Impacts of redd superimposition on the spawning success of listed tule fall Chinook salmon in the White Salmon River, Washington

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Abstract

Upriver bright (URB) fall Chinook salmon reared and released from the Little White Salmon and Willard National Fish Hatcheries are known to stray into the White Salmon River. Interactions between hatchery-origin URB strays and ESA-listed tule fall Chinook salmon are believed to lead to a loss in productivity of the native tule population through hybridization and redd superimposition. Tule fall Chinook salmon generally spawn earlier in the fall (September – October), which puts their redds at risk of superimposition by URB fall Chinook salmon that typically spawn later (late October – November). Superimposition may result in egg displacement and reduce egg-to-fry survival leading to a loss in productivity of the tule fall Chinook population. A pilot feasibility study was conducted in the fall (September – November) of 2022 to assess the superimposition of tule redds by URB fall Chinook salmon within the lower White Salmon River. Redd locations were documented during weekly spawning ground surveys using ArcGIS Field Maps and an Arrow RTK GNSS Receiver resulting in centimeter-level location accuracy. The degree of overlap and level of disturbance to tule redds were used to document superimposition. A surprisingly high incidence (71 percent) of tule redds were superimposed by URBs, with approximately 88 percent of all tule redds surveyed disturbed in some way. These results draw further attention to the potential impacts of hatchery-origin URBs on the ESA-listed tule population. Herein we present results from the pilot feasibility study, evaluate the methodology employed, discuss potential management implications, and suggest future studies to measure the impacts of superimposition.

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INTRODUCTION

When salmonids spawn, they dig gravel nests (i.e., redds) to bury and incubate their eggs. A female salmon will use her caudal fin to dig a depression or pit to deposit her eggs, which are fertilized simultaneously by one or more males. The female will then cover the eggs with a layer of gravel and rocks free of fine sediment. The eggs are typically deposited in a series of pockets and laid in an upstream progression (Burner 1951). The eggs and embryos will remain in the gravel for roughly two to eight months, depending on species, location, water temperature, dissolved oxygen level, and other factors that influence the rate of development (Groot and Margolis 1991). During this long incubation period, salmonid eggs are especially vulnerable, facing mortality threats from stream bed scour and fill, predation, changes in water quality and temperature, and superimposition (Montgomery et al. 1996; Taniguchi et al. 2000; Smialek et al. 2021). Superimposition is defined as the creation of a redd on top of a previously established redd. Redd superimposition can result in significant mortality by damaging, dislodging, and preventing eggs from maturing (Fukushima et al. 1998). In the present study, we assessed the superimposition of fall Chinook salmon redds in the White Salmon River, Washington.

Upriver bright (URB) fall Chinook salmon reared and released from the Little White Salmon (LWS) and Willard (WI) National Fish Hatcheries (NFHs) are straying into the White Salmon River and interbreeding and competing with the native ESA-listed tule fall Chinook salmon (Figure 1 ; Smith and Engle 2011; NMFS 2017; Smith et al. 2021). Various environmental and anthropogenic factors have been proposed to explain the incidence of hatchery-origin strays entering the White Salmon River, though the exact causes are not well known (Silver et al. 2020). Interactions between Little White Salmon NFH URB strays and native tule fall Chinook salmon in the White Salmon River are believed to lead to a loss in productivity of the native tule population (NMFS 2017). Hatchery-origin URB strays from other programs, such as Willard NFH, may also affect the productivity of the native tule population. The URB hatchery stocks from LWS and WI NFHs were derived from fall Chinook stocks that spawned above the historic Celilo Falls area and are not considered part of the Lower Columbia River Chinook Salmon ESU. Tule fall Chinook salmon generally spawn earlier in the fall (September – October), which puts their redds at risk of superimposition by URB fall Chinook salmon that typically spawn later (late October – November). Due to difficulties in directly assessing the impact of redd superimposition, the abundance of hatchery-origin URB spawners is used as a surrogate to measure impacts on the tule population (NMFS 2017). Annual spawning ground surveys conducted by the Washington Department of Fish and Wildlife (WDFW) are used to estimate the tule and URB fall Chinook salmon spawning populations in the White Salmon River and provide information on the hatchery origin of URB strays from coded-wire tag (CWT) recoveries. Based on surveys from 2013-2019, the WI and LWS NFHs represented 90 – 100 percent of annual CWT recoveries, with the LWS NFH component averaging 90 percent of annual recoveries (Silver et al. 2020). Previous studies have focused on the potential risk of hybridization between tule and hatchery-origin URB populations by examining out-migrating juveniles (Smith and Engle 2011; Smith et al. 2021). This study focused on potential impacts on the tule population from redd superimposition by hatchery-origin URB fall Chinook salmon. Smaller late-spawning salmonids (e.g., coho salmon and steelhead) are also present in the White Salmon River and could superimpose tule redds where spawning habitats overlap, though egg displacement may be less likely due to size differences among species and shallower egg burial depth (DeVries 1997).

Produced by: Justin Baker; Projection: Mercator Auxiliary Sphere; Datum: WGS 1984; Date: 4/20/23

Figure 1. Location of Willard, Little White Salmon, and Spring Creek National Fish Hatcheries (NFHs) with the Little White Salmon and White Salmon Rivers.

In addition to providing estimates of adult Chinook salmon spawner abundance, WDFW surveys also provide information on the spatial distribution of tule, and URB fall Chinook salmon spawning (Figure 2). In 2020 approximately 91.6 percent of tule spawner abundance and 98.6 percent of URB spawner abundance were within the first 2.3 KM (1.44 RM; i.e., three tier falls to the mouth) (Olk and Dammerman 2021). This spatial pattern is consistent across survey years (2013-2021), with the greatest spawner abundances in the lower section of the White Salmon River. GPS coordinates taken during WDFW surveys also help identify general spawning locations within river reaches (Figure 2).

