

2017 Elwha River Smolt Enumeration Project Report

March 31, 2018



Submitted to Olympic National Park

In partial fulfillment of

Contract #P16PC00426 with the Lower Elwha Klallam Tribe

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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 2017 outmigration season. This represents the second year of monitoring during the post dam removal period. River conditions have stabilized, reducing the impacts to trapping operations reported in the dam removal period. In 2017, at the mainstem site we generated watershed production estimates, 95% credible intervals, 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+) chinook and Coho salmon and for steelhead smolts for the second consecutive year. We estimated a total outmigration of 73,684 (range 60,574-106,008) and 4,065 (3,250-5,521) for Chinook 0+ and chum 0+ smolts from the Elwha River in 2017. The 0+ Chinook salmon outmigration estimates for the Elwha River in 2017 was approximately two times greater than in 2016, but was still within the range measured in the pre-dam removal period (2006-2011). In 2017, a single efficiency trial with larger bodied smolts produced capture efficiencies comparable to the small bodied fish and were able to generate a steelhead outmigration estimate for the second consecutive year. The steelhead estimate of 11,722 (range 9,085-17,521) doubled over 2016 and suggests that that population continues to increase. Production of chum and pink salmon remains very low in the Elwha River and suggests that these populations have not begun to recover from the combination of low population size at the beginning of dam removal and impacts from dam removal itself.

At the tributary sites, smolt trapping was nearly continuous and we successfully operated over 98% of potential fishing days. For Indian Creek we generated estimates for Coho salmon (ages 0+ and 1+), Chinook salmon (ages 0+ and 1+) and steelhead. Little River again produced low total numbers of fish and we were only able to generate estimates for 0+ and 1+ Coho salmon. Indian Creek had consistently higher numbers of outmigrants than Little River for all species and is likely producing a significant proportion of the total Elwha smolt production for some species. Indian Creek produced an estimated 17,428 Coho salmon (1+) smolts. This number is greater than the production of entire watersheds draining in the Strait of Juan de Fuca. Steelhead and lamprey populations also continue to expand in Indian Creek. We estimated a total steelhead outmigration of 3,162 steelhead which represents ~25% of the total Elwha steelhead production for 2017. Pacific lamprey populations also continue to expand as the largest numbers of juveniles (ammocoetes) and outmigrating (macrothemia) captured to date were encountered in 2017.

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 is 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 that 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 process the Elwha Monitoring and Adaptive Management (EMAM) plan was developed for federally listed populations of Chinook salmon (*Onchynchus tshawytscha*) and steelhead (*O. mykiss*) (Peters et al. 2014). The EMAM provides quantitative performance targets that affect management actions through the 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 are thus intrinsically connected to the recovery of depleted and federally listed Elwha salmon populations. Additionally, 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 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 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 trap also can be used to support tagging studies or collect other life history information. 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 highly degraded Elwha River.

Throughout the dam removal period¹ (2012-2015), trapping conditions deteriorated rapidly as the Elwha River eroded large volumes of sediment and wood debris stored in the former reservoirs (Warrick et al. 2015) that filled the channel and interfered with trapping operations. In 2012, we were able to generate Elwha mainstem outmigration estimates with some difficulty using a smaller 5' rotary screw trap. However, in the 2013 season we abandoned mainstem trapping efforts as the trap was simply overwhelmed with sediment and debris and no estimates of production were possible (McHenry et al. 2014). In 2014, mainstem trapping efforts were reinitiated, however operations were impacted by river conditions and over half the potential fishing days were lost. During the dam removal period, LEKT added two additional trapping sites: one at Indian Creek and one at Little River, two large tributaries located just above the former Elwha Dam site. These tributaries have been the site of both natural and human assisted (adult relocations) recolonization events. Little River and Indian Creek are also being used as study sites for studies of movement, growth and survival of native salmon populations. LEKT has successfully been able to estimate production for the aforementioned species from the tributaries during the dam removal period.

The 2017 trapping season represents the second 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

¹ Although dam removal was initiated in the spring of 2011 trapping was unaffected by dam removal as significant sediment transport did not begin until the fall/winter of 2012.

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

Mainstem Site

In 2017, we utilized similar site selection criteria previously established by LEKT for the tributary sites. For the mainstem site, we reoccupied the lower river fishing site at the end of Lower Elwha Road (Rkm 0.3) and used the larger trap 8' screw.

History of Operations

During the pre-project and dam-removal periods, 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. 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 months (Kinsel et al. 2008; Kiyohara and Zimmerman 2012). As Chinook salmon colonize areas above the dams it is anticipated that a bimodal outmigration pattern will redevelop similar to other Puget Sound rivers.

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. 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 has been able to reoccupy the lower river site using the larger 8'screw.

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 4.43 (Figure 1). 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 2). 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 (Figure 2) that LEKT could physically operate as the river was not deep enough to support the larger trap. During the 2016 season enough sediment had evacuated the lower river fishing site to support the operation of the larger 8' screw trap.

LEKT established tributary smolt monitoring sites on Little River in 2012 and Indian Creek in 2013. Because of the difficulty accessing the lowermost portions of those drainages, we chose county road bridge crossings in each tributary for trap deployment. The bridges make for convenient launch sites (Figure 3) and we contracted a local crane operator for trap deployment and retrievals. The traps are lifted from transport truck to the river by the crane and deployment is complete in less than 15 minutes. For Little River, we used the bridge crossing on Hot Springs Road located at Rkm 0.2. For Indian Creek, we used 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. Both traps have fished with excellent results to date and it is not anticipated that additional changes will be made at the tributary sites.

Daily Operations-2017

In 2017, LEKT commenced trapping operations in the mainstem on February 2 and ceased trapping efforts on August 3 when the main bearing failed. A significant number of fishing days were lost because of the combination of high flows (Figure 4), damage by debris, hatchery releases and bearing failure on the mainstem in 2017. In total we were able to fish the mainstem trap for 111 of the 182 (61%) total fishing days in the 2017 fishing season. This was a reduction in effort from 2015 and 2016 but was a significant improvement over 2014 when frequent spring freshets resulted in the loss of half the potential fishing days (McHenry et

al. 2015). The majority of lost fishing days occurred from May 29-July 9 when the trap was damaged by a log, repaired and then suffered a bearing failure. Fishing was not impacted by fine sediment and woody debris as in the dam removal period.

For Indian Creek, trapping commenced on January 24 and ceased operations on November 2. At Little River trapping was also initiated on January 24 and was concluded on July 12. Flow conditions in Little River did not appear to affect trapping operations as was reported in previous years. For the tributary sites, the traps were also nearly fished continuously. Indian Creek fished for a total of 287 out of 290 (99%) fishing days, setting a record for number of days fished. The Little River trap fished a total of 175 of 175 (100%) possible fishing days, also setting a record.

Field Methods

For all sites, the traps were inspected and cleaned 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 juvenile coho and steelhead produced at the Elwha Hatchery.

Determining the origin (hatchery vs natural) of most Elwha salmon species is facilitated by unique marks applied at the two hatcheries, although only a small percentage of the hatchery Chinook salmon are adipose clipped or marked with a detectable CWT². WDFW has two age classes of hatchery chinook releases on Elwha: one in early April of 1+ Chinook, and another in June of 0+ Chinook. We typically cease fishing for a period of several days immediately following any hatchery release. However, residual hatchery fish can remain in the system for several weeks and are inevitably captured in the trap. The hatchery 1+ Chinook salmon are generally larger than natural 1+ Chinook salmon and their origin is determined by size and timing. The smaller 0+ Chinook salmon are difficult to determine origin as they are of very similar size and appearance to naturally produced Chinook salmon. This has led to some uncertainty in determining the origin of Chinook salmon in past years. Elwha hatchery Chinook salmon are thermally marked in the hatchery and that results in a unique growth pattern which

² Of the WDFW chinook release 200,000 are adipose clipped and carry a detectable CWT

can be determined from an analysis of otoliths. In 2017 we collected 50 Chinook salmon over a several week period for otolith analysis following resumption of fishing two weeks after the release of hatchery 0+ Chinook salmon. Those fish were sent to the WFDW laboratory to determine origin. That proportion was applied to the total 0+ Chinook salmon catch during the period following 0+ Chinook salmon hatchery releases.

In order to evaluate catch efficiency (proportion of total outmigrants captured), we attempted to conduct continuous mark recapture tests at all three trap sites. Several trap efficiency trials on the mainstem had to be cancelled as a result of interruptions in fishing due to flow or mechanical breakdowns. 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. For the mainstem trap we used, or attempted to use, separate efficiency estimates for large (1+) and small (0+) bodied fish. However, because there were only two trials in each case we used all trials for large and small bodied fish. For the small bodied fish there were two valid trials on May 2nd and May 10th. These were both for Chinook 0+ fish with release sizes of 1000. The total fish recaptured was 145 and 138, respectively resulting in an average efficiency of $(145+138)/2000 = 14.2\%$. For the large bodied fish there was a very large release of hatchery coho 1+ fish on March 28th (25,772) and a smaller continuous release of coho 1+ marked at the Indian Creek smolt trap (988). The recaptures were 2,189 and 28, respectively. We averaged these two releases by calculating the two efficiencies and then averaging them ($2,189/25,772 = 8.5\%$, $28/988 = 2.8\%$, $(8.5\% + 2.8\%)/2 = 5.7\%$). For the large bodied trials we assumed each release size was 1000. This gave the trials equal weight, and reduced the implied confidence in the efficiency from the hatchery trial. Because there were few efficiency trials, the trials were not evenly dispersed across the trapping period, and the fish used in the efficiency trial were not always representative, the credible intervals and CVs generated by the statistical model do not reflect the true uncertainty in these estimates.

At all sites we used Bismarck brown dye to give the fish a distinctive mark, 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 (Figure 5). The subsample of marked smolts was released 100 m above each tributary trap site and approximately 1000 m above the mainstem site. The percentage of smolts recaptured was highly variable depending upon flow and site conditions. In general, the tributary sites had relatively high recapture rates (Indian Mean 18.6%/Little Mean 23.4%). The mainstem recapture rates had higher variability (0.008-14.5%, average=5.3%). Trap calibration tests for all sites in 2017 are summarized in Table 1.

Data Analysis

The sum of daily catch data along with efficiency trials was 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. See appendix A for more details. 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).

Results

Smolt trapping on the Elwha River was successfully completed at all sites although flows, damages and hatchery releases resulted in a large number of lost days (39%) which likely affected the precision of our estimates. The 2017 trapping season was not significantly interrupted by sediment or small woody debris at the mainstem site and river conditions appear to have mostly stabilized following dam removal. During the dam removal period, trapping operations were impacted by sediment and debris leading to numerous lost days of fishing. In 2015, 2016 and 2017 we have been able to fish the mainstem trap for a total of 155 of 166 days (93%), 142 of 171 days (83%), and 111 of 182 days (61%), respectively. In comparison, during 2014 (dam removal period) we were only able to fish the mainstem site <50% of the days.

Catch rates for all species remained relatively low on the mainstem Elwha River in 2017 and ranged from 7% for 1+ coho to 14% for steelhead. However, we were again, as in 2016, able to generate estimates for more species/life histories than in previous years. We produced estimates for 0+ Chinook salmon, 1+ Chinook salmon, 0+ Coho salmon, 1+ Coho salmon, chum salmon and steelhead at the mainstem site in 2017 (Table 2). This is similar to 2016 except for pink salmon which are primarily an even year outmigrant and a significant improvement over 2015 when estimates could only be developed for Chinook salmon 0+ and coho salmon 0+. We generated estimates for larger bodied Coho salmon (1+), Chinook salmon (1+) and steelhead because of improved capture efficiency and because of a successful trap efficiency trial using hatchery coho salmon releases in two separate mark-recapture experiments. During that trial we were able to recapture 8.5% of the total 1+ Coho hatchery releases. Low capture

rates of large bodied smolts such as coho salmon and steelhead has been problematic since smolt trapping was initiated on the Elwha in 2006. This result, now repeated in two consecutive years, represents a significant improvement in the overall smolt monitoring program.

In 2017, steelhead and 0+ Chinook salmon were the most numerous species captured in the mainstem trap and while their relative numbers are relatively low (994 and 4,978 total catch, respectively) this represents an approximate doubling over 2016. We estimated a total outmigration of 73,684 0+ Chinook salmon, 593 1+ Chinook salmon, 2,570 0+ coho salmon, 2,552 1+ coho salmon, and 11,772 steelhead for the Elwha River in 2017. The 0+ Chinook salmon estimate, while still low, represents an increase over the dam removal period. Also relevant was the result of the Chinook salmon otolith analysis which indicated that 80% of the 50 sampled fish were of natural origin. These results suggest that natural Chinook salmon production is beginning to increase on the Elwha. The estimate for steelhead is particularly significant achievement for the program and suggests that natural production of this species may be amplifying rapidly. Our estimate for 2017 is nearly double that of 2016. Low numbers of chum were also encountered and we estimated a total outmigration of only 4,065 smolts.

The 2017 tributary trapping season was again a tale of two sites. Both sites were fished nearly continuously with only one break in fishing operations at Indian Creek due to elevated streamflow in early spring. The weighted efficiency at Indian Creek ranged from 10% for 1+ chinook to 37% for 0+ Chinook. Indian Creek continues to be the early star of Elwha salmon recovery and we measured continued high levels of production for a number of species. We generated estimates for 0+ Chinook salmon (1,183), 1+ Chinook salmon (622), 0+ coho salmon (22,104), 1+ coho salmon (17,428), and steelhead (3,162) at Indian Creek (Table 3). Trapping was affected by extremely low catches of all species at Little River and on 32 separate days no fish of any kind were captured. As a result, species specific estimates were only generated for 0+ coho salmon (8,250) and 1+ coho salmon (95) (Table 4). No Chum salmon or pink salmon were captured at either tributary in 2017 and therefore no estimates were made for those species. A total of 14 steelhead smolts were captured at Little River and no estimate was made for that species.

We compared the total outmigration estimates between tributaries and found some striking differences in abundance and timing. 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 at all sites. For 1+ coho salmon smolts, Indian Creek produced an

estimated 17,428 fish, an increase of 40% from 2016. In contrast, we captured 1,793 0+ coho salmon and 28 1+ coho salmon in Little River in 2017. Curiously, despite the large numbers of juvenile rainbow rearing in Little River only 14 steelhead were captured in 2017.

