North American Journal of Fisheries Management

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1002/nafm.10269

MANAGEMENT BRIEF

Identification of Summer-Run Chinook Salmon Spawning Areas in the Main-Stem Columbia River Upstream of Wells Dam, Washington

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Abstract
Summer-run Chinook Salmon *Oncorhynchus tshawytscha* historically spawned in the Columbia River as far upstream as British Columbia, Canada, but the upstream extent of main-stem spawning in the contemporary Columbia River has been documented in the tailrace of Wells Dam, Washington. We utilized radiotelemetry and video monitoring equipment between 2011 and 2013 to track wild summer-run Chinook Salmon upstream of Wells Dam and document any main-stem spawning sites. Two small spawning areas totaling 3,389 m^2 were identified within 1.76 km downstream of Chief Joseph Dam and were used by spawning salmon in each year of the study. Redd deposition totaled 70, 59, and 134 redds in 2011, 2012, and 2013, respectively. When considered with tributary redd counts upstream of Wells Dam from the Methow and Okanogan rivers, main-stem spawning represented between 1.6% and 2.9% of the annual redd deposition upstream of Wells Dam within each spawning year. Redds were located in depths between 3.7 and 7 m, with spawning occurring between late October and mid-November in each year. These novel results are the first to detail main-stem spawning locations of summer-run Chinook Salmon upstream of Wells Dam and should inform population monitoring metrics, such as annual escapement and prespawn mortality estimates.

Adult Chinook Salmon *Oncorhynchus tshawytscha* passing Wells Dam (river kilometer [rkm] 830) on the Columbia River exhibit two distinct life histories based on migration and spawning patterns: the spring run, which generally returns before June 28 and spawns in tributary headwaters; and the summer/fall run (hereafter, “summer run”), which returns after June 28 and spawns in higher-order streams (Wydoski and Whitney 2003; FPC 2018). Prior to the construction of Grand Coulee Dam (rkm 957), summer-run Chinook Salmon had access to main-stem spawning areas in the Columbia River up to Kettle Falls, Washington, at rkm 1,124 and into British Columbia, Canada (Chapman 1943). The completion of Grand Coulee Dam in 1942 and Chief Joseph Dam (rkm 874) in 1955, both of which lack fish passage facilities, moved the migration and spawning terminus of anadromous salmonids in the Columbia River downstream about 250 km to the Chief Joseph Dam tailrace (Hanrahan et al. 2004). Although the area impounded by these dams was historically accessible to all anadromous fish, Chinook Salmon and Sockeye Salmon *O. nerka* were likely the species most impacted by the loss of habitat (Chapman 1941, 1943; Fulton 1968, 1970).

Spring-run and summer-run Chinook Salmon in the upper Columbia Basin are genetically distinct, but current populations of summer-run Chinook Salmon spawning in upper Columbia River tributaries (e.g., Wenatchee, Methow, and Okanogan rivers) show little genetic distinction between spawning areas (Utter et al. 1995). This apparent homogenization likely resulted from fish culture and movement practices implemented under the Grand Coulee Fish Maintenance Project (GCFMP). The intent of the GCFMP was to mitigate for the eventual loss of salmon production above Grand Coulee Dam because no fish passage facilities were being constructed at the project. To preserve the production potential of fish originating from upstream of the dam site, returning adult fish were collected downstream at Rock Island Dam (rkm 729) between 1939 and 1943 to support hatchery- and natural-production mitigation strategies. Most summer-run Chinook Salmon returning in these years were collected and either used for hatchery production (1940–1943) or released into enclosed areas of the Wenatchee River (1939–1943) or Entiat River (1939–1940) to spawn naturally (Fish and Hanavan 1948).