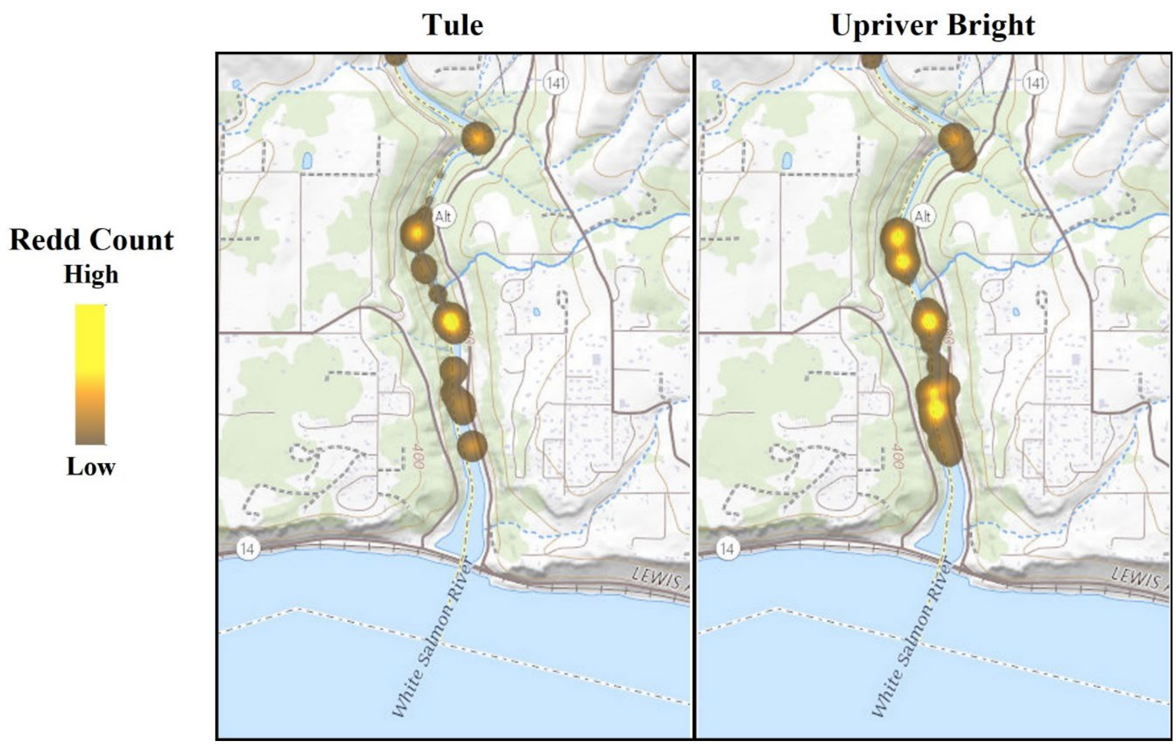

Figure 2. Heat map of the lower White Salmon River to RM 1.44 showing the spatial distribution of tule and upriver bright fall Chinook salmon redds during WDFW spawning ground surveys in 2021.

This pilot feasibility study aimed to supplement annual WDFW spawning ground surveys in the White Salmon River with more detailed surveys of lower river reaches to assess late run URB fall Chinook salmon superimposing upon tule fall Chinook salmon redds. High-density spawning areas in lower survey reaches are frequently disturbed with large areas of cleared substrate (Elise Olk, WDFW, personal communication, June 2021). Individual redd boundaries may overlap extensively in these areas posing several challenges to documenting superimposition, including difficulties in marking individual redd locations and distinguishing among overlapping spawning runs of tules and URBs. One of the main goals of this feasibility study was to test and evaluate methods for identifying the superimposition of tule redds by URB fall Chinook salmon within the lower White Salmon River. Another goal was to fill in critical knowledge gaps by better understanding the incidence of redd superimposition. Results from this initial pilot study could be used to make informed decisions and potential changes to the methodology of surveys in 2023. A better understanding of the incidence of superimposition on tule redds within the lower White Salmon River could also have important management implications, such as limiting production, and help to understand better the potential impacts the Little White Salmon NFH URB program is having on the listed tule population.

STUDY AREA

The White Salmon River is a 5th-order stream with a basin of approximately 1,000 km^2 (386 mile^2) that enters the lower Columbia River at RKM 269 (RM 168) in Washington State. The river originates from Mount Adams in the Cascade Mountain Range and flows south 72 km (45 miles) before entering the Columbia River at Underwood, Washington. This initial feasibility study focused on spawning locations within the first river mile of the White Salmon River (Figure 3). Four survey reaches were selected to monitor the distribution of spawning tule fall Chinook covering an area of approximately 82,500 ft^2 and 1,000 ft of the river (Table 1). Reaches surveyed ranged from approximately 200 to 400 ft long with areas of 15,000 to 35,000 ft^2. Two reaches were side channels, and two were the river's main sections above riffles (Figure 3). This lower section of the White Salmon River had consistently high densities of spawning fish observed in past WDFW spawning ground surveys (Figure 2; Sean Kramer, WDFW, personal communication, August 2022) and were readily accessible by foot and could be easily observed. A more extensive upstream section was initially surveyed during the first three events in September. However, it was not surveyed during the remainder of the study due to deep water and swift currents.

Table 1. Length and area of stream reaches surveyed in 2022.

