North American Journal of Fisheries Management 24:1421–1426, 2004

Imaging Fall Chinook Salmon Redds in the Columbia River with a Dual-Frequency Identification Sonar

KENNETH F. TIFFAN* AND DENNIS W. RONDORF

U.S. Geological Survey, Western Fisheries Research Center, 5501A Cook-Underwood Road, Cook, Washington 98605, USA

JOSEPH J. SKALICKY

U.S. Fish and Wildlife Service, Lower Columbia River Fisheries Program Office, 1211 SE Cardinal Court, Suite 100, Vancouver, Washington 98683, USA

Abstract.—We tested the efficacy of a dual-frequency identification sonar (DIDSON) for imaging and enumeration of fall Chinook salmon *Oncorhynchus tshawytscha* redds in a spawning area below Bonneville Dam on the Columbia River. The DIDSON uses sound to form near-video-quality images and has the advantages of imaging in zero-visibility water and possessing a greater detection range and field of view than underwater video cameras. We suspected that the large size and distinct morphology of a fall Chinook salmon redd would facilitate acoustic imaging if the DIDSON was towed near the river bottom so as to cast an acoustic shadow from the tailspill over the redd pocket. We tested this idea by observing 22 different redds with an underwater video camera, spatially referencing their locations, and then navigating to them while imaging them with the DIDSON. All 22 redds were successfully imaged with the DIDSON. We subsequently conducted redd searches along transects to compare the number of redds imaged by the DIDSON with the number observed using an underwater video camera. We counted 117 redds with the DIDSON and 81 redds with the underwater video camera. Only one of the redds observed with the underwater video camera was not also documented by the DIDSON. In spite of the DIDSON's high cost, it may serve as a useful tool for enumerating fall Chinook salmon redds in conditions that are not conducive to underwater videography.

Fall Chinook salmon *Oncorhynchus tshawytscha* in the Snake and Columbia rivers typically spawn in main-stem habitats (Fulton 1968; Groves and Chandler 1999; Dauble and Geist 2000). Redds can be excavated in a range of water depths, which complicates efforts to enumerate them. Historically, redd searches by use of aerial surveys have been conducted each year in the Hells Canyon reach of the Snake River and the Hanford reach of the Columbia River (Dauble and Watson 1997; Groves and Chandler 1999; Visser et al. 2002). However, Garcia et al. (1997) found that redds constructed in deep water (>3 m) accounted for more than 50% of the total redds counted in the Snake River in some years, and were difficult to detect from aircraft. In the Hanford reach, Swan (1989) reported fall Chinook spawning in water up to 9 m deep; in the Columbia River below Bonneville Dam, Mueller (2002) found redds in water up to 4.6 m deep. As such, underwater video equipment deployed from boats has become the primary tool for conducting deepwater redd searches in the Snake and Columbia rivers (Groves and Garcia 1998; Dauble et al. 1999; Groves and Chandler 1999; Mueller 2002).

Underwater videography works well for identifying fall Chinook salmon redds because of their size and distinct morphology (e.g., very pronounced mounds of gravel, or tailspills, at their downstream ends), particularly when video equipment is deployed from a towed sled (Groves and Garcia 1998). However, underwater videography is only useful in relatively clear water, and can be rendered useless under turbid conditions following large rain events. In addition, the horizontal field of view is generally not more than about 1.5 m when 105° wide-angle lenses are used. This small field of view often makes it difficult to distinguish between cleaned gravel and actual redds if tailspills are not seen. We sought to overcome these limitations by using a new technology—the dual-frequency identification sonar (DIDSON)—to image fall Chinook salmon redds.