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Received October 3, 2018; accepted January 8, 2019

These actions, and the habitat reduction and inundation resulting from the subsequent construction of Chief Joseph Dam and Wells Dam, respectively, would have compelled main-stem-spawning Chinook Salmon stocks to utilize tributary spawning habitat to persist. This displacement was suggested by Meekin (1967a), who documented considerable summer-run Chinook Salmon spawning activity in the main-stem Columbia River between Chief Joseph Dam and the then-future site of Wells Dam. Similar surveys conducted in the Methow River basin prior to the construction of Wells Dam suggested that the Methow River summer-run Chinook Salmon population increased greatly from the influx of displaced main-stem Columbia River fish (Meekin 1967b). Thus, evidence suggesting that extirpated populations of summer-run Chinook Salmon from the upper Columbia River had a morphology and life history similar to those of contemporary summer-run Chinook Salmon (Miller et al. 2011) is not surprising.

Estimating the spawning escapement of summer-run Chinook Salmon populations upstream of Wells Dam provides important biological data to assess trends in stock recruitment, survival, and exploitation for populations in two tributaries: the Methow and Okanogan rivers. Estimates of spawning escapement to these tributaries are generally calculated by expanding redd count data by a fish-per-redd ratio developed within each run-year through systematic sampling of the run passing Wells Dam (Hillman et al. 2014). Fish counted as passing Wells Dam that are not accounted for in spawning escapement estimates or harvest estimates or that are not detected as falling back below Wells Dam are considered to be prespawn mortalities. This approach overestimates prespawn mortality if a significant number of summer-run Chinook Salmon are spawning in the main-stem Columbia River between Wells Dam and Chief Joseph Dam, as redd surveys are not conducted in this area (M. Miller, BioAnalysts, Inc., personal communication).

Summer-run Chinook Salmon may utilize main-stem Columbia River habitats exclusively during their freshwater life cycle and thus were greatly affected by the loss of main-stem Columbia River habitats through inundation and the development of the hydropower system (Chapman 1941, 1943; Fulton 1968, 1970; Dauble et al. 2003). Today, upper Columbia River populations are supported primarily through tributary spawning, including considerable releases of hatchery-reared fish (Hillman et al. 2014); the relative contribution from main-stem-spawning fish upstream of Wells Dam was unknown prior to the present study. We used radiotelemetry and underwater video technology to identify main-stem summer-run Chinook Salmon spawning areas between Wells Dam and Chief Joseph Dam. Our objective was to quantify redd deposition in this area and compare it in context with local tributary redd deposition to estimate relative abundance from each spawning area upstream of Wells Dam. Secondarily, we recorded general physical and environmental attributes associated with individual redds to understand the general spawning location, timing, and depth at which main-stem spawning occurs in the Columbia River upstream of Wells Dam.

METHODS

We radio-tagged and released 517 wild summer-run Chinook Salmon over 2 years (2011 and 2012) as part of a study to describe stock-specific migration timing over Wells Dam (Mann and Snow 2018). These fish were collected between late June and late October of each year by operating adult salmonid trapping facilities at the west-bank and east-bank fish passage ladders at Wells Dam. Weekly tagging objectives were derived from the mean (10-year) weekly passage proportion of the overall run to achieve an approximate representation of the entire run within each year. Study fish were anesthetized with tricaine methanesulfonate (MS-222), and biological data, including FL (cm), sex, and scale samples, were collected from each tagged fish. Additionally, fish were examined for hatchery marks (e.g., adipose fin clip) and tags (e.g., coded wire tags) and were scanned for PIT tags. Fish with an intact adipose fin and lacking a coded wire tag were considered wild. We tagged wild fish with radio transmitters (MCFT2-3EM, 12 × 53 mm, 10 g in air, 4.5 g in water; or MCFT2-3A, 16 × 46 mm, 16 g in air, 6.7 g in water; Lotek Wireless, Newmarket, Ontario, Canada) and inserted a PIT tag if no existing tag was detected. Radio transmitters had two 4-mm bands of surgical tubing attached to reduce regurgitation and were coated with food-grade glycerin as a lubricant to assist tag application. Radio transmitters were inserted gastrically using a dowel-rod trochar, and only fish with FLs greater than 69 cm were tagged. After tagging, fish were allowed to fully recover in freshwater and then were released (upstream of the trapping facility) into the fish ladder from which they were collected. Our previous article (Mann and Snow 2018) provides more detail on fish collection and tagging.

