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Estimating Winter Steelhead pHOS in the Elwha River: 2021

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Abstract

A native broodstock hatchery program was developed to assist with the preservation and restoration of winter Steelhead (*Oncorhynchus mykiss*) in the Elwha River during and following dam removal. Monitoring data are required to assess recovery progress and inform future management decisions. We assessed in-river distribution and entry timing of hatchery-origin (HOR) and natural-origin (NOR) steelhead, estimated the proportion HOR winter steelhead spawners (pHOS) and collected broodstock to help meet egg-take and integrated stock goals. We sampled 32 sites from river kilometer 0.3 to 31.0 from January 11 to June 8, 2021 (21 weeks) using a tangle net. River entry timing of NOR steelhead were more protracted, and they were distributed over a larger spatial extent compared to HOR steelhead, resulting in site specific (~300 m to several km) pHOS estimates that varied from 0 to 1. Due to this variation, we only used data from six lower river sites where HOR and NOR steelhead were assumed to display similar migratory behavior (i.e., are migrating through the sites) when developing the overall pHOS estimate. A P-spline was fit to pHOS values from these lower sites, providing daily estimates of pHOS that were applied to daily passage estimates from SONAR imaging. Based on this method, the 95% credible intervals suggest HOR steelhead made up between 31% and 64% of the overall spawning population. In contrast to previous years, the variation was not as dramatic in the lower river. This may be due to the apparent increase in HOR steelhead this year compared to previous years (approximately double). Since HOR steelhead are apparently remaining in the lower river, the increased abundance may lead to increased distribution further downstream and into the sites used for the P-spline pHOS estimate. If this is the case it would increase the potential bias at these sites by increasing their probability of capture and inflating the pHOS estimates. Through our sampling effort, 20 steelhead (5 NOR steelhead and 15 HOR steelhead) were provided to the hatchery for broodstock, representing 21.7% of the total broodstock and 100% of the NOR broodstock in 2021. We recommend increasing sampling effort in the lower river (i.e., downstream of the mainstem and Hunts Road side channel) to provide a larger sample size for pHOS estimates and between rkm 5 and 14 to gain a better understanding of HOR distribution in the river.

Introduction

Hatcheries have played a prominent role in the preservation and subsequent recovery of Pacific salmon (*Oncorhynchus sp.*) and steelhead (*O. mykiss*) following dam removal in the Elwha River (Ward 2008; Peters et al. 2014). Two factors important to consider when hatcheries are used in recovery programs include the proportion of hatchery-origin (HOR) relative to natural-origin (NOR) spawners (pHOS) (e.g., Paquet et al. 2011; HSRG 2015).

Winter steelhead in the Elwha River are currently in the preservation phase of recovery, for which there is no pHOS criteria. However, due to a transcribing error, the Biological Opinion (NMFS 2015) lists criteria for the number of natural spawners (i.e., spawners not of hatchery-origin), although the cited document lists this as naturally spawning adults (i.e., spawners of any source naturally spawning in the river) (Peters et al. 2014). The NMFS 2015 document is the guiding document, which therefore requires an estimate of natural spawners, which in turn requires a pHOS estimate to derive an estimate for natural spawner steelhead. In addition, there is a pHOS trigger to move from the recolonization phase into the local adaptation phase (0.10) and managers recognize the importance of monitoring for pHOS and NOR steelhead abundance even during the early stages of recovery (Peters et al. 2014). In addition, it is recognized that obtaining an unbiased estimate may be difficult because of apparent differences in entry timing and distribution of HOR and NOR steelhead, which could result in different catch rates between HOR and NOR steelhead (Peters et al. 2020, 2021). While the proportion of HOR steelhead caught during species composition sampling for SONAR population estimates was reported prior to 2019 and ranged from 0.25 (2013) to 0.87 (2015), the author stressed that these values would be biased if used to represent pHOS. The estimates were assumed to be biased since the sampling was intended to provide species composition data to the SONAR passage data and was not designed to estimate pHOS. The sampling from 2013 - 2018 was heavily concentrated near the LEKT hatchery during the bulk of the HOR steelhead return and no attempt was made to correct for timing and distribution differences between HOR and NOR steelhead and are therefore biased towards HOR steelhead (Denton et al. 2013–2018). Data collected during 2019 and 2020 support this assumption (Peters et al. 2020, 2021). This potential bias is due to the concentration of sample sites near the LEKT hatchery, with two sites either starting or ending at the hatchery attraction channel, where hatchery fish preferentially home. The hatchery program for winter steelhead on the Elwha River has transitioned from a captive brood program to an integrated recovery program, and will ultimately be eliminated, once a self-sustaining natural-origin population of steelhead capable of sustaining meaningful harvest is established without continued hatchery support (LEKT and WDFW 2019; LEKT 2012).

The objectives of this project were to assess the entry timing and distribution of HOR and NOR steelhead in the Elwha River to improve our ability to estimate pHOS and estimate pHOS for the 2021 return of winter steelhead in the Elwha River. The 2021 effort supplements data collected during 2019 and 2020 (Peters et al. 2020, 2021). A final objective was to provide broodstock to the Lower Elwha Tribe (LEKT) hatchery to help maintain the integrated hatchery program. This was a cooperative effort between K. Denton and Associates LLC (KDA), U.S. Fish and Wildlife Service (FWS), NOAA Fisheries, and the LEKT.

Methods

Field Data Collection

Sampling occurred from the lower Elwha River to just upstream of Rica Canyon in Olympic National Park across the following three general study reaches: lower, middle, and upper (Figure 1). Within each study reach, sample sites were spaced as evenly as possible throughout the overall sampling area, which was dictated by our ability to sample a given site (Figure 2 and 3). Sample site length varied and was determined by our ability to fish the site effectively and safely. The lower reach included the area from the mouth to just upstream of the downstream end of Elwha Canyon (~rkm 0.3–8.0). The middle reach included the area from the upstream end of Elwha Canyon upstream to the downstream end of Glines Canyon (~rkm 8.5–22.5). The upper reach extended from the upstream end of Glines Canyon to Long Creek just upstream of Rica Canyon (~rkm 23.0–31.0; Figure 2).

Elwha winter steelhead were sampled using a tangle net or hook-and-line sampling to assess distribution of HOR and NOR steelhead, estimate pHOS and collect broodstock for the LEKT hatchery. The sampling method varied by reach. The lower river sites were sampled only with a tangle net, the middle river was sampled with a tangle net at discharges less than about 1,500 cfs and using hook-and-line at greater discharges, and the upper river was sampled only with hook-and-line. The different methods were due to differences in gradient and substrate that prohibited safe use of the tangle net in the middle (at greater discharges) and upper river. Sampling events with the tangle net included a single drift through the site, while a hook-and-line sampling event included sufficient casts that the samplers felt the site had been adequately sampled. Sampling occurred throughout the expected entry timing of winter steelhead (January - June; Table 1). Sampling intensity varied among sites and reaches during the study, which depended on how effectively they could be fished and their utility for estimating distribution and deriving pHOS estimates. Lower river sites were generally sampled weekly, while middle and upper river sites were sampled on approximately a monthly basis. Broodstock collection occurred only in the lower reach (Figure 1 and 2). The tangle net was approximately 18 m long, 2 m deep, with loosely hung 10 cm stretch mesh composed of very fine monofilament (#6-8). We drifted the net through each sample site using a crew of three samplers.

We collected biological data from all captured steelhead after sampling the entire site, noting fish origin as hatchery or natural (based on the presence/absence of the adipose fin), sex, and fork length. In addition, scale samples (aging) and fin clips (DNA analysis) were collected and provided to NOAA Fisheries for on-going assessments. If steelhead were not retained for broodstock, they were Floy tagged (T-bar spaghetti tag) prior to release to assess recapture rates.

Steelhead were only retained for the broodstock program if they appeared ripe and ready to spawn and the LEKT was ready to spawn them. Both sexes of HOR and NOR steelhead were provided to the hatchery to help ensure selection factors associated with the different sexes were incorporated into the integrated hatchery program. We set the maximum number of NOR steelhead retained for broodstock at 30 fish to minimize the impacts on colonization of the upper Elwha River watershed. We also attempted to keep the number of NOR females included in the brood to a minimum (ideally 10) since females are the primary mechanism for recolonizing new habitat in the upper Elwha River. The goal was to incorporate fish collected throughout the run to limit potential selection effects (e.g., Weigel et al. 2019). Brood fish were put into a live bag,

which was then put into a tote filled with well water from the hatchery. The tote and fish were transported back to the hatchery. Once the fish were delivered to the hatchery, ripe females were sacrificed and spawned immediately. Males were live spawned as needed and marked with an opercle punch to indicate they had been spawned. Green females and males were placed in the brood pond separated by sex and allowed to mature. Following spawning of the last ripe female, the remaining live HOR males and green females were returned to the river.

Assessing Spatial and Temporal Distribution

We assessed spatial and temporal differences among HOR and NOR steelhead using two methods. First, we used a chi-square test (Zar 1999) to assess differences in the number of HOR and NOR steelhead by groups of sites and month. We used this level of spatial and temporal groupings to ensure the sample size was adequate (Zar 1999). Second, we compared spatial and temporal differences by calculating pHOS by groups of sites for each month of sampling. The lower reach sites were separated into four groups (Bluff, Hunts Rd, Old Mainstem, and WDFW; Figure 3). The middle and upper reaches each served as separate groups. This resulted in six groups of sites to assess spatial and temporal differences among HOR and NOR steelhead. The pHOS estimate for each group was calculated by dividing the number of HOR steelhead caught by the total number of steelhead caught at each group of sites during each month. Recaptured fish were only included in the pHOS estimate at the site where they were first caught.

