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MANAGEMENT BRIEF

Adfluvial Life History in Spring Chinook Salmon from Quartzville Creek, Oregon

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Abstract
Through spawning ground and snorkel surveys, we confirmed the presence of adfluvial spring Chinook Salmon *Oncorhynchus tshawytscha* in a tributary upstream from a high-head dam in the upper Willamette River in northwest Oregon. Spring Chinook Salmon previously had been extirpated above the dam but juvenile hatchery fish were released in the reservoir in subsequent years. In 2012, we recovered six carcasses of adfluvial Chinook Salmon adults, identified nine live adults, and recorded nine redds. Analyses of scales from carcasses revealed those fish were ages 5–6. Otolith microchemistry from an unmarked adult female Chinook Salmon did not indicate ocean residence, and no hatchery thermal marks were observed, suggesting this fish was the progeny of adfluvial adults. In 2013, we observed one live, unclipped adult and three juvenile Chinook Salmon. We conclude that adfluvial spring Chinook Salmon exist in Green Peter Reservoir and successfully reproduce. This is the first documentation of adfluvial Chinook Salmon in Oregon, and this unusual life history should be considered in the context of research, monitoring, and recovery actions pertaining to ongoing reintroduction programs for threatened Willamette River spring Chinook Salmon above dams.

Anadromy is often considered a defining characteristic for Pacific Salmon *Oncorhynchus* spp. (Rounsefell 1958), although adfluvial populations are known to exist (Northcote 1997). Perhaps the best known adfluvial salmon populations are Pink Salmon *O. gorbuscha*, Coho Salmon *O. kisutch*, and Chinook Salmon *O. tshawytscha*, which have been successfully established in the Laurentian Great Lakes, and Sockeye Salmon *O. nerka*, which naturally include adfluvial life history types that do not migrate to sea (Quinn and Myers 2004). Chinook Salmon are thought to be anadromous under natural conditions, but may adopt alternate life histories when artificial barriers prevent migration between fresh- and saltwater habitats (Quinn and Myers 2004). Dams and associated reservoirs can influence the life history patterns expressed by Chinook Salmon produced or released upstream of dams (Connor et al. 2005; Keefer et al. 2012). In some cases, adfluvial forms may develop, whereby adult Chinook Salmon spawn in rivers or streams, after which their offspring migrate to lakes (or reservoirs) to rear to adulthood before returning to spawn in riverine habitats. This life history has been documented in Chinook Salmon introduced into lakes in Washington (WDFW 2002; Skokomish Indian Tribe and WDFW 2007), Idaho (Maiolie and Davis 1995), and California (Bacher 2010; J. Rowan and K. Thomas, 2010 memorandum to the California Department of Fish and Game, on snorkel survey for South Fork American River above Folsom Lake), but not Oregon.

Our study was conducted upstream of Green Peter Dam in Quartzville Creek, a third-order stream (Strahler 1957) in the Willamette River basin of Oregon (Figure 1). Historically, Quartzville Creek, the middle Santiam River, and an 8-km reach upstream of Cascadia on the South Santiam River supported 85% of the wild spring Chinook Salmon production upstream of Foster Dam (Mattson 1948, as cited in Wevers et al. 1992; Figure 1). Currently, Quartzville Creek is not considered critical habitat for upper Willamette River spring Chinook Salmon (BiOp section 3.3.1.6; NMFS 2008) but plans are being considered to reintroduce broodstock from the South Santiam Hatchery upstream of Green Peter Dam to aid population recovery (BiOp section 2.10.3).