Three 0+ Chinook salmon were encountered at the Little River trap in 2017. The number of 0+ Chinook salmon produced from Indian Creek (1,183) was also much lower than observed in previous years. In 2016 a total of 28 and 1 Chinook salmon redds were observed in Indian Creek and Little River, respectively. The majority of redds in Indian Creek were observed below the trap site, while the single redd from Little River was also well downstream of the trap site (McHenry et al. 2017). Since Elwha Dam was removed in 2014, Little River has had several years where few or no Chinook salmon have entered the system. We hypothesize this is due to the combination of low attraction flows along with location of the mainstem on the west side of the valley in some years.

For steelhead, Indian Creek produced an estimated 3,162 (2,074-5,792) outmigrating smolts in 2017, an increase of 47% over 2016. We were unable to estimate steelhead production in Little River in 2017 for the second consecutive year due to low catch rates (14 captures). It is important to note that large numbers of juvenile steelhead 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, 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. The steady increase in smolt outmigration, at least in Indian Creek, suggests rebuilding is occurring rapidly. 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.

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 5). 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 and cutthroat 0+, 1+ and 2+ age classes that were captured at Indian Creek in 2017 (Table 5). Conversely, only small numbers of trout were encountered at Little River (Table 5). This was similar to 2015 and 2016 but opposite of what was reported in 2014 (McHenry et al. 2015) when all ages of trout were more numerous in

Little River. No bull trout were captured in Little River and 6 were encountered at Indian Creek. Additionally, we only encountered cutthroat smolts in Indian Creek (3) and at the mainstem site (2). Anadromous forms of cutthroat trout were thought to be rare on the Elwha, at least in the years immediately prior to dam removal. Indian Creek/Lake Sutherland supports the largest and most diverse source of cutthroat trout in the Elwha watershed, including an adfluvial population that spawns in upper Indian Creek in the fall (MacMillan et al. 2015). The presence of cutthroat trout smolts may suggest a “reawakening” of this life history form in the Elwha over time.

Such recolonization also appears to be 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. Small numbers (7) Pacific lamprey were captured in 2015. Ammocoetes were first encountered at Indian Creek in 2013, one year following the initial recolonization event by adults in 2012. Lamprey populations 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. We expected that downstream migrating microthalamia 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 and Crossman 1973). However, in 2016 we encountered a total of 71 Pacific Lamprey macrothalamia (Figure 6) and in 2017 that number increased to 600.

At the mainstem trap, we continue to encounter marine species that are of ecological significance. In 2017, we report the continued presence of eulachon (*Thaleichthys pacificus*) encounters in the trap with a total catch of 7. This population appears to vary greatly in abundance by year in the Elwha but is consistently observed. In 2015 a large number of eulachon were observed in the lower Elwha River during January and large numbers of bald eagles (>100) were observed fishing for them. In 2016 and 2017 we captured herring (*Clupea harengus*) and American Shad (*Alosa sapidissima*).

American shad are not native to the west coast of North America but are well established in the Columbia River. The captured shad were all sub-adults that are likely rearing as subadults in Puget Sound. The only other non-native fish encountered during trapping operations are brook trout, which are well established in Indian Creek. Brook trout encountered at the traps are removed from the system.

Discussion

Smolt trapping on the Elwha was initiated in 2006. The period from 2006-2011 represents pre-dam removal conditions when anadromy was limited to 7.9 kilometers of degraded habitat and hatchery production dominated salmon returns. Smolt outmigration estimation from 2012-2015 represents the production of salmonids during dam-removal period. This period is characterized by the highest rates of sediment transport as the river eroded and transported millions of yards of accumulated sediment in the former reservoirs (Warrick et al. 2015). Mainstem smolt trapping efforts during the dam removal period have been challenging and in 2012 and 2013 we were forced to abandon trapping because of the very high level of sediment and debris interfering with trap operations. 2014 was also problematic but primarily due to elevated spring flows and large woody debris. While trapping conditions were much improved in 2015, those outmigrants were subjected to incubation conditions in 2014. We believe that the worst of the impacts from dam removal on smolt trapping operations have occurred. The 2016-2017 seasons represents the first years of post-dam removal data and provides a benchmark to assess the state of recovery early in the recovery process.

The return of the 8' screw trap to the mainstem site improved smolt estimation for both small and large bodied smolts in 2016 and 2017. In 2015 estimates were only made for 0+ Coho salmon and 0+ Chinook salmon on the mainstem Elwha River. The outmigration estimates for Elwha 0+ Chinook salmon smolts in 2017 was 73,684 (range 60,574-106,008), approximately double the 2016 estimate. This is within the range of production measured from the Elwha River during the pre-project period, but on the low end of the range (Figure 7). In 2016, adult Chinook salmon escapement to the Elwha River was 2,638 salmon. This was similar to 2015, however fewer redds were observed in 2016 (615 versus 937) (McHenry et al. 2016; 2017). 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 and unstable bed conditions. A negative correlation between peak flows and Chinook survival has been reported in Puget Sound (Greene et al. 2005). Unstable bed conditions associated with peak sediment transport during dam removal has also likely limited the survival of incubating embryos on the Elwha River to date.

We used the estimates of Potential Egg Deposition for chinook (Weinheimer et al. 2016 & 2017) in the Elwha with 0+ chinook smolt estimates at the mainstem trap to estimate egg to smolt survival for the 2015 and 2016 brood years. In 2015 that survival was 0.65% and in 2016 it was 1.23%. Chinook egg to smolt survival rates are known to vary considerably and chinook are vulnerable during years of high winter peak flows. These rates appear quite low and we note that the average egg to smolt survival on the Green River (2000-2018) and Skagit Rivers

(2000-2008) are 5.7% (Unpublished Data, WDFW) and 12.4% (Zimmerman 2015). However it should be noted that both systems are regulated with multiple dams. Whether the low egg to smolt survival is related to flows, unstable bed conditions, genetic fitness or some combination of factors is unknown. The 2016-17 flood year was moderate in terms of peak flows with one flood exceeding 20,000 cfs and three others exceeding 10,000 cfs. The increasing trend of 0+ Chinook outmigrants over the last two years is encouraging in that it suggests production of natural chinook are potentially increasing.

While the trends for chinook outmigrants are encouraging, the total number of chum and pink salmon outmigrants is alarmingly low. Both populations entered dam removal at low levels and it is likely that dam removal itself has further stressed both populations (Figure 8). The 2017 Elwha chum estimate was 4,065 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 2017 outmigration year. For years in which we caught enough pink smolts to generate a production estimate those numbers show a steadily declining trend (Figure 8). 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 (reference). If these trends continue, project managers should consider interventions that could amplify both populations.

We tabulated smolt outmigration data collected by WDFW on the Nisqually River (Kungle et al. 2017) for the period from 2019-2015 in order to compare the relative numbers of smolts being produced between the Elwha and Nisqually Rivers. In general, the Nisqually River is producing from several times to orders of magnitude of total outmigrants depending upon species (Table 6). While this is not surprising, given that the Elwha is in early the early stages of recovery, the data does provide some indication of the levels of production that might be expected in the future.

We compared the outmigration timing of all species at all trap sites (Figures 9-14). In general and consistent with previous years, outmigration timing is earlier for 0+ Chinook salmon and both age classes of Coho salmon from Indian Creek as compared to Little River. For 0+ Chinook salmon the bulk of outmigration was completed as in previous years by second week of March, while in Little River it was completed by the first week of April. Interestingly, 0+ Chinook appear to have established a bi-modal outmigration timing (Figure 9). This pattern was lacking during the pre-dam period. For Coho salmon yearlings outmigration timing was about a month earlier between systems. These differences appear to be temperature driven. Little River has a northern aspect and drains off Hurricane Ridge and has much greater elevation landforms than Indian Creek. Little River has a snowmelt hydrology while Indian Creek is primarily rainfall driven and moderated by a large lake in its headwaters. As a result, Little River

is significantly cooler than Indian Creek. Maximum temperatures in Little River are on the order of 7-10° C, while in Indian Creek maximum temperatures average 10-15° C. Little River also is severely degraded in terms of in stream habitat features. A recent assessment of the watershed shows that the system has lost most of its in-channel large wood and has incised by 0.5-3.5 meters (NSD 2016). As a result, pool habitat and over-winter habitat types are limited. Without adequate pool structure, juvenile coho salmon have fewer areas to rear and may be seeking other habitats downstream.

Indian Creek has consistently produced larger numbers of coho salmon outmigrants relative to Little River over the period of monitoring. Since 2012, surplus coho salmon adults from the LEKT hatchery have been relocated to the two middle Elwha tributaries (Table 7). 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). While the number of adults relocated into the two tributaries is similar (Table 6), the differences in production are not. 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 91% of the total production from the Elwha watershed.

Smolt trapping operations have documented several ecologically significant events that suggest the "reawakening" of anadromy or natural recolonization events. Those include the documentation of sockeye salmon smolts from Indian Creek/Lake Sutherland in previous years, the natural recolonization of Indian Creek by Pacific Lamprey, and the continued presence of eulachon in the lower river. 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 are 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 Indian Creek since Elwha Dam was removed, the numbers have been very low and spawning has not been documented. This would 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.

Neither tributary to date has been colonized by significant numbers of returning adult chum or pink salmon. The lack of chum salmon and pink salmon to both tributaries is a serious concern to project co-managers. There is concern that passage conditions at the former Elwha Dam site are problematic for some species and at some flows (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 observations³. Similarly, passage through Glines Canyon has only recently been improved, but it is unclear if chum and pink can pass this area. 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.

Sources of Error

While we have strived to keep the aforementioned sources of uncertainty low in order to stay within a coefficient of variation of 15% or less, 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

³ Pink and Chum salmon were observed in moderate numbers above Elwha Dam for the first time in 2015 indicating that passage conditions were adequate during that year. Additionally, 11 adult chum were relocated to Indian Creek in 2016. Fish passage conditions through the former Elwha Dam site are dynamic and may change between years and flow conditions.

2014. In contrast to the dam removal years, when large portions of the fishing season were lost, the biggest source of uncertainty confronting smolt trapping programs on the mainstem Elwha in 2017 was due to the combination of missed trap days and but the low numbers of some species of fish captured. The Coefficient of Variation (CV) for mainstem trapping estimates ranged from 15% (1+ coho) to 30% (1+ Chinook salmon) and averaged 18% for all species. In 2017 CV were near targets for all species except 1+ Chinook salmon (15-18%). 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. Due to missed fishing days immediately after trap efficiency tests, only three efficiency trials were used to expand all numbers for the mainstem. One of these was for coho 1+ and the other two for chinook 0+. We chose to use all three efficiency trials for the both large and small bodied species. This introduces a substantial amount of uncertainty to the mainstem estimates that is not accounted for in the confidence intervals and CVs.

In contrast, fishing on the tributaries was relatively trouble free and ~99% of the potential fishing days were fished and continually per 24 hour day. Little River had lower CV for 0+ and 1+ coho salmon than in 2016. Little River estimated CV was 9% for 0+ Coho salmon and 20% for 1+ coho salmon (the only species estimated). For all species the CV for the Little River site was 14.5%. Indian Creek CV's were significantly higher than observed in past years and ranged from 9% for steelhead to 40% for 1+ Chinook salmon. For all species the CV for the Indian Creek site was 28%. The high CV values in Indian Creek are attributable to two trap efficiency tests with either no or few recaptures.

Recommendations

Based on our experiences conducting smolt trapping on the Elwha River during the dam removal period we will implement the following changes for 2018 operations. For the mainstem Elwha River trapping effort we will continue the trapping operations at the downstream site at Rkm 0.3. A 1.5-2.0 m deep pool has reformed there and we intend to fish the 8' screw trap at the downstream site for the immediate future. This will maintain our overall catch and trap efficiency relative to the 5' trap. The long term future of the mainstem trap site is threatened by the dynamic nature of the river in the vicinity of the trap site. Dramatic changes in channel position may limit our ability to launch the trap from the terminus of Lower Elwha Road. Additionally, Lower Elwha Road is threatened by overflow channels that could erode the road to the point that it is no longer accessible to vehicles. If this access point is lost, we propose to move the trap upstream in the vicinity of Elwha River Road bridge. This is the only reliable road access point. It places the trap further upstream than desired, 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 attempting to maximize fishing time as outlined above. In theory more fishing time should result in higher catches of large smolts such as steelhead and Coho salmon 1+. However, the other problem for these species is the expansion of raw catch estimates to generate production estimates. To 2016, all mainstem trap efficiency tests on the Elwha River have relied on small sized 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 2017 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. 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).

Our final recommendation is to add 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 has been 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 and daily maintenance thus LEKT will postpone this action until road access is reestablished.

Acknowledgements

We are indebted to the technicians and biologists of the Lower Elwha Klallam Tribe for operating the traps through difficult conditions. Those personnel include Ernest Sampson, Gabe Youngman, Kim Williams, Wilson Wells, Rebecca Paradis, Raymond Moses, Allyce Miller, Laurel Moulton and Justin Stapleton. Robert Dohrn from Americorps also assisted with trapping operations in 2017. Washington Department of Fish and Wildlife provided the

majority of 0+ chinook and the Lower Elwha Klallam Hatchery provided 0+ chum salmon for trap testing.

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Tables

Table 1. Results of mark-recapture tests for Elwha River, Indian Creek and Little River for the 2017 smolt outmigration season.