Calculating pHOS

We estimate overall pHOS by applying the hatchery fraction observed in the eight most downstream sites in the lower reach (end of road, below high bluff lb, DS Hunts High Bluff, DS High Bluff drift 2, US high bluff, US high bluff rb, bottom OM, lower HRC) [$\sim$ rkm 0.3 – 1.6]) to the daily SONAR passage estimates (see Denton 2022 in press for details of the SONAR estimates). These sites were assumed to be the least biased with limited differences in distribution between NOR and HOR steelhead. This assumption was due to the fact that they are either downstream of the main channel split or at the downstream end of the two converging channels (the Hunt Road channel) one of which bypasses the LEKT hatchery and one (Old Mainstem) which passes by the LEKT hatchery. In addition, a braid from the Old Mainstem channel enters the lower Hunt Road Channel upstream of the lower HRC site so fish captured at the lower HRC site could migrate up either the OM or HRC.

A daily pHOS estimate for Elwha winter steelhead was calculated by fitting a P-spline to the pHOS observed during our 13 survey dates across the eight most downstream sites in the lower reach in 2021. We then multiplied the daily estimates of pHOS (from the spline fit) by the estimated number of fish entering the river (from the imaging SONAR), to estimate the daily number of HOR steelhead entering the river. Lastly, we calculated pHOS by summing the total number of HOR steelhead entering the river and dividing by the total number of fish entering the river.

The P-spline is a type of smoothing spline which fits a smooth curve through a series of points with the smoothness determined by the model (Eilers and Marx 1996). That is, non-smooth

curves that jump around to fit the data are penalized based on the data. The P-spline is a popular smoothing method that is applied across many fields including fisheries management (e.g., Bonner and Schwarz 2011). Here we used a Bayesian implementation based on JAGS code available at

(https://github.com/andrewcparnell/jags_examples/blob/master/R%20Code/jags_spline2.R; See Appendix B for more details). We added a synthetic sampling event on the first day of SONAR operation to anchor the early season when sampling had not yet begun. The sample contained a single NOR steelhead, which mirrors pHOS from the first few sampling events over the year (Peters et al. 2020, Peters et al. 2021).

Because we are using a statistical model that accounts for uncertainty in the model form and data, the final product is not a single estimate but a distribution of plausible estimates. If this distribution is wide, then focusing on a specific “best” estimate may be counterproductive. Here we use a Bayesian approach so this distribution, the posterior distribution, can be used to make statements like, “there is a 70% chance that pHOS is between value 1 and value 2”. Thus, if there is strong evidence in the data for an abrupt change, the spline will attempt to accommodate this change.

Results

Sampling and Catch Summary

We sampled 32 sites ranging from 50 to 442 m in length from January 11, 2021 to June 8, 2021 (21 weeks) (Table 1, Figure 1-2). This included 17 sites in the lower river (total length = 3,253 m), nine sites in the middle river (total length = 2,042 m), and six sites in the upper river (total length = 1,081 m). Each site was sampled from 1 to 22 times with a total of 61.1 km, 10.4 km, and 4.0 km sampled in the lower, middle, and upper Elwha River, respectively. Our sampling resulted in 264 samples, of which 85 resulted in steelhead capture (32%). The proportion of sampling events resulting in steelhead capture was 28% in the lower river (66 of 237 samples), 67% in the middle river (12 of 18 samples), and 78% in the upper river (7 of 9 samples).

Across all sites, we sampled 174 fish representing three species and two life history forms of *O. mykiss*. We caught 125 steelhead, 27 Bull Trout (*Salvelinus confluentus*), 2 Chinook Salmon (*O. tshawytscha*), and 17 resident *O. mykiss* (Appendix A). Of the 128 steelhead caught 80 were females and 41 were males, with sex not noted for the rest (i.e., escaped before sex could be determined) and 39 were HORs (31.3%) (Table 2).

We recaptured six of the 96 tagged steelhead released back into the river during our sampling. Three of these recaptures were NOR's and three were HOR's. One NOR was recaptured on the same day of the original capture at a site downstream. The other two recaptured NOR's were both originally tagged in the middle river, one was recaptured just upstream about a month later, while the other was recaptured in the lower reach about two weeks later. All three recaptured HOR's were originally tagged in the lower reach and were all recaptured in the lower reach. One HOR was recaptured twice after originally being captured upstream near the WDFW hatchery outlet. The first recapture occurred downstream at the upstream end of the Hunts Rd Side channel one month after the original capture. This fish was caught the following week downstream of the second recapture location. The second, moved from the lower Hunts Road channel to the Old Mainstem near the hatchery and was recaptured two weeks later. The last

recaptured HOR was caught at the DS High Bluffs Drift 2 site and was recaptured at Willey's bucket near the hatchery outlet 12 days later.

Assessing Spatial and Temporal Distribution

There were spatial and temporal differences in catch of HOR and NOR steelhead throughout the river, including the lower Elwha River (Tables 2 and 3; Figure 4). Counts of HOR and NOR steelhead varied among sites (Chi-Square: $P = 0.0002$). These differences were due to the lack of HOR steelhead observed in the middle and upper river. There were no differences observed by site when just the lower reach sites were used (Chi-square: $P = 0.3832$). Counts of HOR and NOR steelhead also varied by month (Chi-square: $P = 0.0005$). Differences by month remained even after removing January and February from the analysis, since no HOR steelhead were observed during those months (Chi-square: $P = 0.0134$).

The differences detected by the Chi-square statistics also resulted in differences in pHOS calculated across spatial and temporal groupings. Natural-Origin steelhead represented a slightly greater proportion of the catch in the channel not associated with the hatchery (Hunts: 0.29), while HOR steelhead were slightly more prevalent at the WDFW group (0.42) of sites which are all upstream of the channel split. No HOR steelhead were caught in the middle or upper reaches even though we sampled 38 NOR steelhead in these sites. Natural-origin steelhead dominated the catch during January through March, with the first HOR steelhead being caught on March 2, 2021. Hatchery-origin and NOR steelhead were caught in similar numbers during April and May, while only HOR's were caught during June. Except for the Hunts group in April, HORs represented an equal or greater percent of the catch in the lower reach groups from April through June (Table 3).

Estimated pHOS

The P-spline characterized the temporal trend in the pHOS values, and the associated uncertainty (Figure 5, top panel). The credible intervals for the daily pHOS estimates did not exceed 0.1 until March, ranged from approximately 0.3 to 0.7 through the end of April, and then increased to about 0.7 to 1 for the rest of the run. This resulted in little HOR passage until mid-February, with a majority of the HOR passage occurring from March through April (Figure 5, middle panel). This period also coincides with a general increase in cumulative passage (Figure 5, bottom panel). This led to a pHOS estimate with 95% credible intervals that ranged from 0.31 to 0.64 (Figure 6). Table 4 presents additional credible intervals.

Broodstock Collection

Twenty steelhead caught during this work were provided to the LEKT hatchery for broodstock (Table 5). This included steelhead caught from April 6, 2021 to May 11, 2021. Five of these fish, one male, three females, and one sex undetermined, were NOR. Fifteen of these fish, five males, nine females, and one sex undetermined were HOR (Table 5). The 20 fish provided to the hatchery represented 21.7% (20 of 92) of the total broodstock collected. The remaining adults

(27 females, 42 males) volunteered into the hatchery. The five NOR's contributed through this effort represented all the NOR steelhead incorporated into the broodstock and 5.4% (5 of 92) of the brood. Three live females were returned to the river once it was clear no additional females would ripen in the hatchery.

Discussion

Spatial and temporal differences in pHOS exist throughout the Elwha River winter steelhead population; however, the lower river differences were not as dramatic as in previous years (Peters et al. 2020, 2021). No HOR steelhead were caught in the middle or upper reaches despite significant effort this year (e.g., 27 drifts). Despite the reduced variation in pHOS throughout the lower river during 2021, the method of developing a pHOS estimate using only the river sites downstream of approximately rkm 0.6 is still warranted, due to the greater variation observed during the previous two years (Peters et al. 2020, 2021). The pHOS estimate was much greater in 2021 than the previous two years (2019: 0.3-0.4 [Bayesian approach]; 2020: 0.09-0.42). This year's estimate may have greater bias than previous years due to the apparent increase in abundance of HORs and their limited distribution (primarily the lower river) relative to NORs. The apparent lack of movement by HORs into the upper basin, even during years with greater abundance, is cause for concern that pHOS estimates derived from the lower river may have increased bias during years of increased HOR abundance relative to years with decreased HOR abundance since greater numbers of fish are concentrated in the lower river. This may lead to increased spawning activity near the lower sites used to derive the pHOS estimate.

Although, we believe NOR and HOR steelhead behavior and exposure to the sampling in the lower river sites represents the least bias sampling locations in the river, the potential bias at these sites may change with HOR abundance. In general, we assume that most NOR and HOR steelhead migrate past the sites used to derive the pHOS estimate and spawn upstream. This assumption is based on the fact that they are located either downstream or at the downstream end of the channel split whereby one channel leads passed the LEKT hatchery and the other channel bypasses the hatchery. One would expect mixing of HOR and NOR steelhead even a short distance upstream of the split as steelhead determine which channel to follow. This milling behavior would likely be influenced by the presence of water from the Old Mainstem entering the Lower Hunt Roads channel via a braid from the Old Mainstem Channel upstream of the lower HRC site. In addition, relatively few steelhead redds have been observed in or downstream of this group of sites; although, turbidity often limits the effectiveness of mainstem spawner surveys through much of the season (McMillan et al. 2019). Thus, although sites used to calculate pHOS are likely the least biased, bias may occur and may vary with HOR abundance. Therefore, additional exploration of spawning distribution in the lower river is warranted when possible.