The DIDSON forms near-video-quality images based on sound instead of light and has the advantage of being able to image in zero-visibility water to a range of 12 m in its high-frequency (1.8-MHz) mode. The horizontal field of view at this range is about 6 m. We suspected that, because of the large size and unique morphology of fall Chinook salmon redds, a DIDSON towed upstream

* Corresponding author: ken_tiffan@usgs.gov

Received October 24, 2003; accepted January 26, 2004

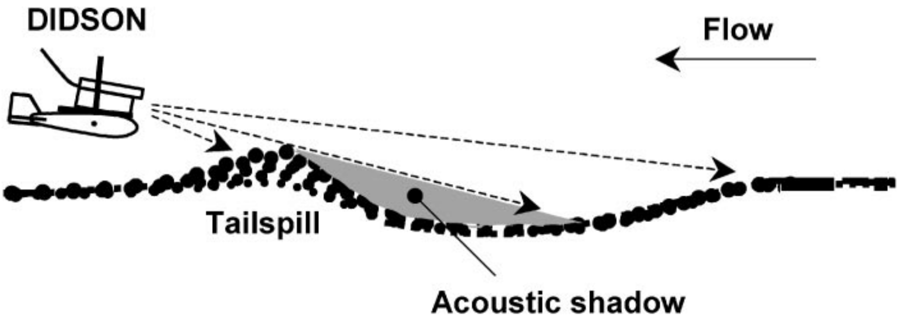

FIGURE 1.—A conceptual depiction of the way in which the morphology of a fall Chinook salmon redd enables acoustic imaging by a dual-frequency identification sonar (DIDSON).

near the river bottom might produce an image of a redd by casting an acoustic shadow from the tailspill over the redd pocket (Figure 1). Our objectives were to (1) test this new technology's efficacy in identifying fall Chinook salmon redds and (2) to determine whether redd counts produced from the DIDSON were comparable to or higher than those obtained from an underwater video camera during a redd survey.

Methods

Study area.—We conducted fall Chinook salmon redd searches in the main channel of the Columbia River below Bonneville Dam near Pierce and Ives islands (river kilometer 228.5, as measured from the river mouth) during December of 2002 (Figure 2). This is a primary main-stem spawning area for fall Chinook salmon in the lower Columbia River; a total of 329 redds were counted in the area during 2002 (Pacific Northwest National Laboratory, unpublished data; Washington Department of Fish and Wildlife, unpublished data). Spawning in this area typically occurs from late October to early December. Redd construction sites are characterized by 2–4-m water depths, 0.3–1.3-m/s water velocities, and 7.5–25.0-cm-diameter cobble substrates (Mueller and Dauble 2000; Mueller 2001). The riverbed is alluvial and has a homogenous topography.

Equipment.—We tested the utility of the DID-

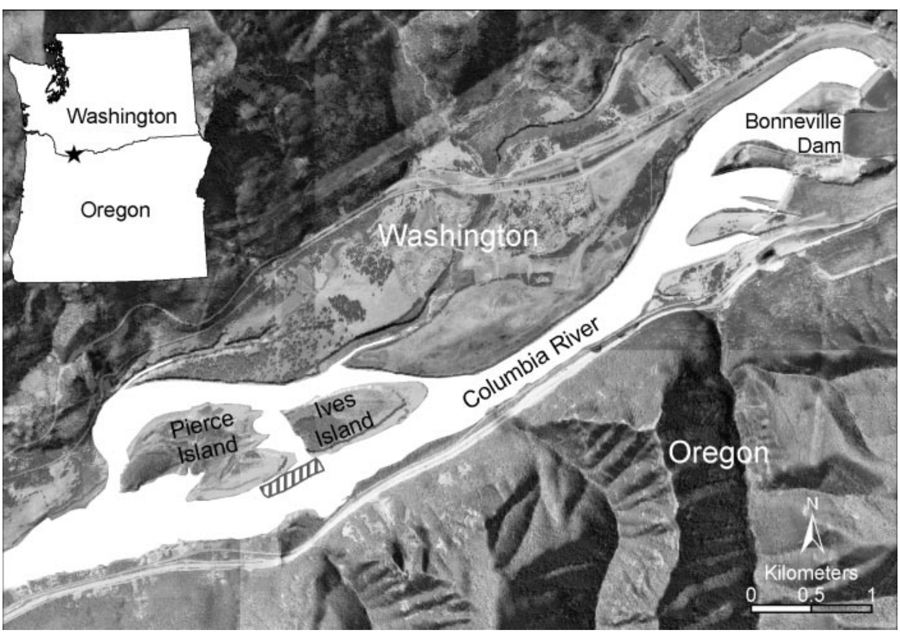

FIGURE 2.—Map of the Columbia River showing the main-channel fall Chinook spawning area (crosshatches) on the south side of Pierce Island, which is located about 4 km downstream of Bonneville Dam.