As with many native North American salmonids, of which 61% of the 38 described species are considered imperiled (Jelks et al. 2008), anthropogenic activity caused a large decline in the spring Chinook Salmon population of the Willamette River basin. Green Peter Dam (Figure 1) is one of 13 dams constructed by the U.S. Army Corps of Engineers from 1941 to 1968 in the upper Willamette River basin, primarily for flood control. Collectively these dams are called the Willamette Valley Project. Many of the dams, including Green Peter Dam, were inadequately equipped to pass adult and juvenile migrants. Operations to pass adults upstream of the 100-m-tall dam were discontinued

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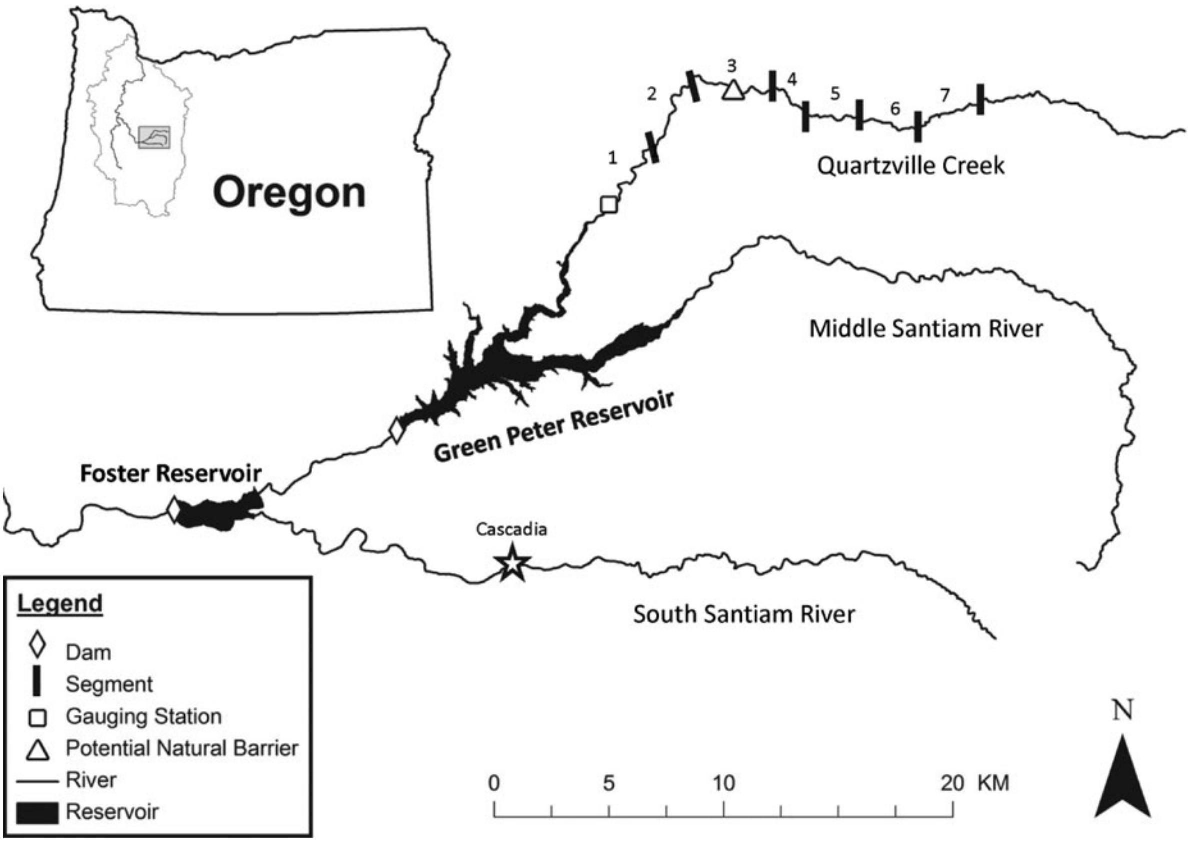

FIGURE 1. The South Santiam River, Foster Reservoir, Green Peter Reservoir, and Quartzville Creek. Numbers denote spawning ground survey segments. Segment 1 begins at the U.S. Geological Survey gauging station. The gray outline represents the Willamette River Basin, and the shaded box highlights the area visible in the enlarged map.

in 1988 after studies indicated problems with upstream passage of adults and downstream passage of juveniles through the reservoir (BiOp section 5.5.1.3; NMFS 2008). Similar to other areas across North America, hatcheries were constructed to mitigate for the loss of native fishes, upstream spawning and rearing habitats, and reduced angling opportunities (e.g., Schramm and Piper 1995). In some cases, Chinook Salmon produced by these hatcheries have been released above Willamette Valley Project dams for nutrient supplementation, reintroduction, as prey for native Bull Trout *Salvelinus confluentus* (BiOp section 2.10.1; NMFS 2008), and for dam passage research, occasionally with the added benefit of fisheries augmentation. The last releases of spring Chinook Salmon by the Oregon Department of Fish and Wildlife (ODFW) upstream of Green Peter Dam occurred in 2007 and 2008 (Table 1).

