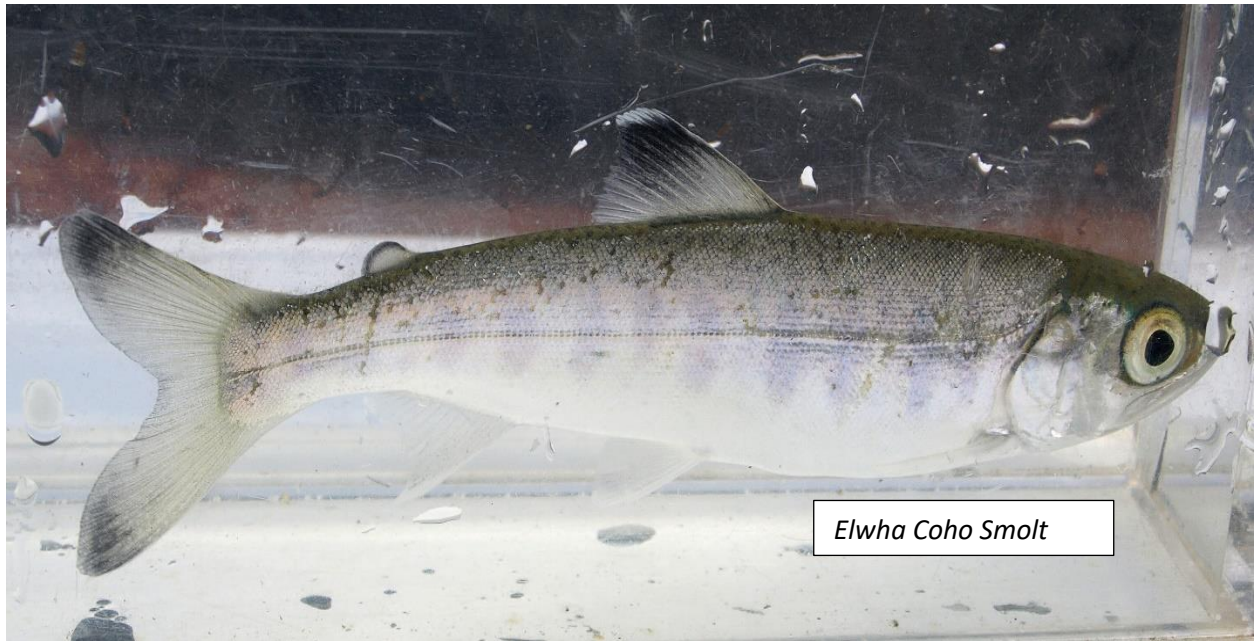




2019 Elwha River Smolt Enumeration Project Report

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Submitted to Olympic National Park by the Lower Elwha Klallam Tribe

In partial fulfillment of the agreement for performance of monitoring pursuant to the National Park Service's Chinook and Steelhead Monitoring Plan for the Elwha River

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Executive Summary

Smolt enumeration monitoring was conducted on the mainstem Elwha River and in two tributaries, Little River and Indian Creek, during the 2019 outmigration season. This represents the fourth year of monitoring during the post dam removal period, and the 14th consecutive year of smolt monitoring on the Elwha River. The mainstem trap was relocated to a site above both hatcheries in the lower river, and we were able to operate for nearly 100% of the possible fishing days. In 2019, we generated watershed production estimates, credible intervals (CI), and coefficient of variation (CV) estimates for smaller bodied (Age 0+) Chinook, Coho, and chum salmon. Additionally, estimates were generated for larger bodied (Age 1+) Coho salmon and steelhead smolts for the fourth consecutive year. We estimated a total outmigration of 496,456 (range 387,791-669,225) and 2,896 (1,927-4,600) for Chinook 0+ salmon and chum 0+ salmon smolts to the mainstem trap in 2019. We estimate an additional 75,361 0+ Chinook smolts were produced from spawners located downstream of the trap in 2019. The combined estimate of 571,817 Chinook 0+ salmon outmigration estimates for the Elwha River in 2019 represents a significant increase in natural production, and eclipses the long term average (2006-2018) by a factor of eleven. For Coho salmon smolts we estimated a total outmigration of 69,874 (range 42,258-133,420), which is a substantial increase over previous years. The steelhead estimate of 17,648 (range 10,214-31,503) represents an increase of 35% from 2017 and 2018. Production of chum salmon remains very low in the Elwha River and suggests that this population has not begun to recover from the combination of low population size at the beginning of dam removal and the impacts from dam removal itself. Elwha pink salmon are primarily an odd year spawner and were not encountered in 2019.

At the tributary sites, smolt trapping was nearly continuous and we successfully operated over 80% of potential fishing days. For Indian Creek we estimated Coho salmon (ages 0+ and 1+), Chinook salmon (ages 0+ and 1+) and steelhead production. For Little River we produced estimates for 0+ and 1+ Coho salmon and 0+ Chinook, as well as steelhead. The production of 107,644 0+ Chinook at Little River was a record since trapping was initiated. We estimate a production of 1,856 coho smolts and 284 steelhead smolts from Little River in 2019. Indian Creek had consistently higher numbers of outmigrants than Little River for all species and may be producing a significant proportion of the total Elwha smolt production for some species including coho and steelhead. Indian Creek produced an estimated 129,759 (66,176-366,267) Chinook salmon (0+) smolts and 38,759 coho 1+ smolts. Steelhead and lamprey populations also continue to expand in Indian Creek. In 2019 we estimated a total steelhead outmigration of 2,550 (1,922-3,517), which represents 14% of the total estimated Elwha steelhead outmigrants. Pacific lamprey populations also continue to expand throughout the watershed as significant numbers of juveniles (ammocoetes) and outmigrating (macrothemia)

were captured at the mainstem trap in 2019. Additionally we measured a significant increase in sculpin numbers in 2019.

Introduction

Removal of two mainstem hydroelectric dams on the Elwha River was completed between 2011 and 2014. This action was authorized by the Elwha River Ecosystem and Fisheries Restoration Act of 1994 (PL 102-495) and represents the largest dam removals attempted to date in the United States. The Elwha Act was designed to recover native salmon populations and their associated ecosystems. Dam removal on the Elwha has generated national attention and there is great interest amongst state, federal, and academic scientists to assess the effects of Elwha dam removals on aquatic and terrestrial ecosystems. The response of Pacific salmon to dam removal is of particular interest, and for the Elwha Project recovery goals have been developed. These goals include: 1) the preservation of native anadromous salmon before, during and after dam removal, 2) reestablishing self-sustaining anadromous salmon populations and habitats as quickly as possible, and 3) restoring the physical and biological processes of the ecosystem (Ward et al. 2008).

To evaluate the salmon recovery and adaptively manage restoration of Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead (*O. mykiss*) on the Elwha River, specific guidelines were developed in the Elwha Monitoring and Adaptive Management Plan (EMAM) (Peters et al. 2014). The EMAM (and closely related guidance in the hatchery biological opinions for the Elwha hatchery operations) provides quantitative performance targets that could be used to affect management actions necessary to achieve recovery of the populations. The EMAM uses performance indicators coupled with management triggers to guide project managers through four stages of recovery including: 1) preservation, 2) recolonization, 3) local adaptation, and 4) viable natural population. Performance indicators used in the EMAM are based upon Viable Salmon Population (VSP) metrics including abundance, productivity, spatial distribution and diversity (McElhany et al. 2000). These factors were chosen because they are predictors of extinction, reflect general processes important to salmon, and are measurable. They can be intrinsically connected to the recovery of depleted and federally listed Elwha salmon populations. Most importantly the National Park Service (NPS) submitted a Chinook and Steelhead Monitoring Plan pursuant to paragraph 6 of the Terms and Conditions and Reasonable and Prudent Measures sections within the July 2, 2012, National Marine Fisheries Service (NMFS) Biological Opinion for the Elwha River Restoration Project (as amended by letter dated November 30, 2012, from NMFS to ONP). This monitoring plan, based upon a draft version of the EMAM was approved by NMFS on March 7, 2012, and describes the specific tasks that NPS intends to undertake to document dam removal impacts to listed salmon species and meet the requirements of the Biological Opinion. Smolt outmigration monitoring is one of the required components of the Biological Opinion. This action has been contracted to the Lower Elwha Klallam Tribe by National Park Service (NPS).

Fundamental questions regarding the recovery and trajectory of Elwha River salmon populations can in part be addressed through smolt enumeration. These include not only abundance and productivity trends, but life history parameters such as the timing and size at outmigration. The Lower Elwha Klallam Tribe (LEKT) established a smolt enumeration program on the Elwha River beginning in 2006. During the pre-dam removal period (2006-2011) the tribe successfully estimated the number of small bodied species including Chinook salmon, chum salmon (*O. keta*) and pink salmon (*O. gorbuscha*) smolts using an 8' rotary screw trap fished at river kilometer 0.3. Funding of trap operations during this period was provided by the Pacific Coast Salmon Recovery Fund (NOAA). This effort has resulted in estimates of pre-project (dam removal) production for the aforementioned species. Estimation of larger sized Coho salmon smolts and steelhead smolts has historically been more problematic because of their relative lack of abundance in the formerly highly degraded Elwha River combined with their ability to avoid the trap.

The 2019 trapping season represents the fourth year of main stem Elwha monitoring following dam removal. The beginning of the post-dam removal period is a significant project benchmark and metrics associated with smolt outmigration will be important for assessing rates of recovery for Pacific salmon. The objectives of this document are: 1) to describe and to discuss the changes in abundance for natural origin salmon, 2) report on the ecological significance of those changes, 3) document field protocols for smolt outmigration data acquisition in the mainstem and tributary sites; 4) develop a procedure for deriving a smolt production estimates from raw catch counts; 5) describe the sources of uncertainty; and lastly to 6) document issues that resulted in a coefficient of variation greater than 15%.

Methods

History of Operations

During the pre-project (2006-2011) and dam-removal periods (2012-2015), mainstem trapping operations were initiated in mid to late February and continued until late June. These dates were predicated by flow and tidal conditions in the early portion of the season and interactions with releases of up to 3.5 million of 0+ Chinook salmon smolts from the WDFW hatchery in the later season. LEKT was aware that these dates were not ideal in terms of capturing the early portion of Chinook outmigration (Weinheimer & Zimmerman 2012) and has since extended mainstem trapping efforts during the post dam removal period (2016-2019). During the pre-dam removal period, the end of trap operations was determined by catch rates and the mainstem trap catches tended to drop toward zero by mid to later June likely because the total natural production of salmon in the Elwha was so low. In other Puget Sound

drainages, Chinook outmigration is typically bimodal, with earlier peaks dominated by small recently emerged migrants and later peaks dominated by larger parr migrants that rear in freshwater for several to many weeks (Kinsel et al. 2008; Kiyohara and Zimmerman 2012).

During the pre-dam removal period, the mainstem 8' screw trap was fished continuously (24 hours/day) except when flows exceeded ~2000 cfs (~56 cubic meter/second). During the dam-removal period (2011-2014), sediment and debris entrained in the river negatively affected trapping operations. Conditions were so poor in 2013 that trapping operations were discontinued as sediment and small organic debris overwhelmed the trap box and unacceptable level of fish mortality occurred. The changes in fishing conditions forced changes in both trap size and mainstem location during the dam removal period. River conditions have steadily improved since 2015 and LEKT was able to reoccupy the lower river site using the larger 8'screw (Figure 1).

This site was temporarily abandoned during the 2013-2014 seasons because of sediment aggradation associated with dam removal and operations were moved upstream to the Spruce Hole site at Rkm 2.5. By the early winter of 2015, the lower river site had evacuated enough sediment to support trapping operations with the smaller 5' screw trap. Changes in stream channel morphology during the dam removal period have not only affected the mainstem fishing site, but also the size of trap used. During the pre-dam removal period (2006-2011) river conditions were quite stable and LEKT utilized an 8' rotary screw trap fished at Rkm 0.3 (Figure 1). However, as dam removal progressed into 2013 the pool at Rkm 0.3 rapidly filled and was reduced from greater than 3.0 m to less than 1.0 m in depth. This forced a reduction in the size of trap to a 5' screw trap that LEKT could physically operate as the river was not deep enough to support the larger trap. Since the 2016 season enough sediment had evacuated the lower river fishing site to support the operation of the larger 8' screw trap. In 2019, LEKT decided to abandon the lower river trap site in favor of a site located above both lower river hatcheries at Rkm 4.0. This decision was made because the annual release of hatchery produced smolts caused trap operations to be delayed for days to weeks at a time.

LEKT established tributary smolt monitoring sites on Little River in 2012 and Indian Creek in 2013. Because of the lack of access to the lower portions of those drainages, we chose county road bridge crossings in each tributary for trap deployment. For Little River, we use the bridge crossing on Hot Springs Road located at Rkm 0.2. For Indian Creek, we use the bridge crossing on Aldwell Reservoir Road located at Rkm 0.6. Both crossings are maintained by the Clallam County Road Department and their permission was obtained to utilize these sites. On Little River for the 2012-2015 period we used a standard 5' diameter screw on pontoons that floats in a pool approximately 1.5 m deep. In 2016 we retrofitted the Little River trap with a 4' screw to reduce drag during low flow periods. The Indian Creek site is narrower and shallower

and to fish this site effectively LEKT used a 4' screw on a narrower pontoon since the inception of fishing (Figure 2). Both traps have fished with excellent results to date with the exception of Little River in the later season which can be prone to low flows that are insufficient to turn the screw. To resolve this issue we motorized the screw in 2018 using batteries and solar panels. The location of the traps within the Elwha watershed is depicted in Figure 3.

Daily Operations-2019

LEKT made the decision to relocate the mainstem trapping site to Rkm 4.0 in order to fish upstream of the two lower river hatcheries. Fish releases from those facilities had resulted in frequent interruptions to trapping operations since the inception of the monitoring program. In 2019, LEKT commenced trapping operations in the mainstem on February 22 and ceased trapping efforts on July 30 when flows and daily catches declined to very low levels. In contrast to previous seasons, when multiple days were lost to the combination of flows, damage by debris and hatchery releases we were able to fish the mainstem trap for 158 of the 159 (99%) total fishing days in the 2019 fishing season. Fishing was not impacted by fine sediment and woody debris as in the dam removal period. The mainstem trapping effort by year is summarized in Figure 4.

For Indian Creek, trapping commenced on January 17 and ceased operations on September 4. At Little River trapping was initiated on January 15 and was concluded on July 23 when flows became too low to turn the screw. For both tributary sites, the traps were fished almost continuously. Indian Creek fished for a total of 216 out of 231 (94%) potential fishing days. The Little River trap fished a total of 157 of 190 (82%) possible fishing days. The tributary fishing effort by year is summarized in Figure 5. For the second consecutive year, LEKT also fished a fyke net just downstream from the Lake Sutherland outlet. The purpose of the netting was to determine if the lake was producing Pacific salmon. The fyke net was installed on May 10th and fished for 21 days.

Field Methods

For all sites, the traps were inspected and cleaned either daily or every other day. All captured fish were removed from the trap box using dip nets and transferred to plastic buckets for identification. Each fish was individually examined for tags or marks, identified to species, counted and immediately released downstream of the trap. We utilize plexi-glass fish viewers to facilitate fish identification. A weekly subsample of all species caught was measured and weighed throughout the outmigration period. Fish greater than 55 mm were also scanned for presence of Passive Integrated Transponder (PIT) and coded wire (CWT) tags. PIT tags are being used in the middle Elwha to assess the movements, growth and survival of salmon (Liermann et al. 2017). All fish that had PIT tags were also identified to species, measured, weighed and their

unique tag number recorded. CWT's are inserted into the snouts of a portion of the juvenile coho and yearling chinook salmon reared at the Lower Elwha Klallam (LEKT) Tribal hatchery and Washington Department of Fish and Wildlife (WDFW) hatchery respectively, while all steelhead produced at the LEKT hatchery receive an adipose fin clip.

In order to evaluate catch efficiency (proportion of total outmigrants captured), we conducted multiple mark recapture tests at all three trap sites. On the tributaries, weekly samples of 50 to 100 fish, representative of the species migrating at any given time (i.e. Chinook salmon smolts, coho salmon parr, coho salmon smolts), were given a distinctive mark (Bismark Brown) and released upstream of the trap site. A total of eight and six recapture trials were completed for Indian Creek and Little River, respectively. The recapture rate at Indian Creek was 13.6% and 6.7% at Little River.

For the mainstem trap we used small bodied (0+) Chinook salmon or Chum salmon obtained from the LEKT and WDFW fish hatcheries for trap efficiency trials. For the mainstem trap we conducted seven separate trials between early March and late May using releases of 1,000 bismark brown marked fish. All of the trials were successfully completed and resulted in similar recapture rates (0.7-6.4%) for an average of 2.3%. We also used Coho salmon smolts captured, marked and released from the Indian Creek smolt trap to provide a separate trap efficiency test for larger bodied fish at the mainstem trap. A total of 1,917 1+ coho smolts were marked in Indian Creek, and 11 were recaptured at the mainstem trap for a recapture rate of 0.57%.

/We used Bismarck brown dye at each of the sites to give the fish a distinctive mark that is readily recognizable by trap personnel. This is a non-toxic organic dye that is absorbed into the fish's skin resulting in a brown coloration that contrasts well with silvery smolts. The mark fades over time but is visible for 7 to 10 days following marking. The subsample of marked smolts were released approximately 100 m above each tributary trap site and approximately 1,000 m above the mainstem site. The percentage of smolts recaptured varied depending upon flow and site conditions. In general, the tributary sites had relatively high mean recapture rates in comparison to the mainstem site. Trap calibration tests for all sites are summarized in Table 1.

Data Analysis

The sum of daily catch data along with efficiency trials were used to estimate total production for the season. To incorporate uncertainty due to periods of missing data and expansion based on trap efficiency we applied a flexible Bayesian model (Appendix A). Daily passage was assumed to follow a negative binomial distribution with a mean constrained to

change smoothly with time (a random walk). Catch was modeled as a binomial distribution where the probability of capture was estimated from regular efficiency trials. Period specific efficiencies were assumed to be independent due to observed temporal trends in efficiency for some traps. We summarize the results with the median and 95% credible interval for total passage. We also include the coefficient of variation (standard deviation / mean) and the geometric coefficient of variation (which is more appropriate for skewed distributions). Additional information on production estimation is provided in Appendix A.

Results

Smolt trapping on the Elwha River was successfully completed at all sites. Additionally, moving the trap upstream of the hatchery outfalls eliminated hatchery release impacts. Similar to the last three seasons, the 2019 trapping season was not significantly interrupted by sediment or small woody debris at the mainstem site and river conditions appear to have, in large part, stabilized following dam removal. Flow conditions were benign during the 2019 trapping season with no lost days due to high flow (Figure 6).

Catch rates for several species remained relatively low, while others increased dramatically on the mainstem Elwha River in 2019. In 2019, we produced estimates for 0+ Chinook salmon, 0+ Coho salmon, 1+ Coho salmon, chum salmon and steelhead at the mainstem site (Table 2). For the fourth consecutive year we generated estimates for larger bodied Coho salmon (1+) and steelhead (1+) because of improved capture rates. In 2019, 1+ coho salmon and 0+ Chinook salmon were the most numerous species captured in the mainstem trap even though their relative numbers were low (441 and 8,340 total catch, respectively). We estimated a total 0+ Chinook fry outmigration of 496,456. Using the number of Chinook salmon redds (1,390) counted upstream of the trap in 2018, we calculated that each redd produced an average of 357 smolts. In order to account for the number of Chinook salmon redds constructed below the trap (221) we used the average Chinook salmon smolts/redd value (357) to account for an additional 75,361 chinook fry. Therefore the total 0+ Chinook salmon production for the Elwha River in 2019 is 571,817. In addition, we estimated the production of 16,180 0+ coho salmon, 69,874 1+ coho salmon, and 17,648 steelhead for the Elwha River in 2019. Low numbers of chum salmon were encountered in 2019, resulting in an estimated total outmigration of 2,896 smolts. No pink salmon were captured at the mainstem site in 2019 as Elwha pink salmon are predominantly odd year spawners. Total catch, estimated catch and production estimates for the mainstem trap in 2019 are summarized in Table 2.