Site	Date	Species	Number	Recaptures	Percentage (%)
Elwha	3/28/17	Coho 1+	25,772	2,189	8.5
Elwha	5/2/17	Chinook 0+	1,000	145	14.5
Elwha	5/10/17	Chinook 0+	1,000	138	13.8
Elwha	Continuous	Coho 1+ (from Indian)	988	28	2.8
<i>Elwha Average</i>			<i>100,893</i>	<i>5,293</i>	<i>5.25</i>
Little	3/20/17	Chinook 0+	100	17	17.0
Little	3/29/17	Chum 0+	200	38	19.0
Little	4/10/17	Chinook 0+	200	51	25.5
Little	4/17/17	Chinook 0+	100	57	28.5
Little	4/25/17	Chinook 0+	100	11	11.0
Little	5/2/17	Chinook 0+	100	18	18.0
Little	5/10/17	Chinook 0+	100	46	46.0
<i>Little Average</i>			<i>900</i>	<i>238</i>	<i>26.4</i>
Indian	3/20/17	Chinook 0+	100	40	40.0
Indian	3/29/17	Chum 0+	200	0	0.0
Indian	4/10/17	Chinook 0+	200	81	40.5
Indian	4/17/17	Chinook 0+	100	40	40.0
Indian	4/25/17	Chinook 0+	100	54	54.0
Indian	5/2/17	Chinook 0+	100	42	42.0
Indian	5/10/17	Chinook 0+	100	7	7.0
<i>Indian Average</i>			<i>900</i>	<i>264</i>	<i>29.3</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, 2017 outmigration year. NE = no estimate.

Species	Catch	Estimated Total Catch	Average efficiency (weighted)	Estimated Outmigrants	95% C.I.	CV	gCV
Chinook Salmon(0+)	4,978	7,341	0.1146	73,684	60,574- 106,008	0.16	0.14
Chinook Salmon(1+)	47	109	0.1338	593	389- 1,098	0.3	0.26
Coho Salmon(0+)	239	327	0.1272	2,570	2,022- 3,496	0.56	0.49
Coho Salmon(1+)	204	329	0.1334	2,552	2,022- 3,496	0.15	0.14
Chum Salmon	222	396	0.095	4,065	3,250- 5,521	0.15	0.14
Pink Salmon	NE	NE	NE	NE	NE	NE	NE
Steelhead	994	1,844	0.1385	11,722	9,085- 17,521	0.17	0.14

Table 3. Total catch, estimated outmigrants, 95% C.I., CV and geometric CV for smolt outmigration from Indian Creek, 2017 outmigration year.

Species	Total Catch	Estimated Total Catch	Average Efficiency (weighted)	Estimated Outmigrants	95% C.I.	CV	gCV
Chinook Salmon(0+)	350	350	0.3720	1,183	922-1,641	0.16	0.15
Chinook Salmon(1+)	55	55	0.1033	622	337-1,336	0.4	0.37
Coho Salmon(0+)	4,112	4,112	0.3085	22,104	15,603-38,028	0.25	0.23
Coho Salmon(1+)	1,898	1,899	0.1557	17,428	10,597-32,214	0.30	0.29
Pink Salmon(0+)	0	0	NE	NE	NE	NE	NE
Chum Salmon(0+)	0	0	NE	NE	NE	NE	NE
Steelhead	500	500	0.2900	3,162	2,074-5,792	0.09	0.09

Table 4. Total catch, estimated outmigrants, 95% C.I., CV and geometric CV for smolt outmigration from Little River, 2017 outmigration year.

Species	Total Catch	Estimated Total Catch	Average Efficiency (weighted)	Estimated Outmigrants	95% C.I.	CV	gCV
Chinook Salmon(0+)	3	3	NE	NE	NE	NE	NE
Chinook Salmon(1+)	14	14	NE	NE	NE	NE	NE
Coho Salmon(0+)	1,793	1,793	0.2615	8,250	7,076-10,105	0.09	0.09
Coho Salmon(1+)	28	28	0.3476	95	64-139	0.20	0.20
Pink Salmon(0+)	0	NE	NE	NE	NE	NE	NE
Chum Salmon(0+)	0	NE	NE	NE	NE	NE	NE
Steelhead	14	14	NE	NE	NE	NE	NE

Table 5. Total catch of miscellaneous fish encountered at Elwha River, Little River and Indian Creek smolt traps, 2017.

Site	0+ Trout	1+ Trout	2+ Trout	Bull Trout	Brook Trout	Cutthroat Trout (Smolts)	Cottids	Redside Shiner	Ammocoete	Macrothallimia	Adult Pacific Lamprey
Elwha	13	296	61	1	0	2	217	4	49	47	3
Little	193	332	24	0	3	0	1	0	0	0	0
Indian	556	1,614	410	6	133	3	291	168	3,474	600	16

Table 6. Smolt production from the Nisqually River (2009-2015), (Kungle et al. 2017).

Species	Average	Range
Steelhead	60,667	47,061 - 74,273
1+ Chinook	4,618	2,382 - 7,697
0+ Chinook	165,218	145,264 - 186,187
1+ Coho	161,289	137,007 - 185,573
Chum	258,086	173,892 - 342,280
Pink	17,943,433	14,276,040 - 21,610,829

Table 7. Adult coho relocations and redd counts to Little River and Indian Creek 2011-2017.
NS=Not Surveyed. LS=Limited Surveys.

	Indian Creek		Little River		Mainstem	
	Transfer	Redds	Transfer	Redds	Transfer	Redds
2011	134	95	137	-	326	Not Surveyed
2012	162	38	60	8	0	Not Surveyed
2013	596	126	442	160	0	Not Surveyed
2014	124	30	0	5	0	Not Surveyed
2015	0	0	0	NS*	0	Not Surveyed
2016	327	82	0	21	216	Not Surveyed
2017	146	LS	0	LS	218	Not Surveyed

Figures

Figure 1. Elwha River smolt trap locations.

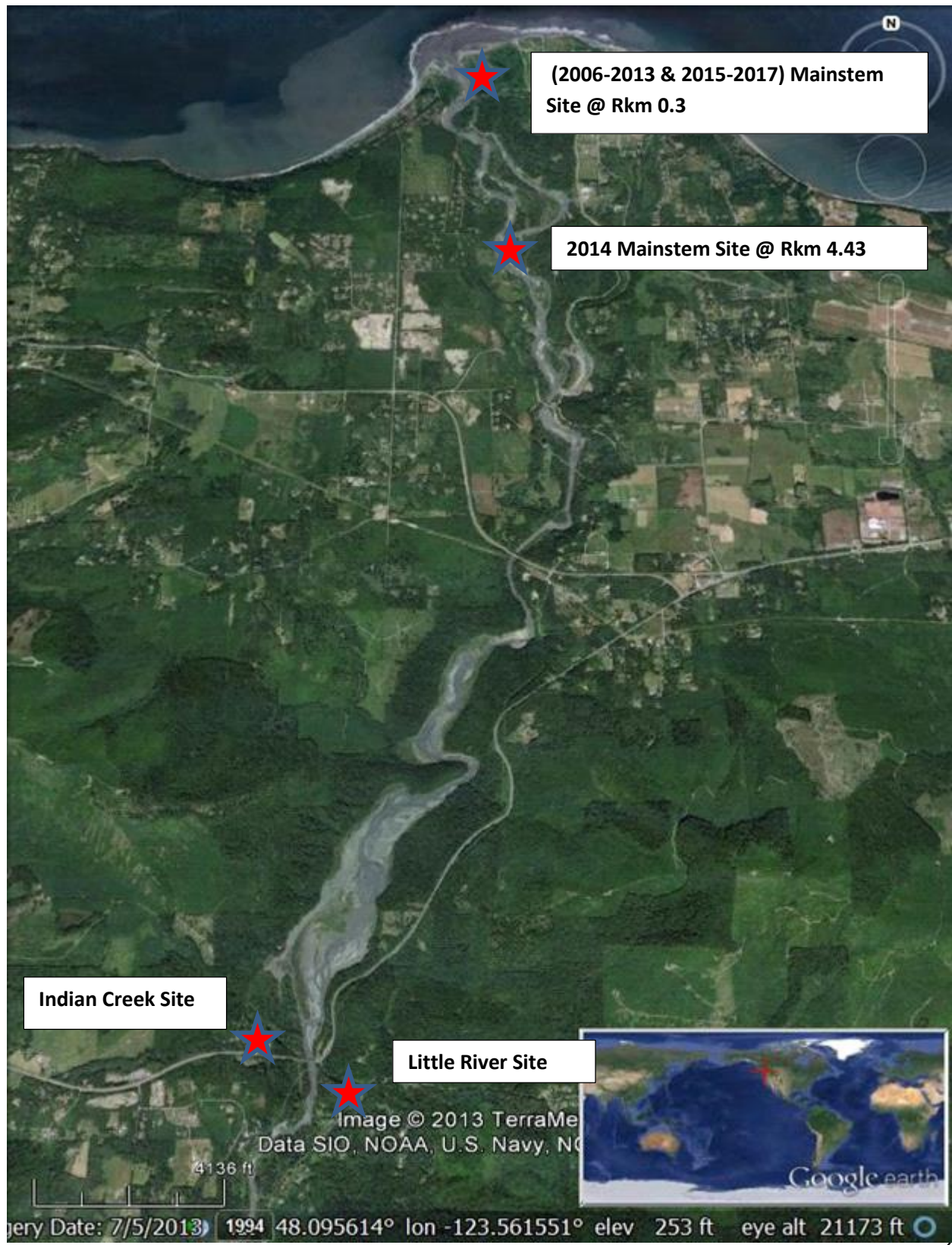


Figure 2. Top Elwha River 8' rotary screw trap fishing at Rkm 0.3 during the pre-dam and post-dam removal periods and bottom 5' rotary screw trap used during the dam removal period.



Figure 3. Little River (top) and Indian Creek smolt traps.



Figure 4. Elwha River flows (cfs) measured at the McDonald Gage Site, January 1 to July 1, 2017.

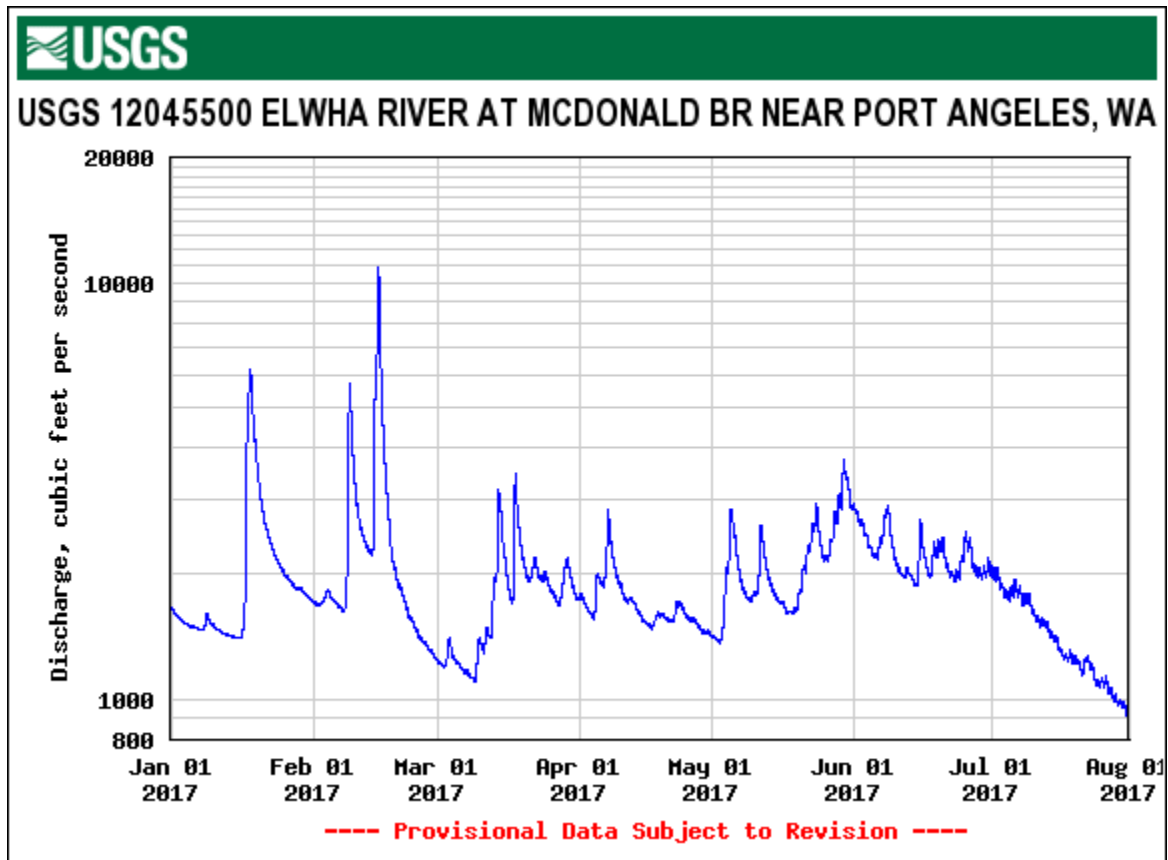


Figure 5. Bismark brown marked 1+ coho salmon for mark-recapture trap calibrations.



Figure 6. Pacific Lamprey ammocotes (top) and macrothalmia (bottom) captured at Indian Creek trap.



Figure 7. Estimated Elwha River Chinook (green) and Chum salmon (red) smolt production (2006-2017).