In response to occasional but consistent anecdotal reports from anglers catching large, adult Chinook Salmon in Green Peter Reservoir (Green 2012; adipose clipped), we initiated spawning ground surveys in 2012 and snorkel surveys in 2013 in Quartzville Creek above Green Peter Reservoir to (1) investigate a previously undocumented life history strategy for Willamette River Chinook Salmon; (2) evaluate the age and size at maturity of spawners, if found; and (3) evaluate evidence for natural production.

METHODS

Spawning ground and snorkel surveys.—We conducted spawning ground surveys on the lower five segments (Figure 1; 21.24 km) of Quartzville Creek weekly between September 26 and October 17, 2012, and between September 17 and October 15, 2013. During the first week of both 2012 and 2013, we surveyed two additional upstream river segments (7.5 km in length), but discontinued surveys of these segments because no fish or redds were observed and spawning habitat was sparse. Except for a small number of pools estimated to be no more than 9 m deep, the relatively small size of Quartzville Creek and easy access combined with high water clarity facilitated spawning ground surveys. Surveyors walked upstream from the start of the survey segment and marked the locations of redds and live fish with handheld global positioning system units. Each Chinook Salmon carcass recovered was checked for the presence of an adipose fin clip, and fork length and sex were recorded. Otoliths were collected for microchemistry analysis, and female

TABLE 1. Number and mean FL of surplus juvenile Chinook Salmon released upstream of Green Peter Dam, 2007–2008; AD = adipose clipped, OT = otolith thermal marked.

Brood year	Hatchery	Number released	FL at release (mm)	Mark	Release date	Release site
2006	S. Santiam	7,856	137	AD	Sep 5, 2007	Green Peter River
2006	Willamette	101,217	66	AD, OT	May 24, 2007	Quartzville Creek
2007	S. Santiam	15,000	148	AD	Sep 30, 2008	Green Peter River
2007	Willamette	84,000	64	AD, OT	Jun 12, 2008	Quartzville Creek

skeins were examined for possible prespawn mortality. We also collected scales for age estimations and to examine for evidence of ocean entry "checks" (see Holtby et al. 1990).

In 2013, we conducted weekly snorkel surveys in the same segments as in 2012 from July 2 to August 22 to determine when the earliest returning adults migrated from the reservoir and into Quartzville Creek to spawn and to verify whether the timing of their river/stream entry was consistent with that of anadromous Willamette River Chinook Salmon.

Otolith analysis.—Otoliths were removed from all adult salmon carcasses recovered during spawning ground surveys and stored in 95% ethanol for chemical analysis and identification of thermal marks. Thermal marking is used to mark the otoliths of hatchery fish by subjecting them to controlled, short-term temperature fluctuations during incubation to provide a secondary hatchery mark with adipose fin clipping (Volk et al. 1999). Otoliths from one unmarked female, suspected to be progeny from an adfluvial Chinook Salmon, were sent to the Washington Department of Fish and Wildlife (WDFW) Fish Ageing and Otolith Lab for analysis. One sagittal otolith was mounted sulcus side up in thermal plastic resin. This sample was then ground to the otolith core while the otolith edge was maintained for chemical analysis. The sectioned sample was then viewed for the presence of a thermal mark to verify hatchery origin. To determine whether evidence of marine residency was present, we analyzed the chemical composition of the otoliths, using a New Wave DUV 193 nm ArF laser coupled with a Thermal Elemental PQ Excell quadropole inductively coupled plasma mass spectrometer (LA-ICP-MS). Otolith material was sampled from the core to the dorsal posterior edge (detailed methods found in Campbell 2010; Volk et al. 2010). We compared the ratio of strontium to calcium (Sr:Ca mmol:mol) near the core (maternal signal) and along the region of the otolith associated with the last several years of growth (Volk et al. 2000; Zimmerman and Reeves 2002; Campbell 2010).