Reach ID	General Location	Length of Reach (ft)	Area of Reach (ft^2)
	Upstream section*	1,000*	93,400*
1	Middle section (upstream side channel)	270	16,000
2	Middle section	230	34,500
3	Middle section (downstream side channel)	400	17,000
4	Downstream section	180	15,000
	Total	1,080	82,500

* The upstream section was initially surveyed during the first three events in September, but due to deep water and the swift current was not surveyed during the remainder of the study. The total length and area of reaches surveyed does not include the upstream section.

Figure 3. Location of reaches surveyed on the White Salmon River from September – November 2022. The upstream section denoted by the dashed lines was only surveyed during the first three events in September.

METHODS

This initial feasibility study was conducted in the fall of 2022 focusing on spawning locations within the first river mile of the White Salmon River. Surveys were conducted throughout the spawning season (September – November) with varying flow, water level, turbidity, and weather conditions. Four survey reaches located upstream of the first series of riffles at RM 0.45 to RM 0.7 were selected to monitor the distribution of spawning tule fall Chinook salmon (Figure 3). A team of two to three biologists completed surveys weekly by walking upstream throughout each designated reach. Beginning with the start of the tule fall Chinook salmon spawning migration (i.e., week of September 5) and continuing through late fall (i.e., week of November 28), crews completed surveys to identify and collect data on tule fall Chinook salmon redds[2]. No surveys were done the week of November 21 due to unfavorable weather conditions. Due to the similarity in appearance of tule and URB fall Chinook salmon, the week of October 3 was used as a cut-off date to ensure that only redds of spawning tule fall Chinook salmon were assessed for superimposition. This cut-off date corresponds to one and a half to three weeks before URBs were first observed during past WDFW spawning ground surveys[3] (Figure 4). After this cut-off date, new tule redds were recorded but not included in the assessment of redd superimposition. Tule and URB fall Chinook salmon were distinguished by maturation characteristics; tules exhibit advanced maturation and darkened skin at freshwater entry versus URB fall Chinook salmon, which have brighter skin at freshwater entry and mature 1–3 months after freshwater entry (Myers et al. 2006). Currently, there is no reference or identification guide to visually distinguish hybrid individuals.

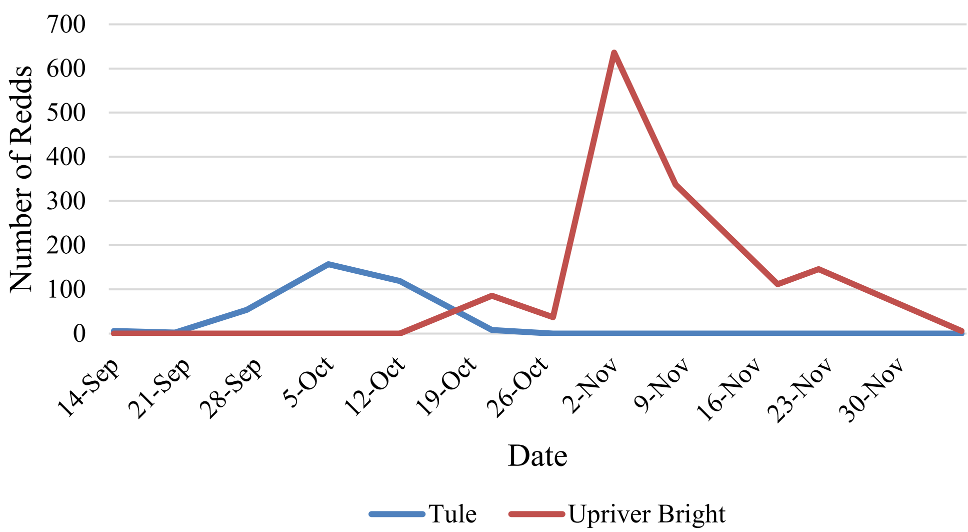

Figure 4. The number of fall Chinook salmon redds observed from RM 1.44 to the mouth of the White Salmon River during WDFW spawning ground surveys in 2021.

[2] Based on WDFW spawning ground surveys from 2015-2021, tule fall Chinook salmon spawners were first observed within the lower 1.44 RM of the White Salmon River between September 2 and October 3 (median date of first observation September 17), and were recorded through late October (i.e., October 21 through October 31).
[3] Based on WDFW spawning ground surveys from 2018-2021, URB fall Chinook spawners were first observed in mid to late October (October 19 through October 31).

Identification of tule redds

Tule fall Chinook salmon redds were identified by wading upstream throughout each designated survey reach. The gravel from recently dug redds appeared lighter colored and less uniformly oriented than the surrounding undisturbed gravel. All mature redds consisting of a pit (i.e., depression) on the upstream end and a tailspill of excavated gravels on the downstream end were identified (Burner 1951; Figure 5). Incomplete or test redds were noted but not counted as new redds until a clearly defined pit and tailspill was observed during subsequent surveys. Attention was taken to distinguish redds from areas of general scouring associated with high flows and large woody debris. Upon encountering a mature redd, surveyors identified the locations of the pit and tailspill area. If possible, pictures were taken of the redd looking downstream, including any landmarks on nearby banks to help identify the redd in subsequent surveys. The location of the redd was marked by taking a GPS point at the upstream end of the tailspill consisting of excavated gravels covering incubating eggs (i.e., egg pocket). Redd locations and associated GPS coordinates were recorded using a tablet computer with ArcGIS Field Maps and an Arrow RTK GNSS Receiver resulting in centimeter-level location accuracy. A polygon was created around clearly defined redds by walking around the outside perimeter of the redd. The boundary of the entire excavated portion of the redd back to the highest point of the tailspill was recorded. The downstream end of the tailspill was not included, as this area typically consists of excavated fine material not covering eggs and can sometimes have an elongated shape due to river currents carrying fines further downstream (Figure 5). In some cases, another polygon was created around the boundary of the redd during subsequent surveys to document the progression and expansion of the redd further upstream. In high-density spawning areas where redd boundaries overlapped, the total dimensional area of redds were recorded by walking around the entire border of the area with the disturbed substrate. A GPS point was also taken at the upstream end of individual tailspills within the disturbed area to document individual redds.