We estimated Chinook salmon productivity (subyearling outmigrants/female spawner) in the Elwha River, Indian Creek and Little River over the period of record using outmigration estimates along with annual redd counts (McHenry et al. 2020) and SONAR escapement estimates (Denton et al. 2019). For the mainstem site, the production of 0+ Chinook averaged 48,185 during the pre-dam removal (2005-2011) period. During dam removal period (2012-2015) the number of subyearling chinook outmigrants did not change significantly and averaged 46,973. During the post-dam removal period (2016-2019) natural chinook production remained low through 2018 but increased dramatically for the 2019 outmigration year. As a result, the post-dam removal average has increased to 178,506 subyearling chinook outmigrants (Table 3).

The 2019 tributary trapping season was once again a tale of two sites. Both sites were fished nearly continuously with only limited breaks in fishing operations due to elevated streamflow in early spring. Production estimates for Indian Creek continue to be high for a number of species. We generated estimates for 0+ Chinook salmon (129,759), 0+ coho salmon (3,530), 1+ coho salmon (38,759), and steelhead (2,550) at Indian Creek (Table 4). A fyke net was also deployed just downstream of the outlet of Indian Creek. Because the fyke net was only fished for a total of 21 days we did not produce a production estimate from Lake Sutherland. However we did capture a total of 110 1+ coho smolts, as well as a steelhead smolt and 2 cutthroat smolts. Of particular interest was the large size observed for coho smolts emigrating from Lake Sutherland (average fork length = 168 mm). Estimates for Little River continue to be low because of low catches of larger bodied species. Species-specific estimates were generated for 0+ Chinook (107,644), 0+ coho salmon (14,831), 1+ coho salmon (1,856), and steelhead (284) (Table 5). One and seven Chum salmon smolts were captured at Indian Creek and Little River, respectively and no estimates of production were made for those species. No pink salmon were captured at either tributary in 2019.

We assembled the miscellaneous species catch records for all three trap sites that included three year classes of *O. mykiss*, three year classes of cutthroat (*O. clarki*), bull trout, brook trout, plus all non-salmonids (Table 6). No total production estimates were made for these species, however total catches were summarized and analyzed for ecological significance. For trout there were large numbers of rainbow 0+, 1+ and 2+ age classes that were captured at Indian Creek in 2019. Conversely, fewer numbers of trout were encountered at Little River. No bull trout were captured in Little River and 8 were encountered at Indian Creek. Additionally, we captured the second greatest number of cutthroat smolts to date at Indian Creek (24). The only non-native fish encountered during trapping operations are brook trout, which are well established in Indian Creek. The 7 Brook trout captured at the trap were removed from the system.

For non-salmonids we report three interesting results: 1) the continued expansion of Pacific lamprey in the Elwha River, 2) the rapid increase in sculpin populations encountered at the mainstem trap, and 3) the rapid decline of redbreasted sunfish (*Richardsonius balteatus*) encountered at Indian Creek. In 2019, Pacific lamprey captures remained strong at Indian Creek (Figure 9) and were the highest to date on the mainstem trap (Table 6). For sculpin the number of encounters were generally less than 600/year during the pre-dam removal period. That number dropped precipitously during dam removal but has rebounded to over 2,000 in 2019 (Figure 9). In 2019 we also identified sculpin to species and found that the vast majority (>95%) of sculpin captured at the mainstem trap were Coastrange (*Cottus aleuticus*). Prickly sculpin (*Cottus asper*) were also encountered at the mainstem but were much more common at Indian Creek. At the mainstem trap, we no longer encounter marine species because of the new trap location at Rkm 4.0. In 2018, we reported the continued presence of eulachon (*Thaleichthys pacificus*) encounters in the trap with a total catch of 23. This population appears to vary greatly in abundance by year in the Elwha but is consistently observed. Eulachon and other marine species likely stray into the lower river on high tides and are subsequently captured in the trap. LEKT is deploying a 5' screw at the lower river site in 2020 to facilitate continued evaluation of the eulachon population.

Discussion

Contemporary History

Smolt trapping on the Elwha was initiated in 2006. The period from 2006-2011 represents pre-dam removal conditions when anadromy was limited to the lower 7.9 kilometers below the dams and hatchery production dominated salmon returns for Chinook salmon, Coho salmon, and to a lesser extent steelhead. Dam removal was initiated in 2011 and smolt outmigration estimation continued through the dam removal period. The period between 2012 and 2015 represents the production of salmonids during dam-removal period. Mainstem smolt trapping efforts during the dam removal period were challenging particularly in 2012 and 2013. This coincided with water years 2013 and 2014 where total sediment transported during the incubation phase for Chinook salmon was 19.6 and 5.7 times higher than prior years. These conditions forced LEKT to abandon trapping because of the amount of sediment and debris interfering with trap operations. Trapping operations during 2014 were stopped because this coincided with the largest amount of sediment transport, which was coupled with movement of large wood and continuous elevated spring runoff. Trapping conditions were much improved in 2015 because those outmigrants were subject to incubation conditions less severe than 2014, but still 10 times higher than prior to dam removal. It is important to note that sediment alone

is not the only factor which influences potential smolt outmigration, and flow can also have detrimental impacts to smolt productivity (McHenry et al 2019).

Lost fishing days is a primary and direct effect of the annual increases in sediment and debris transport during the dam removal time period. During 2014 we were only able to fish the mainstem site <50% of the days. In 2015, 2016, 2017, 2018, and 2019 we have been able to fish the mainstem trap for a total of 155 of 166 days (93%), 142 of 171 days (83%), 111 of 182 days (61%), 140 of 181 days (77%), and 158 of 159 (99%), respectively. The 2016-2019 seasons represents the first years of post-dam removal data and provides a benchmark to assess the state of early recovery. We believe that the worst of the sediment impacts from dam removal on smolt trapping operations have occurred because sediment loads are now at or below what was estimated prior to the initiation of dam removal (Ritchie et al. 2018)

Another confounding factor, irrespective of sediment issues, is the low capture rates of large bodied smolts such as coho salmon and steelhead. This has been problematic since smolt trapping was initiated on the Elwha in 2006. The return of the 8' screw trap to the mainstem site improved smolt estimation for both small and large bodied smolts since 2016. This result, now repeated in four consecutive years, represents a significant improvement in the overall smolt monitoring program. Since 2016, we have been able to generate estimates for more species/life histories than in previous years.

Trends in Smolt Outmigration Over Time

The outmigration estimates for Elwha 0+ Chinook salmon smolts in 2019 was 571,817 a record over the period of record. This estimate is also conservative in that trapping operations were delayed by 3-4 weeks due to prolonged snow on the ground in February. This number is twenty-six times the number produced in 2018 and 9.2 times the average for the period from 2006 to 2018 (Figure 7). In 2018, adult Chinook salmon escapement to the Elwha River was in excess of 7,000 salmon, and the greatest numbers of redds (1601) were enumerated during spawning ground surveys (McHenry et al. 2019). It was previously hypothesized that egg to emergence survival of Chinook salmon that spawned during the dam removal period was low as a result of scour, fill, entombment and overall more variable streambed conditions. This was corroborated by low Chinook salmon and chum salmon production through the 2018 trapping season. A negative correlation between peak flows and Chinook salmon survival has been reported in Puget Sound (Greene et al. 2005). Unstable bed conditions, particularly in the areas affected by peak sediment transport (downstream of Glines Canyon) during dam removal has also likely limited the survival of incubating embryos on the Elwha River to date. We explored the relationship between flow, suspended sediment levels and chinook survival (fry/spawner) on the Elwha River between 2011-2017. The index of flow and suspended sediment was negatively correlated with chinook survival for those years (McHenry et al. 2019). Also of

interest is what appears to be the reestablishment of a bimodal outmigration pattern for Chinook salmon 0+ smolts during the last two monitoring seasons (Appendix B). This pattern is consistent with other Chinook populations in Puget Sound.

We compared the total outmigration estimates between tributaries and found some noticeable differences in abundance and timing (Appendix B). In past seasons for Coho salmon (0+), large numbers of fry outmigrants were moving downstream, presumably to rear in other habitats or immigrating to the Strait of Juan of de Fuca. This life history pattern has been documented in other nearby Strait of Juan de Fuca watersheds (Bennett et al. 2014). This pattern was not observed in 2016, likely as a result of the record low escapement of coho salmon in 2015. This pattern reappeared in 2017, 2018 and 2019 at all sites. For 1+ coho salmon smolts, Indian Creek produced an estimated 38,759 fish, which is a record since the project began. In contrast, we estimated a total production of 14,831 0+ coho salmon and 1,856 1+ coho salmon smolts in Little River in 2018.

The estimated number of 0+ Chinook salmon produced from both Indian Creek (129,759) and Little River (107,644) is the greatest number measured since trapping commenced in 2012. Both systems experienced high numbers of Chinook salmon spawning during 2018, with 144 and 63 redds counted in Indian Creek and Little River, respectively. Since Elwha Dam was removed in 2014, Little River has had several years where few or no Chinook salmon having entered the system. We hypothesize this is due to the combination of low attraction flows and relative small stream size, along with location of the mainstem on the west side of the valley in some years.

Steelhead smolt production in the Elwha River has steadily increased since the LEKT was able to generate its first estimate in 2016 (Figure 7). Prior to 2016 we encountered so few steelhead smolts (less than 50/year) that we were unable to generate an estimate. 2019 represents the fourth consecutive year that a steelhead estimate has been generated. The 2019 estimate of 17,648 is the highest measured to date and is 35% higher than 2017 which was the second highest outmigration number Indian Creek has seen a similar trend increasing steadily from 85 in 2013 to 2,550 in 2019. The increase in steelhead smolt numbers since 2014, in the mainstem Elwha and Indian Creek, suggests rebuilding is ongoing. Little River Steelhead smolt estimates have been considerably more variable and have not shown the same positive trend. In 2014 there were almost 500 estimated smolts, which was similar in 2015, and 2016, followed by a decline to 14 in 2017, no estimate in 2018, and an increase to 284 in 2019. It is important to note that large numbers of juvenile mykiss outmigrate in the fall when the screw trap is not operating in Little River (Unpublished data, LEKT). We have documented this movement since 2012 with passive integrated transponder (PIT) antennas and PIT tagged juvenile *O. mykiss*. Steelhead adults were first observed in both tributaries during the spring of 2012, immediately

following the removal of Elwha Dam. Assuming two years of freshwater residency, 2014 represented the first significant smolt production for both tributaries in over a hundred years.

Small numbers of steelhead smolts were first observed in Little River in 2012 (2 total) and 2013 (24 total) and from Indian Creek in 2013 (16 total). These were likely the progeny of resident rainbow trout populations that have retained anadromous life histories. This strategy has been previously documented in the Elwha during downstream fish passage studies in the late 1980's (Hiss and Wunderlich 1994) and in recent genetic analysis of Elwha wild steelhead (Winans et al. 2017) from 2013-2015.

Indian Creek has consistently produced larger numbers of coho salmon smolt (1+) outmigrants relative to Little River over the period of monitoring (Figure 8). Since 2012, surplus coho salmon adults from the LEKT hatchery have been relocated to the two middle Elwha tributaries. All of these relocated fish have been visually tagged using colored spaghetti tags. Based upon observations on the spawning areas of the tributaries, the majority of the coho salmon spawners to date originated from these relocation efforts (McHenry et al. 2017). Both tributaries received similar numbers of relocated hatchery adult coho salmon between 2011-2013. However, no relocations have occurred in Little River since 2013. The larger numbers of Coho salmon 1+ outmigrants are likely due to the amount and quality of habitat within the sub-drainage. Indian Creek's headwaters include Lake Sutherland which moderates flow and temperature characteristics. Indian Creek also has significant groundwater influence as it flows downstream. A significant Beaver (*Castor canadensis*) population has also hydro-modified large areas downstream of Lake Sutherland and have created excellent rearing habitat for coho salmon rearing. Interestingly, our estimate of Indian Creek 1+ coho salmon outmigrants represents 55% of the total production from the Elwha watershed.

While the overall trends for Chinook salmon smolt outmigrants are favorable since dam removal, the total number of chum and pink salmon outmigrants is still alarmingly low. Both populations entered dam removal at low levels and it is likely that dam removal itself has further stressed both populations. The 2019 Elwha chum estimate was 2,896 fish well below the pre-dam removal average of 141,802 (2006-2012). The Elwha pink population is primarily an odd year timed run and as a result no smolts were captured in the 2019 outmigration year. For years in which we caught enough pink smolts to generate a mainstem production estimate those numbers show a steadily declining trend. Neither tributary to date has been colonized by significant numbers of returning adult chum or pink salmon.

Chum and pink salmon are thought to be critical to the overall Elwha salmon recovery primarily for their contribution to marine derived nutrients to the river. The lack of chum salmon and pink salmon to both Little River and Indian Creek is a serious concern to project co-managers. There is concern that passage conditions at the former Elwha Dam site were

problematic for some species and at some flows during the early post dam removal period (ONP 2014, WDFW 2014). Comparison of historic photographs prior to dam construction with post dam removal conditions suggests that the site is currently significantly steeper (cascade versus pool). It is apparent that a significant amount of boulder debris was left in place in the channel creating numerous hydraulic jumps that have been difficult for some species of fish to ascend at least through the calendar year 2014. Passage conditions appeared to have improved during the winter of 2014-15, following floods that transported several large boulders downstream. However, during the summer of 2015, during very low flow conditions, the base of the former Elwha Dam was discovered. This indicates that the entire structure was not removed and needs to be closely monitored as conditions could change again. The lack of chum and pink salmon upstream of Elwha Dam through 2016 would seem to support those observations. Similarly, passage through Glines Canyon has only recently been improved. A large rock fall in the canyon entrance shortly following the removal of the structure has largely precluded upstream passage. This obstruction was systematically blasted in the fall of 2015 and continues to be monitored. Recovery of upriver populations and life histories is contingent upon successful fish passage at this site. If these trends continue, project managers should consider interventions that could amplify both populations.

Smolt trapping operations have documented several ecologically significant events that suggest the “reawakening” of anadromy or natural recolonization events. Those include the the rapid recovery of steelhead and coho salmon in the tributaries, the first large outmigration of naturally produced chinook salmon, the natural recolonization of Indian Creek by Pacific Lamprey, and the continued presence of eulachon in the lower river. However several other species including pink, chum and sockeye show no signal of recovery. The Elwha Fisheries Recovery Plan (Ward et al. 2008) indicates that for sockeye salmon natural recovery is the preferred means of rebuilding this stock. Because Elwha sockeye salmon were thought to have extirpated by dam construction, the plan states that the primary mechanism for recovery of sockeye salmon is from adults straying from other watersheds or by contribution of smolts originating from the landlocked kokanee salmon population in Lake Sutherland. While there have been adult sockeye salmon observations in the Elwha mainstem and in Indian Creek since Elwha Dam was removed, the numbers have been very low. This may suggest that the Sutherland kokanee population is still producing sockeye smolts, albeit at a very low level. This mechanism has been previously documented in the Coquitlam and Allouette Rivers in British Columbia where sockeye were extirpated by dams constructed in the early twentieth century (Godbout et al. 2011). The retention of anadromous life history by a population of sockeye thought to have been trapped by dam construction in 1914 and retained for 25 generations bodes well for the Elwha River. Indeed, analysis of egg size showed that Sutherland kokanee have a larger egg than other known kokanee populations and are similar only to a land locked population in New Zealand derived from an anadromous population (Quinn et al. 2015). The

authors infer that Lake Sutherland kokanee may have an anadromous origin. We intend to collect tissue samples from sockeye salmon in future years in order to elucidate the origin of this population.

Recolonization is successfully occurring for Pacific Lamprey (*Entosphenus tridentatus*) in Indian Creek, where adult captures were first documented in 2013 and subsequently again in later years at the smolt trap. These adults are early colonizers to Indian Creek. Ammocoetes (juveniles) were first encountered at Indian Creek in 2013, one year following the initial recolonization event by adults in 2012. Lamprey appear to be expanding rapidly in Indian Creek. In 2014, we captured 132 ammocoetes, in 2015 the number increased to 407, and in 2016 the number again increased to 1,805, and in 2017 the number again increased to 3,474. In 2018, we captured 2,029 ammocoetes and in 2019 a new record of 3,914 were captured. We expected that downstream migrating microphthalmia from Pacific Lamprey would eventually be encountered at Indian Creek; however this was not anticipated for several more years because of their prolonged freshwater residency estimated at 5-6 years (Scott & Crossman 1973). However, in 2016 we encountered a total of 71 Pacific Lamprey macrophthalmia and in 2017 that number increased to 600. In 2018 and 2019, the total number of macrophthalmia was 649 and 546, respectively.

Chinook Productivity

We assessed Chinook productivity by calculating the number of smolts produced per female and the number produced per spawner over the period of record (2005-2019). In general the productivity of Elwha Chinook salmon has been low over the period of record. During the pre-dam removal period (2005-2011), productivity averaged 104 (range 22-165) smolts/female. During dam removal chinook productivity further declined further and averaged 85 (13-119) smolts/spawner. During the post dam removal period Chinook salmon productivity remained low until the 2019 outmigration year when productivity increased dramatically and to 339 smolts/spawner. The 2019 outmigration year was the highest on record and increased the post-project average to 118 smolts/spawner (range 43-339). In other Puget Sound Rivers, Chinook salmon productivity is variable and based on data from six Puget Sound Rivers ranges from less 100 to nearly 1,200 smolts/female (average 192 smolts/female) (Unpublished Data, WDFW; Hall et al. 2018).

The low productivity values prior to dam removal are explained by the combination of low numbers of natural spawners, limited habitat area for spawning, degraded spawning habitat conditions (sediment starvation) prior to dam removal. Up until dam removal, the river had moderately incised and its bed coarsened to the point there were only a handful of areas where Chinook salmon could actually construct nests (Pess et al. 2008). Additionally low numbers of returning Chinook salmon adults resulted in the majority of fish being cycled into the hatchery program. During dam removal, large volumes of sediment were released resulting

in unstable channel conditions and high levels of fine sediment creating poor incubation environments for chinook salmon. Based upon smolt production data it appears incubation conditions remained poor into the post project period at least through the 2017 brood year.

Sources of error

We have strived to keep the aforementioned sources of uncertainty low in order to stay within a coefficient of variation of 15% or less. However, the realities of maintaining in-stream infrastructure in a large Olympic Peninsula river continuously for up to 7-8 months inevitably involves the possibility of unknown circumstances reducing the amount of data collected and thereby the accuracy of our outmigration estimates. This phenomenon was exacerbated by dam removal and elevated sediment and debris transport on the Elwha River, at least through 2014. In contrast to previous years, when large portions of the fishing season were lost due to river conditions, mechanical breakdowns and hatchery releases, only one day of fishing was lost in on the mainstem Elwha in 2019. The abundance of fish is also increasing and as a result more fish are being captured. The net effect of this is a reduction in the Coefficient of Variation. In 2019 we recorded the lowest Coefficient of Variation (CV) values since the project was initiated. The CV for mainstem trapping estimates ranged from 12% (0+ coho) to 23% (chum salmon) and averaged 17% for all species.

In 2019 the CV was at or near the 15% threshold for 4 of 5 species estimated at the mainstem site. We expect the CV values to continue to improve over time as populations expand and catch rates rise. During the pre-dam removal period (2005-2011) our annual CV on the mainstem Elwha ranged from 5.5% to 28%, with two of seven years exceeding the 15% threshold. With continuous fishing in 2019 we were able to complete 8 trap efficiency tests on the mainstem. One of these was for coho 1+ and the other seven using chinook 0+. The lack of large bodied trap trials is an area that we need to improve upon. The lack of large bodied efficiency tests introduces the greatest amount of uncertainty to the mainstem estimates.

