredging activities.

We also conducted an assessment of potential impacts of dredging activities (south shore) downstream of Lower Monumental Dam navigation lock near river mile 41 in December 1998. The proposed work involved removing substrate to deepen the shipping channel downstream of the navigation lock. The survey area encompassed 300 ft x 2,100 ft located immediately downstream of the entrance to the navigation lock. A total of 43 transects were run at an intervals of 50 ft (Figure 12). We estimated that ~6.2% or 39,000 ft^2 was covered by the video image track.

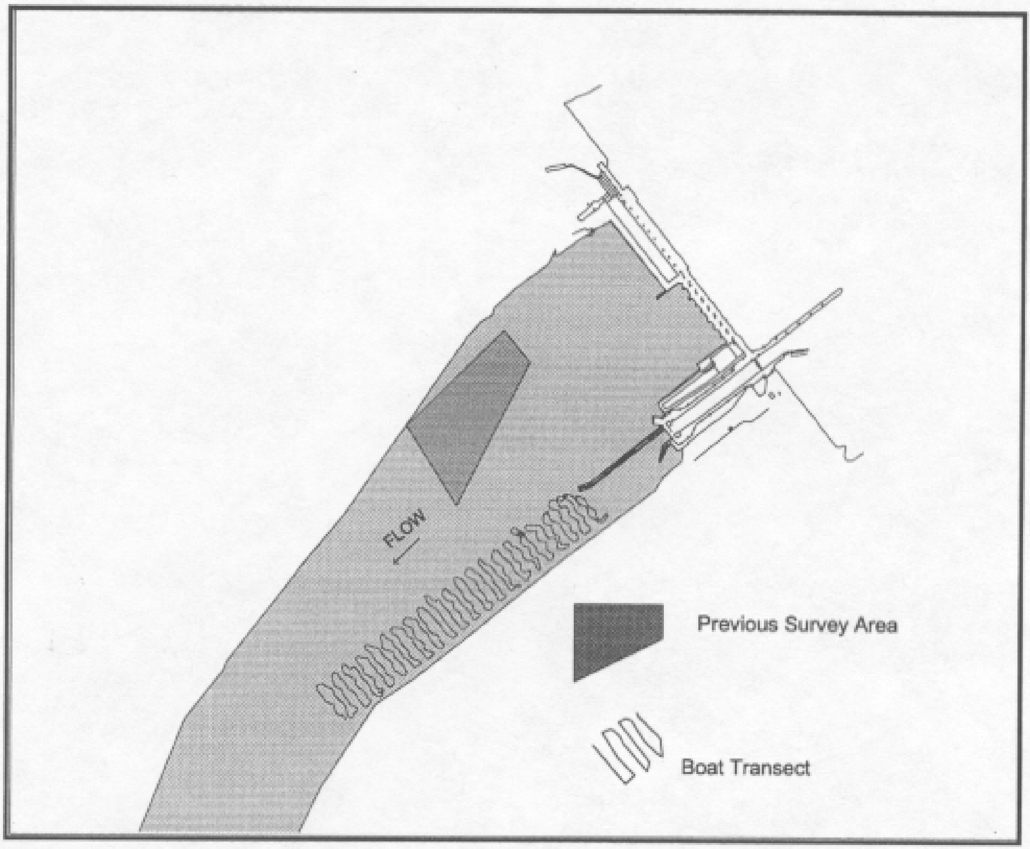

Figure 12. Location of Proposed Dredging Area Downstream of Lower Monumental Dam and Transect Features

No fall chinook salmon redds were observed during the survey. The substrate in the dredge area was comprised predominately of gravel/cobble with areas of boulders, bedrock, and silt. Although a large portion of the area had substrate and depth, which appeared suitable for fall chinook spawning, preferred velocities were low in all but the downstream portion.

Ice Harbor Dam

Redd surveys downstream of Ice Harbor Dam encompassed the largest search area of the four projects. Initially, a low-intensity search was conducted, focusing on the navigation channel downstream of the navigation locks. Because the substrate there was small and the depth of alluvium reduced from past dredging activities, efforts were concentrated on the southeastern shoreline downstream of the powerhouse and other areas that appeared to be more suitable for spawning, based on substrate characteristics. Only one redd was identified and mapped in the tailrace area during the 3 years of surveys -- in 1996 near one of the pilings of a newly constructed bypass pipe outfall. More limited video surveys were conducted near Strawberry Island (river mile 6) in 1994 and no redds were found.