Additional data were recorded for each redd using a tablet computer with ArcGIS Field Maps including: a unique identification number for each redd observed, date, time, field crew, fish species, redd age (e.g., new redd, still present, still present but not measurable, no longer present, poor condition [cannot measure]), superimposed (no/partial/yes), disturbance (none/minor/major), fish presence on the redd (no/yes), fish sex (male/female/unknown), spawning behavior observed (pre-spawning/spawning/post-spawning), and general comments. Additionally, the reach ID and location name, air temperature, water visibility, and weather conditions were recorded for each survey. River discharge and gage height were obtained from the USGS stream gage 14123500 located upstream on the White Salmon River at RM 1.9.

Documentation of superimposition

To document superimposition, tule redds identified during initial surveys (i.e., week of September 5 through the week of October 3) were monitored throughout the remainder of the tule and URB fall Chinook salmon spawning runs (i.e., week of October 10 through the week of November 28). Superimposition was determined in the field by visual inspection of identified tule redds to evaluate whether the redd was excavated on top of by a URB fall Chinook salmon, including documenting fish presence and observations of digging or guarding of the new superimposed redd. When a new redd was observed near a previously documented tule redd, GPS coordinates and redd polygon boundaries, along with associated pictures of the tule redd, were used to assess the degree of overlap. Often a new GPS point and polygon boundary was created for the URB redd to assist in assessing overlap. Observations of tule redd alteration were noted in relation to the degree of overlap of redd boundaries and disturbance. A 0–2 rating system was used to classify the degree of overlap and disturbance to the tule redd and to characterize the level of superimposition observed. If there was no overlap of redds and no disturbance observed, the score was 0. Redds with less than 50 percent overlap and minor structural disturbances observed were scored 1. Redds severely altered with greater than 50 percent overlap were scored 2. Only redds with scores of 2 were identified as superimposed, meaning that a significant overlap of redds had occurred coupled with substantial scouring and deposition to the point where the original tule redd perimeter and shape were unrecognizable. These field observations supported by GPS coordinates and boundaries of tule redds recorded with ArcGIS Field Maps and an Arrow RTK GNSS Receiver (i.e., centimeter-level location accuracy) were used to make determinations on whether the construction of the new redd superimposed a previously documented tule redd.

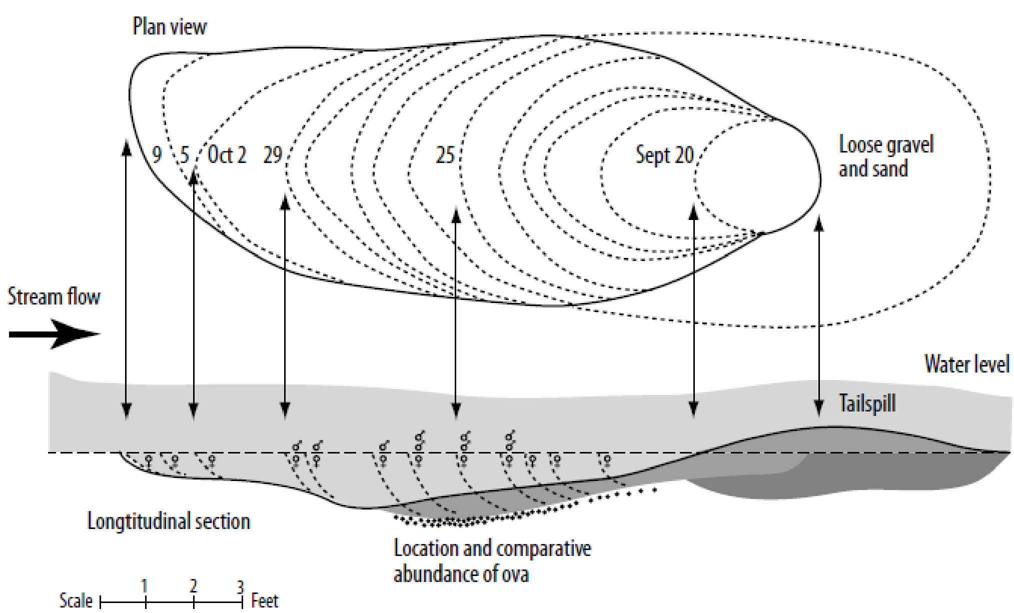

Figure 5. Plan and longitudinal views of a fall Chinook salmon redd measured daily (Illustration from Burner 1951).

While redd boundaries may overlap, the extent of disturbance to the egg pocket of a redd is critical to understanding the potential negative impacts of superimposition. Disturbance to the egg pocket of a redd could result in dislodged fertilized eggs and reduced or lost production. To aid in identifying disturbance specifically to the egg pocket, a large-sized (12-18 cm [5-7 inch] diameter) orange-painted rock was placed on the egg pocket of 15 pre-selected tule redds on October 11 after documented spawning activity for those redds had ceased (Figure 6). The position of the rock was recorded to the nearest centimeter and checked on subsequent surveys. Observations of movement and shifting of the rock helped determine the level of scouring and deposition to the original tule redd and the degree of disturbance associated with superimposition.

Figure 6. Tule redd with an orange painted rock placed on the egg pocket. Several upriver bright fall Chinook can be seen in the background constructing new redds adjacent to the tule redd. Photo taken on October 25, 2022.