After release, we monitored locations of tagged fish in the main-stem Columbia River and in tributaries upstream and downstream of Wells Dam to identify the population of origin for fish passing the dam, consistent with the objectives of our prior work (Mann and Snow 2018). Summer-run Chinook Salmon distribution upstream of Wells Dam was monitored at fixed telemetry sites or through mobile tracking to identify and quantify main-stem Columbia River spawning areas and their relative contribution to the overall spawning escapement upstream of Wells Dam. Each fixed site consisted of a six-element Yagi antenna and an SRX 400 receiver with W7AS firmware (Lotek Wireless), which detected and stored telemetry records. Fixed sites were located in the Methow River basin ($N = 2$); in the Okanogan River basin ($N = 3$); and along the main-stem Columbia River upstream of the Okanogan River confluence ($N = 1$; Figure 1). Fixed sites were powered either by 12-V DC batteries charged on-site from available grid power or from 135-W solar panels. Mobile tracking was conducted throughout the study area via boat or vehicle between late June and late November of each year. These surveys used SRX 400 receivers with W5XG firmware to obtain locations of tagged fish. Tributaries were monitored by automobile using two Yagi antennas (four elements per antenna), mounted in opposite directions, attached to the trailer hitch of the automobile. The main-stem Columbia River between Wells Dam and Chief Joseph Dam (Figure 1) was tracked using a 5.4-m aluminum boat powered by a gas-operated, propeller-driven outboard engine. The boat was equipped with a six-element Yagi antenna attached to a pole, allowing 360° rotation of the antenna. Each shore was monitored separately, and fish location was estimated based on an evaluation of the audible signal strength of the transmitter. Latitude and longitude of each fish location were recorded using hand-held Global Positioning System (GPS) devices.

When radio-tracking, we noted areas in the main-stem Columbia River where summer-run Chinook Salmon were consistently located during periods we expected spawning to be imminent or ongoing (late September to November). To detect the presence of spawning gravel or redds in these areas, we deployed submersible video monitoring equipment during the 2 years of monitoring radio-tagged fish and again in 2013 at previously identified spawning sites because no radio-tagging occurred in that year. In 2011, we used an Aqua-Vu Model MC2x underwater camera and drifted downstream over potential spawning areas to document spawning activity. In 2012 and 2013, we used a higher-resolution camera (Outland Technology UWC-300P) attached between two sounding weights, as described by Groves and Garcia (1998). This weighted camera system was lowered from the bow of an aluminum boat and transmitted live video to a video monitor within the boat via an attached cable. The depth of the camera was controlled by a sounding reel operated from the bow of the boat. With the camera deployed, the boat traversed suspected spawning areas in a systematic pattern, moving upstream approximately one boat length (5.4 m) for each traverse, and the presence of spawning gravel or redds was observed. We used a hand-held GPS device to assist in monitoring boat movement over the survey area, and fixed objects on shore (e.g., trees, rocks, or road signs) assisted in navigation. At a minimum, we surveyed every area where radiotelemetry detections suggested the possibility of spawning activity at least once when spawning was likely to be occurring, and we increased the survey area in some cases where water velocity and substrate size and composition appeared to provide adequate spawning habitat.

When redds were observed on the boat-mounted video monitor, the video was recorded, and the redd depth was determined from a boat-mounted Humminbird Legend Model 2000 fish-finder. The latitudinal and longitudinal