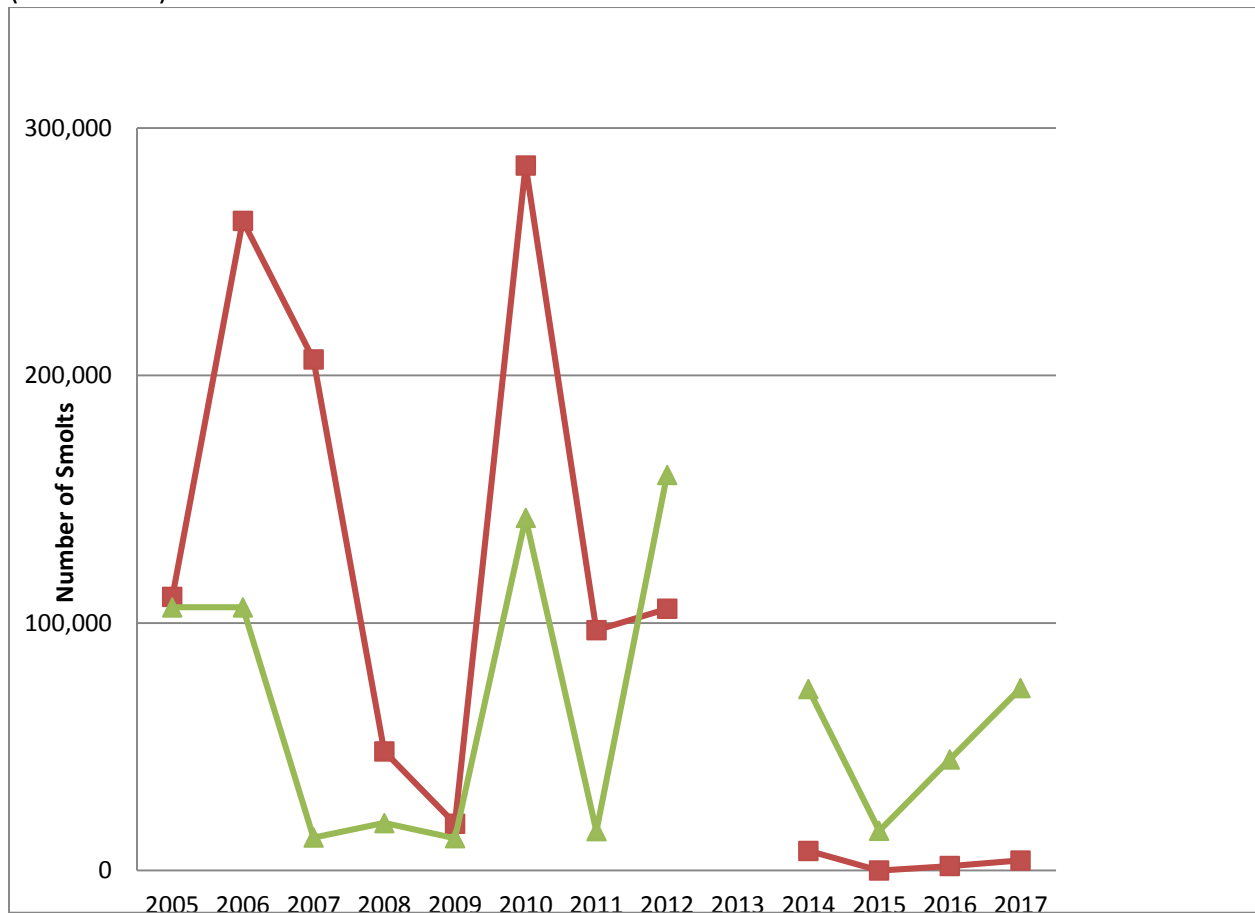


Figure 8. Estimated Elwha River pink salmon (odd year) smolt production (2006-2017).

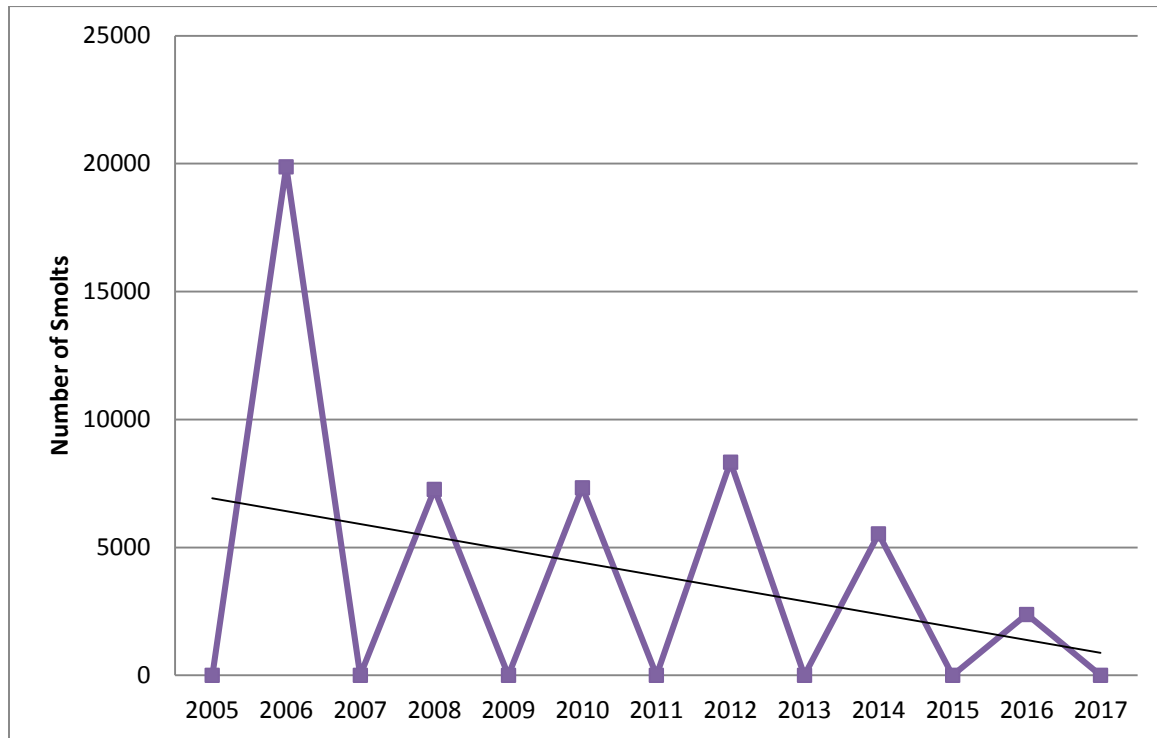


Figure 9. Estimated number of 0+ Chinook outmigrants at Indian and mainstem Elwha trap sites during 2017.

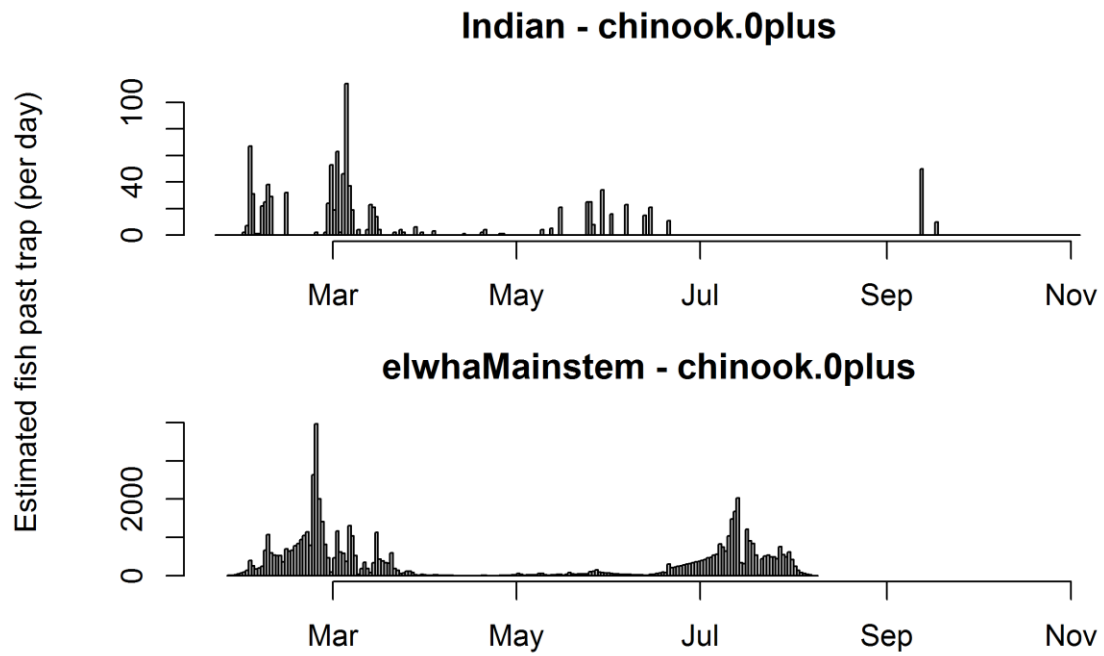


Figure 10. Estimated number of 0+ coho outmigrants at Indian, Little and mainstem Elwha trap sites during 2017.

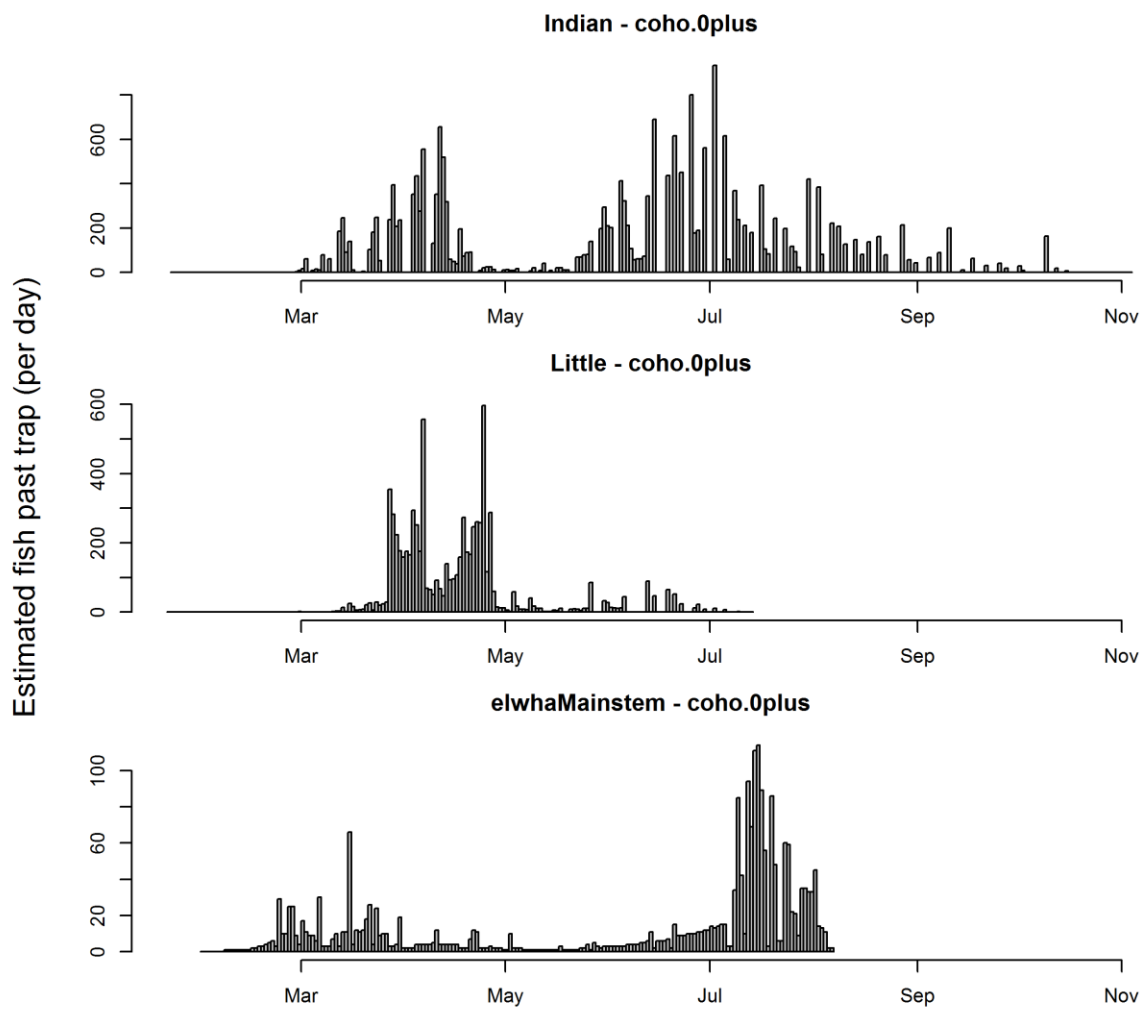


Figure 11. Estimated number of coho, chinook and steelhead outmigrants at the Indian Creek trap site during 2017.

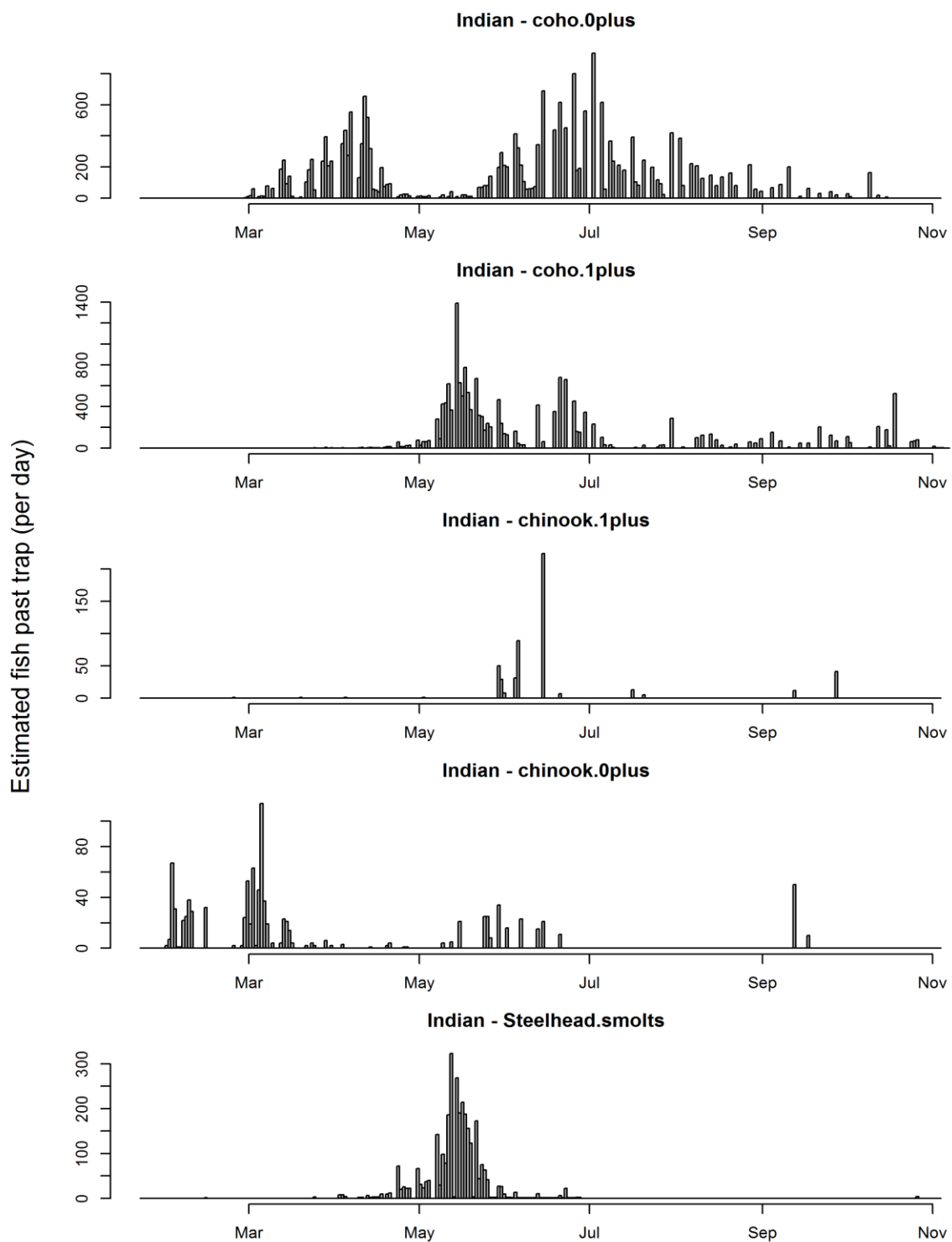


Figure 12. Estimated number and timing of coho outmigrants at the Little River trap site during 2017.