Age estimation.—Scales were collected from fish during surveys of spawning grounds and analyzed by the ODFW Fish Life History Analysis Project (detailed methods described in Clemens et al. 2013). Scale samples were pressed into a Vivak thermoplastic sheet and observed under transmitted light using a microfiche reader. Annuli were counted in the anterior field from the focus to the scale edge. Annuli were identified as the region of scale growth where a transition of narrowly spaced circuli (winter growth) gave way to wider circuli (summer growth).

Age estimation was determined as the number of annuli observed, plus 1 year to account for the time when the alevin was in the gravel prior to scale formation. In addition, for anadromous Chinook Salmon from the Willamette Basin, the Fish Life History Analysis Project determined that if any additional growth was observed on the outside of the last annulus, one additional year should be added to the age because the outermost annulus had likely eroded or resorbed. This determination was validated through analyzing scale patterns of known-age adult hatchery Chinook Salmon that returned to collection facilities after they had been tagged with coded wire tags as subyearlings. However, given the novelty of our samples, we were not certain whether to add an annulus to scales from apparently adfluvial fish that exhibited additional growth near the outside edge of the scale (B. Clemens, ODFW, personal communication).

RESULTS

Spawning Ground Surveys

Nine live adult adfluvial Chinook Salmon were observed during spawning ground surveys and six carcasses were recovered in 2012. The fork lengths of the carcasses ranged from 660 to 810 mm FL (four adipose fin clipped, two unmarked; Table 2). Chinook Salmon returned to Quartzville Creek as age-5 and age-6 adults. We were able to determine the sex of four carcasses, all of which were females that appeared to have successfully spawned (very few eggs remained in skeins upon dissection). Nine redds were documented during spawning ground surveys in 2012. No adult Chinook Salmon or redds were observed in 2013.

TABLE 2. Information from Chinook Salmon carcasses collected in Quartzville Creek, 2012. Asterisk denotes that otoliths were sent for microchemistry analysis; NM = no marks observed, AD = adipose fin clipped. Ages were determined by scale analysis.

Collection date	Sex	FL (mm)	Mark	Age (years)
Sep 28	Female	687	NM*	5
Oct 4	Female	660	AD	5
Oct 15	Female	720	AD	5
Oct 15	Unknown	710	NM	5
Oct 15	Unknown	810	AD	5
Oct 15	Female	740	AD	6

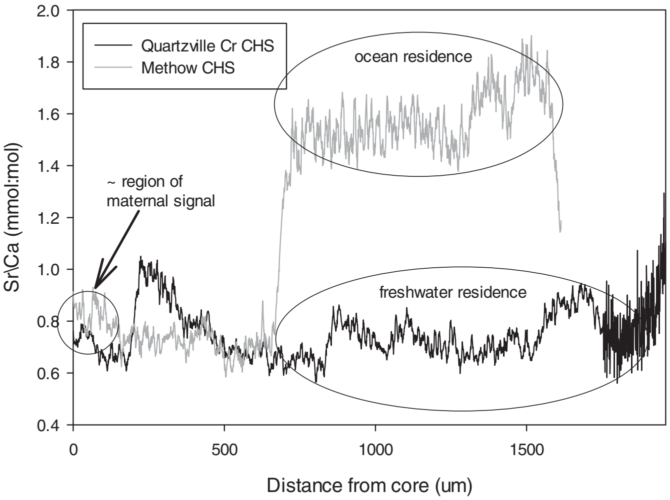

FIGURE 2. Otolith strontium:calcium ratio profiles illustrating ocean residence in an anadromous spring Chinook Salmon from the Methow River (WDFW Fish Ageing Lab) and freshwater residence from an adfluvial Quartzville Creek spring Chinook Salmon collected in this study.