The potential effects of in-channel dredging activities were assessed within two designated areas downstream of the Ice Harbor Dam tailrace (river miles 4.5 to 5.3) in December 1997 (Figure 13). There was no evidence of fall chinook salmon spawning in either of the two survey areas. It was estimated that ~6.5% of the total survey area was covered by the recorded video image during the transect surveys. Area 1 was predominately bedrock, fractured bedrock, and small patches of gravel. The dominant substrate present in Area 2 was bedrock and large cobble. One portion of Area 2, just downstream of the channel bar in the northeastern corner, contained gravel/cobble substrate. However, this location was thought to have low potential for use during spawning because of the generally low velocities (i.e., <2 ft/s) present.

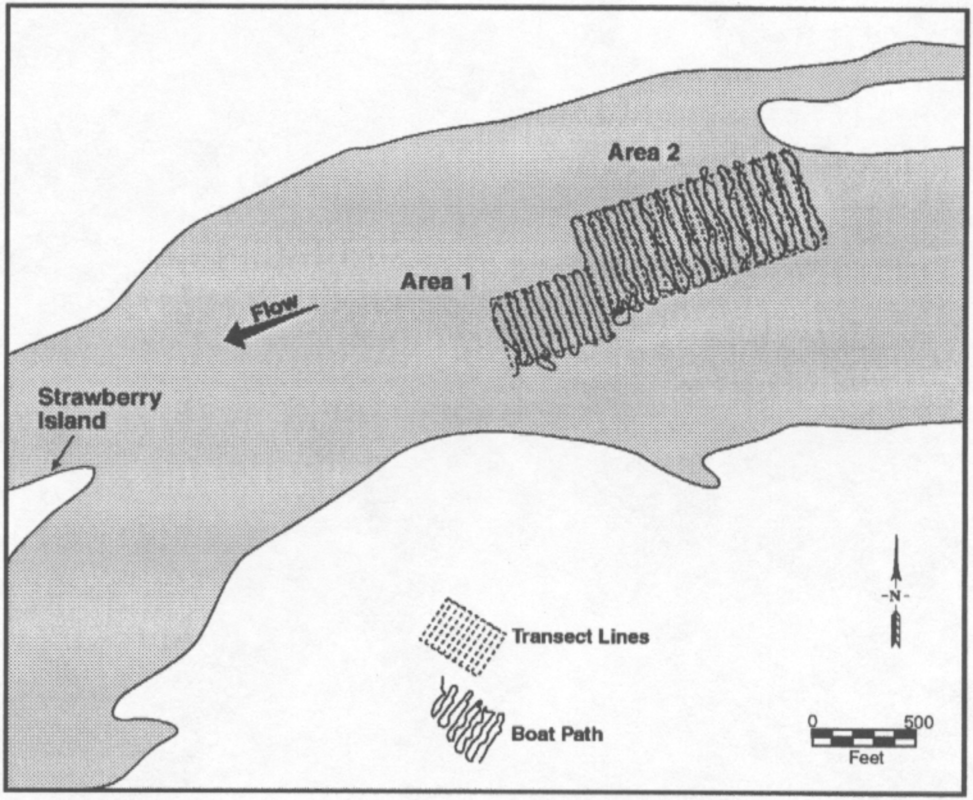

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Figure 13. Location of Proposed Dredging Area Downstream of Ice Harbor Dam and Transect Features

Discussion

Fall chinook salmon spawning areas were located and mapped in the tailrace immediately downstream of four lower Snake River hydroelectric projects during the period 1993 to 1997. No evidence of spawning was found for other survey areas that occurred downstream of the immediate tailrace, including areas where geomorphic features (e.g., channel bars) suggested spawning might occur. These areas were judged not suitable for spawning because of reduced velocities and silted and/or highly compacted substrates. No redds were found within any of the proposed dredging sites. In general, these locations contained dominant substrates larger than those typically used by fall chinook salmon for spawning.

The occurrence of redds in tailrace areas explains some of the apparent interdam loss of adult fall chinook salmon, a loss previously attributed to between-project mortality (reviewed in Dauble and Mueller 1993). Redds found downstream of lower Snake River dams did not represent a significant proportion of production relative to other areas in the Snake River system during the survey years. Although tailrace spawning accounted for ~12% of the mainstem Snake River redds in both 1993 and 1994, spawning was more limited in 1996 and 1997 (Table 5). The relative importance of these tailwater spawning sites to Snake River fall chinook salmon populations is less when tributary use is considered (A. Garcia, U.S. Fish and Wildlife Service, personal communication).