HOR abundance may influence bias at the lower river sites due to their concentration in the lower river. HOR steelhead do not appear to migrate as far upstream as NOR steelhead. For example, NOR steelhead were caught upstream to approximately rkm 25, while HOR steelhead were caught only to approximately rkm 5; although no sampling occurred from rkm 5 to 14. Given this observation, NOR steelhead were distributed over more than twice the possible range of HOR steelhead if one considers tributary habitat which is primarily available in the middle

and upper river. Thus, as HOR abundance increases, HORs may begin holding and/or spawning further downstream than they would when less abundant. The variation in pHOS estimates at the lower river groups of sites had a much narrower range (0.29-0.5; Table 3) during 2021 than they did during the previous years (2019: 0.29-0.84; 2020: 0.15-0.57, Peters et al. 2020, 2021). In addition, the Bluff group, which includes most of the sites used to estimate pHOS had the greatest pHOS observed during the three years of data collection (0.50 compared to 0.29 and 0.15 for 2019 and 2020, respectively). This suggests that HORs were more abundant, distributed further downstream than during previous years, or both.

We estimate that HOR escapement during 2021 was nearly double that of 2019 and 2020. Using the midpoint of the pHOS estimates for each year (0.35, 0.26, 0.5, 2019-2021, respectively), results in HOR abundance estimates of approximately (rounded) 500, 520, and 1,150 HOR steelhead during 2019, 2020, and 2021, respectively. Since no HOR steelhead were observed upstream of rkm 14 during 2019 or 2021 (only one sampling effort during 2020), it appears HORs are not pushing significantly further upstream during years of increased abundance. This means they may be spawning primarily downstream near the hatchery (i.e., release location) and possibly within the rkm 5 to 14 reach. Increased spawning downstream of the hatchery could lead to increased bias at the lower river sites used to calculate pHOS during years of increased HOR abundance. Thus, although the lower river sites used to estimate pHOS may be the least biased, the level of bias may increase as HOR abundance increases.

The broad posterior distribution and credible interval observed for the pHOS estimates are due to the small sample size and temporal gaps in the data that result from logistical difficulties in sampling the Elwha River during late winter and spring. Trying to capture a continuous migration process spanning multiple months with tangle nets in a river the size of the Elwha River is difficult. The nets were only fishing during a small fraction of the migration period (i.e., 1 day/wk), steelhead are highly mobile and able to evade the nets, and some sampling dates were missed due to discharge levels that made sampling unsafe. Due to this uncertainty, we have presented the 95% credible interval (0.32 to 0.65) and sample distribution (Figure 6) rather than a point estimate.

Despite increased effort in the lower river per recommendations from previous years (Peters et al. 2020, 2021) and a smaller temporal data gap, the spread of the 95% credible interval was identical in 2020 (0.33) to 2021 (0.33). The sample size for the data used to develop the P-spline were also nearly identical for 2020 (38) and 2021 (41). A difference between the two years was the lack of data during May in 2020 relative to 2021. This resulted in a wider 50% credible interval for the daily estimates during 2020. The pHOS estimates were greater later in the year during 2021 relative to 2020. We believe this is due to the greater proportion of HOR steelhead in the system during 2021 relative to 2020 rather than the data gap. All four steelhead caught after May were HOR during 2021, while only 1 of three caught during 2020 were HOR.

A pHOS estimate is currently necessary to assess steelhead recovery and their current recovery status. NMFS (2015) cites a “natural spawner” recovery level rather than “naturally spawning adults” due to errors in transcribing draft triggers from Peters et al. (2014). There is a relatively wide 95% credible interval despite increased efforts. NMFS (2015, Table 2) lists natural spawners greater than 196 fish as one criterion to move from the preservation to the recolonization phase. Assessing this criterion is not an issue despite the large variation in pHOS estimates derived from this work. Using the upper limit of the 95% credible interval for our

pHOS estimate would yield approximate HOR and NOR estimates of 1,490 and 733, respectively. Thus, using even the extreme end of the 95% credible interval, NOR steelhead abundance far surpasses the requirement to move to the recolonization phase of recovery. Of greater concern, is our ability to measure pHOS with sufficient precision to determine if the pHOS trigger of 0.10 is met to support moving from the recolonization to the local adaptation phase of recovery in the future (along with several other triggers). Our continuing challenge to estimate pHOS with sufficient accuracy will likely limit future management options unless more precise estimates can be derived.

The Lower Elwha winter steelhead program is designated as an integrated hatchery program, which requires NOR steelhead to be incorporated into the broodstock (LEKT 2012). Prior to 2019, NOR steelhead have largely come from the captive brood steelhead developed from steelhead eggs and juveniles mined from the Elwha River prior to dam removal. One NOR male and female steelhead were incorporated into the program in 2018. The lack of captive brood steelhead, since it terminated on schedule, and the lack of steelhead (HOR and NOR) volunteering into the hatchery led to this effort to maintain the program and its integrated status. The 2019 brood was the first brood year to include significant NOR steelhead since the captive brood fish were used (Peters et al. 2020). The effort continued in 2021, with five (four spawned - one pre-spawn mortality) NOR steelhead contributed to the hatchery broodstock effort. This resulted in a proportion of hatchery brood composed of natural-origin fish (pNOB) estimate of 0.054, significantly less than the previous year.

Recommendations

Based on the analysis in this report we recommend the following:

- 1) Increase the sampling effort at the sites furthest downstream and add sites if new potential sites develop in the future. Ideally, these sites would be sampled twice a week during the bulk of steelhead passage. We understand this will result in a significant increase in effort and cost, due to the protracted and consistent ‘peak’ migration from mid-March through mid-May. These sites and/or sites further downstream will represent the least biased assessment by intercepting predominantly migrating fish based on redd distribution (McMillan et al. 2019). Two additional sites were added for the 2021 season, one sampled only once since it could not be fished effectively, and one located just upstream of the river mouth. Unfortunately, only one steelhead was caught at these two sites.
- 2) Investigate methods for sampling at higher discharges that have precluded sampling in the past. Again, we recognize that this may substantially increase effort and costs associated with the project.
- 3) Continue sampling throughout the lower river to develop a better understanding of the differences in HOR and NOR steelhead distribution and to assess year-to-year variability. This information is critical to understand potential biases associated with sampling locations used to estimate pHOS.
- 4) Develop additional sampling efforts between rkm 5 and 14 to better understand HOR and NOR steelhead distribution in this section of river where limited sampling has occurred.

This will help us better understand the potential biases at the sites used for the P-spline estimate during years of relatively abundant HORs.

- 5) Use the P-spline approach outlined in this report to estimate pHOS in the future and investigate using this method to recalculate historic pHOS estimates.
- 6)

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Table 1: Summary of sampling by site, reach, river kilometer (Rkm), length (m), first sampling date, last sampling date, and the total number of times the site was sampled DS High Bluff Drift 2 site is the same as DS High Bluff but represents a second drift at that location during that sampling day.

Site	Reach	Rkm	Reach Length (km)	First Sample Date	Last Sample Date	# Samples
End of Road	Lower	0.4	330	2021-02-02	2021-06-08	16
below high bluff LB	Lower	0.8	107	2021-02-09	2021-02-09	1
DS Hunts High Bluff	Lower	1.1	313	2021-01-11	2021-06-08	30
DS Hunts High Bluff Drift 2	Lower	1.1	313	2021-01-11	2021-06-08	20
US high bluff	Lower	1.3	185	2021-01-26	2021-06-08	25
US High Bluffs RB	Lower	1.3	185	2021-01-11	2021-06-08	23
bottom OM	Lower	1.4	50	2021-02-09	2021-05-11	14
lower HRC	Lower	1.5	240	2021-01-11	2021-06-08	18
Hunts Rd Sonar	Lower	1.9	109	2021-01-26	2021-06-08	9
LEKT Outlet DS	Lower	2.6	68	2021-01-26	2021-06-08	17
willy's bucket	Lower	2.6	57	2021-03-22	2021-03-22	2
HRC 3	Lower	2.7	119	2021-01-26	2021-06-08	15
Hunts Road Upper	Lower	2.9	166	2021-01-26	2021-06-08	16
LEKT Outlet US	Lower	2.9	442	2021-01-26	2021-06-08	21
Sisson Hole	Lower	4.6	169	2021-02-02	2021-05-11	27
MS US Wdfw Outlet TO	Lower	4.9	188	2021-02-02	2021-05-11	13
MS US WDFW outlet	Lower	5.0	212	2021-02-02	2021-05-11	15
DS gauge rip rap run	Middle	14.1	297	2021-02-08	2021-02-25	4
bedrock below gage	Middle	14.3	289	2021-02-08	2021-02-17	3
bedrock below gage drift #2	Middle	14.3	289	2021-02-08	2021-02-08	1
Gage Tailout	Middle	14.7	200	2021-02-08	2021-03-18	3
Gage Tailout drift #2	Middle	14.7	200	2021-02-08	2021-02-08	1
DS Fishermans Bend 3	Middle	17.2	184	2021-02-17	2021-03-18	11
Fishermans Bend 2	Middle	17.6	122	2021-05-12	2021-05-12	1
US Sanders	Middle	20.1	188	2021-05-10	2021-05-10	1
DS Ranger Station	Middle	20.2	273	2021-02-17	2021-05-10	18
glines US	Upper	23.1	77	2021-04-28	2021-04-28	1
windy arm DS	Upper	24.4	81	2021-05-12	2021-05-12	1
windy arm	Upper	24.6	266	2021-03-18	2021-05-12	9
US Windy Arm	Upper	25.0	131	2021-03-18	2021-04-28	5
boulder MS	Upper	25.1	126	2021-03-18	2021-03-18	3
Geyser Valley	Upper	31.0	400	2021-04-30	2021-04-30	1

Table 2. Catch of hatchery- (HOR) and natural-origin (NOR) steelhead and the proportion of HORs (pHOS) by site and group for all the sites where steelhead were caught. The sites used for the P-spline method to calculate pHOS are noted as are the river km (Rkm) of the site (mid-point).