Snorkel Surveys

We observed a single adult Chinook on July 18, 2013. This adult was unmarked (adipose intact) and holding in an approximately 150-m-long trench pool near the substrate in 16°C, 2.4-m-deep water, under a small bedrock overhang. We also documented three juvenile Chinook Salmon in the upper reaches of Quartzville Creek in 2013 during snorkel surveys.

Otolith Analysis

Of the two unmarked carcasses collected, only one had intact otoliths (Table 2). Microchemistry results suggested that otoliths from this Chinook Salmon did not contain strontium levels indicative of ocean residence (Figure 2). Moreover, although most juvenile Chinook Salmon (89%) released above Green Peter Dam had been thermally marked prior to release, no thermal marks were present on the otoliths from this adult female.

Age Estimation

Age estimation for Quartzville Creek Chinook Salmon (n = 6; Table 2) was consistent with the adipose-fin–clipped juveniles released from the 2006 and 2007 brood years. Although the estimated age range for some of the adipose-fin–clipped hatchery fish was initially ages 4–5, we know that age-4 is not possible because the last hatchery fish released (in 2008) were from the 2007 brood year. Therefore all hatchery fish must be age-5 or older. This suggests that for additional growth observed outside the outermost identifiable annulus of adfluvial Chinook Salmon scales (Figure 3), an additional year should be added