In contrast, fishing on the tributaries was interrupted more than in previous years as mechanical issues and high flows in the early season resulted in lost fishing days. The coefficient of variation at Little River was well above the 15% target threshold and averaged 36%. Low catch rates for large bodied species appear to be the cause of this increase. Little River estimated CV was 21% for 0+ Coho salmon and 35% for 1+ coho salmon, while steelhead was 0%. Indian Creek CV's were variable and ranged from 14% for 0+ Coho smolts to 57% for 0+ Chinook salmon. For all species the CV for the Indian Creek site was 32%.

For all trap sites we plotted estimated catch and expansion factors for all species (Appendix D).

Recommendations

Based on our experiences conducting smolt trapping on the Elwha River during the dam removal period we will implement the following changes for 2020 operations. For the mainstem Elwha River trapping effort we will continue the trapping operations at the upstream site at Rkm 4.0. The long term future of the mainstem trap site has been threatened by the dynamic nature of the river in the vicinity of the trap site over the last several years. Changes in channel position now limit our ability to launch the trap from the terminus of Lower Elwha Road. Additionally, overflow channels that could erode the road to the point that it is no longer accessible to vehicles continually threaten Lower Elwha Road. As a result, we propose to maintain the trap to the site just downstream of Elwha River Road bridge. This is the only reliable road access point in the lower. It places the trap further upstream than desired (Rkm 4.0), but offers the advantage of being above both Elwha River hatcheries.

The problem of low catch rates for larger sized smolts at the mainstem trap will be partially addressed by maximizing fishing time. The new trap location results in fewer lost days from hatchery releases. It will also increase the precision of fish identification, particularly for 0+ Chinook salmon. In theory more fishing time should result in higher catches of all species. However, an ongoing problem for large bodied smolts is the expansion of raw catch estimates to generate production estimates. The majority of mainstem trap efficiency tests on the Elwha River have relied on small bodied hatchery produced smolts including Chinook salmon (0+), chum salmon (0+) and Coho salmon (0+). These sized fish are generally available and were convenient to use for trap efficiency tests. In recent years we added trap tests using larger sized hatchery and natural origin smolts including Coho salmon 1+, steelhead, and Chinook salmon 1+. We will continue calibrating the trap using both small and large bodied smolts in future years. Alternatively, we will use larger sized smolts collected at the tributary sites to provide animals for mark-recapture evaluations on the mainstem. When using large bodied smolts for trap efficiency trials there is evidence that those releases should be made at or near dusk when the natural migration of salmonids occurs (Roper and Scarnecchia 1996). Tattam et al. (2013) assessed the capture efficiency of *Oncorhynchus mykiss* in a screw trap on the South Fork John Day River, Oregon and found that capture efficiency was highest for releases made near dusk. All other trapping operations, including timing and daily trap inspections are anticipated to remain unchanged.

We will continue to refine our estimation approach in an attempt to reduce the sensitivity of the analysis to extreme efficiency values while still maintaining defensible assumptions. In particular, we will investigate hierarchically modeling the efficiency estimates which would provide a compromise between taking the average over all periods and using the individual estimates (Bonner and Schwarz 2011). This will reduce the effects of extreme efficiency trials while still allowing for variation in efficiency over time. We will also further

investigate the sensitivity of the estimates to violations of the model assumptions (Rawding and Rodgers 2013).

The tributary sites have generally performed well with the only real issues being trap performance at the end of the season at Little River. Following the cessation of snow melt, Little River flows may drop to the point that stream velocity is no longer sufficient to turn the screw. In 2019 we employed a battery powered motor to power the screw with some success. In 2020, we will continue to use this approach but power the motor with a thermal electro-generator powered by propane. This will eliminate the need to constantly change and charge batteries as well as lugging them to the site. On Indian Creek, we will continue our efforts to quantify the production of fish directly from Lake Sutherland. In 2019 we used a fyke net to capture emigrating smolts just below the outlet of the lake. The fyke net was difficult to maintain and was constantly clogged with algae and other debris from the lake. In 2020, LEKT will construct a fence weir 0.5 miles downstream from the lake outlet. This should improve overall catch rates and eliminate maintenance associated with the fyke net. It will also allow us to partition the amount of production from Lake Sutherland.

Our final recommendation is to consider adding a fourth smolt trap monitoring site just below Glines Canyon at the former location of the Glines Powerhouse. The purpose of this site is to measure the production of smolts occurring in the upper watershed which is currently in the early phases of recolonization. This action was planned for the 2018 outmigration season and LEKT has a 5' screw ready to deploy. This action was delayed however, because the Hot Springs Road is currently closed one mile upstream of the ONP entrance due to the Elwha River reoccupying its floodplain and washing out the road. The lack of vehicle access precludes trap launching at the Glines site, however an alternate site is available just downstream of the ONP entrance and this site could be used in lieu of the Glines Canyon location.

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Tables

Table 1. Results of mark-recapture tests for Elwha River, Indian Creek and Little River for the 2019 smolt outmigration season.

Site	Date	Species	Number	Recaptures	Percentage (%)
Elwha	3/20/18	Chinook 0+	1,000	28	2.8
Elwha	3/29/18	Chinook 0+	1,000	20	2.0
Elwha	4/27/18	Chum 0+	1,000	42	4.5
Elwha	5/1/18	Chinook 0+	1,000	25	2.5
Elwha	5/22/18	Chinook 0+	1,000	45	4.5
<i>Elwha Average</i>			<i>5,000</i>	<i>160</i>	<i>3.2</i>
Little	3/20/19	Chinook 0+	106	11	10.4
Little	4/3/19	Chinook 0+	100	4	4.0
Little	4/11/19	Chinook 0+	100	4	4.0
Little	4/23/19	Chinook 0+	100	8	8.0
Little	5/1/19	Chinook 0+	100	5	5.0
Little	5/22/19	Chinook 0+	50	5	10.0
<i>Little Average</i>			<i>556</i>	<i>37</i>	<i>6.6</i>
Indian	3/4/19	Chinook 0+	100	10	10.0
Indian	3/14/19	Chinook 0+	100	18	18.0
Indian	3/20/19	Chinook 0+	100	23	23.0
Indian	4/1/19	Chinook 1+	100	8	8.0
Indian	4/11/19	Chinook 0+	100	18	18.0
Indian	4/23/19	Chinook 0+	100	8	8.0
Indian	5/1/19	Chinook 0+	100	9	9.0
Indian	5/17/19	Coho 1+	50	12	24.0
<i>Indian Average</i>			<i>750</i>	<i>106</i>	<i>14.7</i>

Table 2. Total catch, estimated catch (missing catch estimated), average efficiency (weighting by efficiency period length) , days missed (trap not operational during species migration window), estimated outmigrants, 95% C.I., CV, and geometric CV for smolt outmigration from the mainstem Elwha River, 2019 outmigration year. NE = no estimate.

Species	Catch	Estimated Total Catch	Estimated Outmigrants	95% C.I.	CV	gCV
Chinook Salmon(0+)	8,340	8,436	496,456	387,791 - 669,259	0.14	0.14
Chinook Salmon(1+)	4	NE	NE	NE	NE	NE
Coho Salmon(0+)	337	337	16,180	13,039- 20,654	0.12	0.12
Coho Salmon(1+)	441	443	69,874	42,258- 133,420	0.33	0.30
Chum Salmon	44	44	2,896	1,927- 4,600	0.23	0.22
Pink Salmon	0	NE	NE	NE	NE	NE
Steelhead	111	111	17,648	10,214- 31,503	0.30	0.29

Table 3. Estimated number of Chinook salmon subyearling outmigrants and productivity (smolts/female) for the Elwha River, Indian Creek and Little River (2005-2019).

Year	Elwha 0+ Outmigrants	Elwha Smolts /Female	Indian 0+ Outmigrants	Indian Smolts /Female	Little 0+ Outmigrants	Little Smolts /Female
2005	106,348	146				
2006	44,256	62				
2007	16,228	29				
2008	18,352	29				
2009	14,533	22				
2010	125,772	395				
2011	11,808	44				
2012	65,901	165				
Pre-Project Average	48,185	104				
2013	NE	NE	118,109	1,845	38,601	NE
2014	93,981	119	14,290	251	10,628	443
2015	16,200	13	134,909	5,189	8	NE
Dam Removal Average	46,973	85				
2016	45,818	29	93,395	6,226	21,863	429
2017	73,152	60	3,024	108	3	NE
2018	23,236	43	3,916	112	5,205	578
2019	571,817	339	236,523	1,64	125,585	1,993
Post-Project Average	178,506	118				

Table 4. Total catch, estimated outmigrants, 95% C.I., CV and geometric CV for smolt outmigration from Indian Creek, 2019 outmigration year.

Species	Total Catch	Estimated Total Catch	Estimated Outmigrants	95% C.I.	CV	gCV
Chinook Salmon(0+)	7,929	15,296	129,759	66,176-366,267	0.57	0.47
Chinook Salmon(1+)	12	NE	NE	NE	NE	NE
Coho Salmon(0+)	507	524	3,530	2,756-4,737	0.14	0.14
Coho Salmon(1+)	5,935	5,942	38,759	27,812-53,930	.17	.17
Pink Salmon(0+)	0	NE	NE	NE	NE	NE
Chum Salmon(0+)	0	NE	NE	NE	NE	NE
Steelhead	283	290	2,550	1,922-3,517	0.16	0.15

Table 5. Total catch, estimated outmigrants, 95% C.I., CV and geometric CV for smolt outmigration from Little River, 2019 outmigration year.

Species	Total Catch	Estimated Total Catch	Estimated Outmigrants	95% C.I.	CV	gCV
Chinook Salmon(0+)	9,151	11,133	107,644	69,698-213,536	0.31	0.28
Chinook Salmon(1+)	0	NE	NE	NE	NE	NE
Coho Salmon(0+)	1,176	1,189	14,831	10,430-23,122	0.21	0.21
Coho Salmon(1+)	148	151	1,856	1,178-3,298	.29	.27
Pink Salmon(0+)	0	NE	NE	NE	NE	NE
Chum Salmon(0+)	0	NE	NE	NE	NE	NE
Steelhead	21	21	284	163-498	0.30	0.30

Table 6. Total catch of miscellaneous fish encountered at Elwha River, Little River and Indian Creek smolt traps, 2019.

Site	0+ Trout	1+ Trout	2+ Trout	Bull Trout	Brook Trout	Cutthroat Trout (Smolts)	Cottids	Redside Shiner	Ammocoete	Macrothallimia	Adult Pacific Lamprey
Elwha	104	71	0	0	0	0	2,031	0	363	17	2
Little	102	159	0	0	1	0	10	0	2	0	0
Indian	355	816	172	8	7	24	208	27	3,914	546	8

Figures

Figure 1. Top Elwha River 8' rotary screw trap fishing at Rkm 0.3 during the pre-project periods and bottom 5' rotary screw trap used during the dam removal period.



Figure 2. Little River (top) and Indian Creek smolt traps.



Figure 3. Elwha River, Indian Creek and Little River smolt trap locations.



Figure 4. Elwha mainstem smolt trap fishing effort by year, 2005-2019. Green are days fishing, blue is day fishing but trap not checked, and black are days not fishing. Black horizontal bars underneath the multicolored bars represent the four days including and immediately following efficiency trials.

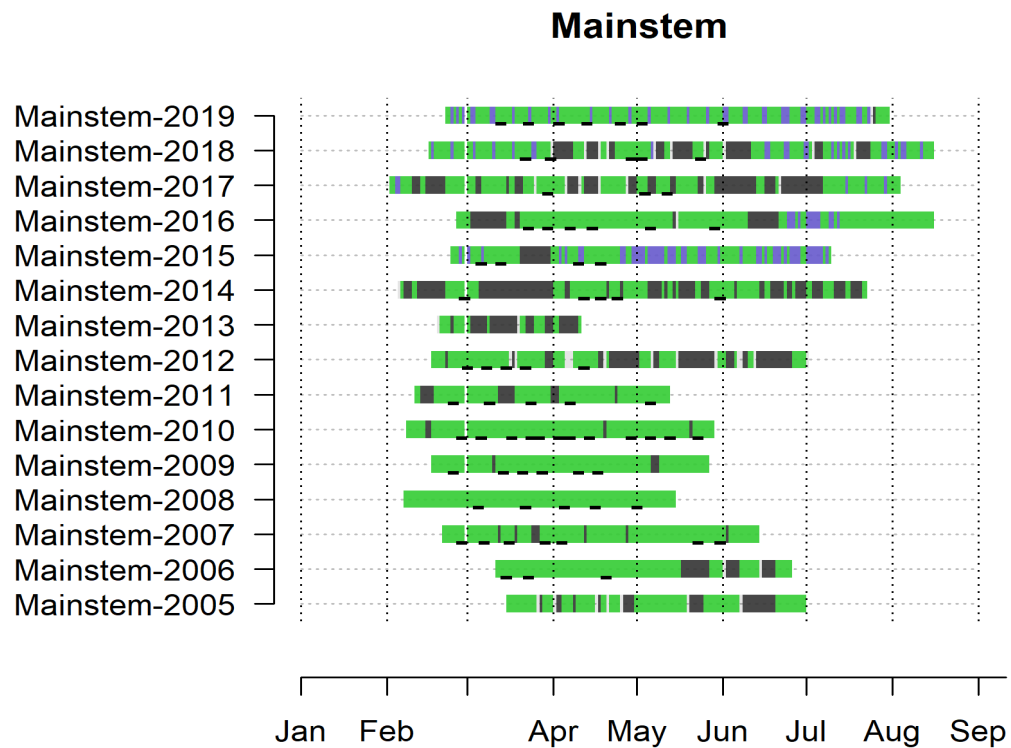


Figure 5. Little River and Indian Creek smolt trap fishing effort by year, 2012-2019. Green are days fishing, blue is day fishing but trap not checked, and black are days not fishing. Black horizontal bars underneath the multicolored bars represent the four days including and immediately following efficiency trials.

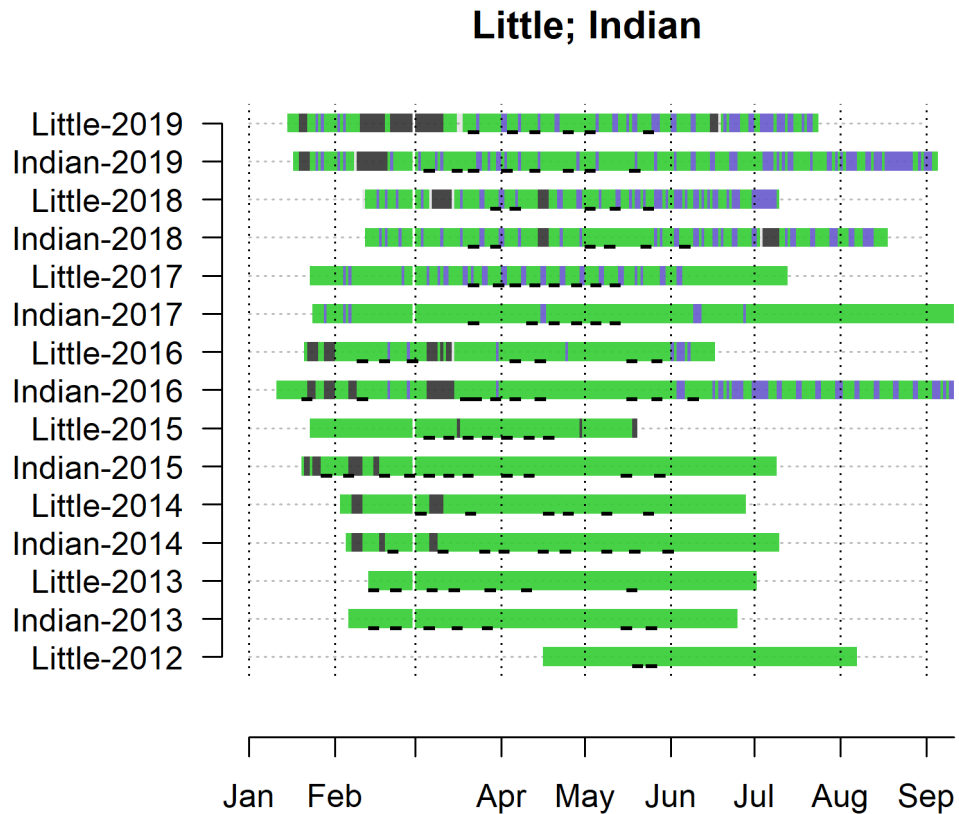


Figure 6. Elwha River flows (cfs) measured at the McDonald Gage Site, September 15, 2018 to February 1, 2019 (top-Chinook salmon incubation period) and February 22, 2019 to July 30, 2019 (bottom-smolt outmigration period).

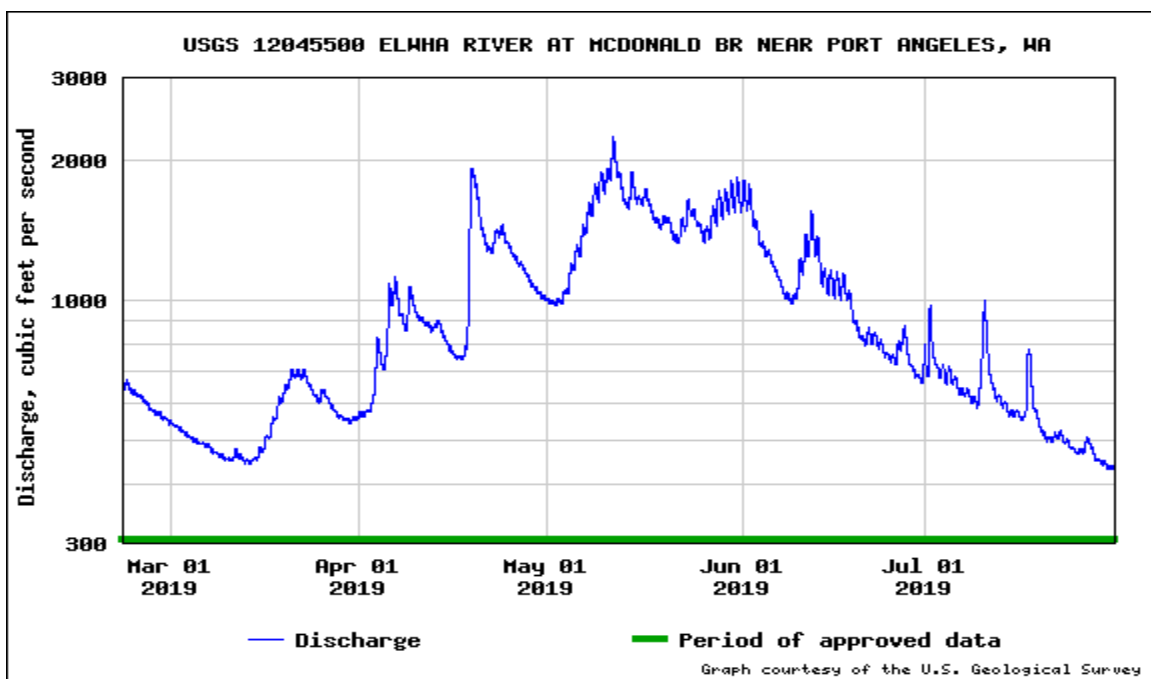
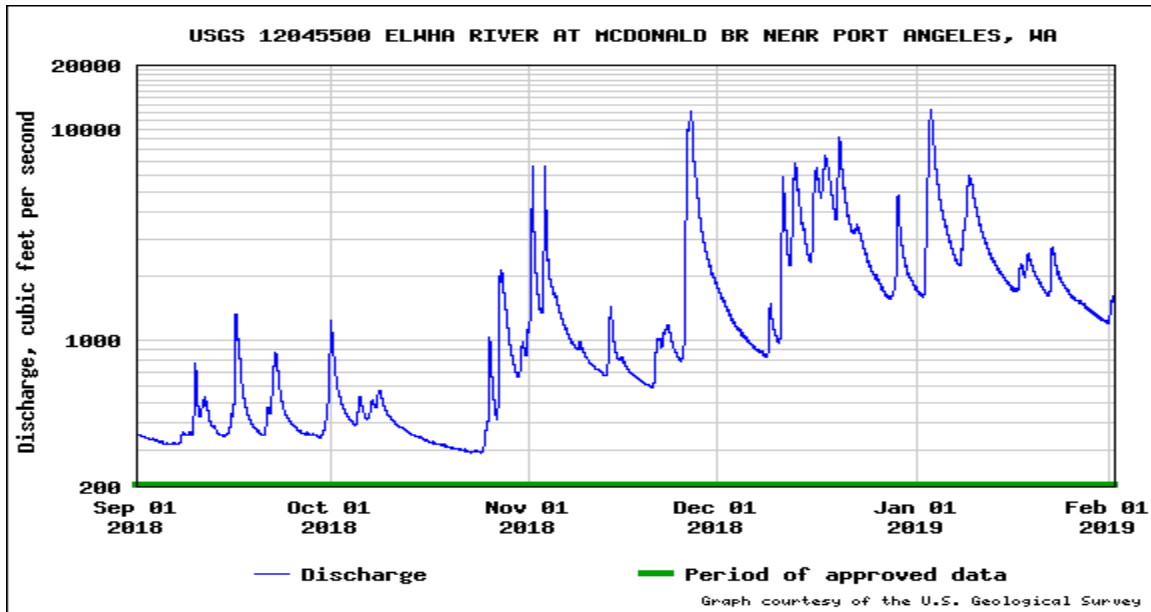


Figure 7. Estimated Elwha River Chinook, Chum and coho salmon smolt production (top) (2006-2019) and steelhead smolt production (bottom) (2015-2019).