RESULTS

Tule redds observed

No mature redds were found during the first survey on September 7, though four incomplete or test redds were observed. The first complete tule redds recorded were on September 13 (n = 7 redds). Over the following three survey events, the number of tule redds encountered increased precipitously from 24 redds recorded on September 20 to 45 redds on September 27 and 39 redds on October 4. A total of 115 tule redds were recorded across all four reaches from the first survey event on September 7 to the cut-off date on October 4 (Table 2; Figure 7). Additional tule redds were observed during surveys on October 11 and 19 but were not included in the assessment of redd superimposition. This was due to the similarity in appearance of tules and URBs that can often make it difficult to determine the identity of spawners, especially when the two fall Chinook spawning runs overlap. Evidence also suggests hybrid individuals comprise a significant component of the spawning population in mid to late October (Mussmann et al. 2023). In 2022, URBs were first observed within the surveyed reaches on October 19.

Ninety-one percent of the tule redds observed through October 4 were revisited at least once during the remainder of the study period, with many of the redds revisited weekly. The ten tule redds not revisited were primarily due to their location in high-flow or deep-water areas.

Table 2. Total number of tule fall Chinook Salmon redds observed and revisited by survey reach, including the number of redds with spawning observed.

Reach ID	General Location	Number of redds observed*	Number of redds revisited†	Redds not revisited in Nov.	Redds with spawning observed
1	Upstream side channel	10	9	4	5
2	Middle section	81	75	7	42
3	Downstream side channel	6	6	1	4
4	Downstream section	18	15	4	7
	Total	115	105	16	58

* Number of tule redds observed through the October 4 cut-off date

† Number of tule redds revisited at least once from October 11 – November 29

An additional 16 of the 105 revisited redds (15 percent) were not surveyed during November (Table 2). Thus, a total of 89 out of 115 observed tule redds (77 percent) were surveyed throughout the entire study period. Spawning pairs of tules were observed on 58 of the redds surveyed, with most spawning observed in reach 2 (middle section) (Table 2). Spawning on the surveyed tule redds was observed as early as September 13 and as last as October 11, with the median date of spawning during the last week of September (Table 3; Figure 7). The median date of spawning observed varied slightly among surveyed reaches, with reach 4 (downstream section) one week earlier than reaches 2 and 3 (middle section and downstream side channel) (Table 3). Spawning observed in the furthest upstream surveyed reach 1 (upstream side channel) was delayed slightly compared with other reaches occurring the first week of October.

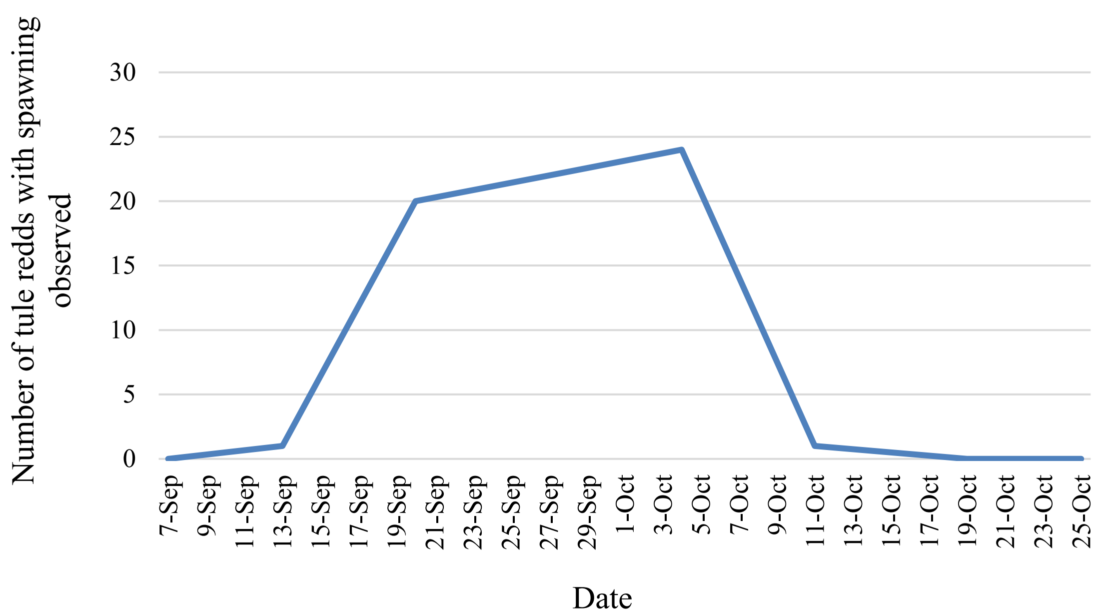

Figure 7. Timing of tule fall Chinook salmon spawning on redds observed from September through the first week in October.

Table 3. Median date of spawning observed on tule fall Chinook salmon redds.

Reach ID	General Location	Median date of spawning observed
1	Upstream side channel	10/4/2022
2	Middle section	9/27/2022
3	Downstream side channel	9/27/2022
4	Downstream section	9/20/2022
	Median date for all reaches	9/27/2022

Redd superimposition

Tule redds identified in September through the first week of October were monitored for superimposition during the remainder of the tule and URB spawning runs (i.e., through the last week of November). Across all surveyed reaches, a total of 63 tule redds were superimposed, meaning the redd was severely altered with greater than 50 percent overlap observed among redds (Table 4; Figures A1-A4). This represented 71 percent of the 89 tule redds observed through the first week of October and monitored during the entire study period. There were an additional 15 tule redds (17 percent of the total) with minor disturbance observed (i.e., redds overlapped < 50 percent and had only minor scouring or deposition) (Table 4; Figures A1-A4). Most of the redds superimposed occurred in middle to late November, approximately four weeks after URBs were first observed within the surveyed reaches (Figure 8). Overall, approximately 88 percent of the 89 tule redds observed were impacted or disturbed in some way during the URB spawning run.