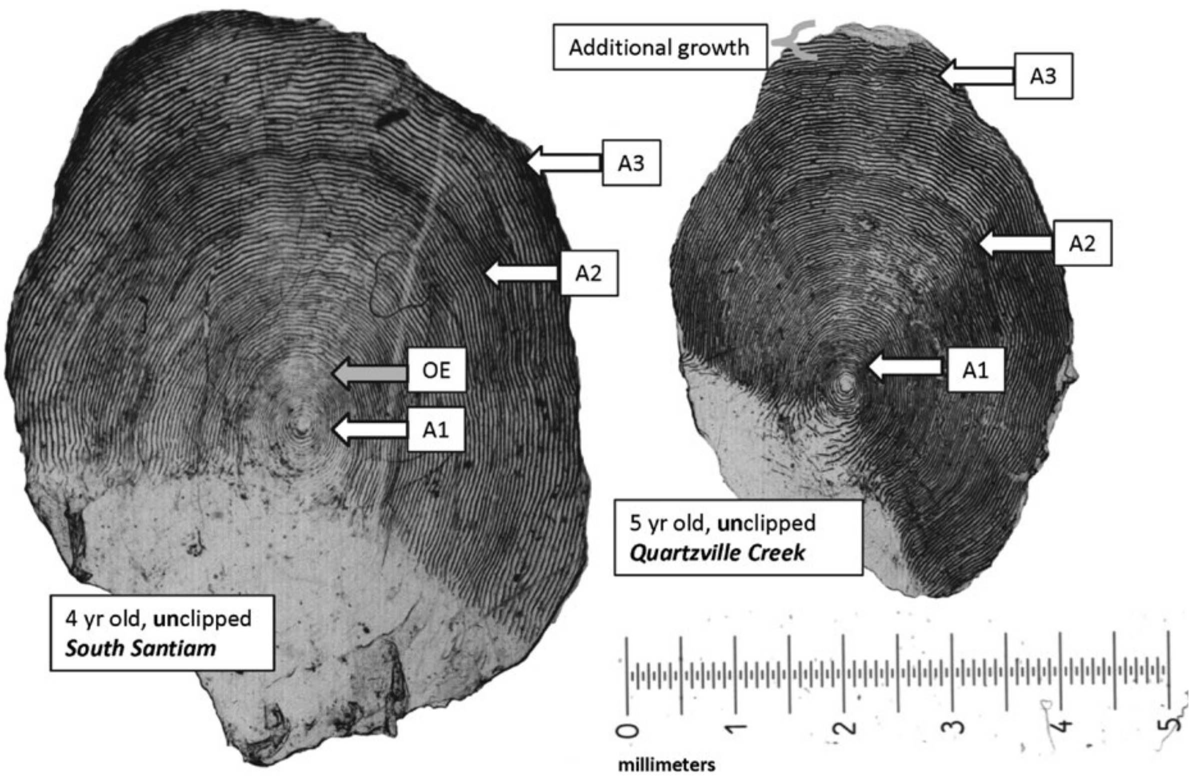

FIGURE 3. Aging analysis of scales from known anadromous spring Chinook Salmon returning to the South Santiam River (left: male, 880 mm FL) and suspected reservoir-reared adult collected in Quartzville Creek in 2012 (right: female, 687 mm FL) photographed at equal magnification. "A" refers to the annulus number and "OE" refers to ocean entry. One year of age is added to account for the winter when eggs are in the gravel prior to emergence. One additional year is added for Willamette spring Chinook Salmon if any additional growth is observed beyond the outermost annulus.

to the age, consistent with the procedure for other Willamette River Chinook Salmon. Five of the returning adults recovered in 2012 were age-5 and one was age-6 (Table 2).

The distance between circuli indicative of accelerated ocean residence growth on anadromous fish scales was not distinctly different from circuli spacing on adfluvial fish scales from Quartzville Creek. Therefore, we were unable to determine adult rearing patterns based on scale analysis alone (Figure 3).

DISCUSSION

Spring Chinook Salmon from the upper Willamette River naturally express a myriad of life history types (Schroeder et al. 2007; Keefer et al. 2012), including juvenile forms that rear in freshwater for various periods and return as adults at different ages (Schroeder et al. 2007). Although not previously documented, our findings suggest that under some circumstances, upper Willamette River Chinook Salmon can forego marine residence and express an adfluvial life history that allows them to spawn as adults despite isolation above impassable dams. This information provides further testament to the species' phenotypic plasticity.

The observation of redds and spawned-out carcasses provides evidence that hatchery juveniles released upstream of the Green Peter Dam likely reared and matured in Green Peter Reservoir and then returned to riverine habitat where they spawned. However, there was still speculation about the origin of adult Chinook Salmon in Quartzville Creek, even though no dam passage for adults is available. Other possible but unlikely explanations include human intervention in the transport of anadromous adults above Green Peter Dam. Therefore, we deemed it important to build a case for the juvenile rearing portion of the life history of these fish, using otolith and scale analyses. We aimed to prove definitively that adfluvial life history was occurring here to strengthen the hypothesis of the probability of such an occurrence elsewhere in the Willamette River watershed.

Run timing, age at maturity, and size ranges for adfluvial spawners were consistent with anadromous upper Willamette spring Chinook Salmon, which typically ascend Willamette Falls from April to August and spawn from August to October with a peak in September. Anadromous spawners are primarily 4–5 years old, but range from 3 to 6 years of age (ODFW and NMFS 2010; Johnson and Friesen 2013); from the scales we collected, we determined that adfluvial Chinook were ages 5–6 ($n = 6$). The range for adult adfluvial Chinook Salmon females from Green Peter Reservoir was 660–740 mm FL, whereas that for adult anadromous, unclipped Chinook Salmon females collected at Foster Dam in 2012 ($n = 368$) was 470–950 mm (mean, 790 mm; ODFW, unpublished data).

Even after acknowledging the possibility of regeneration of adipose fins when clips are incomplete (Thompson and Blankenship 1997), it is still unlikely that the unclipped, nonthermally marked Chinook Salmon identified in 2012 was a hatchery-produced fish. Hatchery fish were supposed to be 100% adipose clipped, and 89% of the hatchery fish released were also thermally marked. All releases of hatchery juvenile Chinook Salmon upstream of Green Peter Dam were discontinued after 2008, and 2013 represented the last run-year for any age-6 spawners released as marked hatchery juveniles.