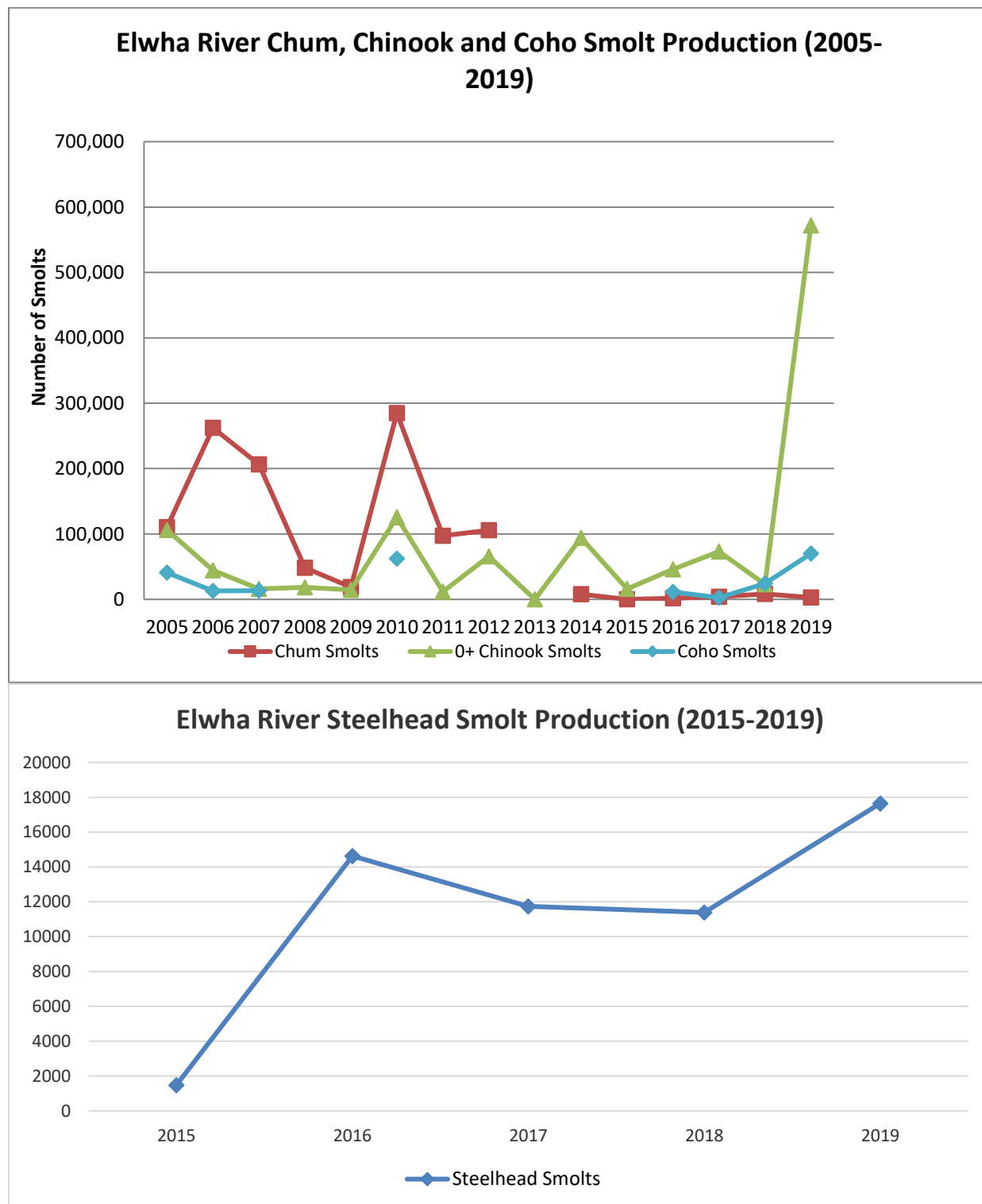


Figure 8. Estimated steelhead and coho smolt production for Indian Creek and Little River (2012-2019).

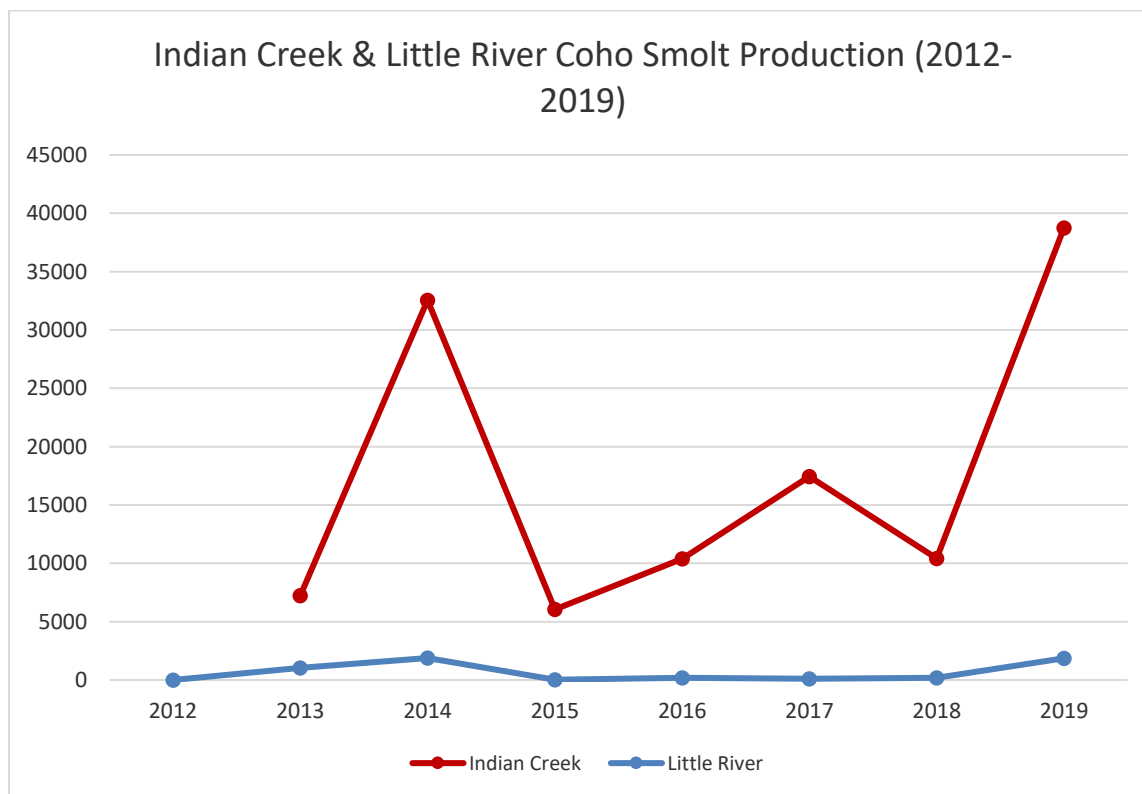
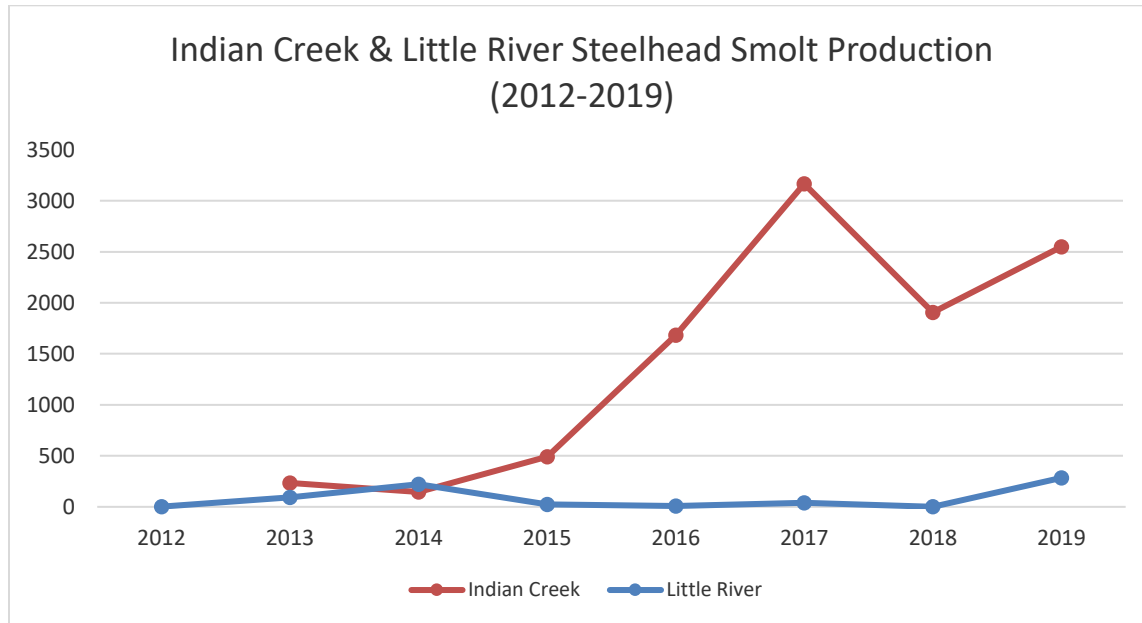
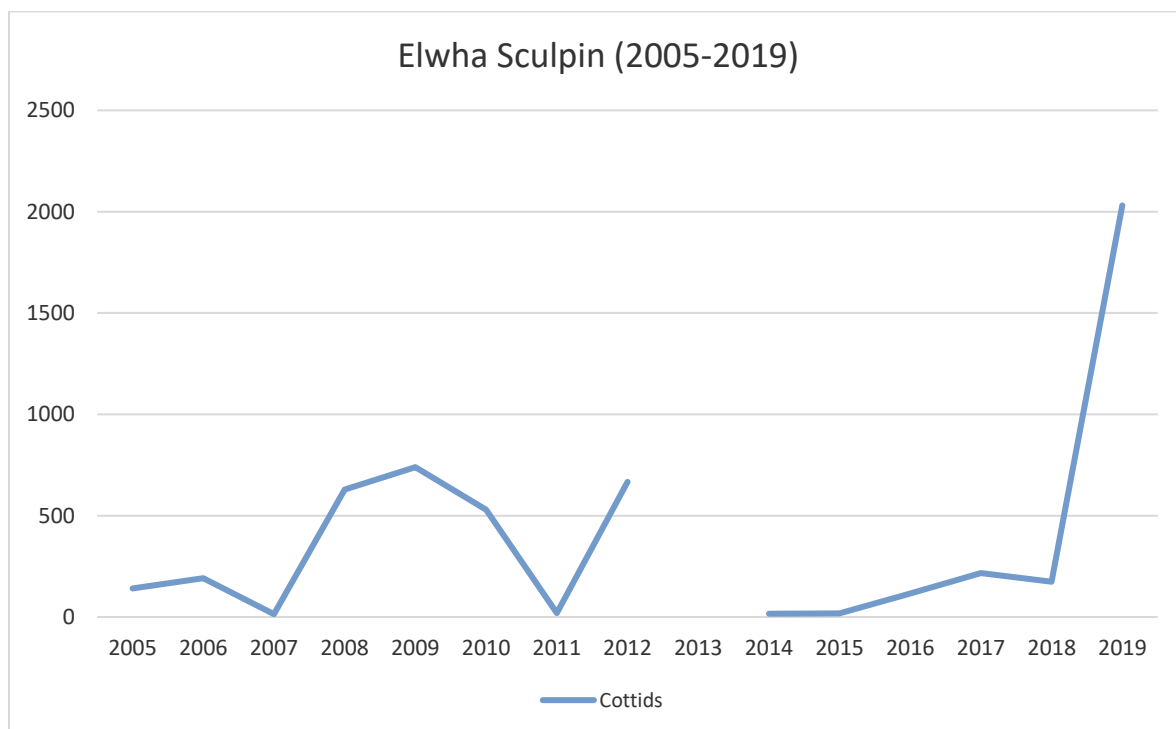
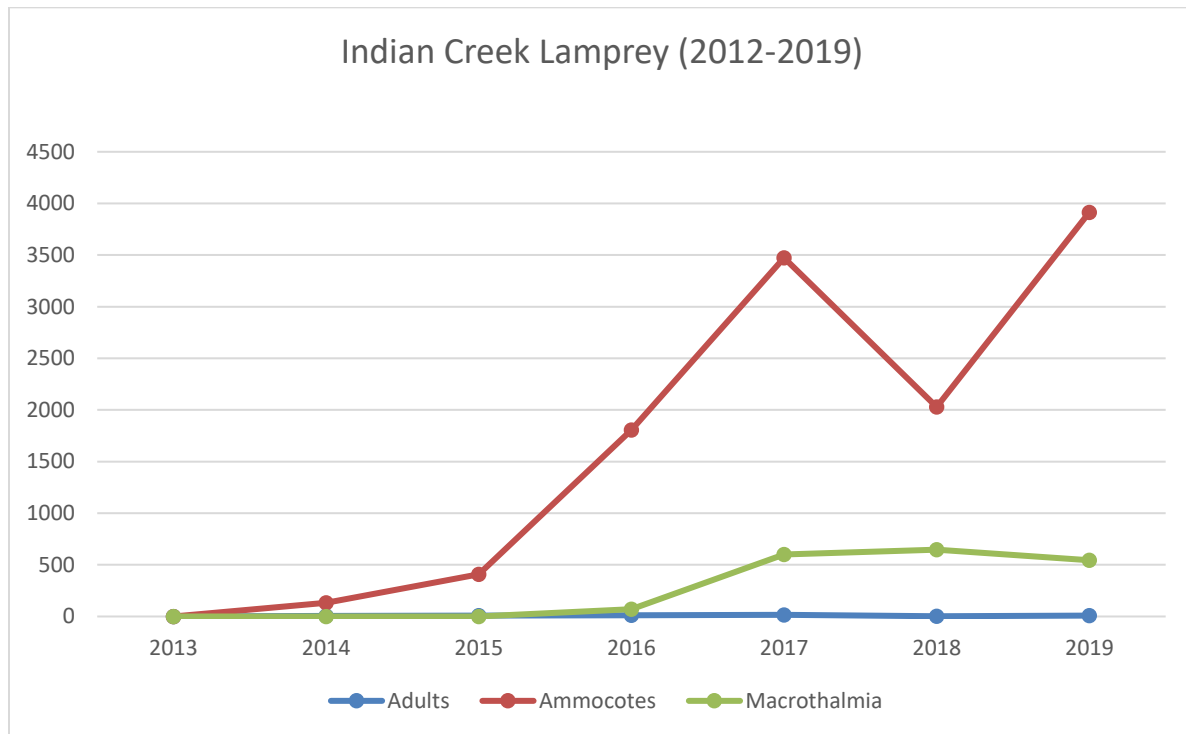


Figure 9. Pacific Lamprey captures at the Indian Creek Smolt trap (top) and sculpin (bottom) at the mainstem trap.



Appendix A.

Total passage past the trap (T_i) was assumed to follow a negative binomial distribution. This allows for over-dispersed counts (i.e. more variability than expected based on other distributions such as the poisson).

$$T_i \sim \text{negbinom}(\text{mean}_i \text{days}_i, \text{disp}_i)$$

$$\log(\text{disp}) \sim \text{normal}(0, 100)$$

Where the mean daily passage is a temporal random walk with the variance of the jump size proportional to the number of days the trap was fished before it was checked (days). This allows the mean to change from day to day but only incrementally.

$$\log(\text{mean}_i) \sim \text{normal}(\log(\text{mean}_{i-1}), \text{rwSD}_i \text{days}_i^{-1/2})$$

$$\text{rwSD}_i \sim \text{normal}(0, 100)$$

The observed catch (C_i) was modeled as a binomial distribution where a period specific proportion (p_i) of total passage past the reader (T_i) was captured.

$$C_i \sim \text{binomial}(p_i, T_i)$$

The proportion captured by the trap (i.e. the efficiency, p_i), was estimated from efficiency trials where a large groups of marked fish (M_j) were released above the trap and the number of marked fish recaptured at the trap (R_j) was recorded.

$$R_j \sim \text{binomial}(p_j, M_j)$$

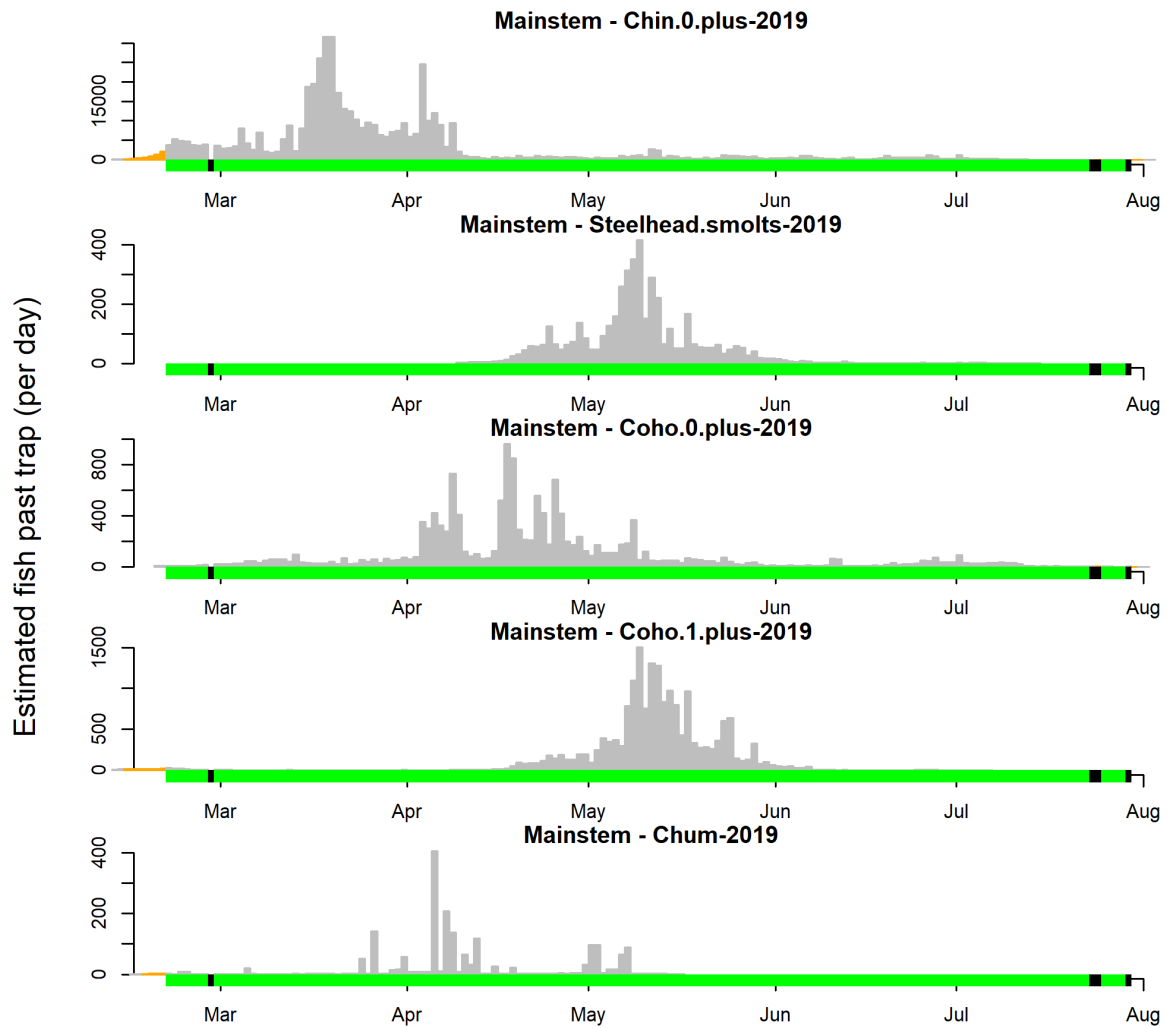
$$p_j \sim \text{beta}(1, 1)$$

The models were implemented in the JAGS software (Plummer 2003) and the R language (R Core Team 2015) was used for all synthesis. Chains were run until the model appeared to converge. Visual inspection of the trace plots and the Rhat statistic were used to assess convergence and determine the appropriate number of simulations. Model fit was also examined using plots of the data with estimated quantities overlaid.