SON for imaging fall Chinook salmon redds. The DIDSON was originally developed at the University of Washington's Applied Physics Laboratory for military use in harbor surveillance. It forms near-video-quality images by simultaneously transmitting and receiving acoustic beams. In its high-frequency mode, the images, or frames, are constructed from 96 beams oriented 0.3° apart from each other in the horizontal plane. At this frequency, images can be formed to a range of 12 m, and the resolution ranges from 3 mm at a distance of 1.5 m to 24 mm at a distance of 12 m. The field of view is 29° in the horizontal plane and 8.5° in the vertical plane. Images can be formed at a rate of 1–12 frames/s. The DIDSON is 30 cm long, 20.5 cm high, and 17.5 cm wide, and weighs 5.5 kg in air. Data from the DIDSON is sent via a cable to routing hardware, where images can be output to video equipment or to a laptop computer with an Ethernet connection.

We mounted the DIDSON on an aluminum sled that was weighted with two 23-kg hydrodynamic sounding weights. The angle of the DIDSON could be adjusted from 0° (horizontal) to 90° (vertical). We oriented the DIDSON to achieve an angle of 15° down from horizontal during our redd searches. In preliminary testing to determine the appropriate DIDSON angle, we found that, at angles less than 15°, large shadows obscured much of the riverbed at further distances. At larger angles, not enough shadow existed to allow reliable identification of redds. An underwater video camera with a 95° wide-angle lens was mounted on the forward end of the sled and adjusted to a 45° downward angle. Finally, a depth-finder transducer was mounted on the sled to monitor the depth of the sled.

The sled was deployed from the bow of a 6.4-m inboard jet boat by use of a remote-controlled, 24-V hoist fitted with 4.8-mm-diameter wire rope. The sled was always towed in an upstream direction at a distance of 0.6–1.0 m from the river bottom. Towing speed was kept as low as possible to produce the clearest DIDSON images and to allow adequate time for redd identification, but was fast enough to maintain upstream headway. Camera and transducer cables were attached to the wire rope that suspended the sled and were connected to equipment on the boat, which included a video home system VCR and monitor, a depth finder, DIDSON equipment, and a laptop computer. The DIDSON was operated in its high-frequency mode and was set to record at 10 frames/s, the rate that produced the clearest images of fall Chinook salmon on redds. The field of view started at 3 m in front of the DIDSON and extended 9 m to a maximum distance of 12 m. Differentially corrected global positioning system (GPS) units with submeter accuracy were used for navigation and for recording redd locations.

Redd identification.—To test the capability of the DIDSON to image fall Chinook salmon redds, we first identified known redds using underwater videography and then subsequently attempted to image them with the DIDSON. During a survey conducted on 5 December 2002, 22 redds were identified with an underwater video camera; redd locations were entered as waypoints in a GPS unit, and their images were recorded with a VCR. We then navigated to each redd waypoint beginning at a distance of at least 50 m downstream and recorded the DIDSON images. We expressed the number of redds observed with the DIDSON as a percentage of the number of redds initially observed with the underwater video camera.

Redd count comparisons.—We compared the redd counts produced by the DIDSON and the underwater video camera during redd searches conducted along transects established parallel to the southern shore of Pierce Island on 19 December 2002. Searches were conducted along four 500-m-long transects that were spaced at approximately 22-m intervals from shore. The route of travel along each transect was recorded with a GPS unit to ensure that no overlap of transects occurred. Each transect was navigated in an upstream direction, and redds observed with the DIDSON and underwater video camera were enumerated. During surveys, we noted the frame number, time, and initial detection distance of each redd observed with the DIDSON, and we recorded whether each redd was observed with the underwater video camera. The locations of redds observed with underwater videography were marked with a GPS unit, and the depths of the redds were noted as well. Turbidity measurements (nephelometric turbidity units [NTU]) were made during each survey with a turbidity meter.