Site	Used for P-Spline	Rkm	Group	HOR	NOR	Total	pHOS
End of Road	Yes	0.4	Bluff	1	0	1	1.00
DS Hunts High Bluff	Yes	1.1	Bluff	6	8	14	0.43
DS Hunts High Bluff Drift 2	Yes	1.1	Bluff	4	3	7	0.57
US high bluff	Yes	1.3	Bluff	8	5	13	0.62
US High Bluffs RB	Yes	1.3	Bluff	0	2	2	0.00
lower HRC	Yes	1.5	Hunts	1	4	5	0.20
Hunts Rd Sonar	No	1.9	Hunts	0	3	3	0.00
HRC 3	No	2.7	Hunts	2	3	5	0.40
Hunts Road Upper	No	2.9	Hunts	1	0	1	1.00
bottom OM	Yes	1.4	OM	0	1	1	0.00
LEKT Outlet DS	No	2.6	OM	2	0	2	1.00
willy's bucket	No	2.6	OM	1	0	1	1.00
LEKT Outlet US	No	2.9	OM	4	7	11	0.36
Sisson Hole	No	4.6	WDFW	9	6	15	0.60
MS US Wdfw Outlet TO	No	4.9	WDFW	0	1	1	0.00
MS US WDFW outlet	No	5.0	WDFW	0	5	5	0.00
DS gauge rip rap run	No	14.1	Middle	0	1	1	0.00
bedrock below gage	No	14.3	Middle	0	2	2	0.00
Gage Tailout	No	14.7	Middle	0	1	1	0.00
DS Fishermans Bend 3	No	17.2	Middle	0	7	7	0.00
US Sanders	No	20.1	Middle	0	1	1	0.00
DS Ranger Station	No	20.2	Middle	0	9	9	0.00
windy arm DS	No	24.4	Upper	0	1	1	0.00
windy arm	No	24.6	Upper	0	9	9	0.00
US Windy Arm	No	25.0	Upper	0	5	5	0.00
boulder MS	No	25.1	Upper	0	2	2	0.00

Table 3. Estimated pHOS, total number of steelhead caught (in parenthesis) by sample site groups and month. The groups are ordered from downstream (top) to upstream (bottom), except that Hunts Rd (Hunts) and Old Mainstem (OM) are at nearly the same river kilometer but represent two channels (i.e., Hunts Rd Side Channel and Old Mainstem). NaN means no estimate was possible since no fish were caught during the sampling event. NA means the site was not sampled that month.

Group	January	February	March	April	May	June	Group pHOS
Bluff	0 (3)	0 (3)	0.4 (10)	0.71 (17)	0.67 (3)	1 (1)	0.51 (37)
Hunts	NaN	0 (2)	NaN	0.17 (6)	0.5 (6)	NaN	0.29 (14)
OM	0 (1)	0 (1)	0.4 (5)	0.67 (6)	0.5 (2)	NaN	0.47 (15)
WDFW	NA	0 (1)	0.5 (12)	0.4 (5)	0.33 (3)	NA	0.43 (21)
Middle	NA	0 (7)	0 (10)	0 (1)	0 (3)	NA	0 (21)
Upper	NA	NA	0 (10)	0 (3)	0 (4)	NA	0 (17)
Period pHOS	0 (4)	0 (14)	0.26 (47)	0.5 (38)	0.33 (21)	1 (1)	0.31 (125)

Table 4. Bounds for credible intervals (CI) with different probabilities. Here, CI is the probability that pHOS is between the lower and upper bounds. For example, there is an 80% chance that pHOS is between 0.39 and 0.61.

CI	Lower	Upper
0.50	0.43	0.54
0.75	0.39	0.58
0.80	0.38	0.59
0.90	0.35	0.63
0.95	0.32	0.65
0.99	0.26	0.70

Table 5. Number of steelhead provided to the Lower Elwha Hatchery for broodstock by date, sex, origin during the 2021 sampling effort. Unk = sex not recorded.

Date	Female HOR	Female NOR	Male HOR	Male NOR	Unk_HOR	Unk_NOR	Total
2021-04-06	1	1	1	0	0	0	3
2021-04-13	2	0	1	1	1	1	6
2021-04-21	3	1	1	0	0	0	5
2021-04-27	2	1	1	0	0	0	4
2021-05-11	1	0	1	0	0	0	2
Total	9	3	5	1	1	1	20

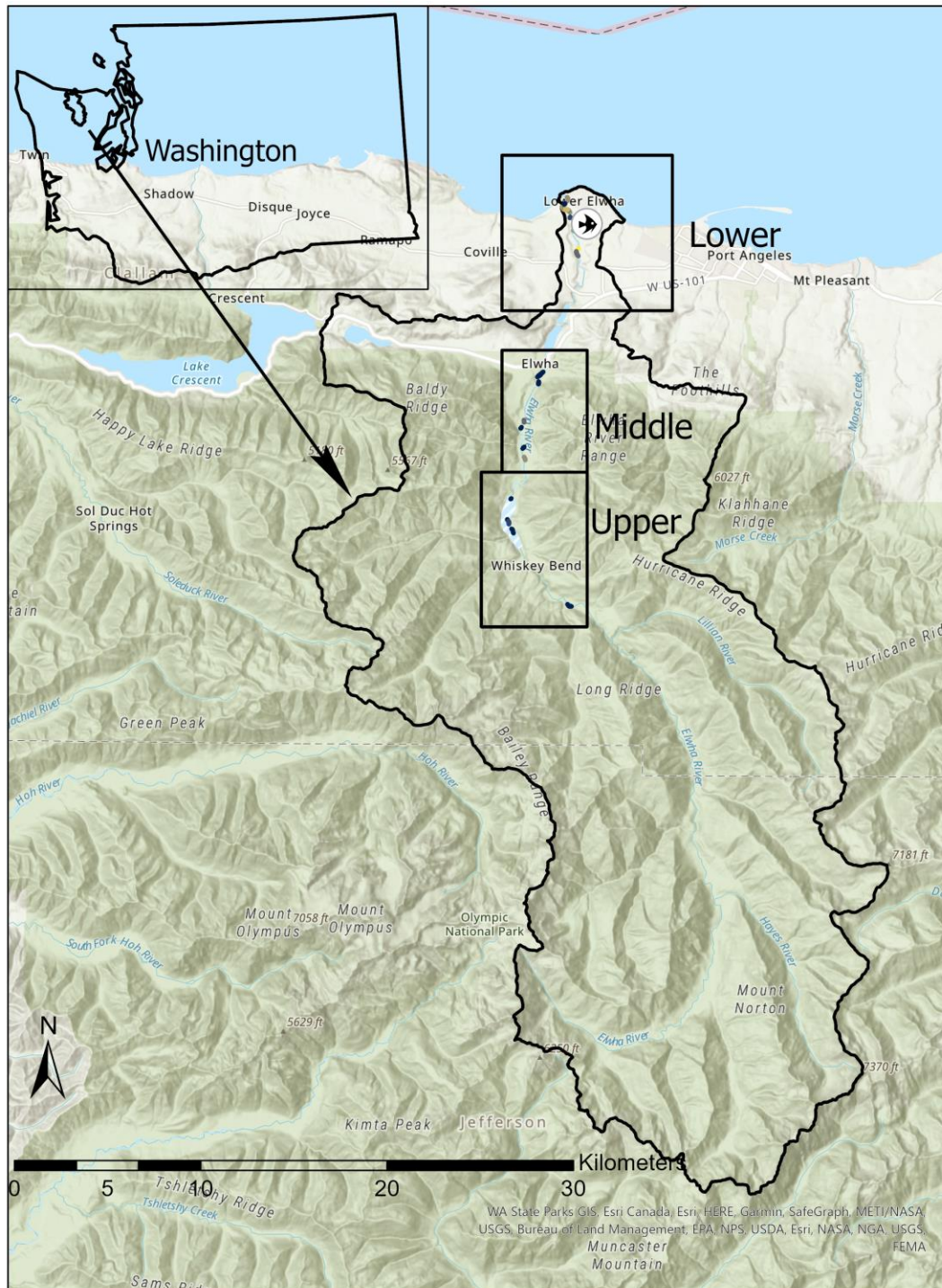


Figure 1. Study area map showing the location of the Elwha basin within Washington State (insert) and sample reaches (lower, middle, upper) and sites within the Elwha basin. The Lower Elwha Tribal (LEKT) Hatchery is noted by the fish symbol. The sample reaches are expanded in Figure 2.