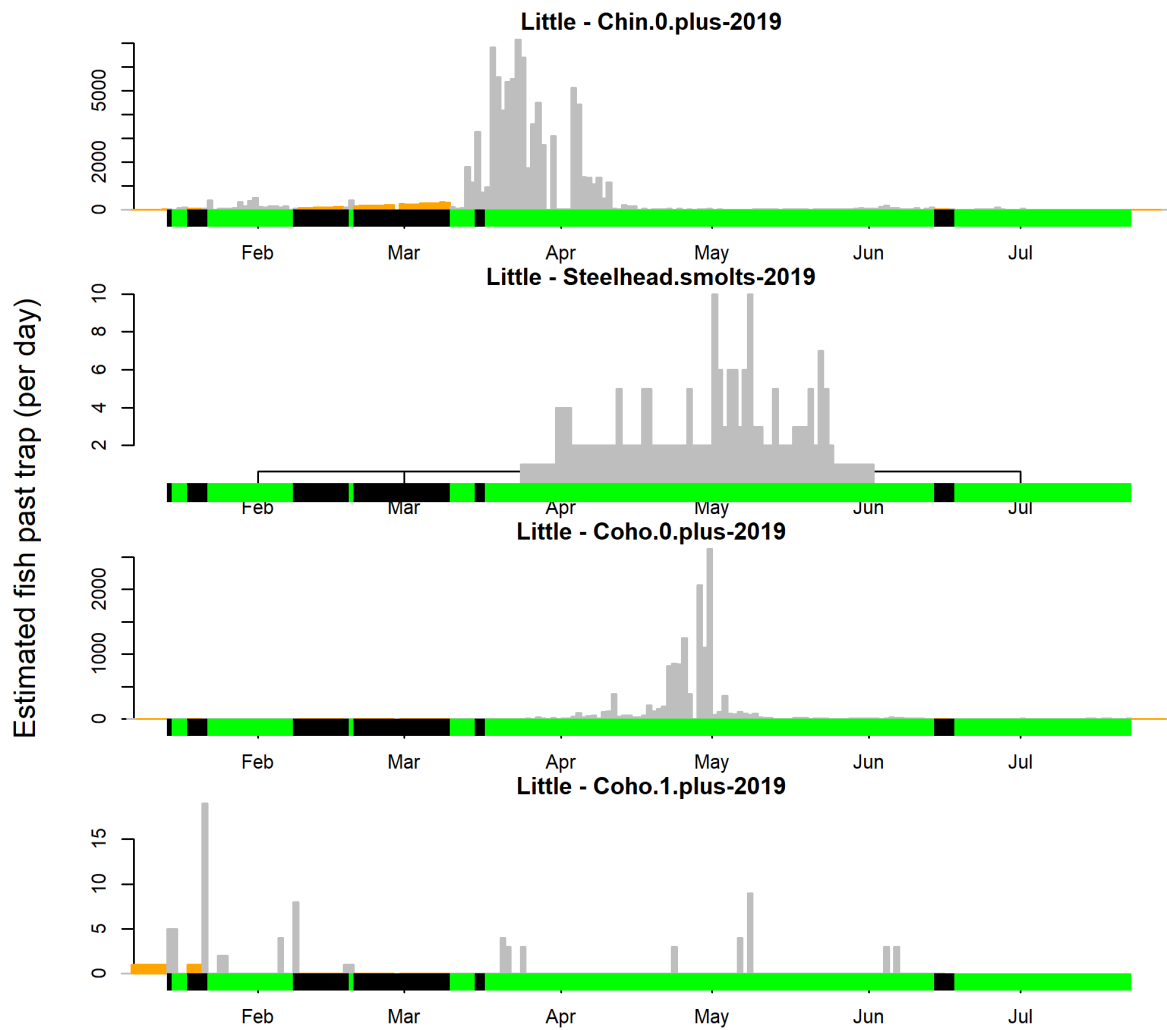
The estimates only incorporate passage during the trap operation. Therefore, if the trap was not in place during fish passage, these fish were not included in the estimate.

Appendix B.

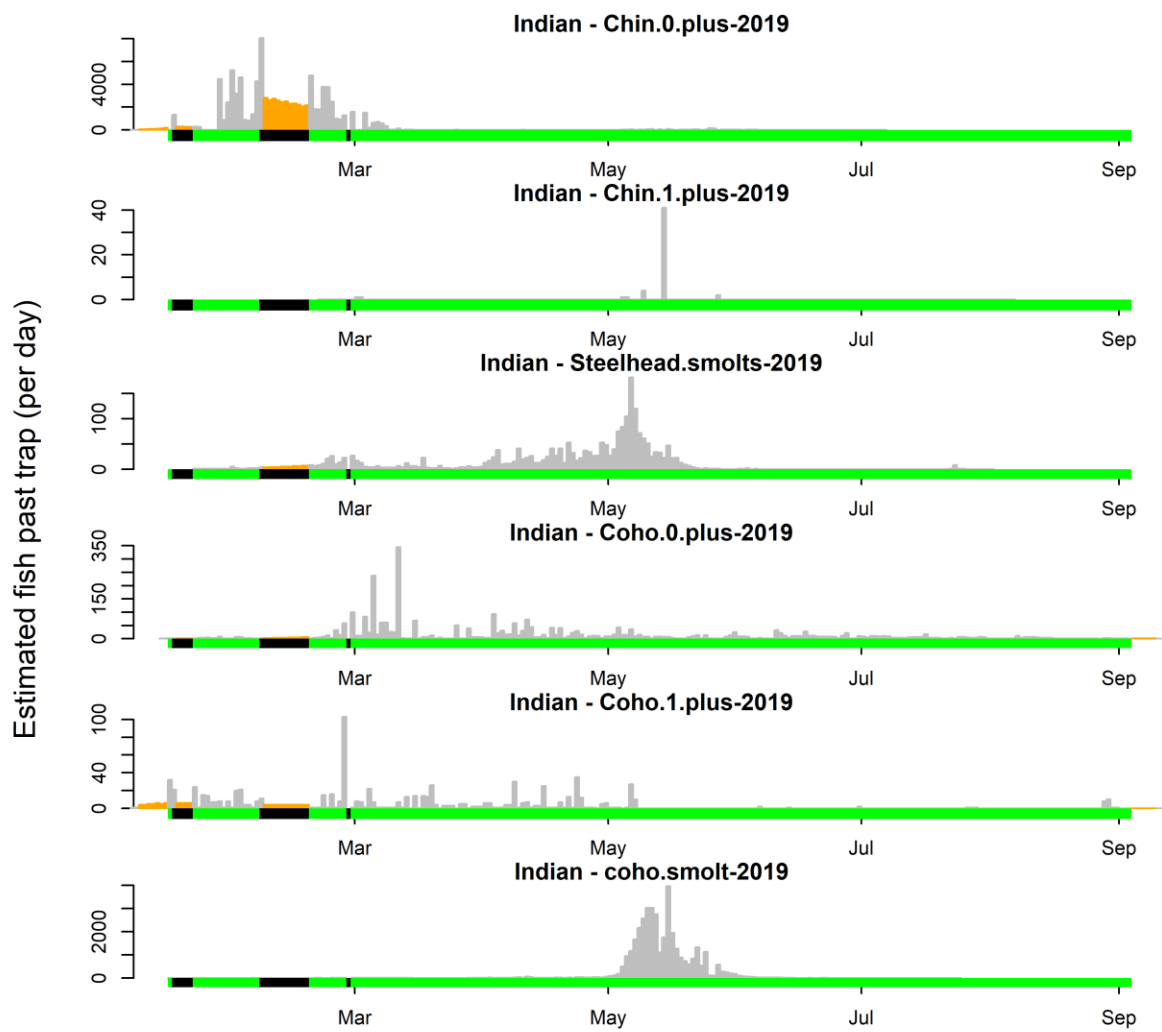
Estimated number of 0+ coho, coho smolts, 0+ Chinook, steelhead and chum outmigrants at the mainstem Elwha trap site by day during 2019.



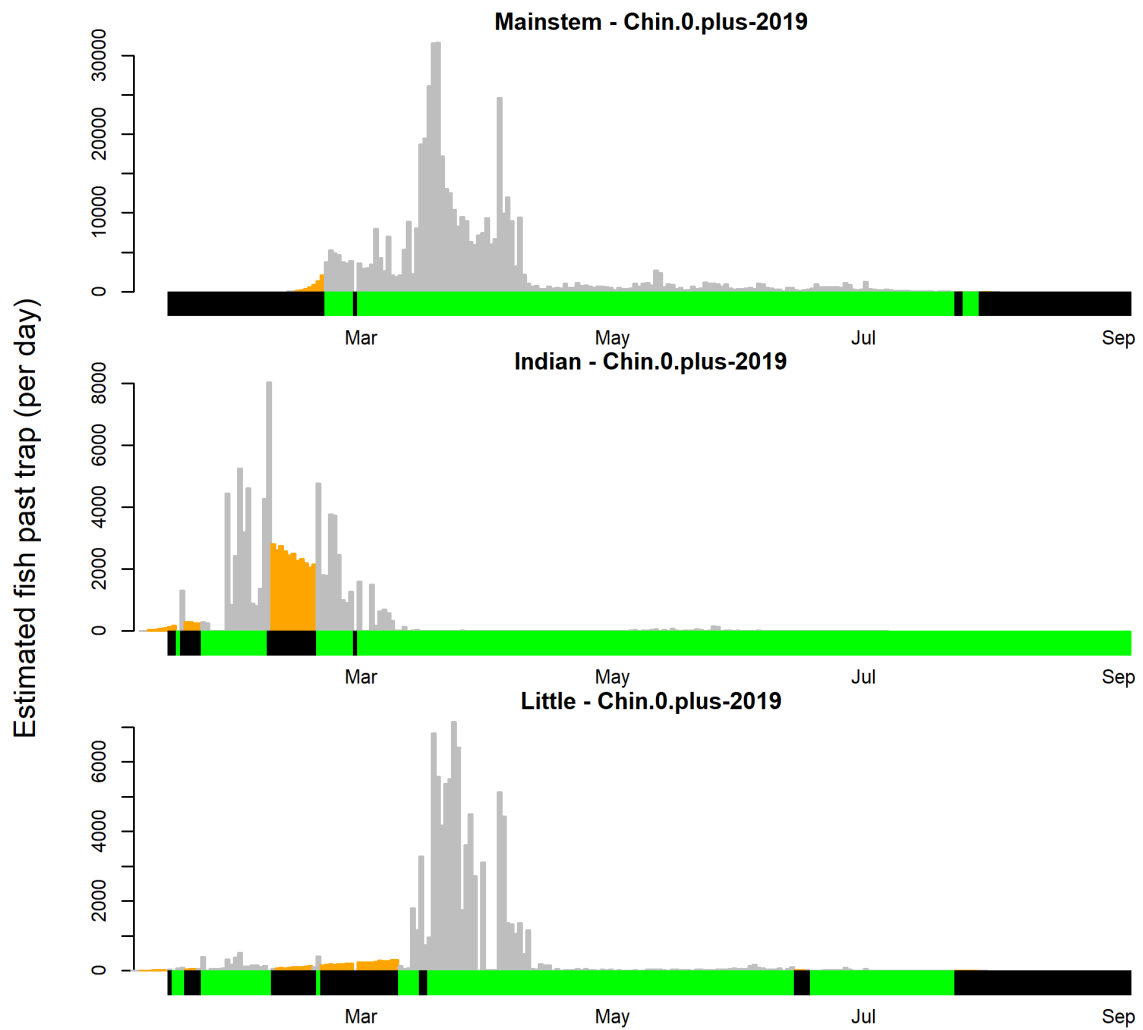
Estimated number of 0+ coho, coho smolts, 0+ Chinook, and steelhead outmigrants at the Little River trap site by day during 2019.



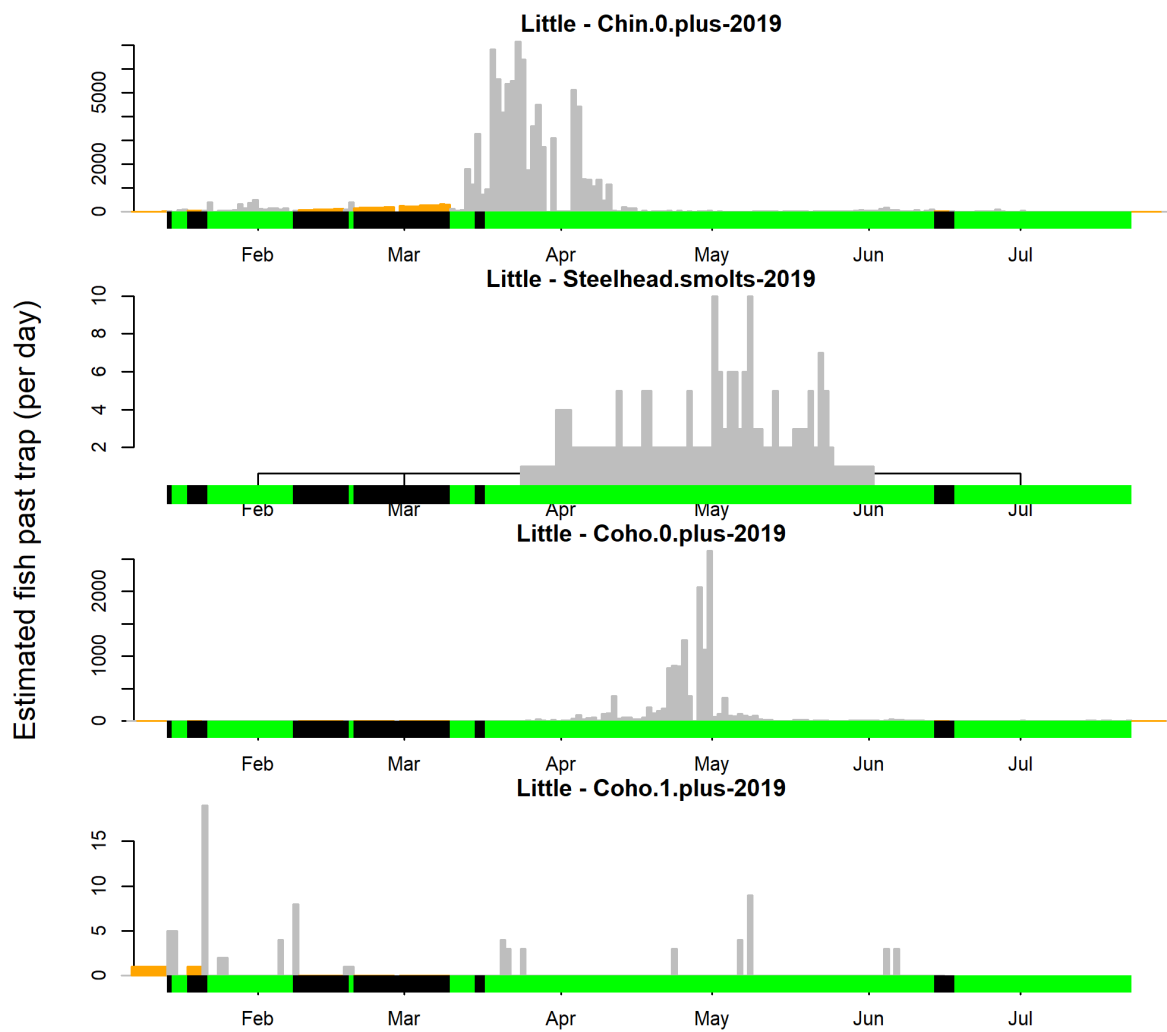
Estimated number of 0+ coho, 1+ coho, coho smolts, 0+ Chinook 1+ chinook, and steelhead outmigrants at the Indian Creek trap site by day during 2019.



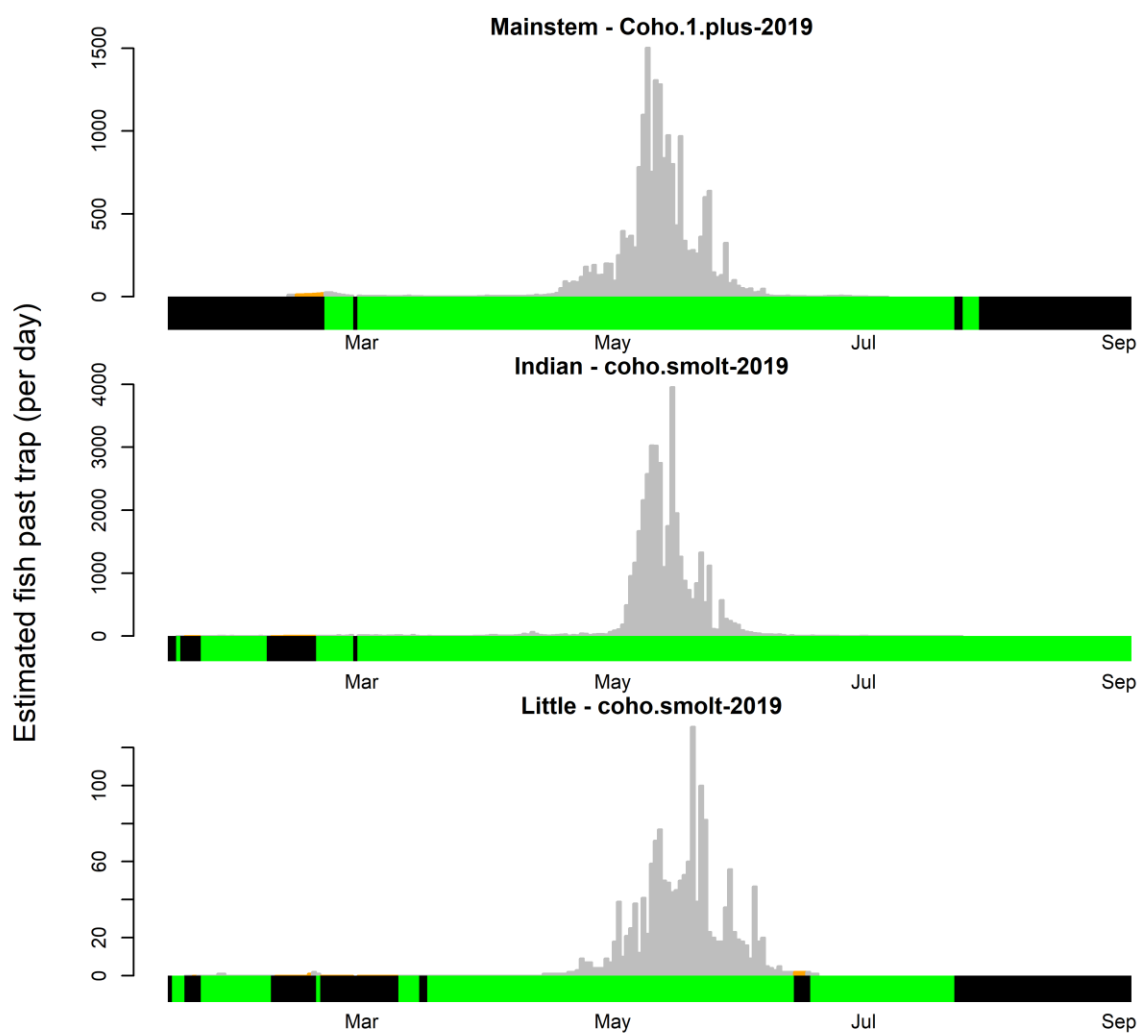
Estimated number of 0+ chinook outmigrants at Indian, Little and mainstem Elwha trap sites by day during 2019.