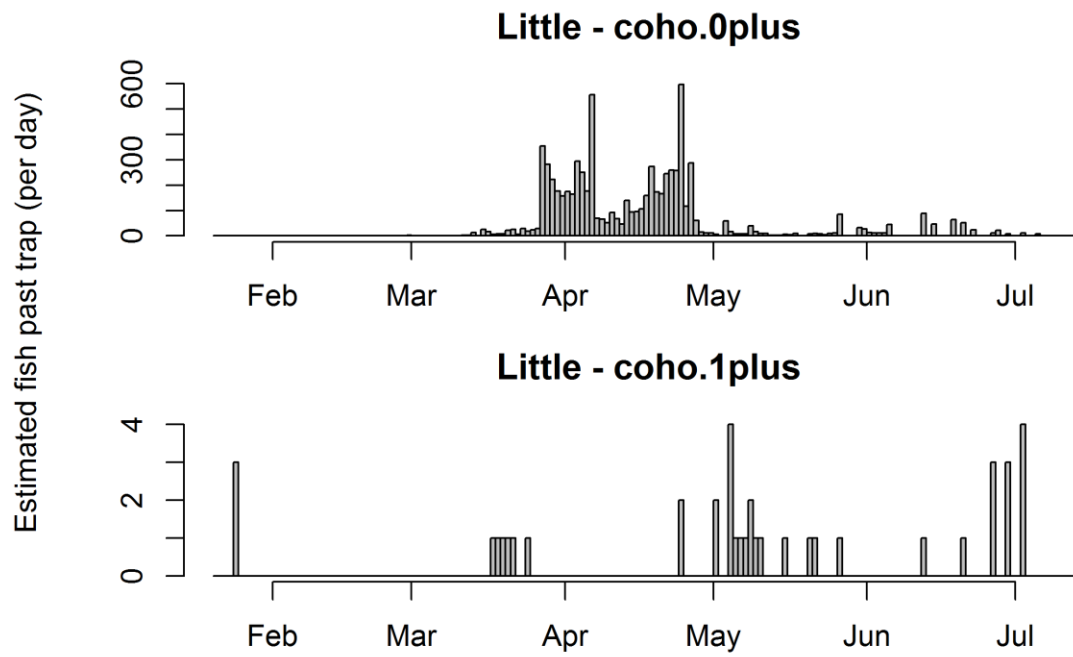


Figure 13. Estimated number and timing of steelhead outmigrants at the Little River and Elwha mainstem trap sites during 2017.

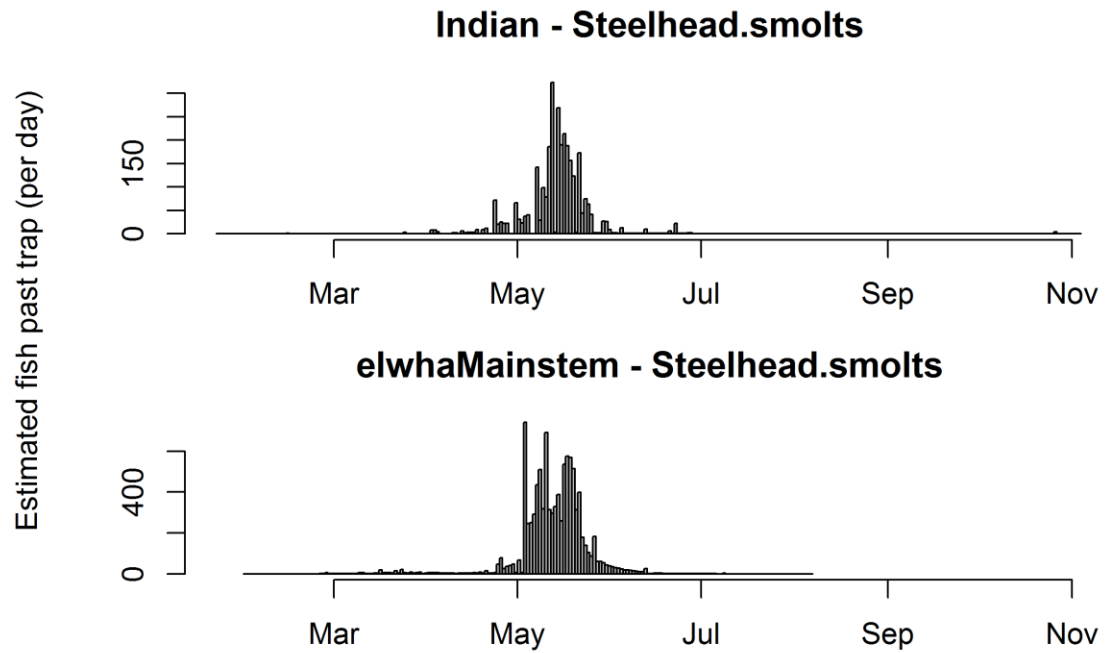
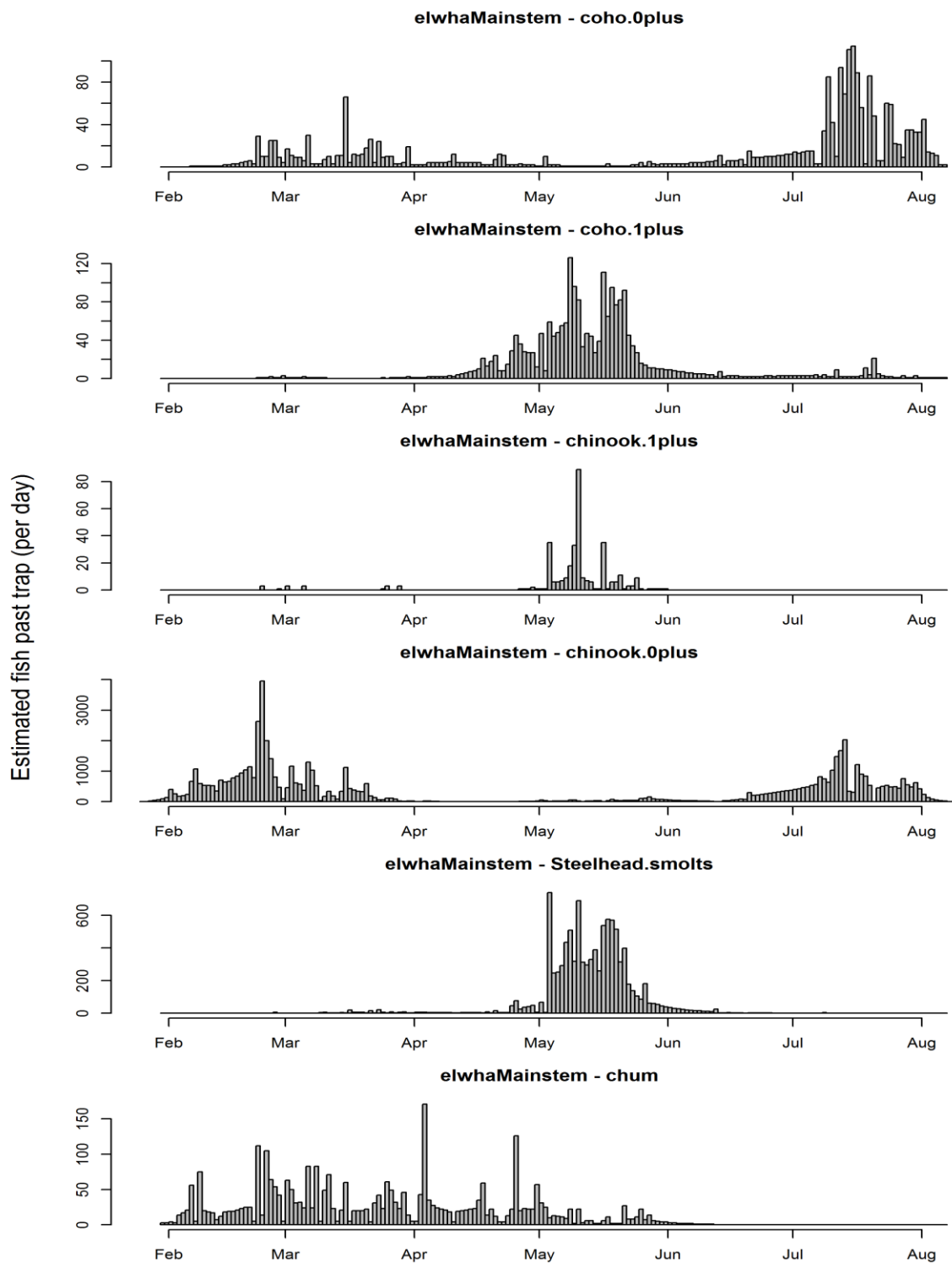


Figure 14. Estimated number and timing of coho, chinook, chum and steelhead outmigrants at the Little River and Elwha mainstem trap sites during 2017.



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.

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

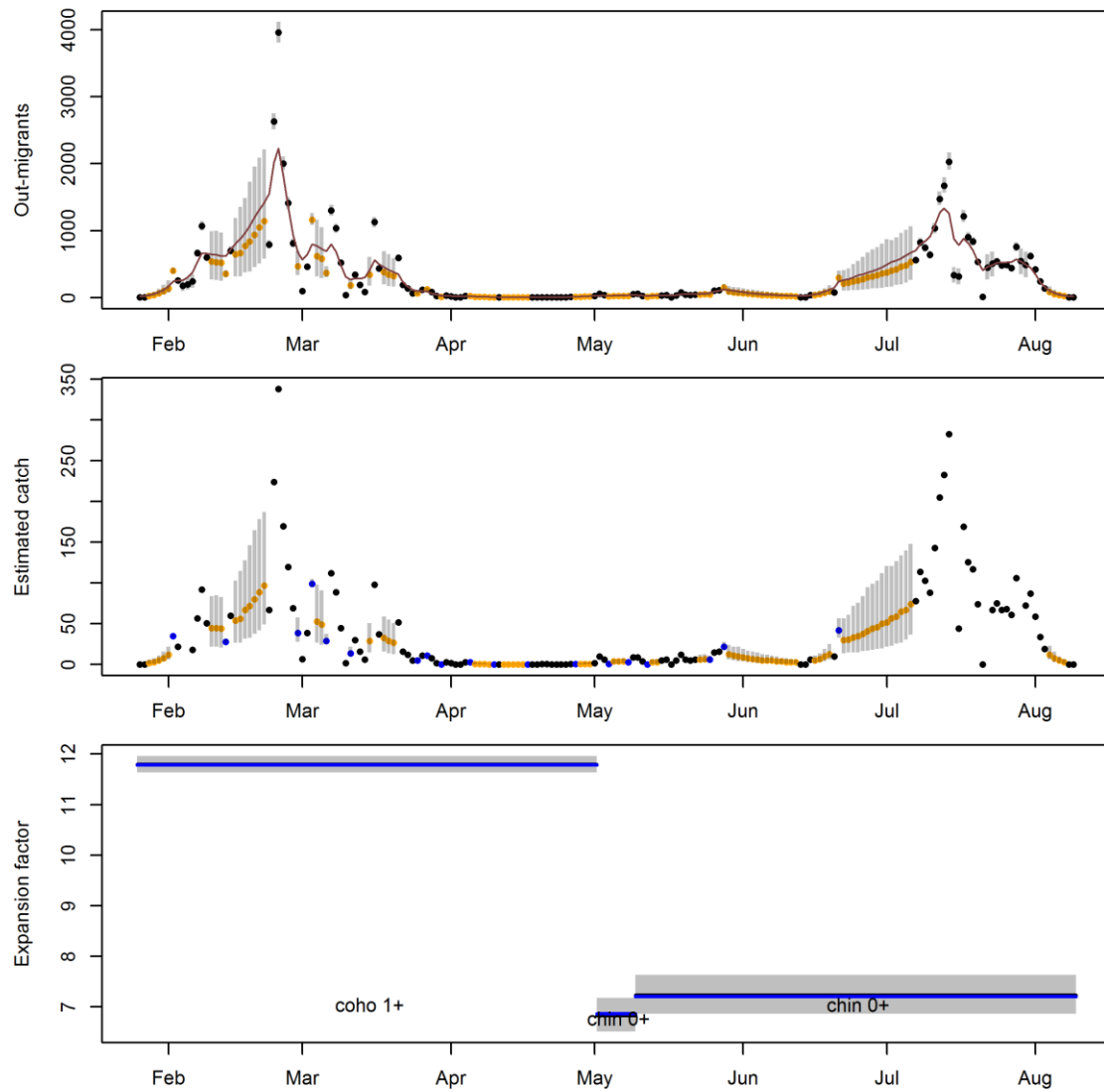
$$p_j \sim \text{beta}(1, 1)$$

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.