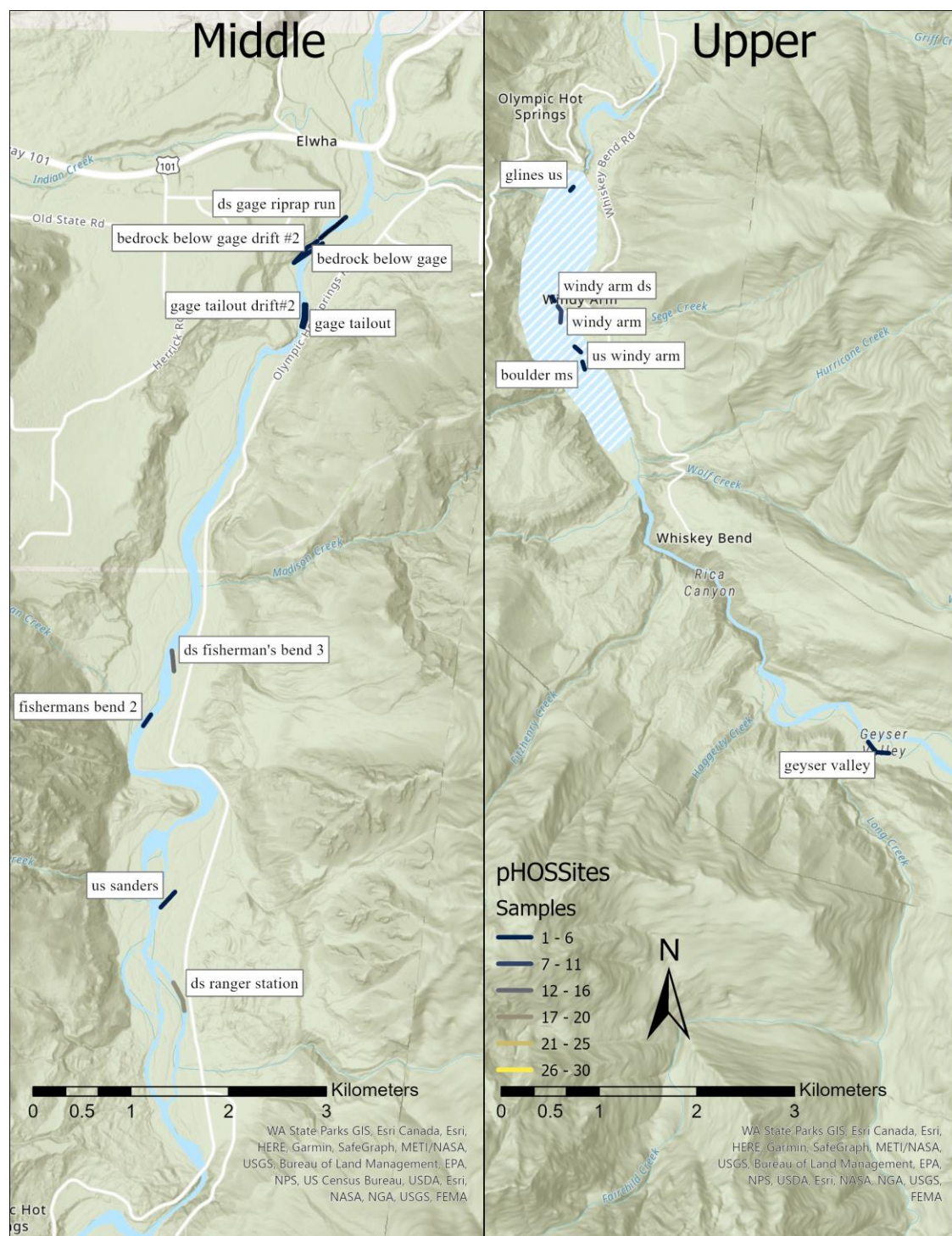


Figure 2. Sample sites in the middle and upper reaches of the Elwha River. The lower reach sites are shown in detail in Figure 3. The number of times each site was sampled is displayed using different colors.

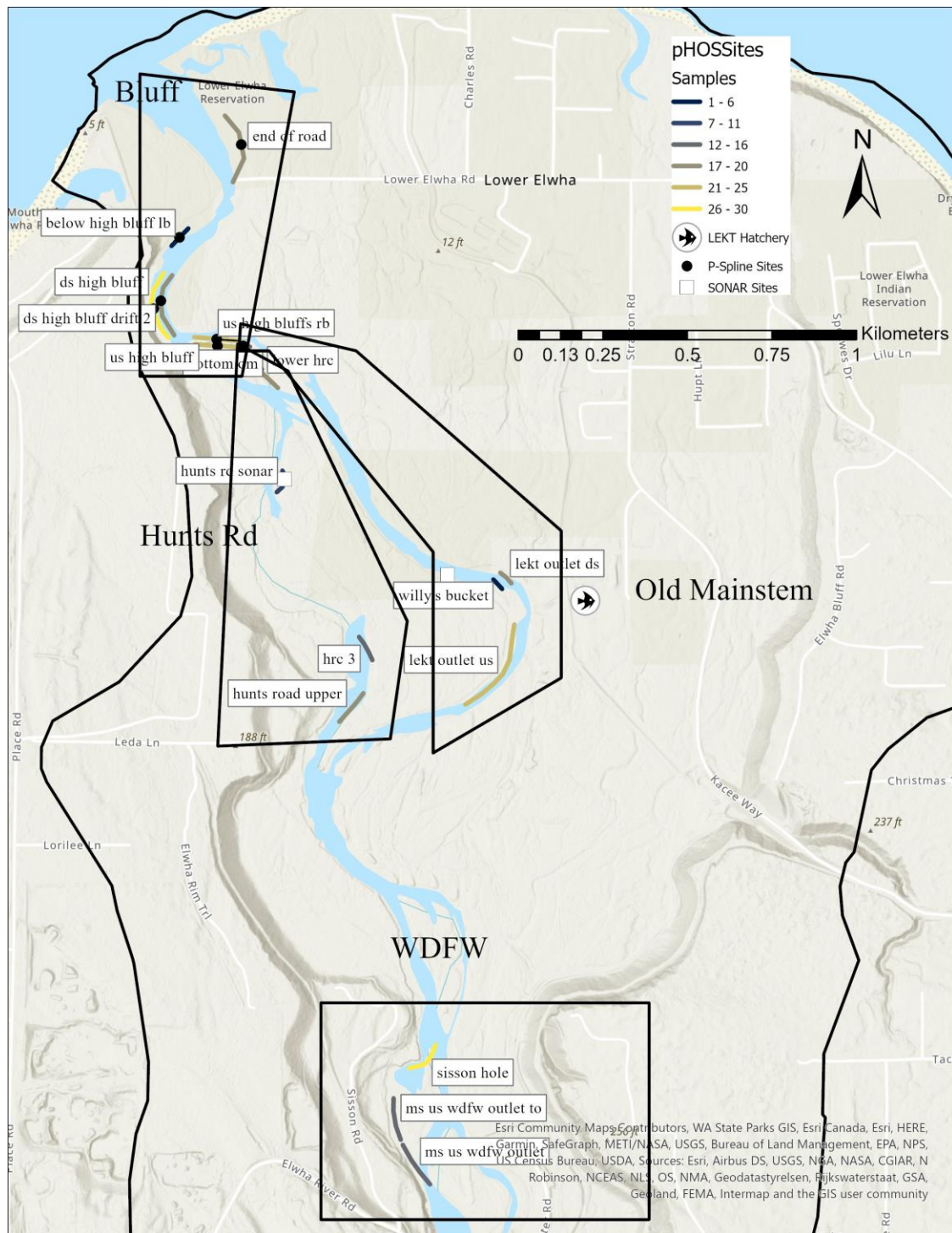


Figure 3. Sample groups in the lower river reach. Sites used to estimate pHOS using the P-Spline are noted by a black dot, the sonar sites are noted by a white square, and the hatchery is noted by a fish symbol.