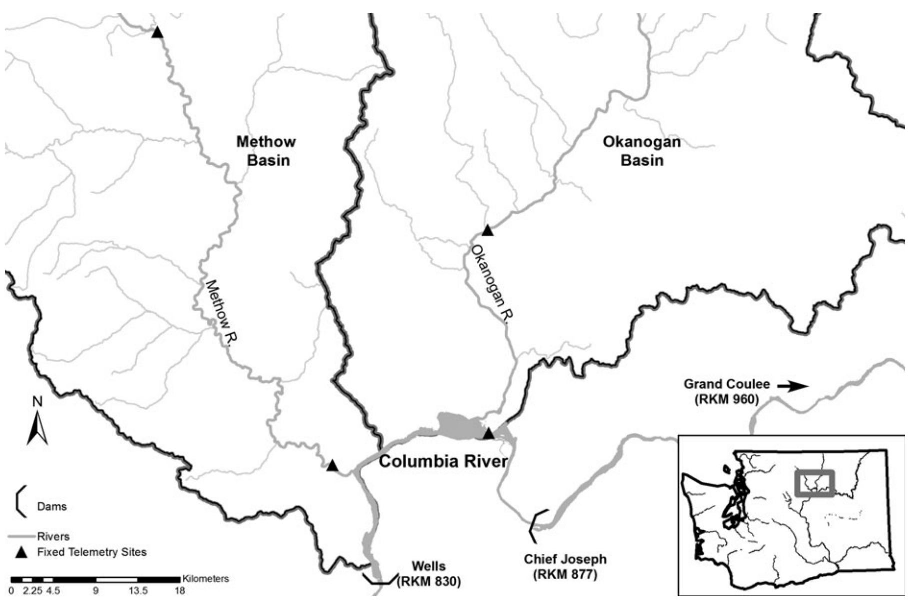

FIGURE 1. Locations of Wells Dam and Chief Joseph Dam on the upper Columbia River, Washington, USA, and the relative locations of fixed telemetry sites (triangles) and primary spawning tributaries (the Methow and Okanogan rivers). Watershed boundaries of the Methow and Okanogan rivers are designated by bold lines.

bounds of each spawning area were recorded using a hand-held GPS device, and the length and width (m) of the spawning area were estimated from these locations by using Google Earth Pro (https://www.google.com). Video recordings were later reviewed in an office setting using a standard computer monitor, and redds were confirmed by morphology (pit and mound) and contrast (clean, sorted gravel). If no redd or suitable habitat was observed on the video monitor, video recordings were not preserved for subsequent review, but the general survey area was highlighted on a map to avoid repeat sampling. The general length and width (m) of each highlighted area were obtained using Google Earth Pro, and the area surveyed was calculated for each general survey area and summed overall to estimate the total area surveyed (km^2). Areas where redds were detected were surveyed at least twice in each year between October 25 and November 29. Redd counts from each survey were hand-plotted on a map and summed at the end of the spawning season to estimate total redd deposition for each area. We assumed that these redd counts represented a complete census of annual redd deposition, and we did not attempt to expand these counts to other areas. This assumption aligns the methods for all areas (main stem and tributaries). Main-stem redd counts were compared with tributary redd count totals provided by Hillman et al. (2014) and A. Pearl (Confederated Tribes of the Colville Reservation, personal communication) to estimate the relative proportion of redds from each overall spawning area in each year.

River discharge (m^3/s) was estimated from Chief Joseph Dam data reported on the Fish Passage Center website (www.fpc.org). Mean daily water temperature (°C) for the Columbia River was derived from hourly temperature data collected at a depth of 6.1 m from the Chief Joseph Dam forebay (S. Stonesifer, U.S. Army Corps of Engineers, personal communication).

RESULTS

We released 255 radio-tagged fish in 2011 and 262 radio-tagged fish in 2012, representing 1.8% and 1.6%, respectively, of the wild summer-run Chinook Salmon passing Wells Dam in those years. Through the subsequent radio-tracking effort, we estimated parameters that affected postrelease distribution and escapement estimation, including tag loss, dam fallback, harvest, and prespawn mortality (see Mann and Snow 2018). However, most fish that were tracked upstream of Wells Dam were spatially and temporally located to suggest survival to spawning (52% of tagged fish), including a small population of Columbia River main-stem-spawning fish (4.8% of tagged fish).