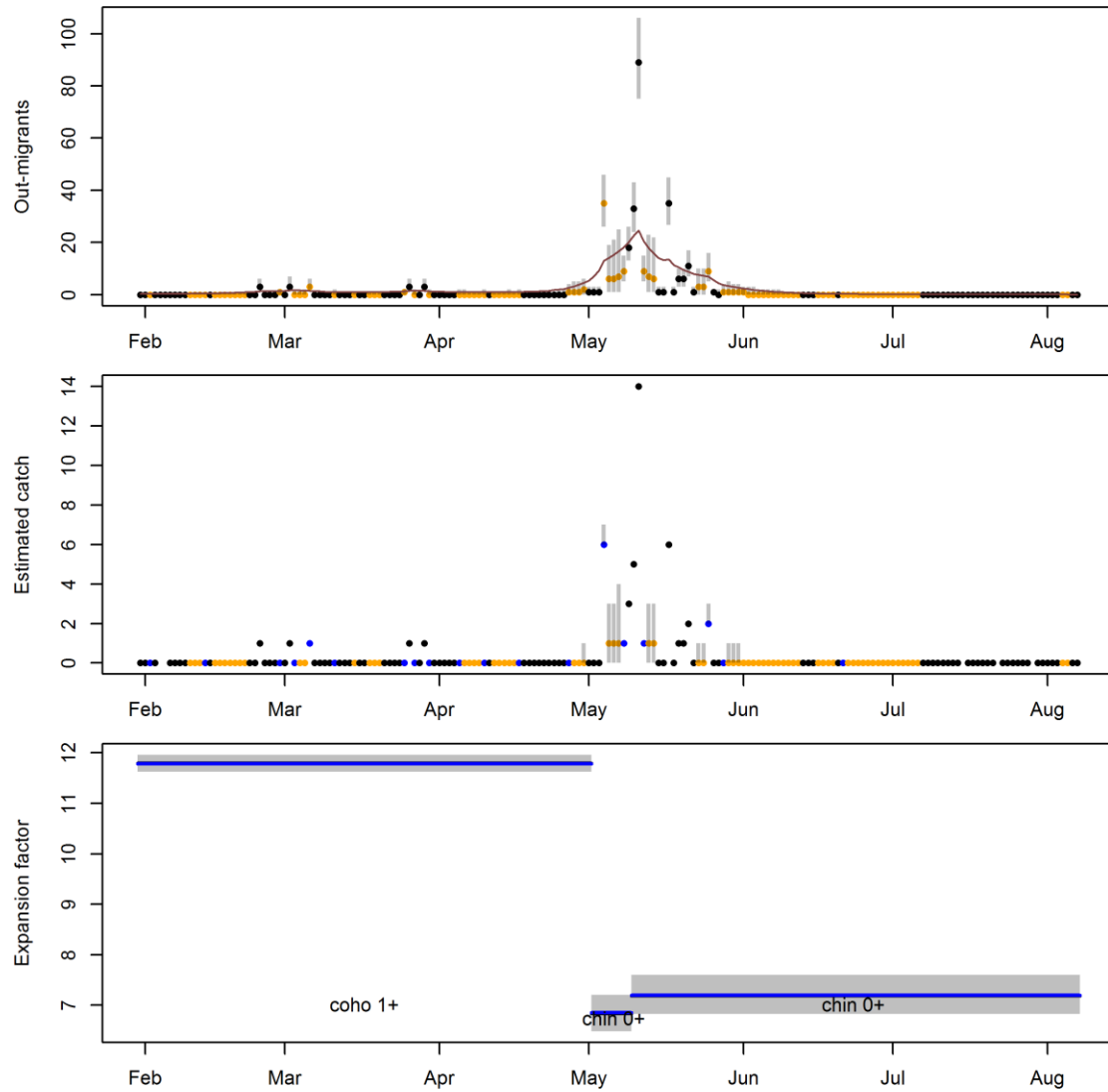
The estimates only incorporate passage during the trap operation. Therefore, if the trap was not in place during fish passage, these fish were not included in the estimate.

Appendix B. Plot of outmigrants, estimated catch and expansion factor by species and trap site for the 2017 smolt trapping season.

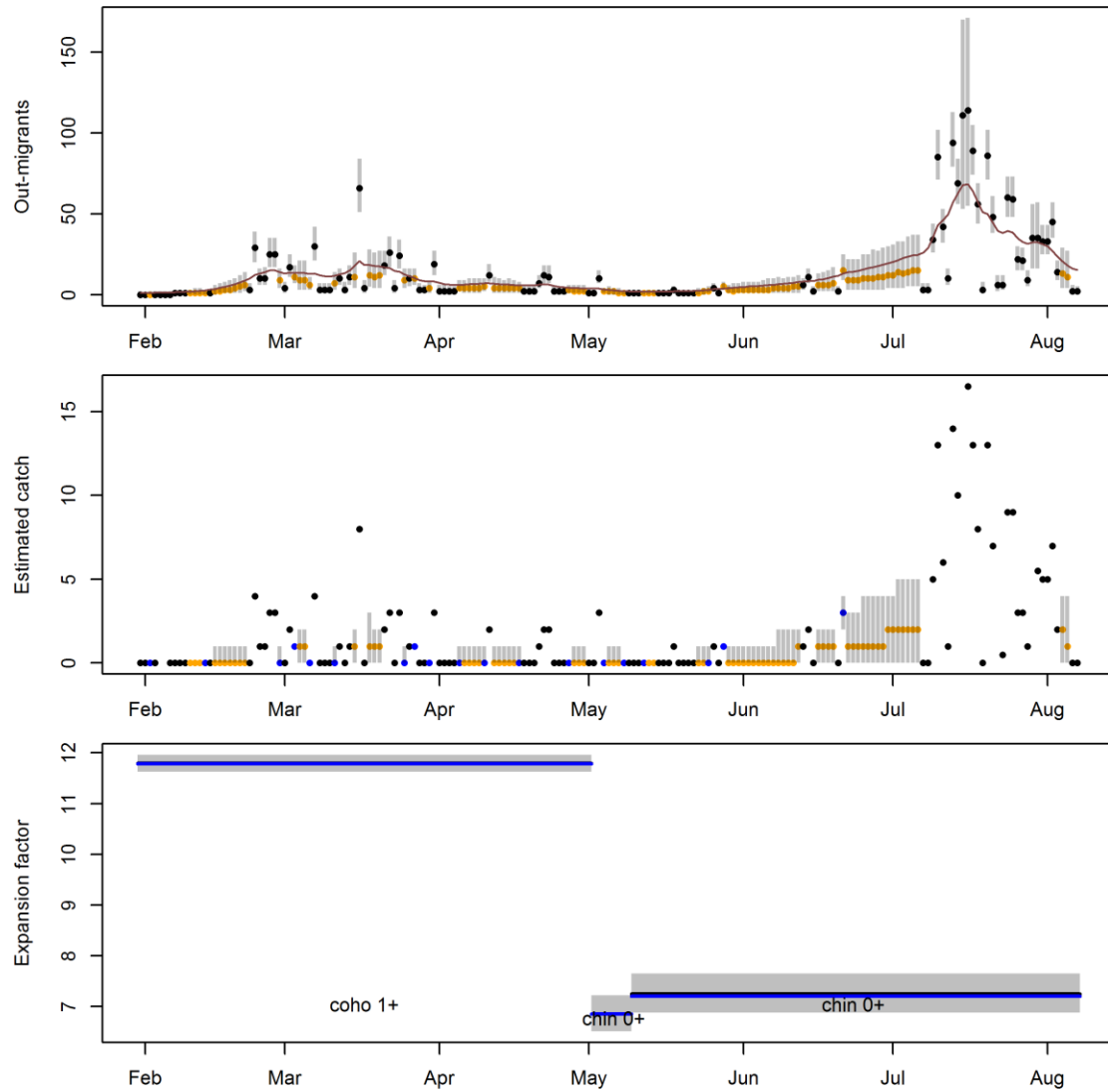
elwhaMainstem-2017-chinook.0plus est = 73,684 (60,574 - 106,008)

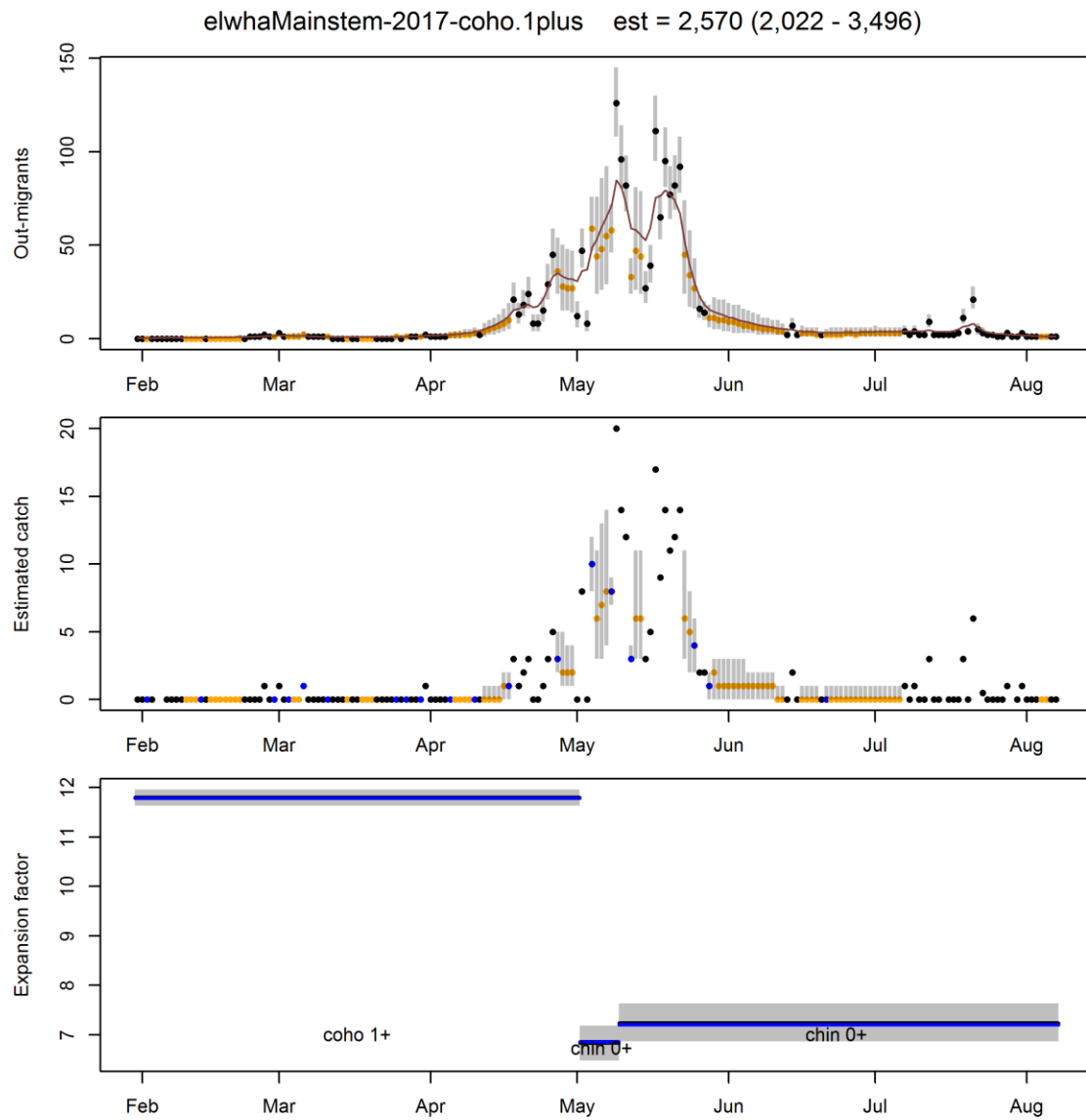


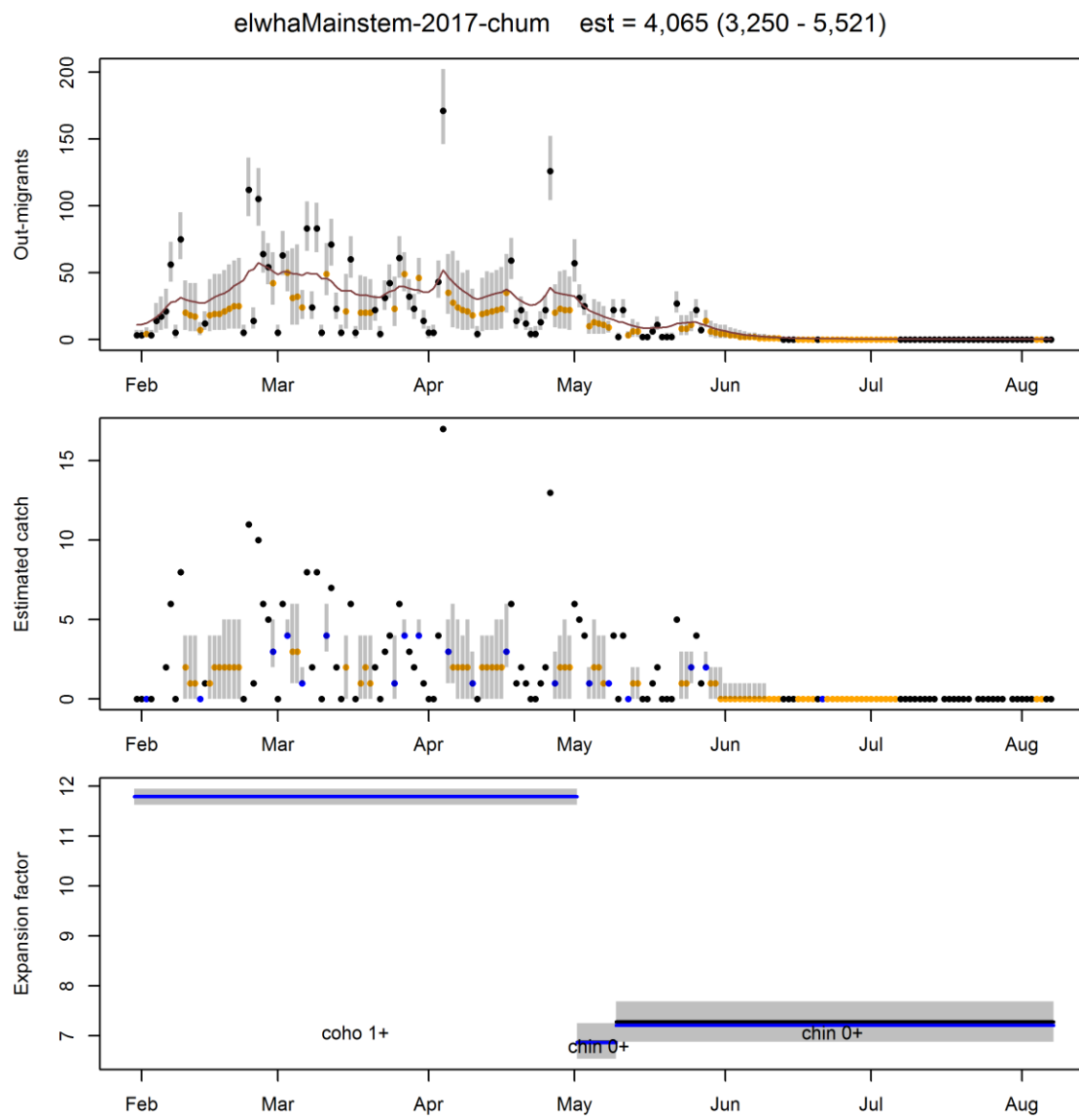
elwhaMainstem-2017-chinook.1plus est = 593 (389 - 1,098)