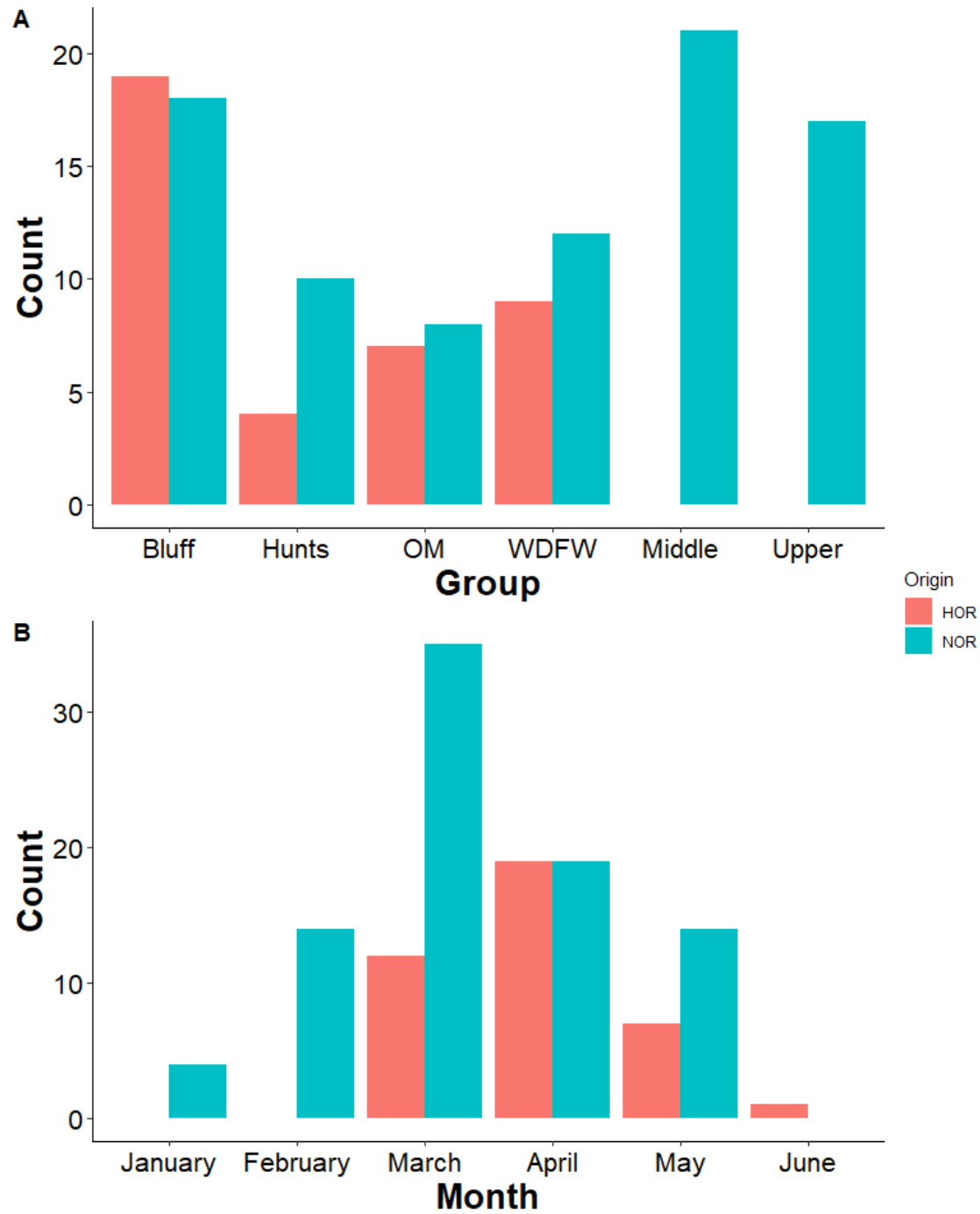


Figure 4. Hatchery- and natural-origin steelhead capture by sampling group (A) and month (B). The groups in panel A are arranged roughly from downstream to upstream (left to right).

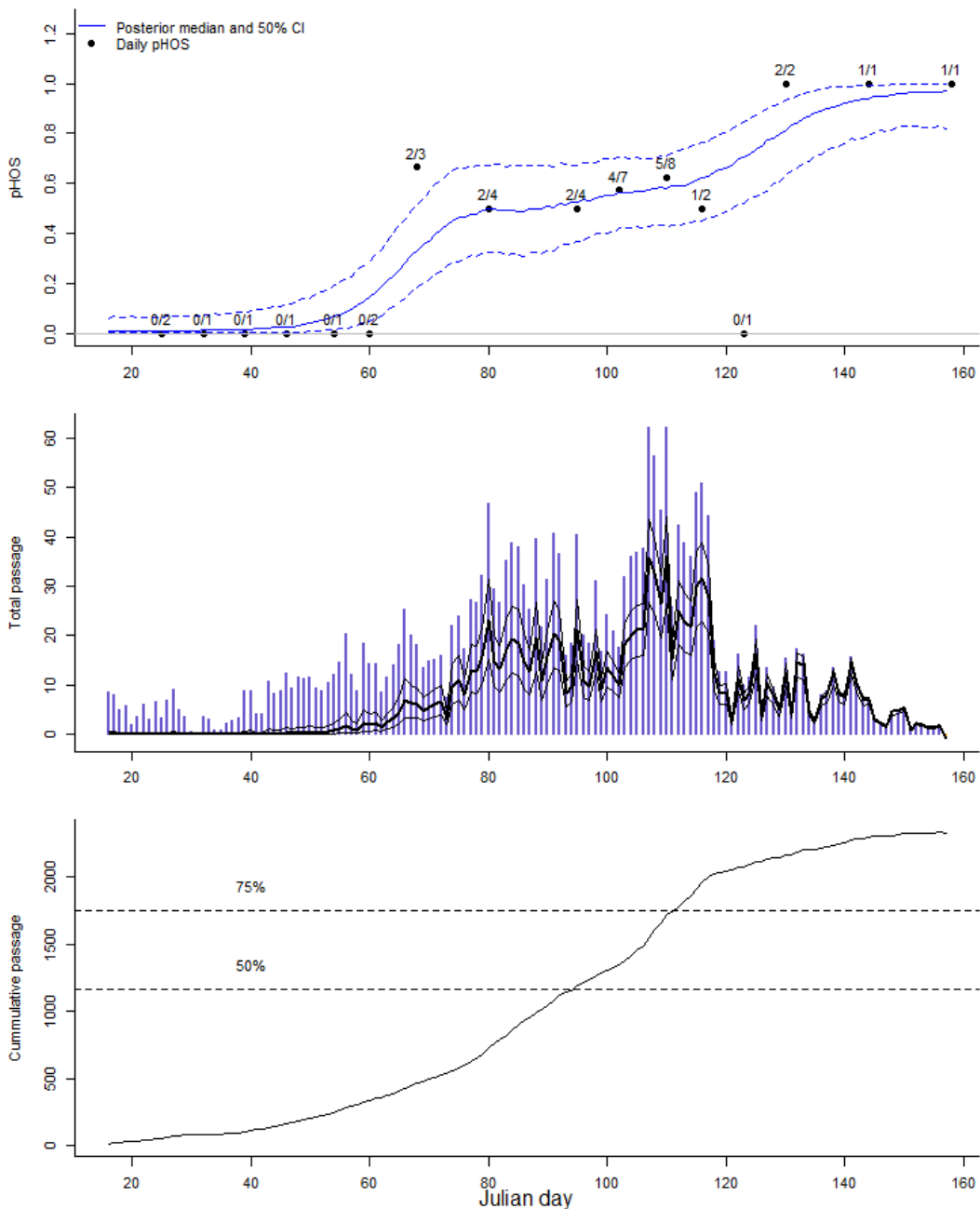


Figure 5. Model results. Top panel: A smoothing spline fit to the pHOS data summarized to a single day. The blue lines are the median (estimate) and 50% credible interval. The points and numbers above the points represent the sum of the hatchery origin fish caught on that day divided by the total number of fish caught on that day. Middle panel: The daily passage estimates based on imaging sonar. The solid and dashed lines represent the estimated number of hatchery fish per day along with a 50% credible interval. Bottom panel: The cumulative passage of all steelhead past the sonar with lines representing 50% and 75% of the total passage.

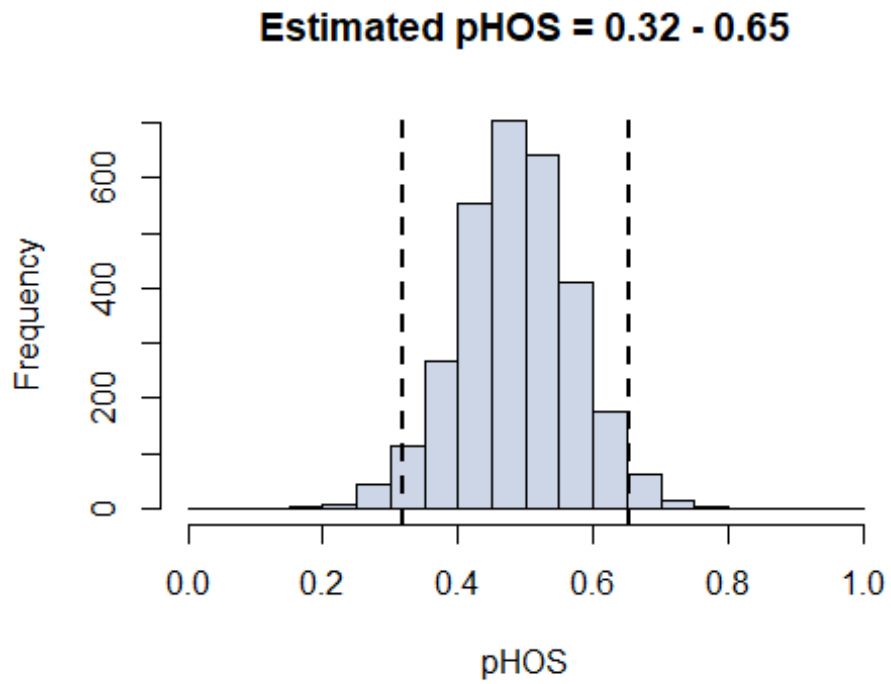


Figure 6. The posterior distribution for the pHOS estimate. The solid line is the estimate, and the dashed lines represent the 95% credible interval (the Bayesian analogue of a confidence interval).