Eleven of the 15 tule redds (73 percent) with orange-painted rocks placed on their egg pockets were superimposed by URBs and severely altered with greater than 50 percent overlap among redds. The other four tule redds with orange-painted rocks showed only minor disturbance or less than 50 percent overlap among redds. Information on the movement and shifting of the painted rocks collected during weekly observations through the URB spawning run helped determine the level of scouring and deposition to the original tule redd and the degree of disturbance associated with superimposition. For example, the weekly sequence of observations for one superimposed tule redd post-spawning was: (week 1) orange painted rock placed on egg pocket of tule redd after spawning; (week 2) recently cleared gravel and rocks from a new redd construction upstream deposited on top of painted rock; (week 3) painted rock appeared to be completely buried under gravel and sediment; (week 4) painted rock may no longer be present; (week 5) painted rock reappeared in the same location, dug up from a new redd pit being constructed. Polygons created around the perimeter of the original tule redd and later constructed URB redds, along with these weekly observations, allowed the determination of superimposition to be made.

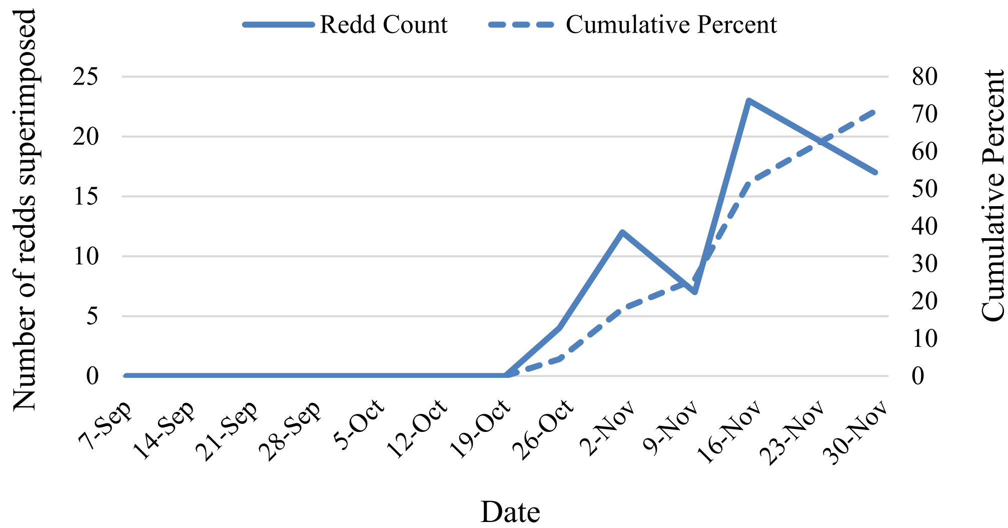

Figure 8. Number of tule fall Chinook salmon redds superimposed by survey date.

Table 4. Number of disturbed and superimposed tule fall Chinook salmon redds observed in each survey reach.

Reach ID	General Location	Number of tule redds monitored	Number of redds with minor disturbance*	Percent of redds with minor disturbance†	Number of redds superimposed‡	Percent of redds superimposed†
1	Upstream side channel	5	1	20	4	80
2	Middle section	68	10	15	50	74
3	Downstream side channel	5	2	40	2	40
4	Downstream section	11	2	18	7	64
	Total	89	15	17	63	71

* Minor disturbance characterized as redds with < 50 percent overlap, minor scouring and deposition
† Percent of redds surveyed throughout the entire study period (n = 89 redds)
‡ Superimposition was characterized as redds with > 50 percent overlap, major scouring and deposition

DISCUSSION, CONCLUSIONS, AND MANAGEMENT IMPLICATIONS

One of the main goals of this feasibility study was to assess the methodology for identifying superimposition of tule redds by URB fall Chinook salmon within the lower White Salmon River. While only focused on four reaches within the first river mile, the methodology employed successfully documented redd superimposition. In fact, this study revealed a surprisingly high incidence (71 percent) of tule redd superimposition by URBs, with approximately 88 percent of all tule redds surveyed disturbed in some way. These results draw further attention to the potential impacts of hatchery-origin URBs on the ESA-listed tule population. In some systems, redd superimposition can result in significant density-dependent mortality by damaging, dislodging, and preventing eggs from maturing (McMichael and James 1995; Fukushima et al. 1998; Dudley 2019; Hendry et al. 2004). These potential impacts on the White Salmon River tule population are also compounded by high levels of hybridization and introgression with URBs. Below we evaluate some drawbacks of the methodology used in the current study, discuss potential management implications, and suggest future studies to measure the impacts of superimposition.

The results of this feasibility study were for only one spawning season and a relatively short section of the river. Thus, the frequency of observed superimposition may not represent the entire spawning population or reflect superimposition across years. If redd superimposition is due to habitat limitation (i.e., density-dependent effects), then years with high spawner abundance would also be expected to have high superimposition estimates. In contrast, years with low spawner abundance would be expected to have low superimposition estimates. Current forecasts for the 2023 Columbia River fall Chinook salmon return have projected a high return for tules from Bonneville Pool Hatcheries (149 percent of the 10-year average return), while a low return for URBs in the Bonneville Pool (49 percent of the 10-year average return) (WDFW, *U.S. v Oregon* Technical Advisory Committee Sub-group, February 21, 2023). Forecasted returns of natural-origin tules to the White Salmon River are unknown. However, based on the current forecasts, the relative percent of tule redds superimposed in 2023 might be expected to be lower than observed in the current study due to lower numbers of URBs present on spawning grounds. An evaluation of redd superimposition over multiple spawning seasons would be required to determine if there is a correlation between spawner densities and rates of superimposition.