Table 5. Comparison of Redd Totals Estimated for Little Goose and Lower Granite Dams, Hells Canyon Reach, and Adults Counted at Lower Granite Dam During the Survey Interval

Year	Tailrace Redds	Hells Canyon Reach Redds	Adults Counted at LGR
1993	18	127	1,170
1994	9	67	791
1996	4	113	1,304
1997	1	58	1,451

Fidelity toward spawning areas appeared high during the survey years, but temporal use patterns were irregular. Sporadic use of defined spawning sites in the tailwater areas is consistent with use patterns in other parts of the Snake River. For example, Groves and Chandler (1996) reported that frequency of use for fall chinook spawning sites in the Hells Canyon Reach ranged from 9% to 77% for the 50 sites they monitored from 1986 to 1995. That redd counts were highly variable among years reinforces the need to monitor population use over several years.

Although suitable physical habitat characteristics appeared to be present throughout much of the tailrace at Lower Granite and Little Goose dams, redds were only found in the area immediately adjacent to large-volume outfalls (Figures 14 and 15). This suggests that the flow pattern, overhead turbulence, and/or pheromones or other odors from the juvenile fish facility may attract migrating adult salmon. Similarly, nearby structures (e.g., outfall pipe supports, barge loading dock) may provide cover for adults prior to spawning. Juvenile bypass structures downstream of Lower Granite, Little Goose, and Ice Harbor dams were modified in 1995 and 1996. While there was no evidence that associated in-channel construction activities affected adjacent spawning habitat, the number of redds present in known spawning areas declined significantly, relative to adult passage over Lower Granite Dam, in both 1996 and 1997.