Appendix A: Catch data

Catch data from this project showing sample date, sample location, species caught, fork length (mm), sex (M = Male, F = Female), adipose fin clip status (Ad Clip, Y = Yes, N = No), and if the fish were taken for hatchery broodstock

Date	Site	Species	Sex	Length (mm)	Ad clip	Brood	Comments
2021-01-19	lower HRC	Bull Trout	NA	420	NA	No	NA
2021-01-26	Hunts Road Upper	Bull Trout	NA	450	NA	No	NA
2021-01-26	Hunts Road Upper	Bull Trout	NA	480	NA	No	NA
2021-01-26	US High Bluffs RB	Steelhead	NA	610	N	NA	NA
2021-01-26	DS Hunts High Bluff	Steelhead	NA	680	N	NA	NA
2021-01-26	DS Hunts High Bluff	Steelhead	NA	650	N	NA	NA
2021-01-26	DS Hunts High Bluff	Rainbow	NA	450	N	No	Resident rainbow
2021-01-26	LEKT Outlet US	Steelhead	M	800	N	NA	NA
2021-02-02	Hunts Road Upper	Bull Trout	NA	480	NA	No	NA
2021-02-02	Hunts Road Upper	Bull Trout	NA	490	NA	No	NA
2021-02-02	Hunts Road Upper	Bull Trout	NA	NA	NA	No	Lost
2021-02-02	DS Hunts High Bluff Drift 2	Steelhead	F	760	N	NA	NA
2021-02-08	Gage Tailout	Rainbow	M	450	N	No	Resident
2021-02-08	bedrock below gage	Steelhead	F	630	N	No	summer run kelt?
2021-02-08	DS gauge rip rap run	Steelhead	F	720	N	NA	NA
2021-02-09	lower HRC	Bull Trout	NA	370	NA	No	NA
2021-02-09	DS Hunts High Bluff Drift 2	Steelhead	F	730	N	NA	NA
2021-02-16	LEKT Outlet US	Steelhead	F	840	N	NA	NA
2021-02-16	DS Hunts High Bluff	Steelhead	F	640	N	NA	NA
2021-02-16	Sisson Hole	Steelhead	M	600	N	NA	NA
2021-02-16	Sisson Hole	Rainbow	M	430	Y	No	residual hatchery fish
2021-02-17	bedrock below gage	Steelhead	F	640	N	NA	NA
2021-02-17	bedrock below gage	Rainbow	NA	440	N	No	NA
2021-02-17	DS Ranger Station	Steelhead	M	870	N	NA	NA
2021-02-17	DS Ranger Station	Steelhead	F	720	N	NA	NA
2021-02-17	DS Ranger Station	Rainbow	NA	400	N	No	NA
2021-02-17	DS Fishermans Bend 3	Steelhead	F	650	N	NA	NA
2021-02-17	DS Fishermans	Steelhead	M	690	N	NA	NA

Date	Site	Species	Sex	Length (mm)	Ad clip	Brood	Comments
	Bend 3						
2021-02-17	DS Fishermans Bend 3	Bull Trout	NA	460	N	No	NA
2021-02-17	DS Fishermans Bend 3	Bull Trout	NA	420	N	No	NA
2021-02-24	lower HRC	Steelhead	F	710	N	NA	NA
2021-02-24	LEKT Outlet US	Bull Trout	NA	500	NA	No	NA
2021-02-24	LEKT Outlet US	Steelhead	NA	650	NA	No	lost, length estimated
2021-02-24	US high bluff	Steelhead	F	710	NA	NA	NA
2021-02-24	DS Hunts High Bluff	Steelhead	NA	650	NA	No	lost, length estimated
2021-02-24	DS Hunts High Bluff	Steelhead	NA	650	NA	No	lost, length estimated
2021-02-24	Hunts Rd Sonar	Steelhead	M	510	N	NA	NA
2021-02-25	DS gauge rip rap run	Bull Trout	NA	450	NA	No	NA
2021-02-25	DS gauge rip rap run	Bull Trout	NA	530	NA	No	NA
2021-02-25	DS gauge rip rap run	Bull Trout	NA	560	NA	No	NA
2021-03-02	LEKT Outlet US	Steelhead	M	600	N	NA	NA
2021-03-02	US high bluff	Steelhead	M	710	N	NA	NA
2021-03-02	US High Bluffs RB	Rainbow	NA	490	N	No	NA
2021-03-02	MS US WDFW outlet	Bull Trout	NA	490	N	No	NA
2021-03-02	Sisson Hole	Steelhead	F	680	N	NA	NA
2021-03-02	Sisson Hole	Steelhead	F	650	N	NA	NA
2021-03-02	Sisson Hole	Rainbow	M	480	Y	No	residualized
2021-03-02	Sisson Hole	Rainbow	M	400	Y	No	residualized
2021-03-02	Sisson Hole	Rainbow	M	420	Y	No	residualized
2021-03-02	Sisson Hole	Rainbow	M	420	Y	No	residualized, escaped fish bag, length estimated
2021-03-02	DS Hunts High Bluff Drift 2	Steelhead	F	780	N	NA	NA
2021-03-10	US high bluff	Steelhead	F	730	Y	NA	NA
2021-03-10	DS Hunts High Bluff	Steelhead	M	600	N	NA	NA
2021-03-10	Sisson Hole	Steelhead	M	870	Y	NA	NA
2021-03-10	Sisson Hole	Steelhead	M	720	Y	No	escaped before samples were taken
2021-03-10	DS Hunts High Bluff Drift 2	Steelhead	M	700	Y	NA	NA
2021-03-16	LEKT Outlet US	Steelhead	F	670	N	NA	NA
2021-03-16	US High Bluffs RB	Rainbow	M	490	N	No	seemed to be a recap based on

Date	Site	Species	Sex	Length (mm)	Ad clip	Brood	Comments
							clip from caudal could be 21-046
2021-03-16	MS US Wdfw Outlet TO	Steelhead	M	720	N	NA	NA
2021-03-16	Sisson Hole	Steelhead	M	590	N	NA	NA
2021-03-18	boulder MS	Steelhead	F	590	N	NA	NA
2021-03-18	boulder MS	Steelhead	F	700	N	NA	NA
2021-03-18	boulder MS	Rainbow	F	440	N	No	NA
2021-03-18	windy arm	Steelhead	F	680	N	NA	NA
2021-03-18	windy arm	Steelhead	F	620	N	NA	NA
2021-03-18	windy arm	Steelhead	F	630	N	NA	NA
2021-03-18	windy arm	Steelhead	F	780	N	NA	NA
2021-03-18	US Windy Arm	Steelhead	F	540	N	NA	NA
2021-03-18	US Windy Arm	Steelhead	F	590	N	NA	NA
2021-03-18	US Windy Arm	Steelhead	F	660	N	NA	NA
2021-03-18	US Windy Arm	Steelhead	F	590	N	NA	NA
2021-03-18	DS Ranger Station	Steelhead	M	670	NA	NA	NA
2021-03-18	DS Ranger Station	Rainbow	M	440	N	No	NA
2021-03-18	DS Ranger Station	Steelhead	F	710	N	NA	NA
2021-03-18	DS Ranger Station	Steelhead	F	625	N	NA	NA
2021-03-18	DS Ranger Station	Steelhead	F	730	N	NA	NA
2021-03-18	DS Ranger Station	Bull Trout	NA	440	NA	No	NA
2021-03-18	DS Ranger Station	Steelhead	M	655	N	NA	NA
2021-03-18	DS Fishermans Bend 3	Steelhead	F	840	N	NA	NA
2021-03-18	DS Fishermans Bend 3	Rainbow	M	430	N	No	NA
2021-03-18	DS Fishermans Bend 3	Steelhead	F	600	N	NA	NA
2021-03-18	DS Fishermans Bend 3	Steelhead	F	580	N	NA	NA
2021-03-18	DS Fishermans Bend 3	Steelhead	M	830	N	NA	NA
2021-03-18	DS Fishermans Bend 3	Steelhead	F	600	N	No	lost transferring to bag, no samples, length estimated
2021-03-18	DS Fishermans Bend 3	Bull Trout	NA	560	N	No	NA
2021-03-18	Gage Tailout	Steelhead	F	600	N	NA	NA
2021-03-22	LEKT Outlet US	Steelhead	NA	500	N	NA	NA
2021-03-22	US high bluff	Steelhead	M	510	N	NA	NA
2021-03-22	DS Hunts High Bluff	Steelhead	F	680	N	NA	NA
2021-03-22	End of Road	Steelhead	M	690	Y	NA	NA

Date	Site	Species	Sex	Length (mm)	Ad clip	Brood	Comments
2021-03-22	MS US WDFW outlet	Steelhead	F	760	N	NA	NA
2021-03-22	Sisson Hole	Steelhead	M	620	N	NA	NA
2021-03-22	DS Hunts High Bluff Drift 2	Steelhead	M	640	Y	NA	NA
2021-03-22	willy's bucket	Steelhead	NA	720	Y	NA	NA
2021-03-22	willy's bucket	Steelhead	NA	NA	NA	NA	NA
2021-03-30	LEKT Outlet US	Steelhead	M	660	Y	NA	NA
2021-03-30	US High Bluffs RB	Steelhead	F	670	N	NA	NA
2021-03-30	MS US Wdfw Outlet TO	Bull Trout	NA	440	NA	No	NA
2021-03-30	Sisson Hole	Steelhead	M	470	Y	NA	NA
2021-03-30	Sisson Hole	Steelhead	M	660	Y	NA	NA
2021-03-30	Sisson Hole	Steelhead	M	660	Y	NA	NA
2021-03-30	Sisson Hole	Steelhead	M	670	Y	NA	NA
2021-04-06	LEKT Outlet US	Bull Trout	NA	780	NA	No	NA
2021-04-06	LEKT Outlet US	Bull Trout	NA	510	NA	No	NA
2021-04-06	US high bluff	Steelhead	F	640	N	Yes	broodstock
2021-04-06	DS Hunts High Bluff	Steelhead	F	650	Y	Yes	broodstock
2021-04-06	DS Hunts High Bluff	Steelhead	M	640	N	NA	NA
2021-04-06	Sisson Hole	Bull Trout	NA	530	NA	No	NA
2021-04-06	Sisson Hole	Steelhead	M	640	Y	Yes	broodstock
2021-04-06	DS Hunts High Bluff Drift 2	Rainbow	M	500	N	No	marked as rbt on first capture
2021-04-06	DS Hunts High Bluff Drift 2	Steelhead	F	690	Y	NA	NA
2021-04-13	US high bluff	Steelhead	M	460	N	NA	NA
2021-04-13	US high bluff	Steelhead	M	740	Y	Yes	broodstock
2021-04-13	US high bluff	Steelhead	F	650	Y	Yes	broodstock
2021-04-13	DS Hunts High Bluff	Steelhead	F	640	Y	Yes	broodstock
2021-04-13	DS Hunts High Bluff	Steelhead	F	630	Y	NA	NA
2021-04-13	DS Hunts High Bluff	Steelhead	F	610	N	NA	NA
2021-04-13	bottom OM	Steelhead	M	680	N	Yes	broodstock
2021-04-13	Sisson Hole	Steelhead	NA	700	Y	Yes	broodstock
2021-04-13	Sisson Hole	Steelhead	NA	625	N	Yes	broodstock
2021-04-13	Sisson Hole	Rainbow	NA	455	Y	No	residual male
2021-04-13	Sisson Hole	Bull Trout	NA	525	NA	No	length estimated
2021-04-21	LEKT Outlet DS	Steelhead	M	635	Y	Yes	broodstock