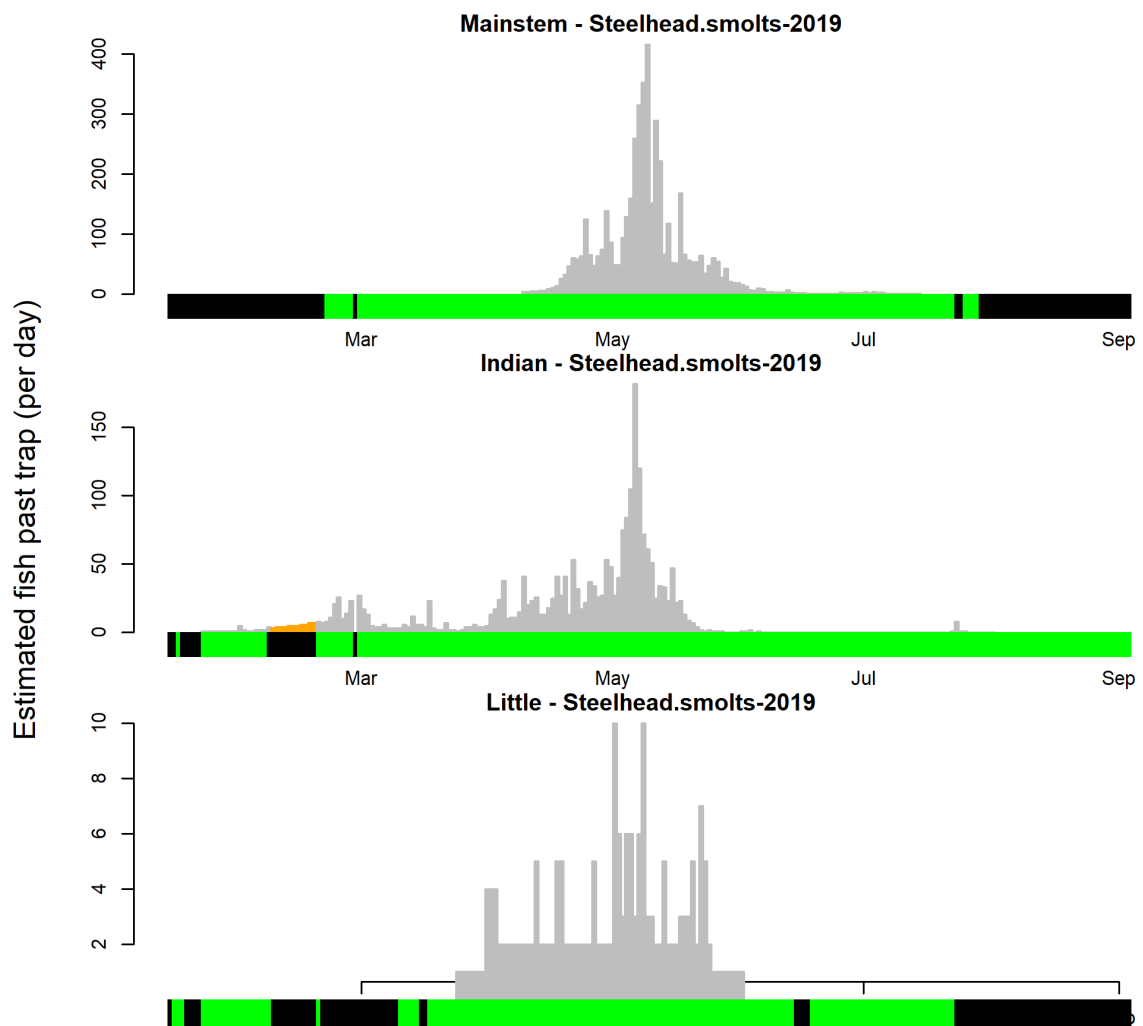
Estimated number and timing of 0+ coho, coho smolts, 0+ chinook and steelhead outmigrants at the Little River trap site by day during 2019.



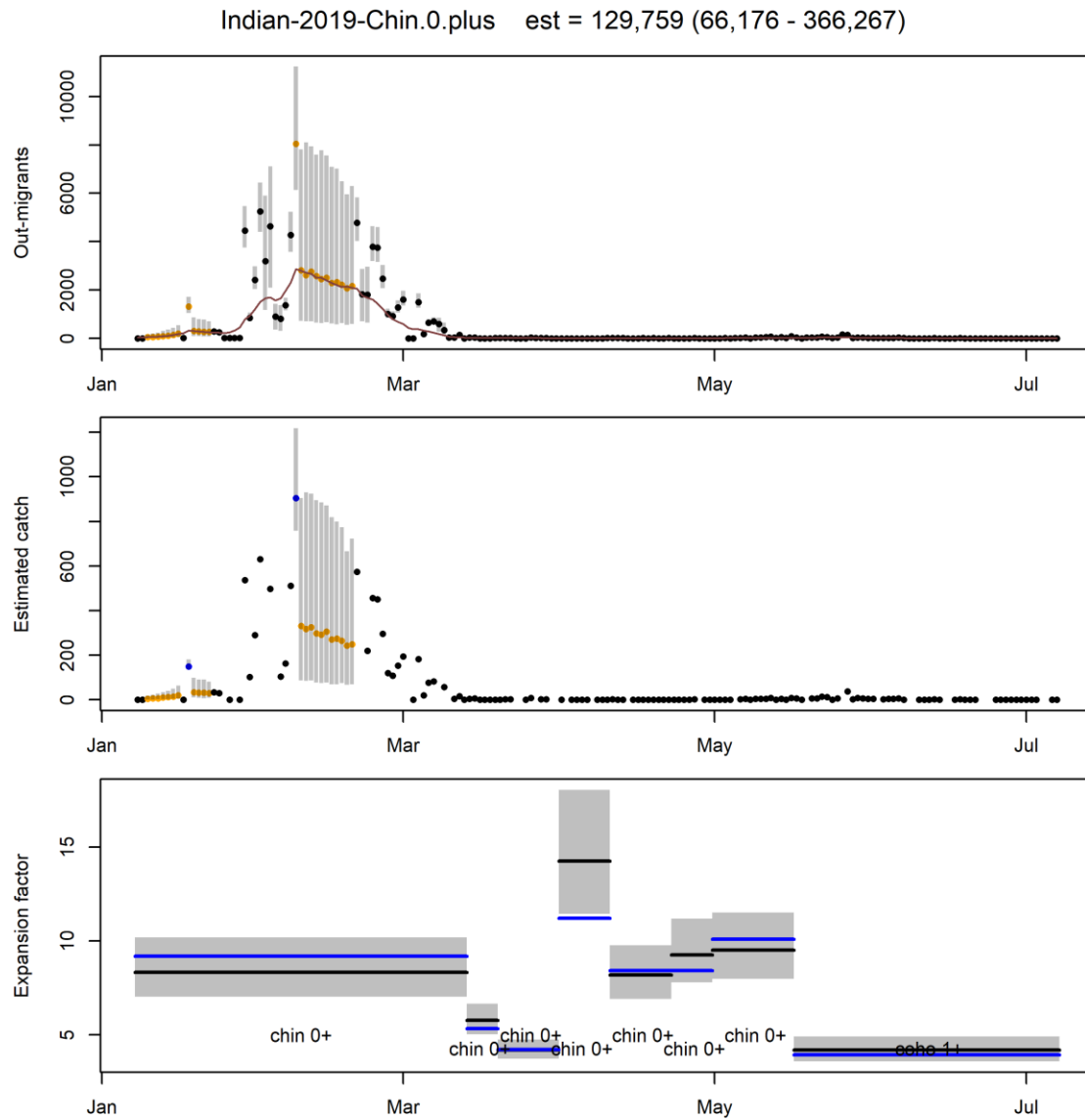
Estimated number coho smolt outmigrants at the Indian Creek, Little River and Elwha mainstem trap sites by day during 2019.



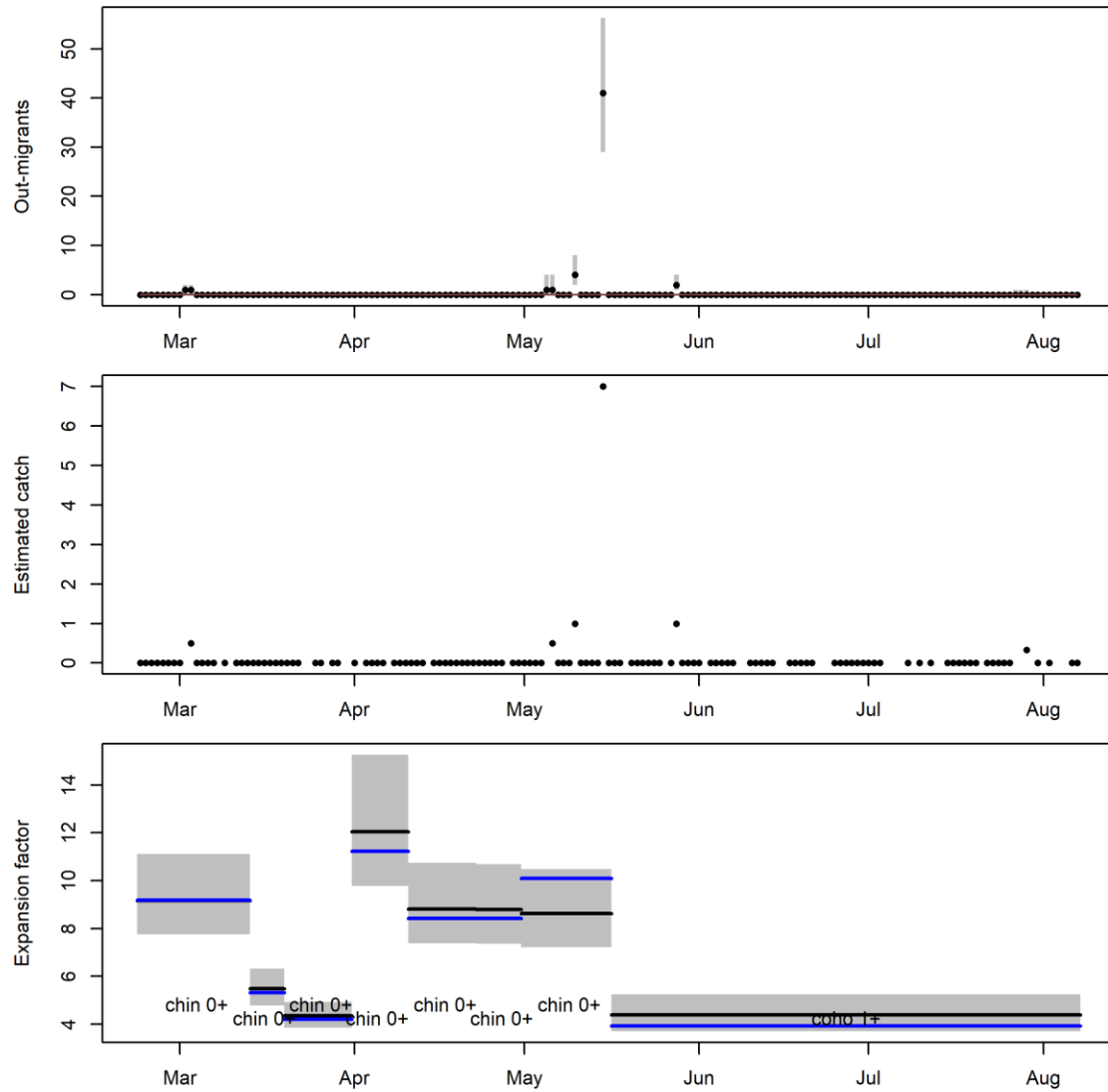
Estimated number and timing of steelhead smolts at the Indian Creek, Little River and Elwha mainstem trap sites by day during 2019.

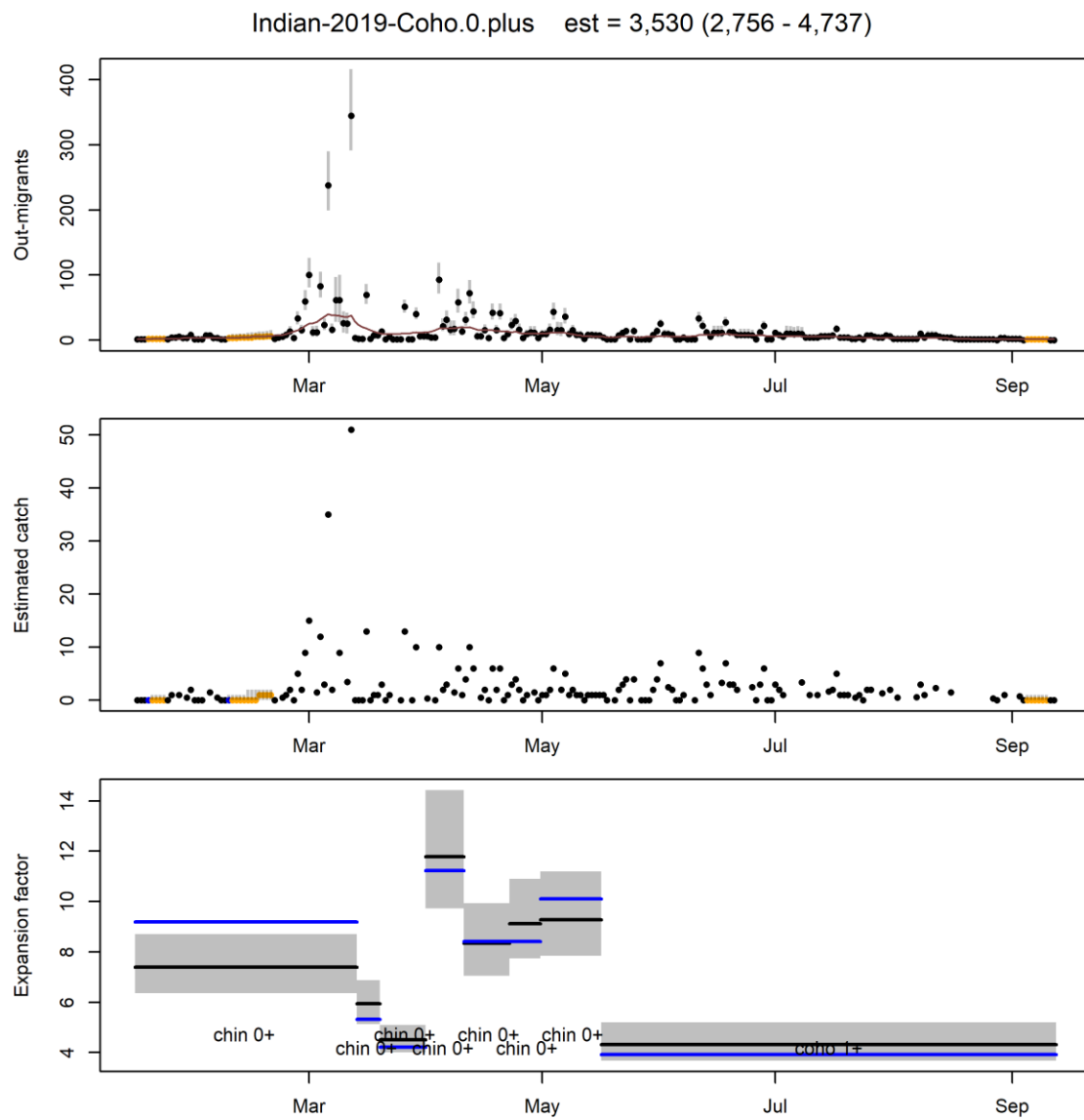


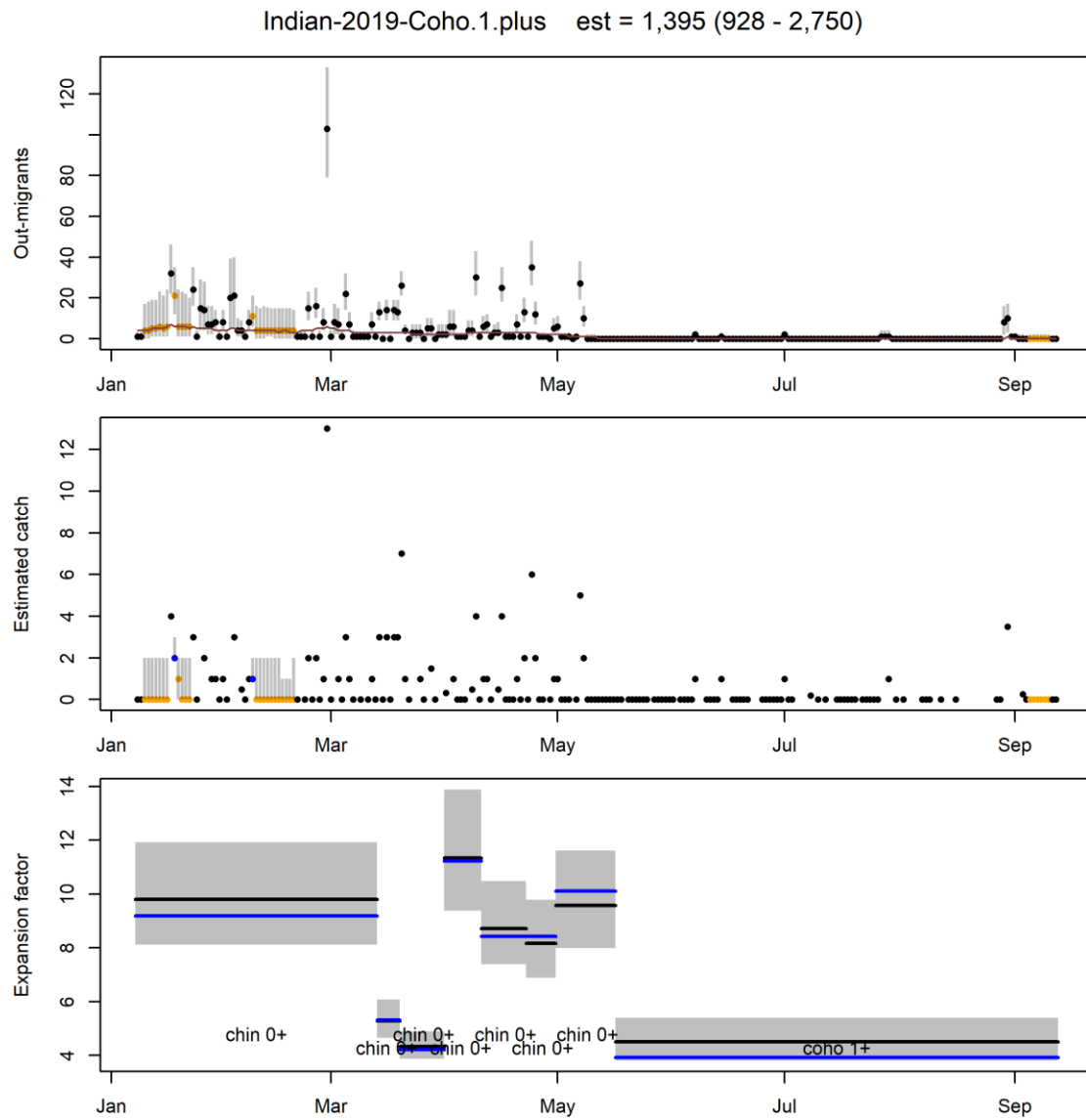
Appendix C. Plots of outmigrants, estimated catch and expansion factor by species and trap site for the 2019 smolt trapping season.