Image files produced by the DIDSON and tapes of underwater video were subsequently reviewed to verify redd images from field surveys. Redds observed with the DIDSON were only counted if they occupied at least 50% of the horizontal field of view. This ensured that enough of the redd was imaged to confirm that it was a redd. In addition, redds were only counted during the boat's movement along a transect, so that the DIDSON and the underwater video camera had an equal chance

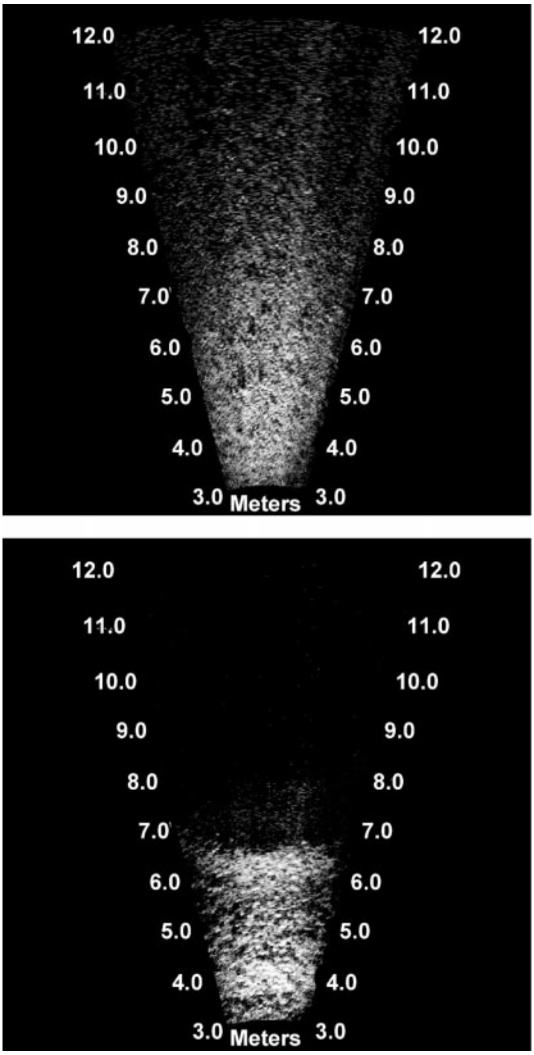

FIGURE 3.—Dual-frequency identification sonar images of an undisturbed portion of the riverbed (top panel) and a fall Chinook salmon redd (bottom panel), which appears as a dark shadow beginning at about 6.5 m.

of observing a given redd. When the boat was held stationary while we marked redd locations with the GPS unit, the DIDSON often observed redds that the underwater video camera did not have the opportunity to detect. These redds were seen when the boat would swing in the current. Redds observed on tapes of underwater video were counted based on the number of observed tailspills, which appeared as large mounds of cleaned substrate. We tabulated and compared the number of redds counted to determine which method identified the most redds.

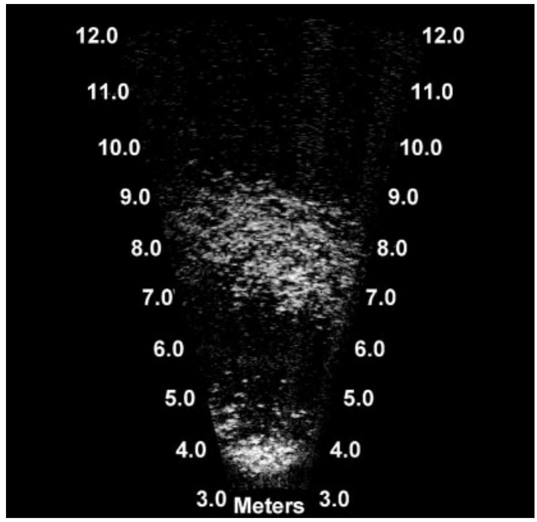

FIGURE 4.—A dual-frequency identification sonar image showing two fall Chinook salmon redds, one beginning at about 4.5 m and the other at 9.0 m.