Date	Site	Species	Sex	Length (mm)	Ad clip	Brood	Comments
2021-04-21	US high bluff	Steelhead	F	720	Y	Yes	broodstock
2021-04-21	US high bluff	Steelhead	F	680	Y	NA	NA
2021-04-21	DS Hunts High Bluff	Steelhead	F	740	Y	Yes	broodstock
2021-04-21	DS Hunts High Bluff	Steelhead	F	790	N	NA	NA
2021-04-21	DS Hunts High Bluff	Steelhead	F	675	Y	Yes	broodstock
2021-04-21	DS Hunts High Bluff Drift 2	Steelhead	F	680	Y	No	escaped, sex and clip status confirmed, length estimated
2021-04-21	HRC 3	Steelhead	F	660	Y	NA	NA
2021-04-21	lower HRC	Steelhead	M	515	N	NA	NA
2021-04-21	lower HRC	Steelhead	F	620	N	Yes	broodstock
2021-04-27	LEKT Outlet US	Steelhead	F	670	Y	Yes	broodstock
2021-04-27	LEKT Outlet US	Steelhead	F	650	N	Yes	broodstock
2021-04-27	LEKT Outlet US	Steelhead	F	590	Y	NA	NA
2021-04-27	LEKT Outlet DS	Steelhead	M	670	Y	Yes	broodstock
2021-04-27	DS Hunts High Bluff	Steelhead	F	670	Y	Yes	broodstock
2021-04-27	MS US WDFW outlet	Steelhead	F	700	N	NA	NA
2021-04-27	MS US WDFW outlet	Steelhead	F	770	N	NA	NA
2021-04-27	Hunts Rd Sonar	Steelhead	F	640	N	NA	NA
2021-04-27	Hunts Rd Sonar	Steelhead	F	600	N	NA	NA
2021-04-27	Hunts Road Upper	Steelhead	NA	NA	NA	NA	NA
2021-04-27	lower HRC	Steelhead	F	770	N	NA	NA
2021-04-28	DS Ranger Station	Bull Trout	NA	430	NA	No	altair bridge
2021-04-28	DS Ranger Station	Bull Trout	NA	510	NA	No	altair bridge
2021-04-28	DS Ranger Station	Bull Trout	NA	440	NA	No	campground
2021-04-28	DS Ranger Station	Steelhead	F	730	N	No	bright but maybe spawned out? Site correct
2021-04-28	DS Ranger Station	Bull Trout	NA	440	NA	No	ranger station
2021-04-28	DS Ranger Station	Rainbow	M	420	N	No	us sanders
2021-04-28	glines US	Rainbow	M	510	N	No	resident
2021-04-28	windy arm	Steelhead	F	690	N	NA	NA
2021-04-28	windy arm	Steelhead	F	540	N	NA	NA
2021-04-28	US Windy Arm	Steelhead	F	690	N	NA	NA
2021-04-30	Geyser Valley	Rainbow	NA	450	N	No	geyser valley
2021-05-04	LEKT Outlet US	Steelhead	M	510	N	No	possible recap, looked like dna clip had previously been taken
2021-05-04	US high bluff	Steelhead	F	690	N	NA	NA
2021-05-04	Sisson Hole	Steelhead	F	690	Y	NA	NA

Date	Site	Species	Sex	Length (mm)	Ad clip	Brood	Comments
2021-05-04	HRC 3	Steelhead	M	690	Y	NA	NA
2021-05-04	HRC 3	Steelhead	M	NA	NA	NA	NA
2021-05-04	HRC 3	Steelhead	F	920	N	NA	NA
2021-05-04	HRC 3	Steelhead	M	820	N	NA	NA
2021-05-04	HRC 3	Bull Trout	NA	490	N	No	NA
2021-05-04	Hunts Road Upper	Steelhead	M	660	Y	NA	NA
2021-05-10	DS Ranger Station	Steelhead	M	630	N	NA	NA
2021-05-10	US Sanders	Steelhead	F	640	N	NA	NA
2021-05-10	DS Ranger Station	Steelhead	F	740	N	NA	NA
2021-05-11	LEKT Outlet US	Steelhead	M	890	Y	Yes	broodstock
2021-05-11	US high bluff	Steelhead	M	830	Y	NA	NA
2021-05-11	US high bluff	Steelhead	F	610	Y	Yes	broodstock
2021-05-11	MS US WDFW outlet	Steelhead	F	640	N	NA	NA
2021-05-11	MS US WDFW outlet	Steelhead	F	620	N	NA	NA
2021-05-12	Fishermans Bend 2	Rainbow	NA	370	N	No	resident, site was behind large rock 100m downstream from fishersman bend
2021-05-12	windy arm	Steelhead	F	630	N	NA	NA
2021-05-12	windy arm	Steelhead	F	640	N	NA	NA
2021-05-12	windy arm	Steelhead	F	650	N	NA	NA
2021-05-12	windy arm DS	Steelhead	F	640	N	NA	NA
2021-05-20	lower HRC	Steelhead	NA	NA	NA	NA	NA
2021-05-25	HRC 3	Steelhead	F	870	N	NA	NA
2021-05-25	lower HRC	Steelhead	F	640	Y	NA	NA
2021-06-07	HRC 3	Bull Trout	NA	400	NA	No	full of fry
2021-06-07	HRC 3	Bull Trout	NA	400	NA	No	full of fry
2021-06-07	lower HRC	Chinook	NA	760	NA	No	NA
2021-06-07	Hunts Road Upper	Bull Trout	NA	450	NA	No	full of fry
2021-06-08	LEKT Outlet US	Steelhead	NA	NA	NA	NA	NA
2021-06-08	LEKT Outlet DS	Bull Trout	NA	480	NA	No	NA
2021-06-08	US high bluff	Steelhead	F	630	Y	NA	NA
2021-06-08	US high bluff	Chinook	NA	800	NA	No	lost
2021-06-08	US High Bluffs RB	Chinook	NA	NA	NA	No	NA

Appendix B: P-Spline Implementation details

Reproducing this analysis

To reproduce this analysis you will need to install the JAGS software (<https://mcmc-jags.sourceforge.io/>). Navigate to the download link (for Windows you will want the file JAGS-4.3.0.exe). In addition you may need to install a few R libraries. In particular, R2jags).

The JAGS code

Here's the code used to fit the spline. This was adapted from a model by Andrew Parnell (https://github.com/andrewcparnell/jags_examples/blob/master/R%20Code/jags_spline2.R).

```
model
{
  # Likelihood
  for (i in 1:N) {
    hCatch[i] ~ dbin(p[i], totalCatch[i])
    logit(p[i]) <- logitP[i]
    logitP[i] ~ dnorm(alpha + inprod(Z[i,], delta), sigma^-2)
  }
  # Priors on the deltas (the RW differences)
  alpha ~ dnorm(0, 10^-2)
  for (i in 1:N_knots) {
    delta[i] ~ dnorm(0, sigma_b^-2)
  }
  # Priors on sigma values
  sigma ~ dt(0, 10^-2, 1)T(0,)
  sigma_b ~ dt(0, 10^-2, 1)T(0,)
}
```

P-spline explanation

At P-spline is a B-spline where a penalty is placed on finite differences (higher order differences) of the coefficients of adjacent B-splines (Eilers and Marx 1996).

$$S = \sum_{i=1}^m \left(y_i - \sum_{j=1}^n \alpha_j B_j(x_i) \right)^2 + \lambda \sum_{j=k+1}^n (\Delta^k a_j)^2$$

For the Bayesian implementation (see above), the differences are hierarchically modeled, with mean zero. In this way, the differences are naturally penalized. This turns out to be very similar to placing a penalty on the second derivative (O'Sullivan 1986 and 1988).

Typically a P-spline would be parameterized as:

$$B\beta$$

where B is the basis matrix and β is the weights. To improve model convergence, the priors are applied to differences in the weights, and the model is reparametrized as:

$$\alpha + Z\delta = \alpha + ZD\beta$$

then α is the mean of β . I imagine in this case then the sum of the squared δ s is minimized?

References

Eilers, P and B. Marx, 1996. Flexible Smoothing with B-splines and Penalties. Statistical Science. 11:2, 89–121

Bonner, S.J. and Schwarz, C.J., 2011. Smoothing population size estimates for time-stratified mark–recapture experiments using Bayesian P-splines. Biometrics, 6:47, 1498-1507

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