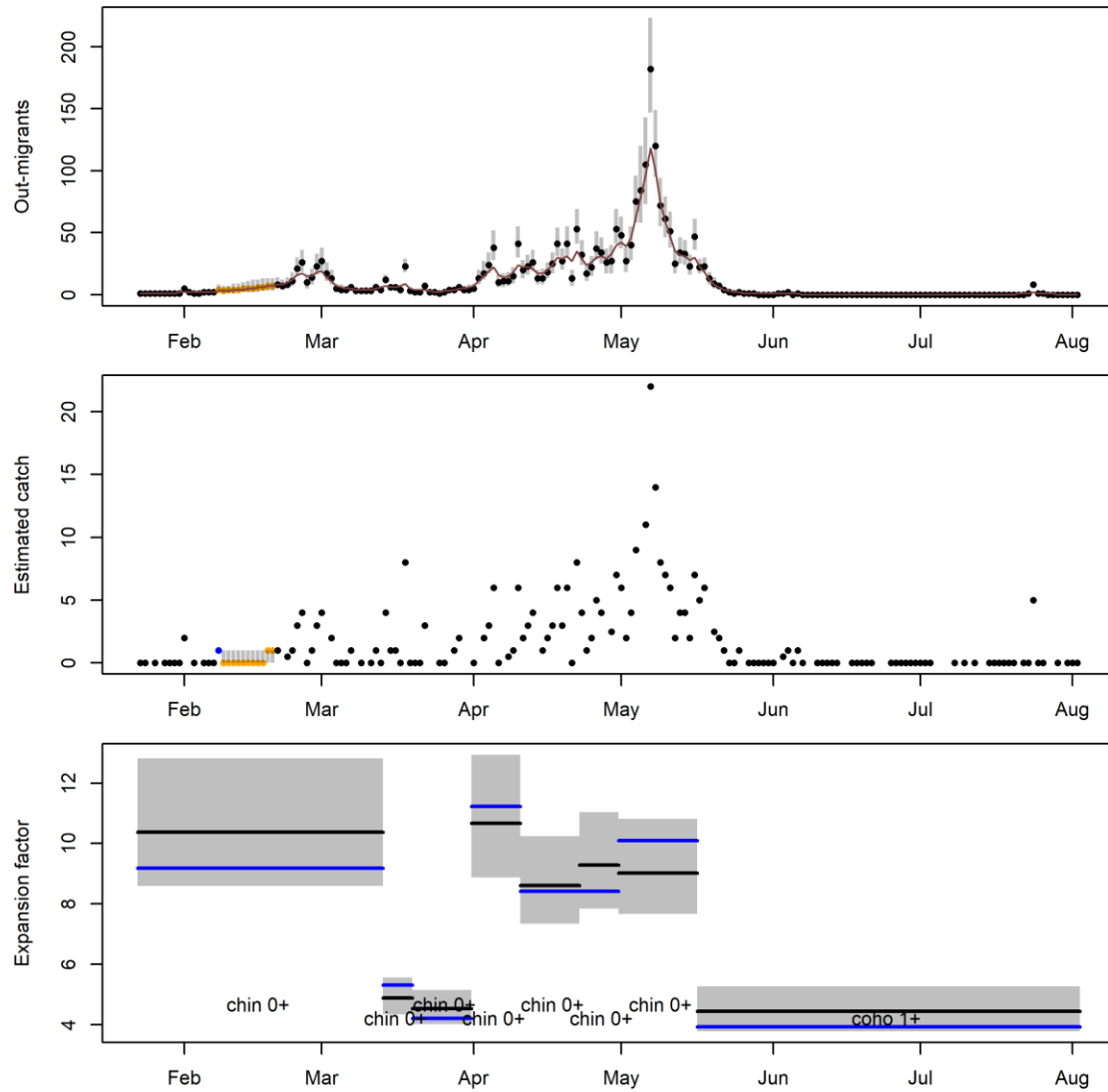
Indian-2019-Chin.1.plus est = 87 (45 - 174)



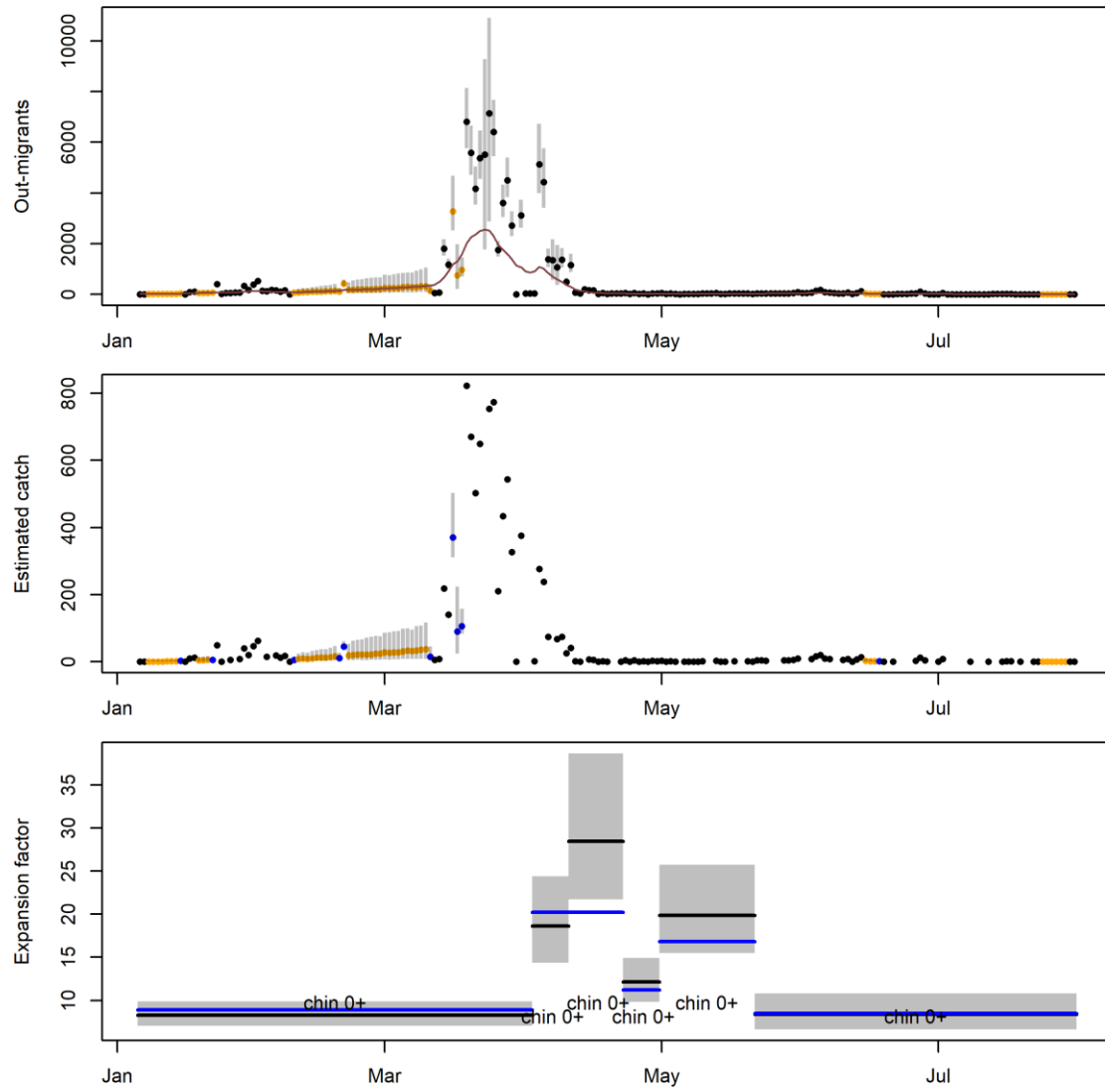




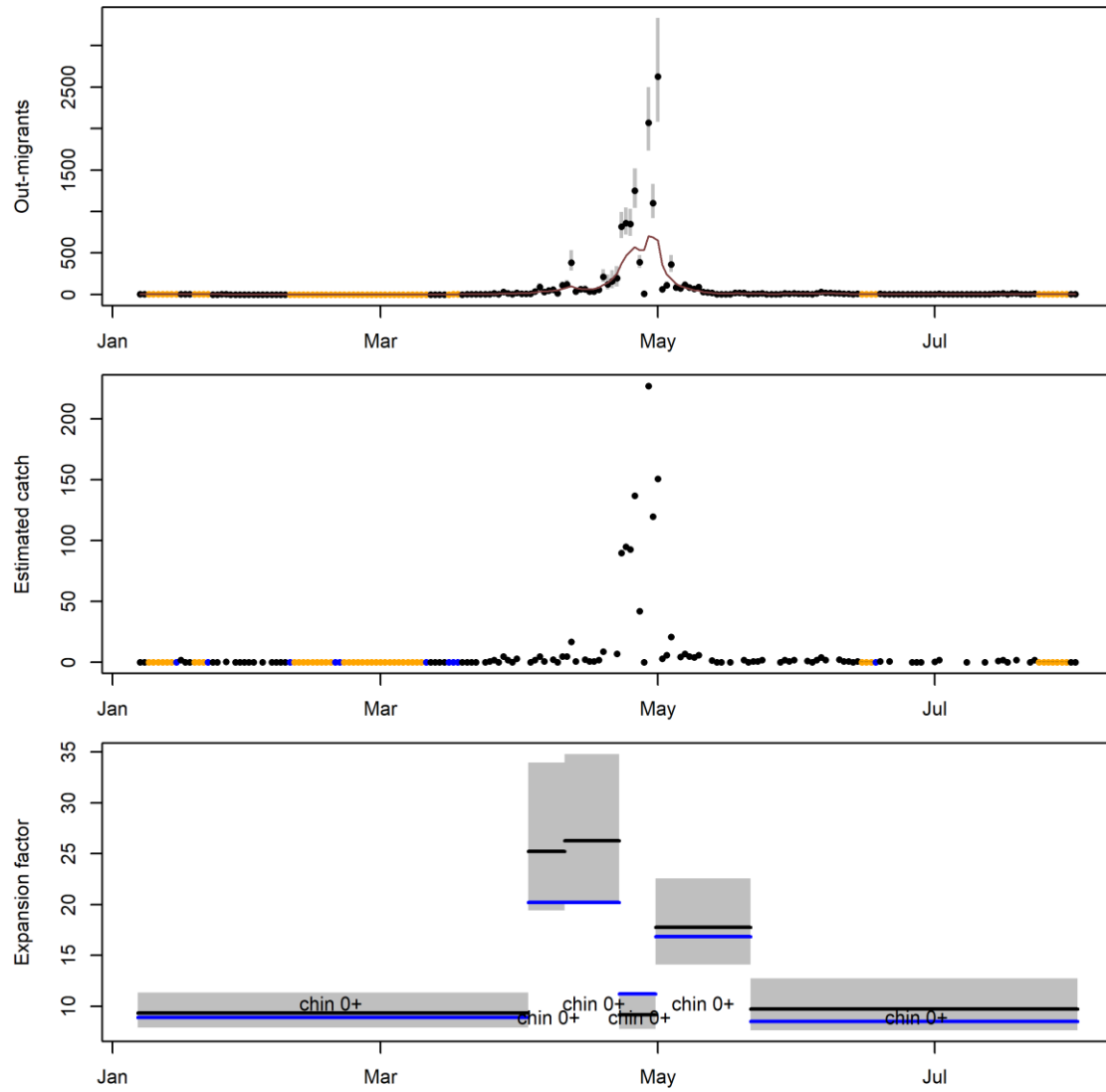
Indian-2019-Steelhead.smolts est = 2,550 (1,922 - 3,517)



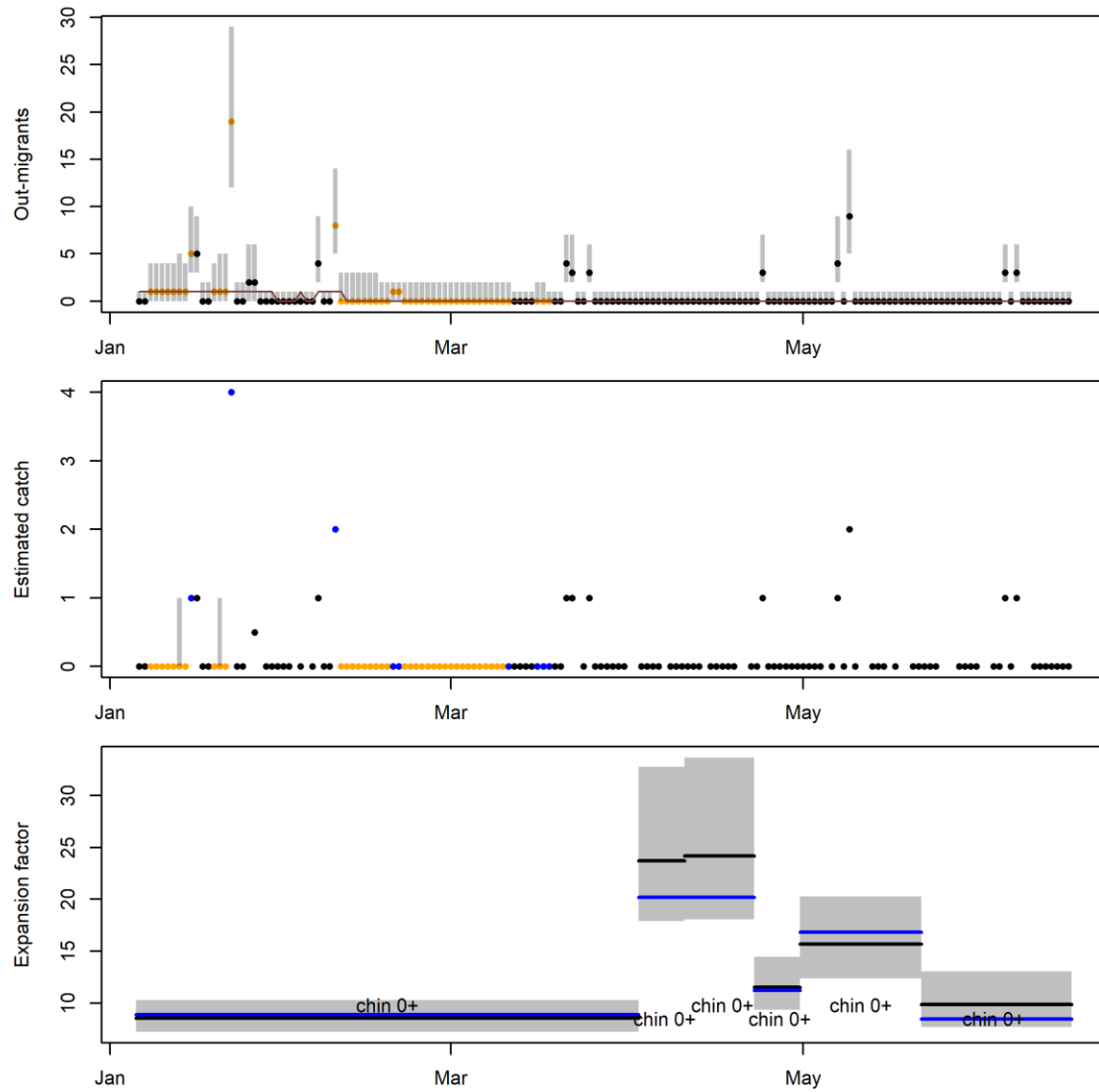
Little-2019-Chin.0.plus est = 107,644 (69,698 - 213,563)

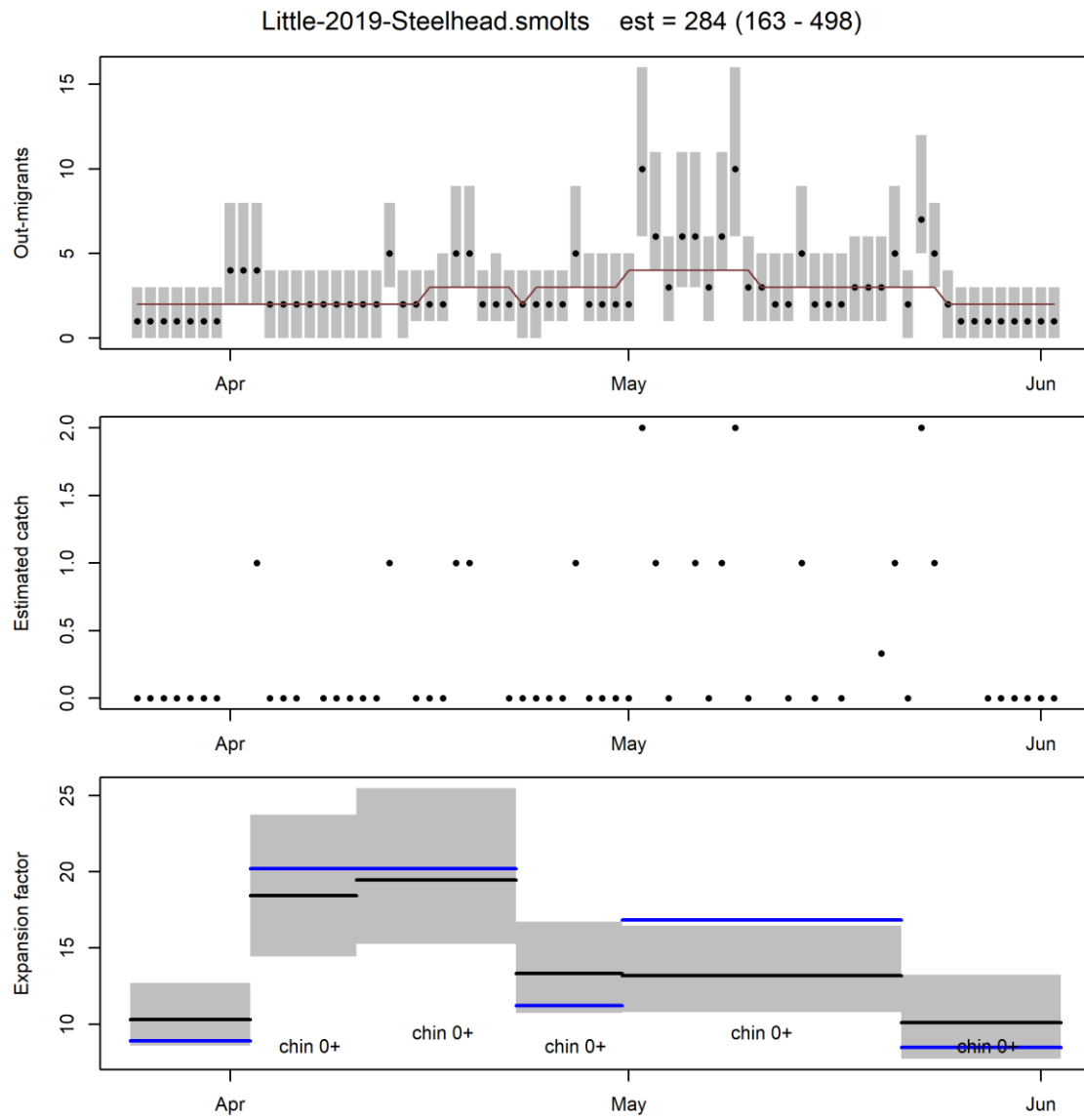


Little-2019-Coho.0.plus est = 14,831 (10,430 - 23,122)