Video monitoring equipment was deployed over an estimated 3.03 km^2 between the Okanogan River–Columbia River confluence and Chief Joseph Dam to identify main-stem spawning sites (Figure 2). We detected redds in two areas: a site beginning approximately 228 m upstream of the Highway 17 bridge (upper site); and another site with an upstream terminus approximately 101 m downstream of the Highway 17 bridge (lower site). The upper site was approximately 170 m long × 23 m wide, providing 3,071 m^2 of spawning area. The lower site was approximately 45 m long × 9 m wide, providing 318 m^2 of spawning area. Both sites were located along the southern shoreline—between the bank and emergent rock islands at the upper site and submerged bedrock features at the lower site.

Because of the relatively low survey frequency and the difficulty in distinguishing unique redds over multiple surveys through video recordings, we were able to estimate a peak redd count in each spawning area during each year but not a cumulative weekly redd count as is typical in most tributary surveys. We estimated that the upper and lower spawning sites had 50 and 20 redds, respectively, in 2011. In 2012, we estimated 41 redds in the upper site and 18 redds in the lower site. In 2013, we estimated 108 redds in the upper site and 26 redds in the lower site. Spawning in both sites combined accounted for an average of 2% of the spawning population based on the total number of summer-run Chinook Salmon redds counted upstream of Wells Dam from 2011 to 2013 (Hillman et al. 2014; Table 1). Our surveys suggested that most redds were constructed in early November, which is about 3 weeks later than the spawn timing reported for tributary populations in 2011–2013 (Hillman et al. 2012, 2013, 2014). Spawning occurred at depths between 3.7 and 7.0 m. Although we did not measure flow at individual redds, discharge (m^3/s) from Chief Joseph Dam was lower during October (mean = 1,920 m^3/s; coefficient of variation [CV] = 7.6) than during November (mean = 2,434 m^3/s; CV = 2.7) over the years observed but was relatively consistent within months (Figure 3). Mean water temperature during the peak spawning period in the tributary locations (week of October 15) ranged from 6.4°C to 12.4°C over the 3 years, while main-stem water temperature measured at the Chief Joseph Dam forebay ranged from 15.2°C to 16.0°C during the (presumed) peak spawning week (week of November 1; Table 2).

DISCUSSION

We identified two summer-run Chinook Salmon spawning areas, totaling a combined 3,389 m^2, in the main-stem Columbia River within 1.76 km downstream of Chief Joseph Dam. Although spawning was documented in this river section prior to the completion of Wells Dam