Results

Redd Identification

We were able to successfully image fall Chinook salmon redds using a DIDSON. As suspected, a redd appeared as a large shadow in the field of view in an otherwise homogeneous image of bottom substrate (Figure 3). The mean distance from the DIDSON to the detected redds was 8.1 m (range, 3.5–11.0 m); at that distance, the horizontal field of view was 4.1 m. The wide field of view at greater distances also allowed us to document the presence of multiple redds in the DIDSON image (Figure 4). Of the 22 redds observed by underwater videography, all (100%) were detected by the DIDSON. Turbidity was low during redd surveys and averaged 3.6 NTU.

Redd Count Comparisons

During the redd searches conducted along transects, we counted 117 redds using the DIDSON and 81 redds using the underwater video camera (Table 1). One redd observed with the underwater video camera was not documented with the DIDSON. Thirty-seven redds detected by the DIDSON were not detected by the underwater video camera. The mean water depth at redd locations was 2.7 m (range, 1.1–4.4 m).

Discussion

The DIDSON was effective at imaging fall Chinook salmon redds in a main-stem spawning area

TABLE 1.—The number of fall Chinook salmon redds counted on four transects in the Columbia River south of Pierce Island by use of dual-frequency identification sonar (DIDSON) and underwater videography in 2002. Also shown are the mean DIDSON redd depths and detection distances; ranges are given in parentheses.

Transect	Transect length (m)	DIDSON redd count	Underwater videography redd count	Mean redd depth (m)	Mean detection distance (m)
1	499	32	19	2.8 (2.1–3.2)	8.5 (3.5–11.0)
2	512	31	24	2.2 (1.5–2.7)	8.4 (5.0–11.0)
3	507	20	18	4.1 (3.4–4.8)	8.1 (6.0–11.0)
4	501	34	20	1.6 (1.1–1.8)	7.4 (5.0–10.0)
Total/mean		117	81	2.7	8.1

of the Columbia River. Our ability to image redds was largely due to their size and morphology. Chinook salmon redds can be as large as 17 m^2 and have pronounced tailspills up to 30 cm high (Chapman et al. 1986). As such, small redds with poorly developed tailspills may not be imaged as well as larger redds; this may explain why one redd was observed by the underwater video camera but not by the DIDSON. The tailspill height was responsible for creating an acoustic shadow over the redd pocket when the redd was viewed with the DIDSON from downstream and at a slight (15°) downward angle. From preliminary deployment tests, we determined that towing the DIDSON near the river bottom allowed us to obtain optimal bottom relief for successful redd imaging. However, we often had to quickly raise the sled to avoid hitting tailspills during our surveys.

We observed more fall Chinook salmon redds with the DIDSON than with underwater videography. One reason for this is that the DIDSON's greater detection range and larger field of view allowed us to detect more redds. The DIDSON detected redds at distances of up to 11 m; the horizontal field of view for this detection range was approximately 5.5 m, which facilitated redd detection. Because redds could be detected at relatively long distances, more time was available for observing redds with the DIDSON. In contrast, a redd had to be directly in front of the underwater video camera to be viewable at a distance of about 1.5 m. Consequently, the underwater video camera probably missed many of the redds that were observed with the DIDSON if the boat did not pass directly over them.

Another reason why we detected more redds with the DIDSON may be that bottom features other than redds were mistakenly classified as redds. Although we assumed that the riverbed was generally smooth because of its alluvial nature, we did not survey the study area before the fall Chinook salmon spawning season to confirm this. However, no large bottom features other than redds were observed with the underwater video camera, which otherwise showed a generally smooth riverbed.

The DIDSON's large field of view makes it well suited for conducting reconnaissance-level surveys of fall Chinook salmon spawning activity in new areas. More area can be searched per unit time with the DIDSON than with underwater videography. Unlike underwater video cameras, the DIDSON also has the advantage of being able to form images in zero-visibility water. Although we did not evaluate this ability, the DIDSON would be useful for conducting redd searches during periods of high turbidity (e.g., glacial rivers or rain events) or low-light conditions.