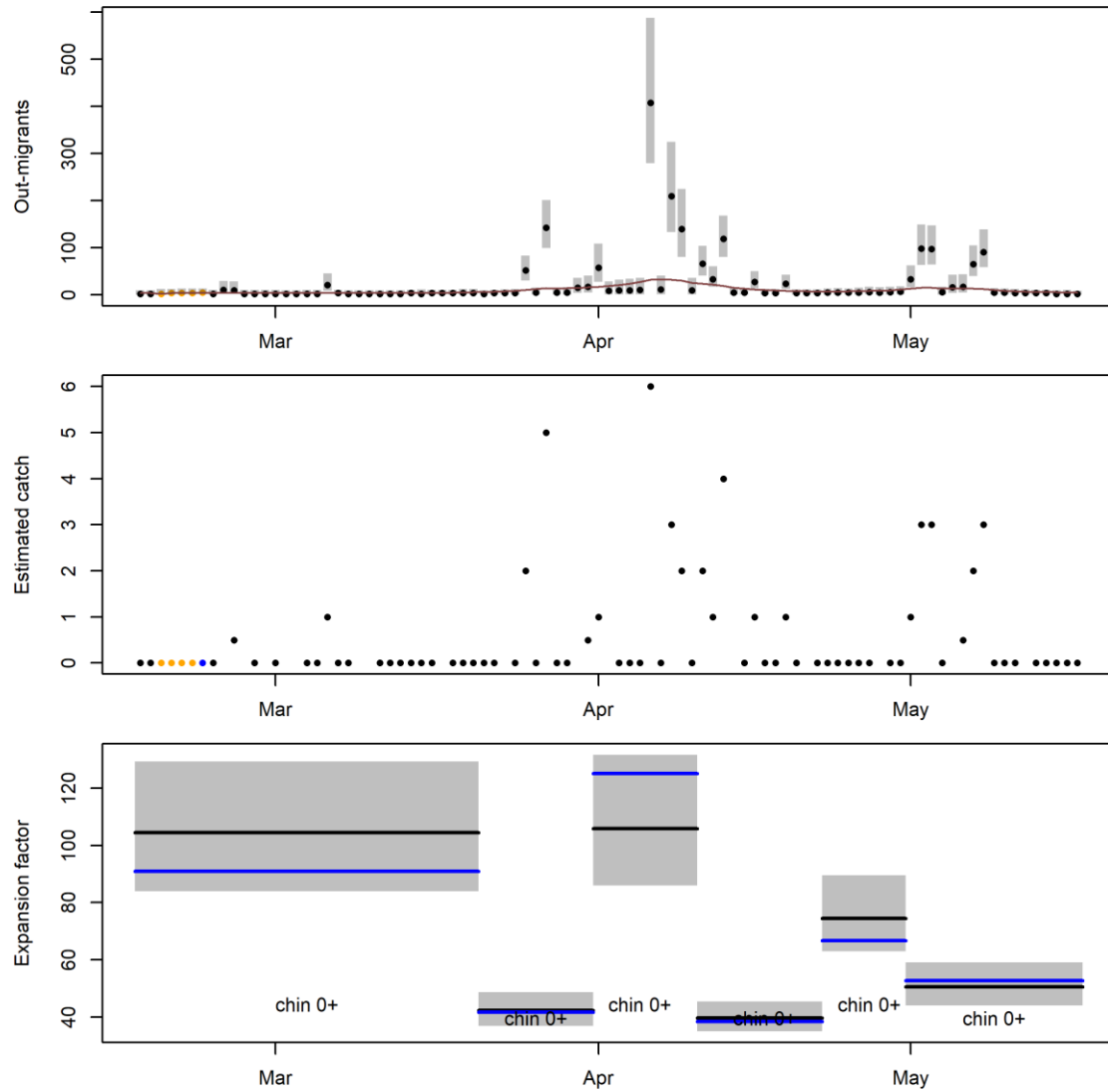


Little-2019-Coho.1.plus est = 316 (164 - 822)

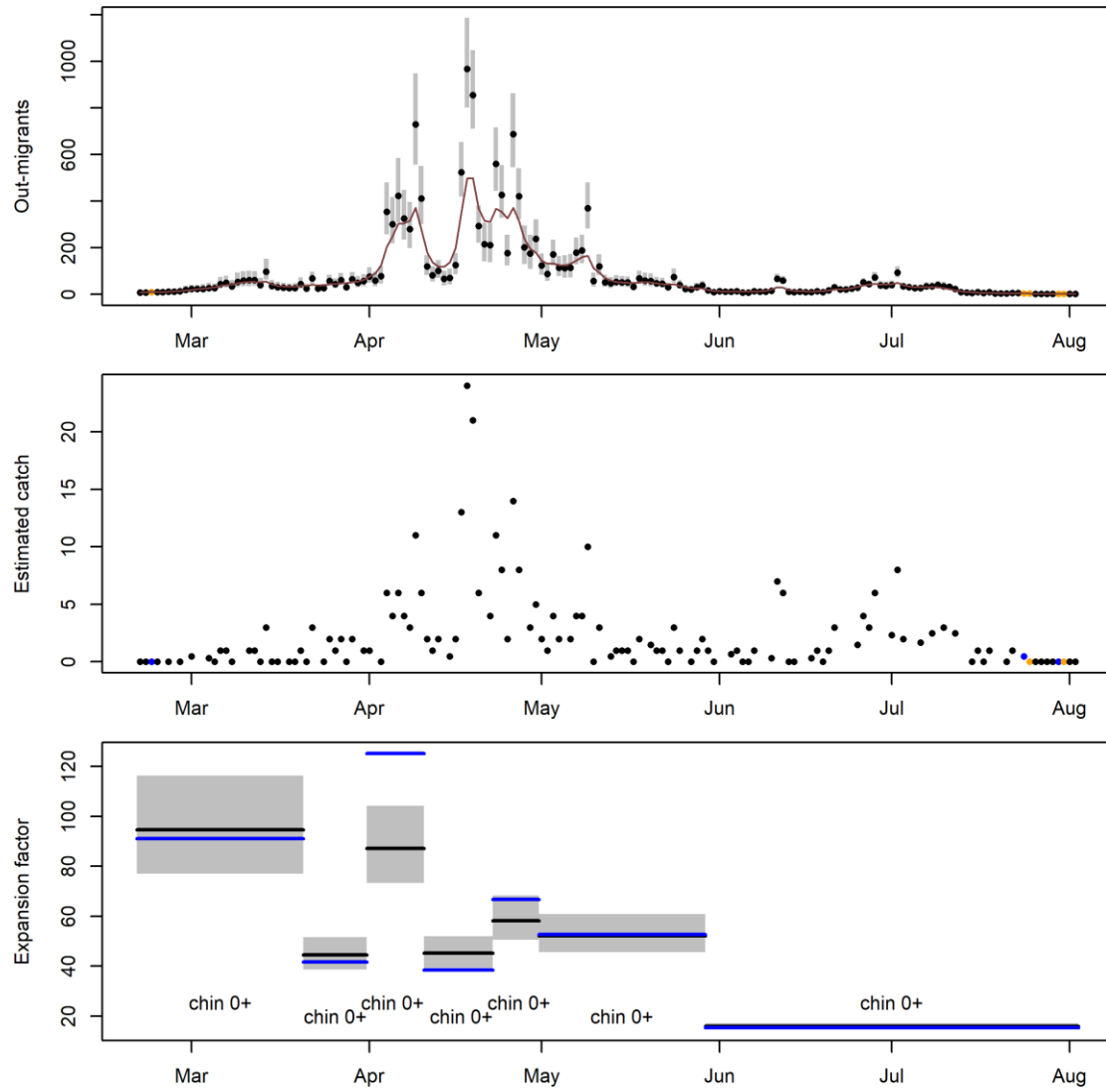




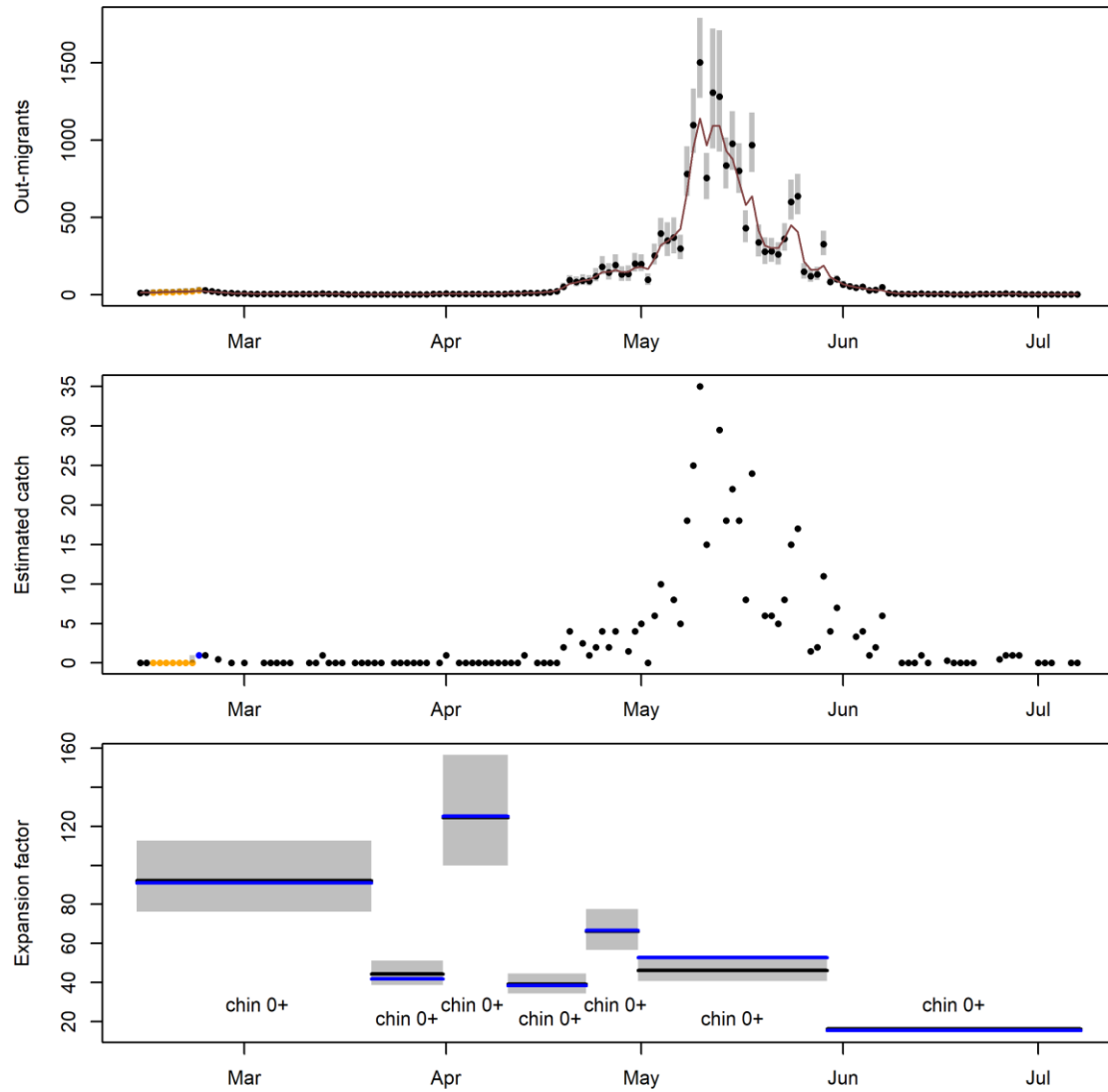
Mainstem-2019-Chum est = 2,896 (1,927 - 4,600)



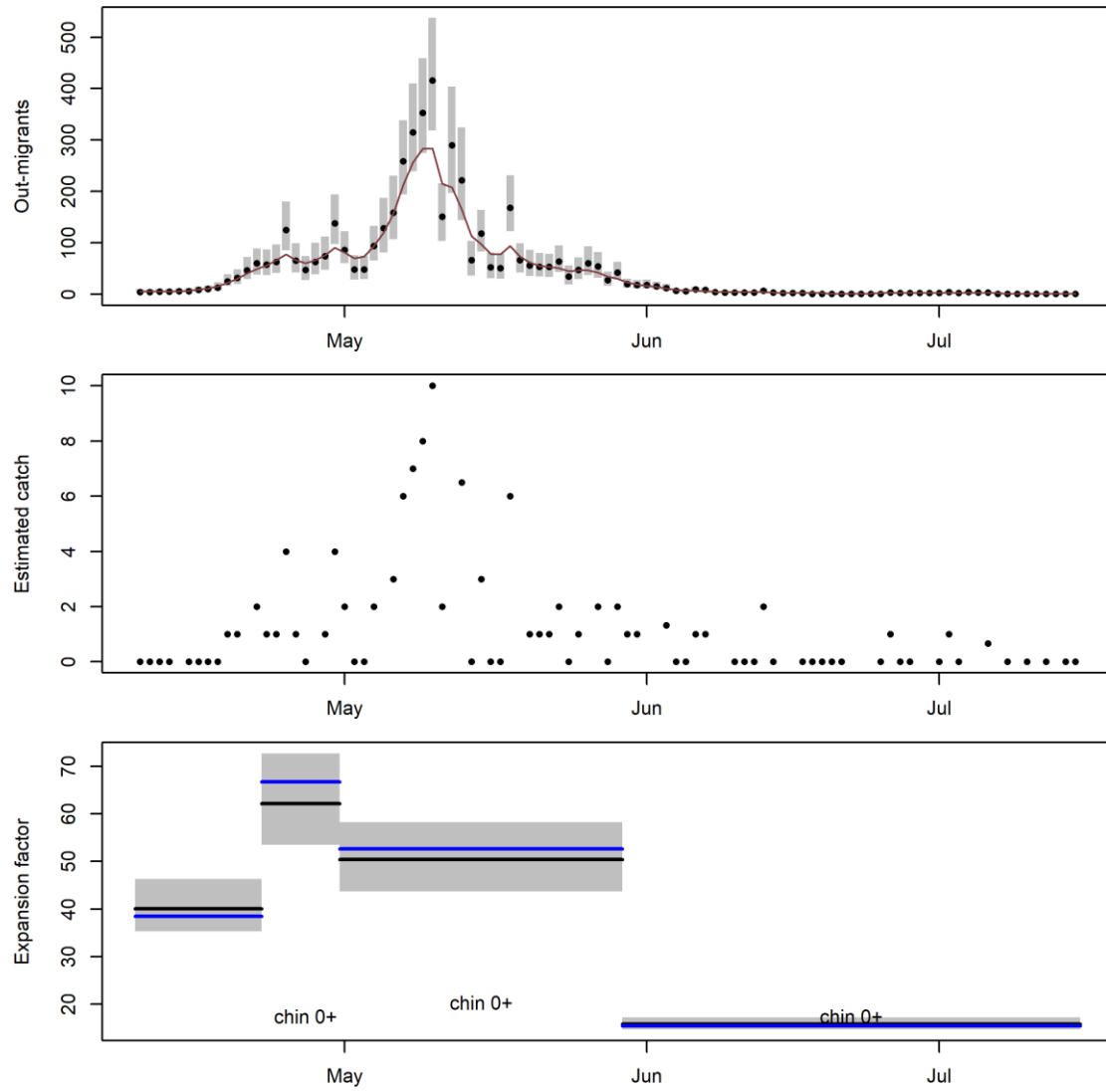
Mainstem-2019-Coho.0.plus est = 16,180 (13,039 - 20,654)



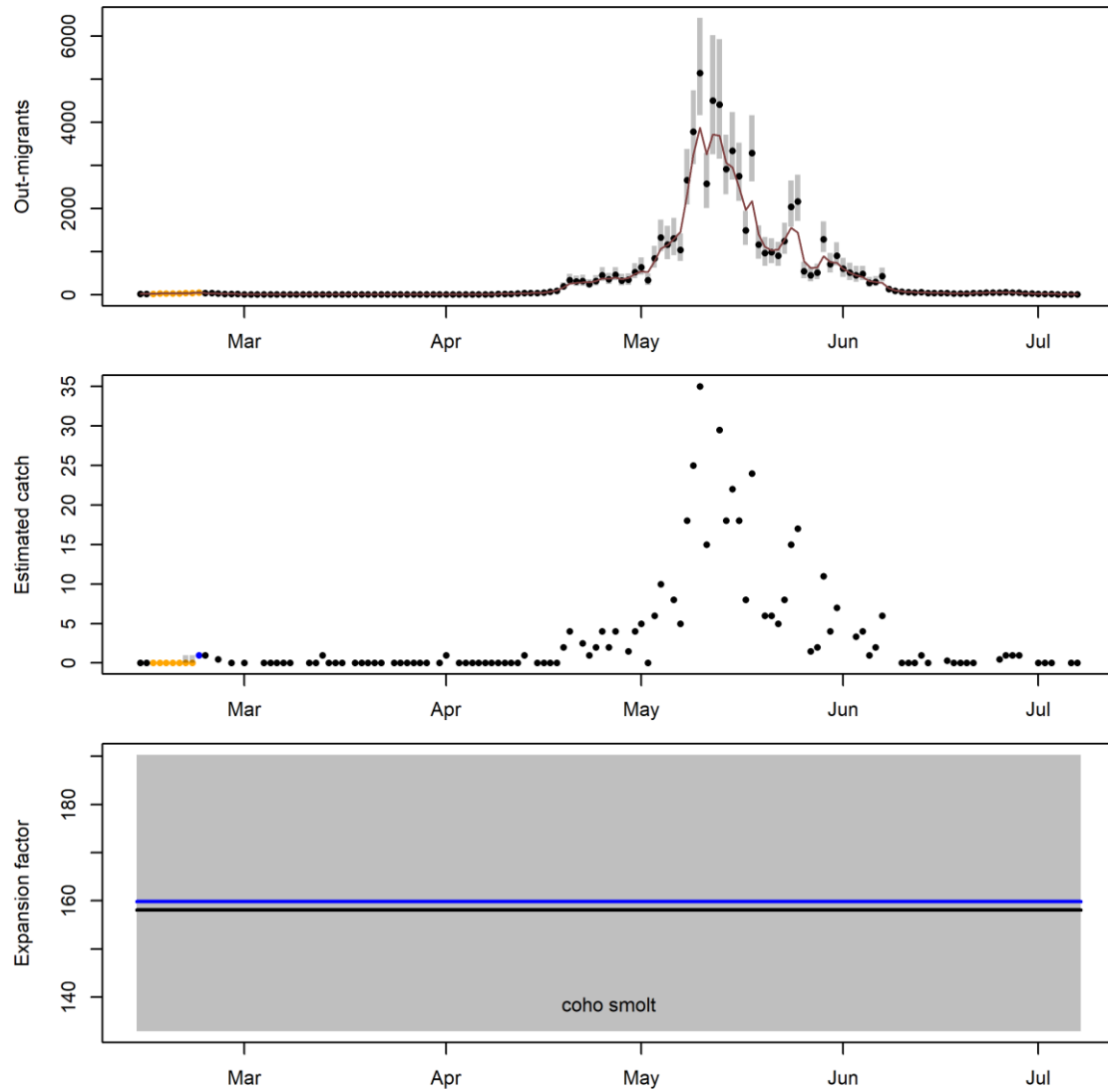
Mainstem-2019-Coho.1.plus est = 19,822 (14,499 - 28,512)



Mainstem-2019-Steelhead.smolts est = 5,122 (3,538 - 7,740)



Mainstem2-2019-Coho.1.plus est = 69,874 (42,258 - 133,420)



Mainstem2-2019-Steelhead.smolts est = 17,648 (10,214 - 31,503)