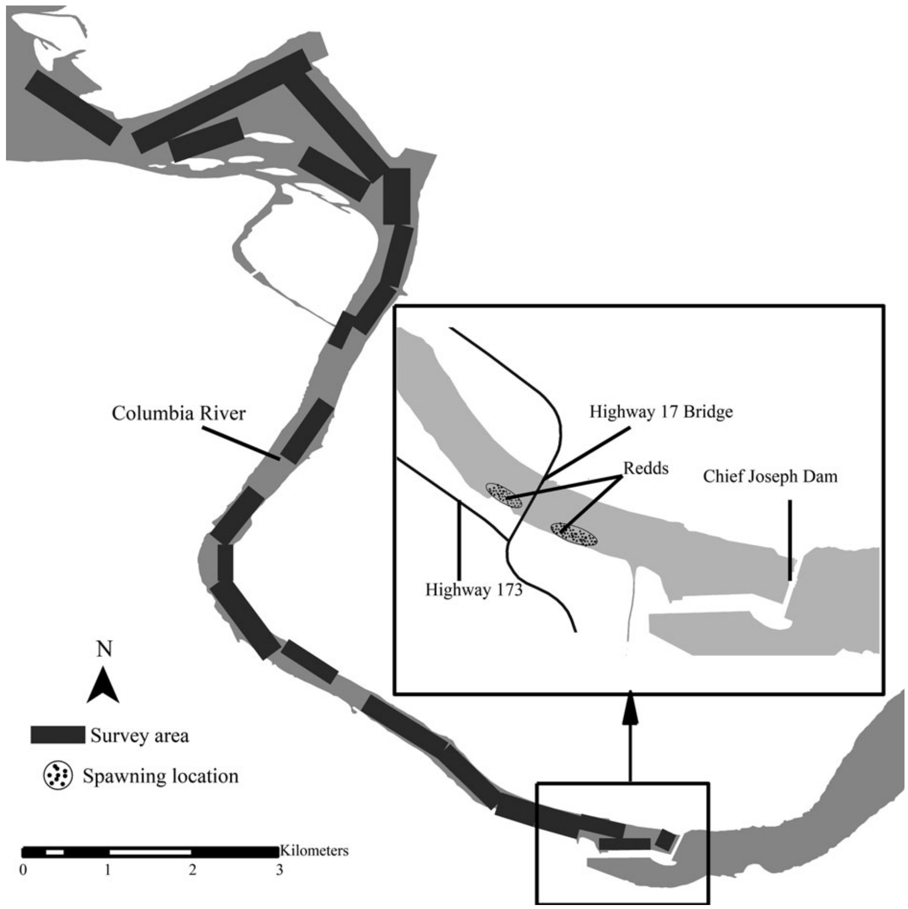

FIGURE 2. Summer-run Chinook Salmon underwater video survey and spawning areas in the main-stem Columbia River downstream of Chief Joseph Dam.

TABLE 1. Summer-run Chinook Salmon redd counts by year for spawning areas upstream of Wells Dam, Washington. Redd count data for the Methow and Okanogan River populations are from Hillman et al. (2014) or from Pearl (personal communication: 2013 Okanogan River data).

	Redd counts (% of total) by spawning area			
Year	Methow River	Okanogan River	Columbia River	Total
2011	941 (22.8)	3,123 (75.5)	70 (1.7)	4,134
2012	960 (26.0)	2,679 (72.4)	59 (1.6)	3,698
2013	1,551 (29.5)	3,547 (67.6)	154 (2.9)	5,252

(Meekin 1967a, 1967b), only limited aerial surveys have been conducted in this area since (Hillman et al. 2011), and to our knowledge, ours is the first detailed reporting of main-stem spawning upstream of Wells Dam since inundation. Despite the limited number of radio-tagged fish that were released, tracking of these fish throughout the spawning seasons in 2011 and 2012 revealed likely spawning areas upstream of Wells Dam, but spawning activity was only detected in the Chief Joseph Dam tailrace area.

We did not attempt to quantify site-specific spawning habitat or environmental variables (e.g., flow, depth, or temperature) in any of the areas we surveyed unless redds were detected. Like most of the main-stem Columbia River that was utilized as spawning habitat prior to the completion of the Columbia River hydrosystem, suitable spawning areas were either completely blocked or were made unsuitable by increased depth and decreased velocity after inundation (Chapman et al. 1994). The spawning areas we identified downstream of Chief Joseph Dam were relatively small areas where suitable velocity and substrate were still present. Although we documented spawning in these areas during each year we surveyed, we do not know whether this is a recent phenomenon or whether summer-run Chinook Salmon have spawned in these areas annually since inundation. The latter seems likely, but habitat in these areas could ultimately have been created or reduced by the construction of Chief Joseph Dam and the