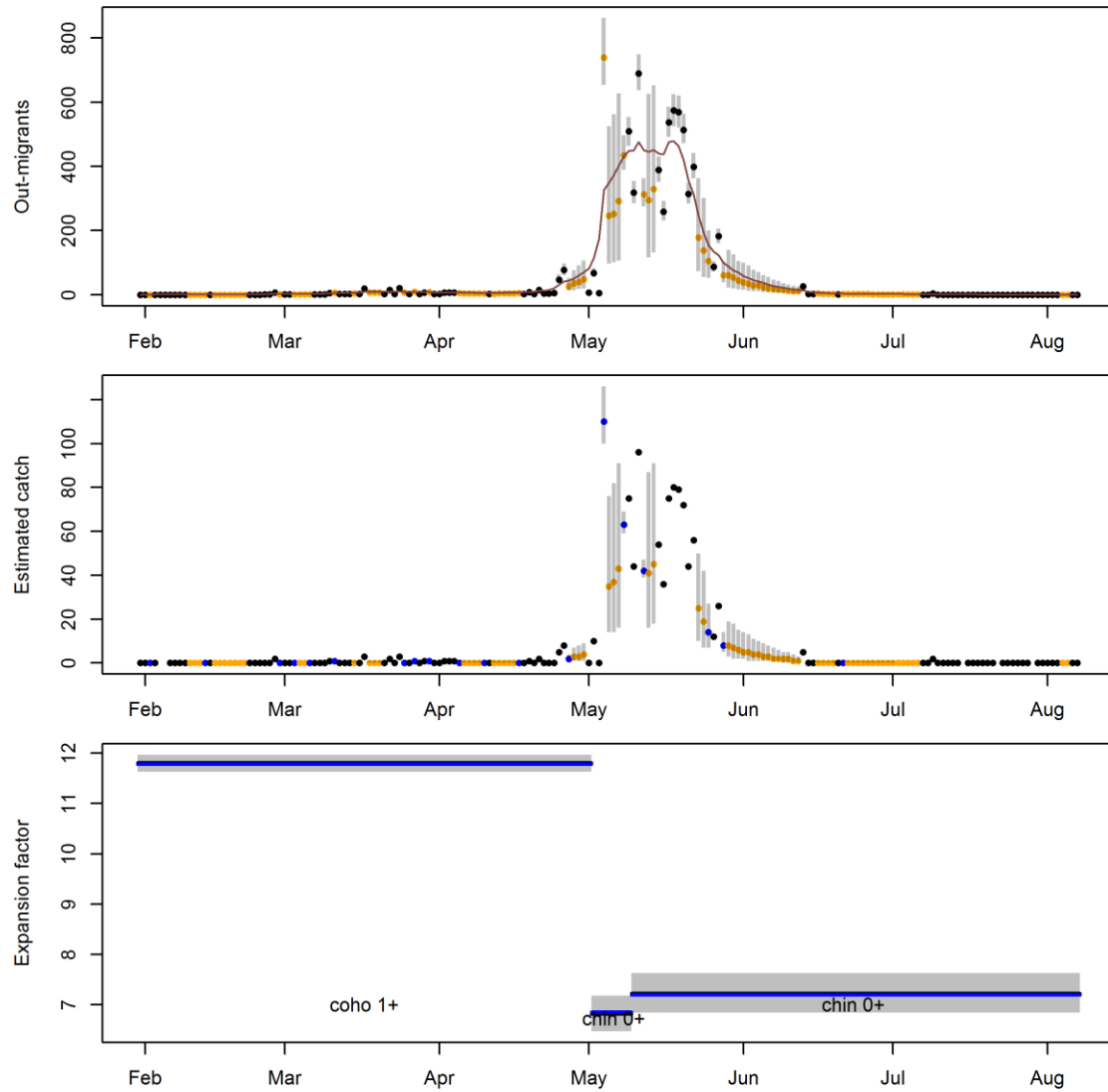
elwhaMainstem-2017-coho.0plus est = 2,832 (2,235 - 4,071)



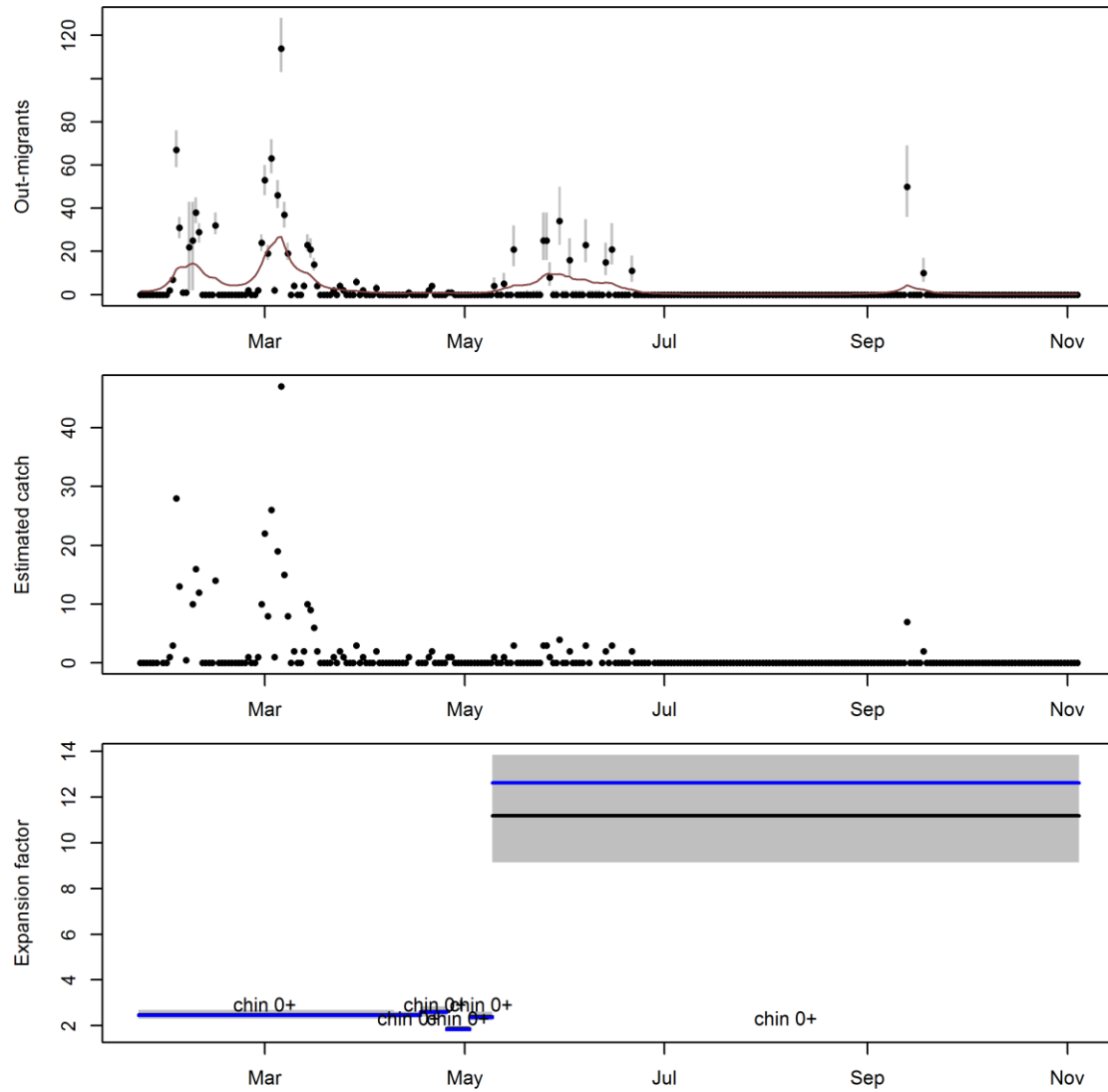


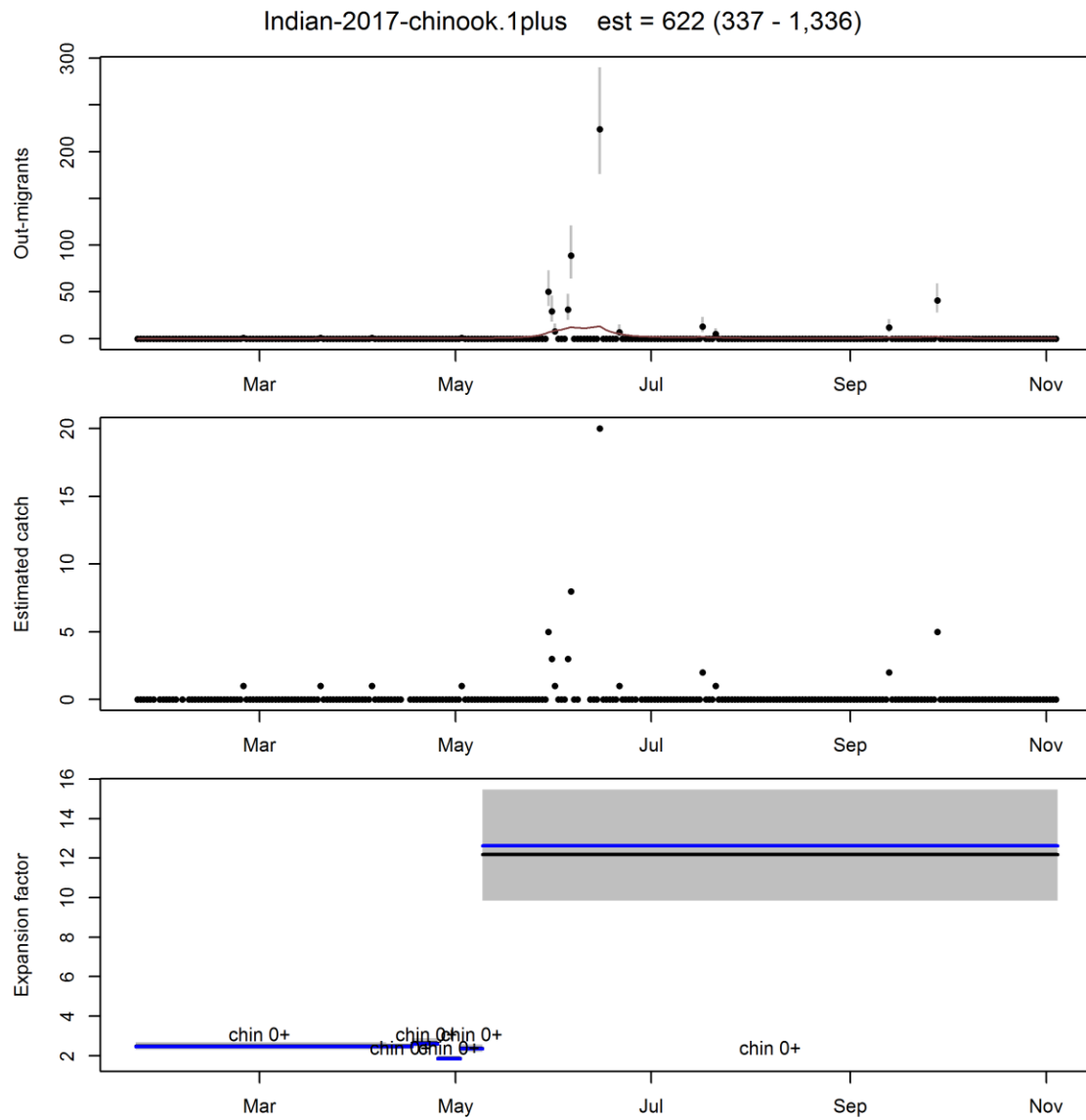


elwhaMainstem-2017-Steelhead.smolts est = 11,722 (9,085 - 17,521)