Although it is possible for Chinook Salmon to live beyond age-6 (Groot and Margolis 1991), it would not be typical for adults in the upper Willamette River (Johnson and Friesen 2013). Unmarked adult Chinook Salmon observed above Green Peter Dam from 2013 forward are likely progeny of adfluvial adults. No adult fish were observed during the fall 2013 spawning ground surveys. However, we did observe one unclipped adult and three juveniles in Quartzville Creek during summer 2013 snorkel surveys. At least three large, unclipped adult Chinook Salmon were captured in Green Peter Reservoir by anglers, one reported in a local newspaper (Struble 2013) and two more on the social media webpage ifish.net discussion board (http://www.ifish.net). All of the pictured fish had intact adipose fins, further supporting the hypothesis that they were naturally produced progeny of adfluvial adults.

Natural production of adfluvial Chinook has been established in other places when environmental conditions are conducive. The most widely recognized example of successful adfluvial reproduction as a tenable life history strategy for Chinook Salmon comes from the Laurentian Great Lakes, where Chinook Salmon were introduced in 1967. Natural production of Chinook Salmon continues to contribute a substantial proportion of the fish captured in the Great Lakes sport fishery (Peck et al. 1999). Our study provides the first evidence to confirm anecdotal reports of this life history in Oregon. However, in addition to the current small population size, Chinook Salmon above Green Peter Reservoir will likely be affected by extensive anthropogenic influences we observed while conducting the surveys, including suction-dredge mining and recreational activities. Low stream levels and high temperatures during the holding and spawning seasons present additional challenges. The lethal temperature for juvenile Chinook Salmon is 25°C and the preferred temperature range is 11.7–14.7°C (Richter and Kolmes 2005). Each year (2009–2012) maximum temperatures in Quartzville Creek have exceeded 20°C, and in 2009 a temperature of 24.8°C was recorded (U.S. Geological Survey gauge 14185900). The relatively small size of the stream and the low flow levels common during the spawning season make spawning adults very easy to locate. Females that protect redds are particularly vulnerable to poaching and harassment during this period. In the absence of sustained hatchery releases, it is unlikely that natural production will be long-term in Quartzville Creek, given the low numbers of redds counted in 2012 and the absence of redds in 2013.

Confirmation of adfluvial spring Chinook Salmon in Green Peter Reservoir presents challenges for fisheries managers in the upper Willamette basin regarding recovery goals set in the upper Willamette River Conservation and Recovery Plan for Chinook Salmon and steelhead (ODFW and NMFS 2011) and the Willamette Biological Opinion (BiOp; NMFS 2008). Upper

Willamette spring Chinook Salmon are listed as threatened under the Federal Endangered Species Act (NMFS 1999). Increasing reports of large Chinook Salmon captured in other reservoirs (notably Detroit Reservoir on the North Santiam River) suggest that a proportion of the spawning population upstream of other dams consists of adfluvial Chinook Salmon. Unlike Green Peter Reservoir, where release of juveniles and outplanting of adult Chinook Salmon ceased in 2008, 8 of the 13 Willamette Valley Project dams currently have adult Chinook Salmon outplanted upstream of the dams each year (Sharpe et al. 2013). In these systems, adfluvial spawners would not have to be self-sustaining to contribute to the gene pool where spawning opportunities with outplanted fish exist. In addition, run-timing and size (as previously discussed) would make them visually indistinguishable from anadromous fish. If Chinook Salmon in other Willamette River subbasins also express an adfluvial life history, adfluvial spawners may confound results for ongoing monitoring, research, and reintroduction programs. Examples of potential challenges include, but are not limited to, reduction in the rate of anadromy for populations upstream of dams, inflated estimates of individual female production, artificially inflated redd counts, and production of unassignable fish detected through genetic pedigree studies.

Published reports of adfluvial Chinook Salmon in the Pacific Northwest are scarce and appear mainly as grey literature: annual reports from state wildlife management agencies and anecdotal reports (e.g., newspaper articles). Such cases highlight the importance of publishing these data to inform researchers and resource managers where such anomalies may affect ongoing research, conservation, or reintroduction efforts.

We recommend that future research be initiated to evaluate the presence and prevalence of adfluvial life history expression in other Willamette River subbasins. This issue currently remains unaddressed in a system where extensive effort and resources are being directed to monitor and promote the recovery of Willamette spring Chinook Salmon, and may be a relevant consideration for any system where anadromous reintroductions upstream of dams are being considered.

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