Expanding the area surveyed in the current study to encompass larger sections of the White Salmon River could be challenging with the methods employed. Deep water and swift currents in some sections could prevent crews from accessing spawning areas. Similarly, higher river flows may prevent crews from safely completing surveys in years with heavy precipitation. An additional consideration would be the amount of time required to complete surveys. In the current study, a crew of two to three biologists could survey the designated reaches in one day. Expanding the study area might require an additional three to four days, depending on the area surveyed and the number of redds observed. A stratified random sample design (Irvine et al. 1992) could allow for a more extensive study area while accounting for financial and logistic constraints. Under a stratified random approach, the study area would be divided into segments of equal length, then a specified number of segments would be randomly selected for surveys. The average density of tule redds, or relative percent of redds superimposed in those randomly selected segments, could then be multiplied by the entire length of available spawning habitat in the study area. This approach has several advantages, including incorporating statistical uncertainty associated with estimates. However, it does not account for areas inaccessible due to deep water or swift currents or consider other factors like redd clustering (i.e., spawners may be highly selective of habitat and spawn together in clusters).

Ground surveys like those employed in the current study supplemented with concurrent aerial surveys using an unmanned aerial vehicle (UAV) could provide high-resolution georeferenced imagery of spawning grounds. Images from sequential flights of surveyed areas could be viewed simultaneously, side by side, using ArcGIS software to determine weekly changes in the spatial pattern of redd locations. This would allow newly constructed redds that overlap with previously observed redds to be identified (i.e., superimposition). Counts of redd superimposition from UAV surveys might be more accurate than ground surveys because staff could review high-definition georeferenced images multiple times, zooming in and panning as needed to allow redds to be quantified more clearly. Images could also be taken of spawning areas inaccessible to ground survey crews due to deep water and swift currents. Images of high-density spawning areas could also aid in identifying redd superimposition, as these areas often contain large contiguous clusters of disturbed gravel.

Notwithstanding some of the limitations of the current feasibility study, the high incidence of superimposition observed could have important management implications. The 2017 Biological Opinion (BiOp) for the URB program at LWS NFH lists several Terms and Conditions (T&C) to minimize impacts on the ESA-listed tule fall Chinook salmon population (NMFS 2017). Among these T&C includes 2b. (page 132, NMFS 2017) which states: "*The USFWS shall manage the program such that the abundance of hatchery-origin URB fall Chinook produced under the Proposed Action that spawn naturally in the White Salmon River shall not exceed 3,000 adults, based on a 3-year moving average*". In this case, the estimated abundance of hatchery-origin URB spawners is used as a surrogate for the level of incidental take by loss of productivity due to the production of hybrids and redd superimposition. The current study provides important information on the incidence of redd superimposition that could be used during the reinitiation of consultation on the BiOp in 2024 (NMFS 2017; Page 133, Section 2.10). The LWS NFH has been actively taking steps to reduce the number of stray hatchery-origin URBs spawning in the White Salmon River. However, efforts thus far have not significantly reduced straying. One potential step that the Service has proposed is to shift a portion of the brood year 2023 URB production (500,000 URBs) off-station for rearing and release (e.g., rearing at Bonneville Hatchery with acclimation and release in the Umatilla River). These potential changes could help reduce the number of hatchery-origin URBs straying to the White Salmon River in the future.

More detailed studies would be required to evaluate the negative impacts of superimposition, including quantifying production lost from egg displacement or damage. One approach often used to estimate survival from egg to fry is redd caps or emergent fry traps. These traps are set to encompass an entire redd and typically consist of an outside steel or PVC frame with a nylon mesh net attached with a funnel feeding a collection device (Tagart 1984). The traps are checked daily or every other day during fry emergence to identify, enumerate, and release fry. There are several drawbacks to using redd caps in the White Salmon River to estimate egg-to-fry survival of superimposed tule redds, including: (1) installing redd caps may require excavating part of the tule redd to ensure the trap is placed correctly and secured; (2) river flows during winter months are often at peak flow and could result in lost or fouled gear and cause difficulties checking traps for fry emergence; (3) potential confounding effects associated with redd physical characteristics (e.g., surface area, water velocity, substrate particle size, etc.) could result in different survival among redds irrespective of superimposition; (4) fry potentially escaping the trap would cause an underestimation of egg survival; (5) difficulties in identifying fry of tule versus URB would require taking genetic samples; and (6) hybridization among adult tule and URB could complicate assessment of superimposition impacts on "pure" tule redds.

An alternative approach to assess the negative impacts of superimposition could be to estimate egg-to-fry survival using tule eggs outplanted in egg boxes (e.g., Vibert boxes). A known number of fertilized tule eggs from Spring Creek NFH[4] (e.g., 200 eggs/box) could be added to an egg box with gravel and planted into an artificially constructed redd before the URB spawning run. The boxes would be placed in excavated pits and positioned to lie approximately 25 cm below the gravel surface (i.e., egg burial depth of fall Chinook salmon) (DeVries 1997). The artificial redds would be checked throughout the URB spawning run to document disturbance and redd superimposition. After the spawning season, the egg boxes would be recovered to examine the condition of the eggs, enumerate dead eggs, and document fungal growth. To estimate egg-to-fry survival rates, the percent of viable eggs could be compared among superimposed and undisturbed redds. Combined with the relative percent of tule redds superimposed based on spawning ground surveys, these estimates could be used to quantify production lost from superimposition.