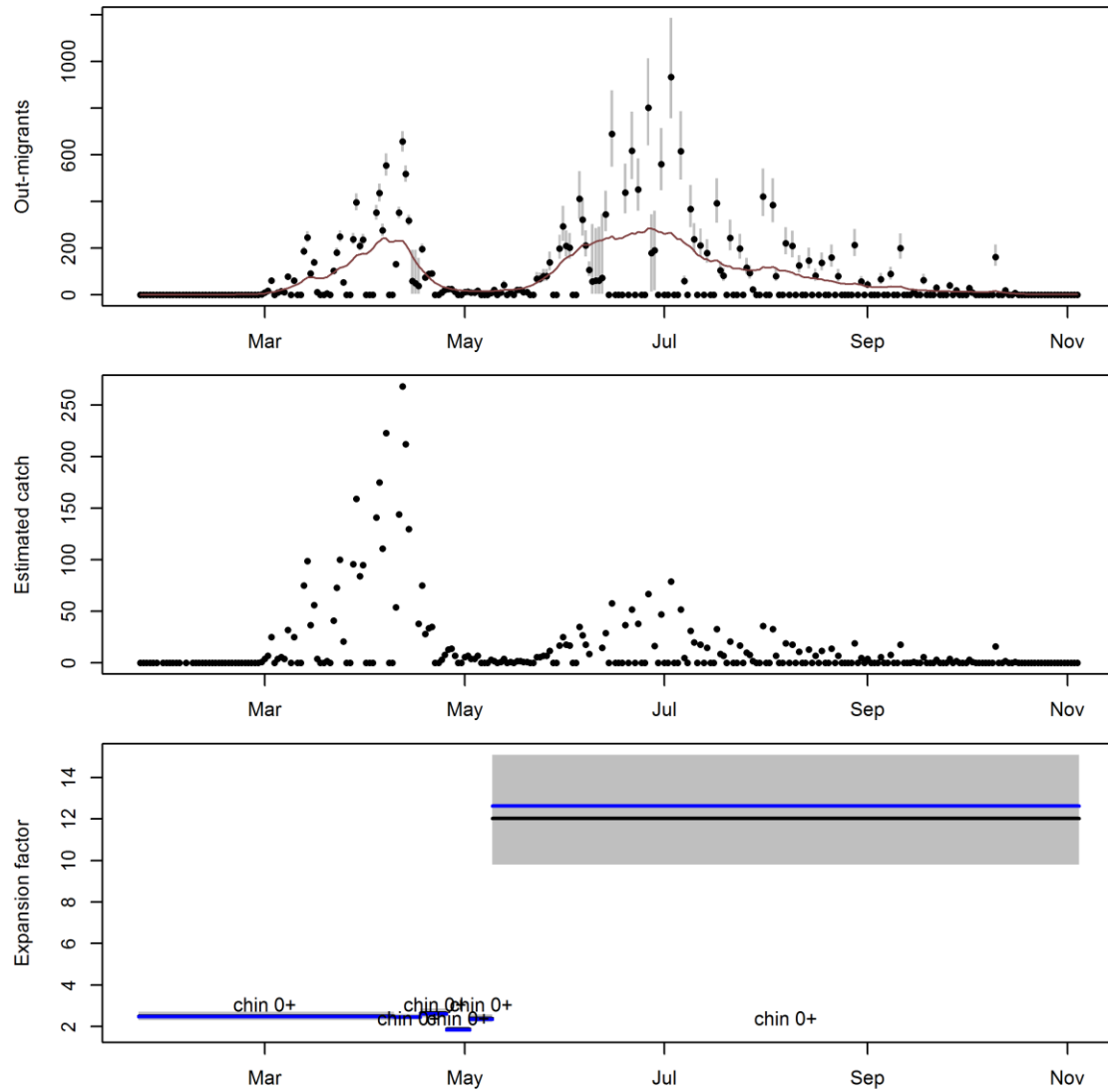


Indian-2017-chinook.0plus est = 1,183 (922 - 1,646)

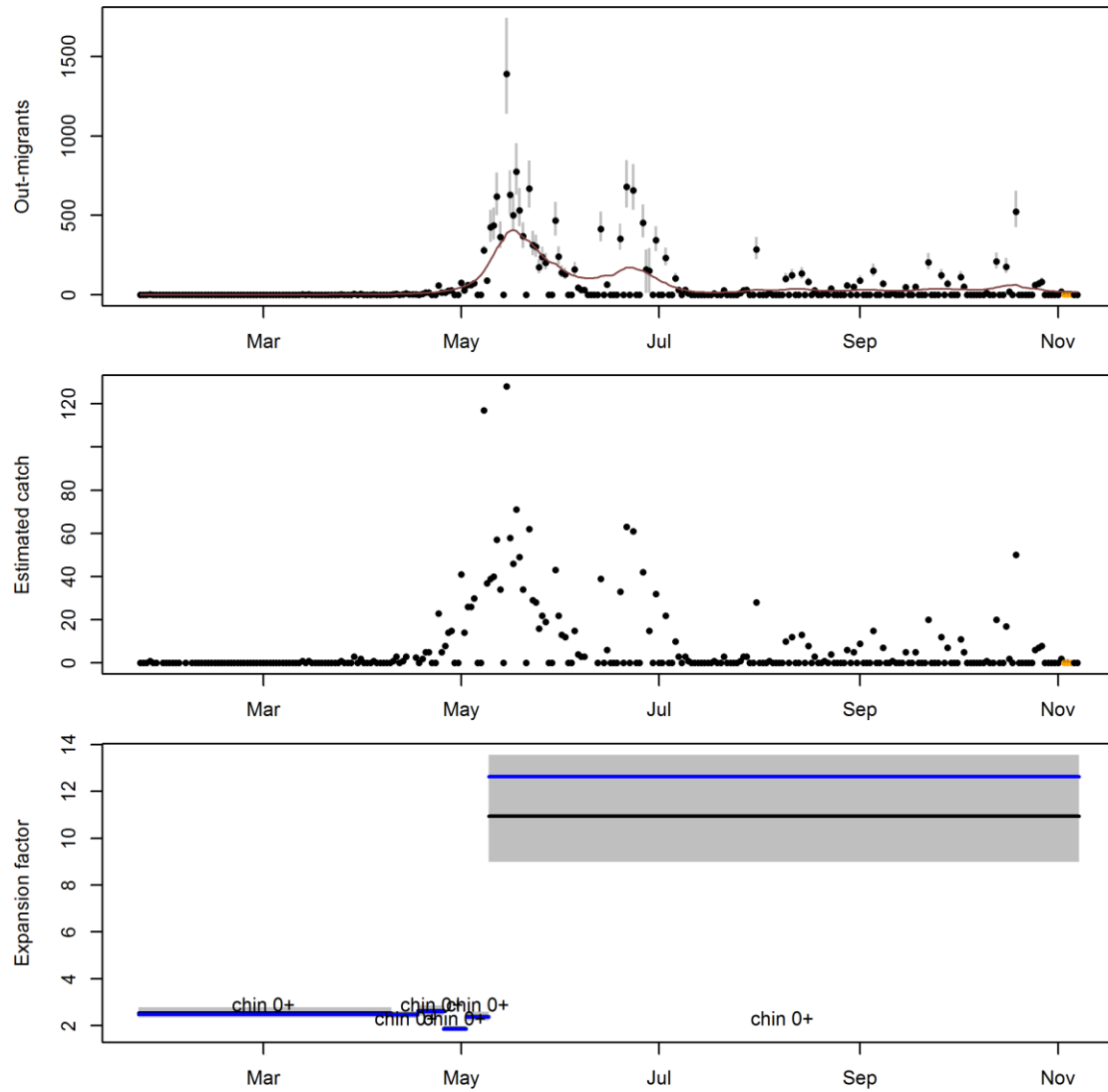




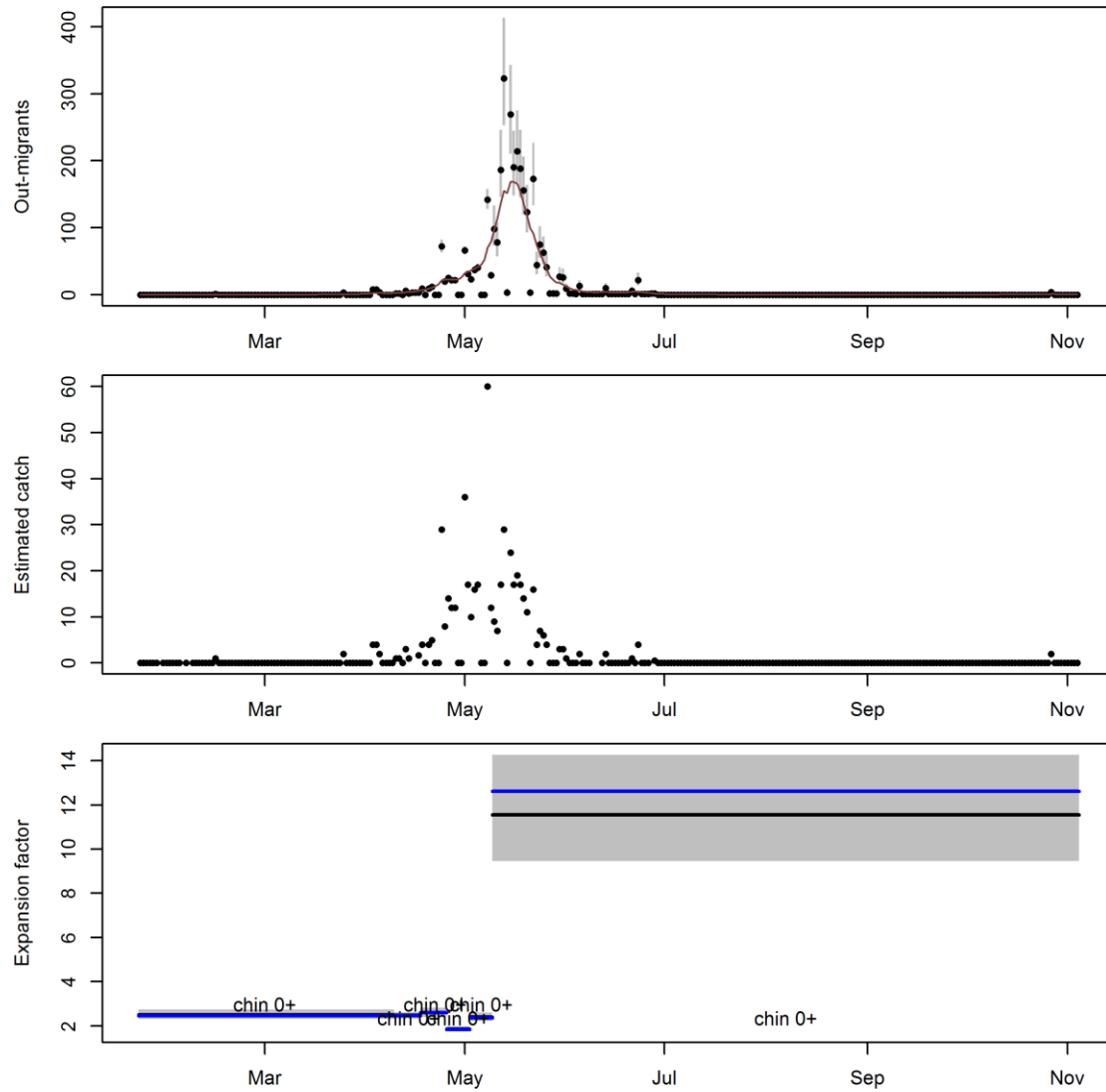
Indian-2017-coho.0plus est = 22,104 (15,603 - 38,028)



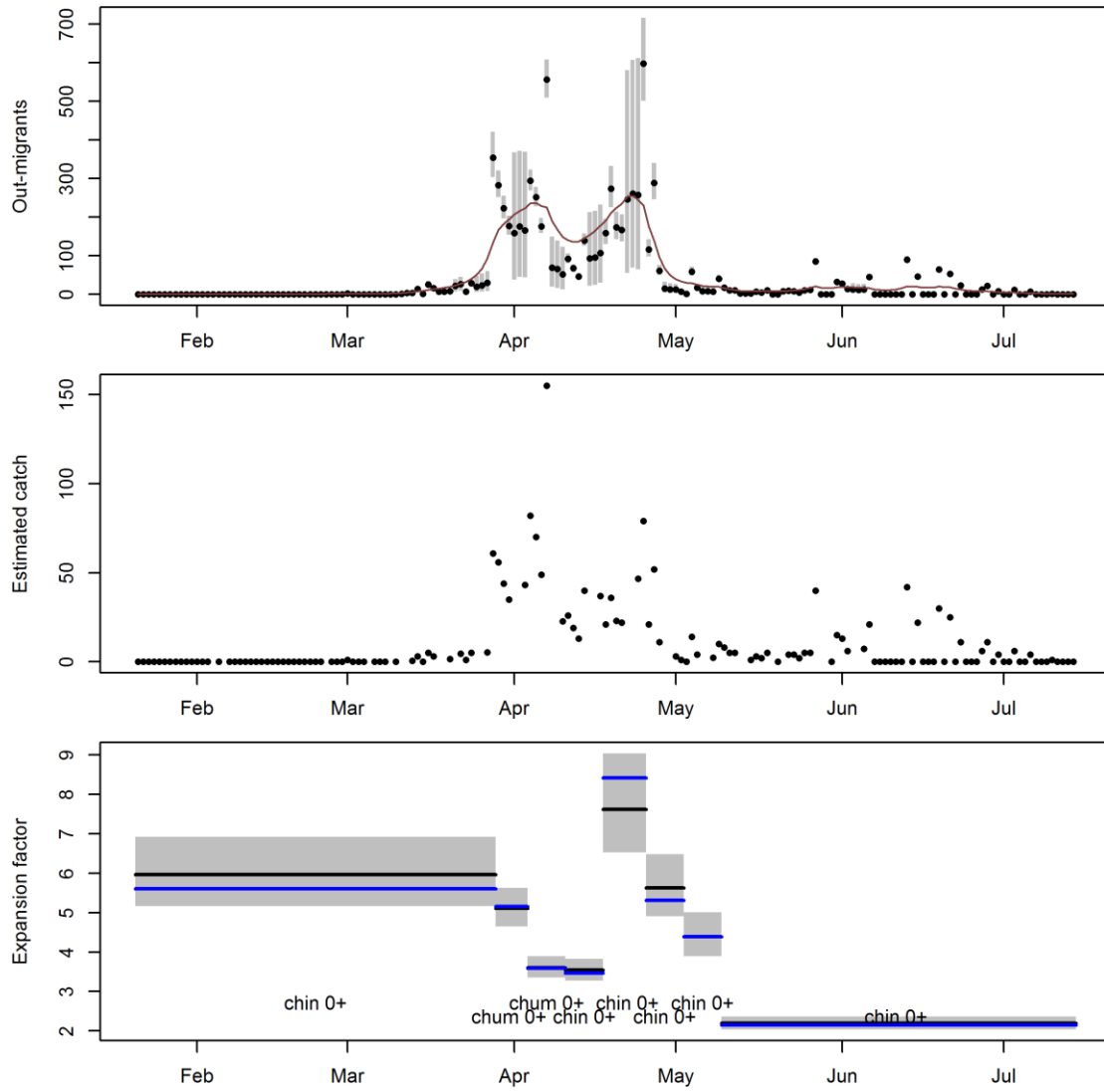
Indian-2017-coho.1plus est = 17,428 (10,597 - 32,214)



Indian-2017-Steelhead.smolts est = 3,162 (2,074 - 5,792)



Little-2017-coho.0plus est = 8,250 (7,076 - 10,105)



Little-2017-coho.1plus est = 95 (64 - 139)