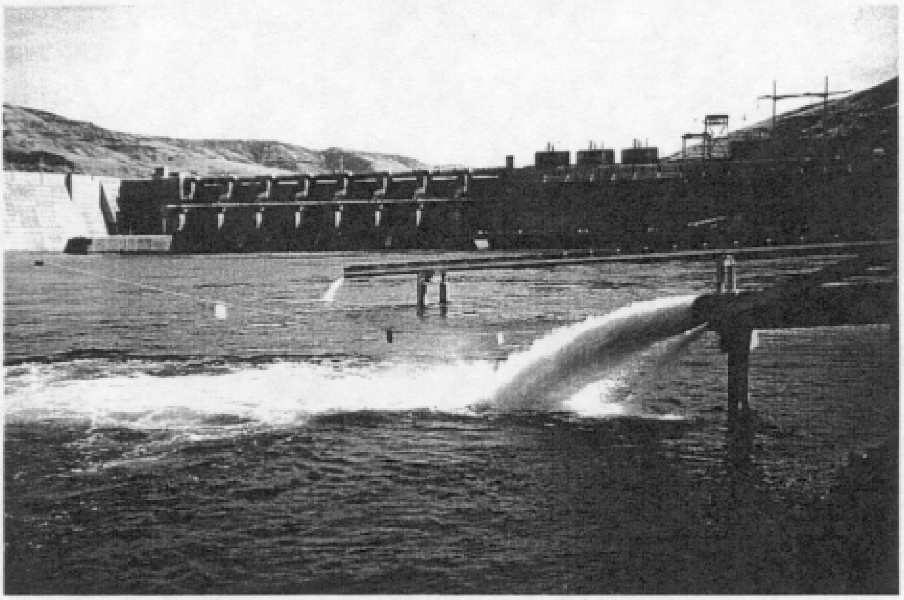

Figure 14. Lower Granite Dam Spawning Area and Juvenile Bypass Discharge Pipe

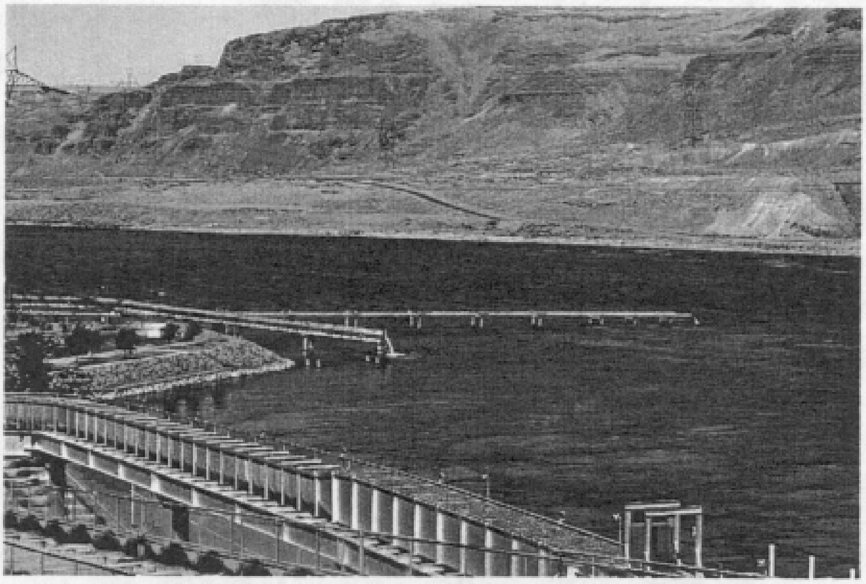

Figure 15. Little Goose Dam Spawning Area and Juvenile Bypass Discharge Pipe

Redd locations may have also been influenced by powerhouse operations. Operational variables, such as the relative amount of discharge through the powerhouse, influence both substrate size and mobility that are key spawning habitat attributes. Gravel movement was documented in 1996, following high project discharge and spilling that occurred during the spawning season. Locations in the mid-Columbia River where spawning occurs downstream of the powerhouse include Wanapum (Rogers et al. 1988, Horner and Bjornn 1979), Rock Island (Horner and Bjornn 1979) and Wells Dams (Giorgi 1992).

The primary purpose of the GIS-based habitat evaluation described in this report was to effectively direct initial search efforts. Because the range of physical habitat values used for model input was wide, available spawning habitat was not quantified. However, Parsley and Beckman (1994) applied GIS technology, in conjunction with Physical Habitat Simulation System (Bovee 1982) to quantify rearing habitat for juvenile white sturgeon. Thus, this tool can be refined to provide predictions of potential or available habitat. It was also found that GIS was useful for linking across two or more spatial data sets. For example, GIS was used to develop cross-section profiles for individual redds that showed their location relative to channel morphology and velocity vectors.

Underwater video technology was not used widely for locating salmon redds in large river systems prior to 1993. However, this technology is now used routinely in the Snake and Columbia Rivers to characterize spawning habitat and to search for redds (Garcia et al. 1994a; Groves and Chandler, in press). Underwater video was used to locate fall chinook salmon redds at depths ranging to 25 ft in the Snake River and to 30 ft in the Hanford Reach of the Columbia River. This value compares to depth limitations of 10 to 14 ft for observing redds during aerial surveys conducted under similar conditions of visibility (Dauble and Watson 1997). In terms of increased coverage, safety, and documentation, searches with the video camera have advantages over other underwater techniques (i.e., SCUBA) commonly used to verify salmonid spawning locations. However, the limitations of underwater video systems include initial equipment costs and relatively small field of view.

Several new tools were developed during the course of this research project that increased survey efficiency and spatial resolution of redd locations. For example, the use of infrared light arrays on the camera sled enhanced visibility when turbidities were high and ambient light levels were low. Application of real-time GPS to the spawning surveys resulted in a major advance in spatial resolution and efficiency. This method, in combination with new mapping software, allowed the creation of precise maps of the survey areas and redd locations within minutes of video surveys. Further development of scanning sonar techniques would enhance search capability under environmental conditions that restrict use of the underwater video system.

These studies show that operation of existing hydroelectric facilities in the lower Snake River has created physical habitat conditions suitable for spawning by fall chinook salmon. Suitable conditions appear to exist for only short distances downstream of most of the hydroelectric projects. Thus, any modifications to tailrace areas, including channel dredging, addition of in-stream structures (e.g., bypass outfalls), and changes to project operations (e.g., reservoir drawdown, spilling) that could affect substrate and hydraulic characteristics beneficial to spawning and incubation need to be carefully evaluated to ensure that potential impacts to fall chinook salmon are minimized. Similarly, it may be possible to enhance the use of tailrace areas by manipulating reservoir pool elevations and altering project discharge. Collectively, the studies demonstrate that future recovery planning for listed fall chinook salmon (NMFS 1995) needs to consider the relative importance of this riverine habitat to remaining mainstem and tributary populations.

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