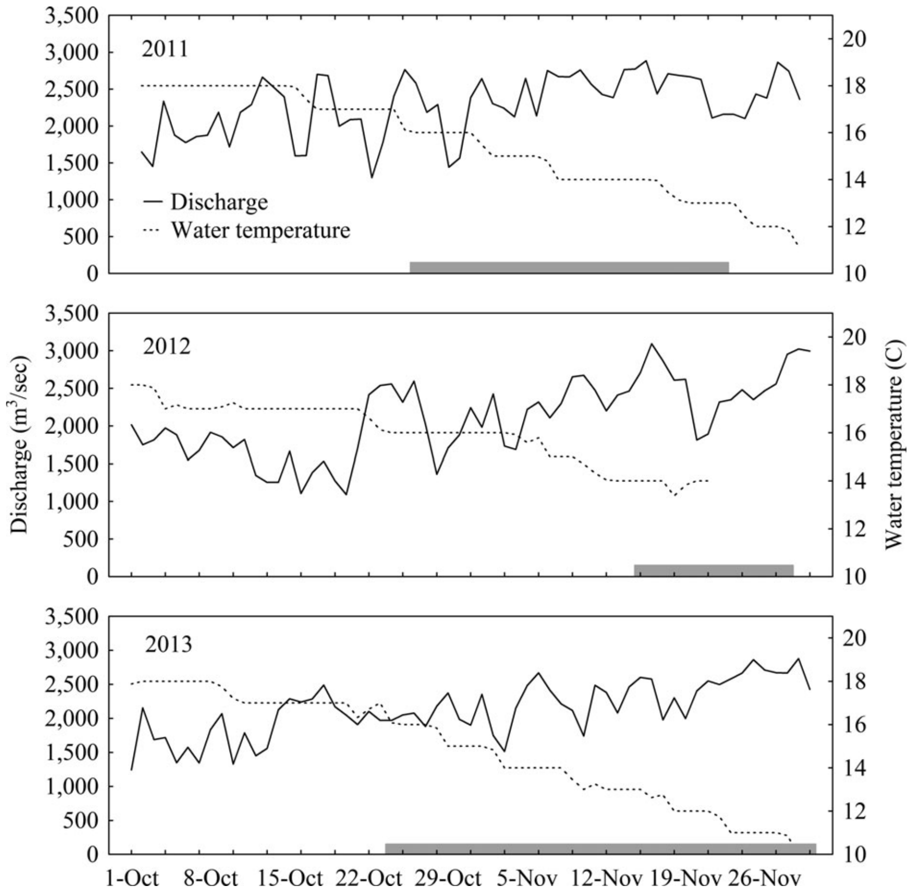

FIGURE 3. Mean daily discharge (m^3/s) and water temperature (°C) at Chief Joseph Dam on the upper Columbia River in October and November 2011–2013. The annual redd survey period in each year is denoted by the gray bar on the *x*-axis of each panel.

TABLE 2. Mean water temperature (Temp; °C) and discharge (m^3/s) during the expected week of peak spawning activity by summer-run Chinook Salmon in the main-stem Columbia River (Chief Joseph Dam, week of November 1) and tributaries (week of October 15).

	Chief Joseph Dam		Methow River		Okanogan River	
Year	Temp	Discharge	Temp	Discharge	Temp	Discharge
2011	15.4	80,246	10.0	18	12.3	34
2012	16.0	67,240	11.5	12	12.4	27
2013	15.2	72,756	6.4	29	9.6	60

associated bank stabilization and bridge construction downstream of the dam that occurred as part of the overall project.

Overall, spawning escapement to the main-stem spawning areas was low relative to local tributary spawning populations, and we were not able to estimate the genetic composition of the spawners (i.e., hatchery or wild) because only wild fish were radio-tagged and too few postspawn carcasses were recovered to infer genetic composition within years. Furthermore, our redd estimates should be considered minimum values due to the lack of weekly surveys over the spawning period in 2011 and 2012 and the difficulty in identifying superimposition from video files in all 3 years. We could not estimate weekly redd deposition or quantify superimposition from video files because individual redds were not marked to allow accurate identification in subsequent surveys. Additionally, the margins of individual redds often overlapped or were indistinguishable late in the spawning season due to the confined nature of these spawning areas. Shore-based redd surveys often georeference individual redds with flagging or collect latitude and longitude data for individual redds so that spawn timing and superimposition can be estimated. Future surveys in this area should include the deposition of unique georeference markers (similar to those used by Dauble et al. 1999) during the period prior to spawning so that video recordings include visible references to assist in the identification of individual redds over multiple surveys.