Although the DIDSON has certain advantages over underwater videography, its disadvantages may limit its usefulness in some applications. Because the DIDSON uses sound to produce images, the patches of substrate cleaned of periphyton that might denote redd construction activity cannot be distinguished as is possible with underwater videography. Furthermore, redds must exhibit sufficient morphology (i.e., well-developed tailspills) to be imaged. The DIDSON will only be useful in places where the topography of the riverbed is somewhat smooth so that redds will not be confused with other bottom features. However, this condition is usually present in fall Chinook salmon spawning areas, which are generally characterized by alluvial riverbeds (Dauble and Geist 2000). Because of the aforementioned limitations, we recommend the use of an underwater video camera in conjunction with the DIDSON to confirm redd identification. Finally, the DIDSON's high cost, US$80,000, makes underwater videography a more practical, relatively inexpensive alternative in some instances. However, the DIDSON may still serve as a useful tool for enumerating fall Chinook salmon redds in conditions that are not conducive to underwater videography.

Acknowledgments

We thank Jon Kirby and Jonathon Miller for their help with data collection. The reviews of Dena Gadomski, Sam Lohr, Tim Whitesel, and others greatly improved this manuscript.

References

Chapman, D. W., D. E. Weitkamp, T. L. Welsh, M. B. Dell, and T. H. Schadt. 1986. Effects of river flow on the distribution of Chinook salmon redds. Transactions of the American Fisheries Society 115:537–547.

Dauble, D. D., and D. R. Geist. 2000. Comparison of main-stem spawning habitats for two populations of fall Chinook salmon in the Columbia River basin. Regulated Rivers: Research and Management 16: 345–361.

Dauble, D. D., R. L. Johnson, and A. P. Garcia. 1999. Fall Chinook salmon spawning in the tailraces of lower Snake River hydroelectric projects. Transactions of the American Fisheries Society 128:672–679.

Dauble, D. D., and D. G. Watson. 1997. Status of fall Chinook salmon populations in the mid-Columbia River, 1948–1992. North American Journal of Fisheries Management 17:283–300.

Fulton, L. A. 1968. Spawning areas and abundance of Chinook salmon (*Oncorhynchus tshawytscha*) in the Columbia River Basin: past and present. U.S. Fish and Wildlife Service, Special Scientific Report, Fisheries 571, Washington, D.C.

Garcia, A. P., W. P. Connor, R. D. Nelle, R. D. Waitt, E. A. Rockhold, and R. S. Bowen. 1997. Fall Chinook salmon spawning ground surveys in the Snake River, 1995. Pages 1–17 *in* D. W. Rondorf and K. F. Tiffan, editors. Identification of the spawning, rearing, and migratory requirements of fall Chinook salmon in the Columbia River basin. Annual Report to the Bonneville Power Administration, Contract DE-AI79-91BP21708, Portland, Oregon.

Groves, P. A., and J. A. Chandler. 1999. Spawning habitat used by fall Chinook salmon in the Snake River. North American Journal of Fisheries Management 19:912–922.

Groves, P. A., and A. P. Garcia. 1998. Two carriers used to suspend an underwater video camera from a boat. North American Journal of Fisheries Management 18:1004–1007.

Mueller, R. P. 2001. Deepwater spawning of fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning near Ives and Pierce Island of the Columbia River, 2000. Report to the Bonneville Power Administration, Contract 00000652-6, Portland, Oregon.

Mueller, R. P. 2002. Deepwater spawning of fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning near Ives and Pierce Island of the Columbia River, 2001. Report to the Bonneville Power Administration, Contract 00000652-10, Portland, Oregon.

Mueller, R. P., and D. D. Dauble. 2000. Evidence of deepwater spawning of fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning near Ives and Pierce Island of the Columbia River, 1999. Report to the Bonneville Power Administration, Contract 00000652-2, Portland, Oregon.

Swan, G. A. 1989. Chinook salmon spawning surveys in deep waters of a large, regulated river. Regulated Rivers: Research and Management 4:355–370.

Visser, R., D. D. Dauble, and D. R. Geist. 2002. Use of aerial photography to monitor fall Chinook salmon spawning in the Columbia River. Transactions of the American Fisheries Society 131:1173–1179.