Sliding-bead monitor scour chains could also measure the degree of scouring and deposition from superimposition. These scour chains allow accurate, direct measurement of maximum scour depth and subsequent deposition while not interfering with the spawning activities of fish (Nawa and Frissel 1993). The sliding-bead monitor scour chain would initially be buried at a known depth prior to URB spawning and monitored throughout the spawning run. If any scouring of the substrate occurs, buried beads would be released into the water column and swept to the end of the unburied portion of the wire. The number of beads that moved to the end of the braided wire multiplied by the bead diameter would represent the depth of scour that occurred. Similarly, if any sediment is deposited on top of the monitor, the amount of deposition can be determined by measuring the length of buried wire. The USGS stream gage 14123500 at RM 1.9 on the White Salmon River could be used to monitor daily river discharge to account for possible scour or fill caused by discharge fluctuations. Scour and deposition depths measured with scour chains and attributed to URB spawning activity could be used to measure the degree of disturbance to superimposed tule redds directly.

The evaluation of methodology and potential future studies presented above will be considered along with financial and logistic limitations when developing and implementing study plans for the 2023 field season

[4] Broodstock for the tule program at Spring Creek NFH originated from the White Salmon River located approximately 1.5 kilometers upstream of the hatchery.

identify which uncertainties are most relevant to management and help target study design and data collection.

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APPENDIX A: TULE REDD LOCATIONS FOR EACH SURVEY REACH

Figure A1. Reach 1 survey map of tule fall Chinook salmon redds observed from September through first week in October. Tule redds superimposed are shown in red.

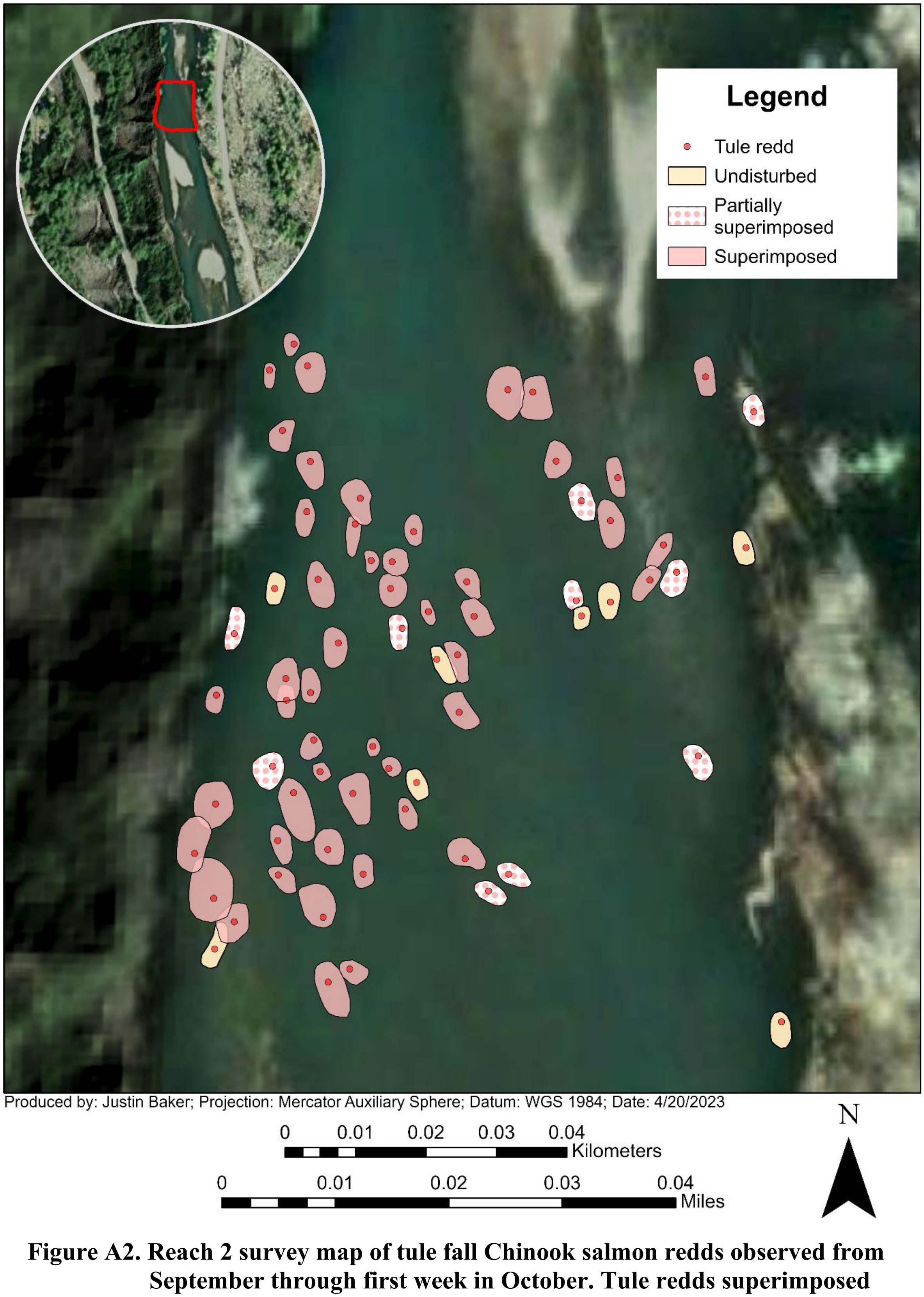

Figure A2. Reach 2 survey map of tule fall Chinook salmon redds observed from September through first week in October. Tule redds superimposed are shown in red.

Figure A3. Reach 3 survey map of tule fall Chinook salmon redds observed from September through first week in October. Tule redds superimposed are shown in red.

Figure A4. Reach 4 survey map of tule fall Chinook salmon redds observed from September through first week in October. Tule redds superimposed are shown in red.

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