Redd depths and water temperatures observed during the spawning periods were similar to those reported for other summer-run Chinook Salmon populations spawning in main-stem areas of the Columbia River basin. We recorded redds at depths between about 3.7 and 7 m, and mean monthly water temperatures during the spawning period were about 13.8°C. These values are similar to those reported for fall-run Chinook Salmon in the Snake River main stem (Dauble et al. 1999; Groves and Chandler 1999) and Columbia River main stem (Swan 1989; Dauble and Watson 1997; McMichael et al. 2005). The water temperature data we report were collected in the Chief Joseph Dam forebay and may not represent actual temperature values from the tailrace spawning area. More importantly, the water temperature regime in the tailrace of Chief Joseph Dam may be considerably different than that of tributary spawning areas, which may impart differential survival when compared to fish incubating and emerging in tributary areas (Connor et al. 2002; Geist et al. 2006).

Identifying and quantifying new spawning populations upstream of Wells Dam would improve the accuracy of prespawn mortality estimates for summer-run Chinook Salmon. Our surveys suggested that estimates of prespawn mortality, as calculated by the spawning escapement divided by the total run over Wells Dam, would have decreased by 1.7% in 2011, 1.6% in 2012, and 2.7% in 2013. Identifying these fish as contributing to spawning escapement benefits management models that are predicated on achieving spawning escapement goals prior to considering whether surplus fish are available for harvest. Undoubtedly, other factors, such as dam fallback and imprecise estimates of harvest and spawning escapements, would likely account for the greater proportions of fish of unknown fates (e.g., Boggs et al. 2004), but the spawning areas we identified would assist in refining annual escapement and mortality estimates.

Main-stem Columbia River summer-run Chinook Salmon spawning habitat has been severely degraded over the last century. These habitat losses, mortality at hydroelectric dams, and lost harvest opportunities have prompted mitigation strategies that rely primarily on releases of hatchery summer-run Chinook Salmon. We have shown that some main-stem spawning still occurs in the Columbia River upstream of Wells Dam, but this main-stem-spawning life history trait is expressed by only a small fraction of the summer-run Chinook Salmon population. Although the change from main-stem spawning to tributary spawning was necessary for the persistence of the race, it represents a major shift in habitat utilization and may have consequences relating to emigration life history and population productivity (Brannon et al. 2004; Copeland and Venditti 2009; Bourret et al. 2016). Our surveys suggest that spawning habitat in the Columbia River between Wells Dam and Chief Joseph Dam is limited, and any further natural gravel recruitment to this area is highly unlikely given the presence of multiple hydropower dams upstream. The ability to increase summer-run Chinook Salmon spawning habitat in the Columbia River downstream of Chief Joseph Dam through project discharge and pool elevation manipulations or through the introduction of spawning gravel should be evaluated. These actions are unlikely to produce results similar to those observed for large populations of main-stem-spawning fish (e.g., Harnish et al. 2014; Hanford Reach Fall Chinook Protection Agreement) because dewatering is likely not an issue at the spawning areas we identified. However, modeling efforts to determine potential changes in available spawning habitat overall may be informative. Recently discovered Chinook Salmon spawning populations (e.g., Small et al. 2011; present study) may be small demographically, but they represent examples (historic or contemporary) of a diversity in life history expression that may be increasingly important in an ecosystem affected by climate change (Crozier et al. 2008; Waples et al. 2009).

ACKNOWLEDGMENTS

We thank S. Bradbury, F. Mullins, and S. Rosenberger (U.S. Fish and Wildlife Service, Idaho Fish and Wildlife Conservation Office) for their assistance and expertise with initial video surveys in the Columbia River; T. Odell (Alpine Welding) for help constructing the camera carrier; C. Moran (Washington Department of Fish and Wildlife [WDFW]) for making the maps used in this article; and T. R. Divis (WDFW) for 3 years of staff work on this study. A. Pearl (Confederated Tribes of the Colville Reservation) provided Okanogan River Chinook Salmon spawning data. Chief Joseph Dam water temperature data were provided by S. Stonesifer (U.S. Army Corps of Engineers). We appreciate A. Murdoch (WDFW), A. Haukenes (WDFW), and two reviewers for editing a draft version of the manuscript. This project was funded by the Pacific States Marine Fisheries Commission (Contract Number 11-16, National Oceanic and Atmospheric Administration Award Number NA10NMF4360439), and we are grateful for their financial and technical support. There is no conflict of interest declared in this article.

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