

2025 Elwha River Smolt Enumeration Project Report



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Executive Summary

Smolt enumeration was conducted on the Elwha River during the 2025 outmigration season. This represents the 11th year of monitoring during the post-dam removal period, and the 19th consecutive year of smolt monitoring on the Elwha River. We fished two mainstem traps in 2025, one was fished upstream of hatcheries and directed at estimating Chinook subyearling (0+) outmigrants. A second trap was fished in the lower river targeting Coho salmon, Steelhead and Chum salmon smolts. At the upper trap we fished 95% of possible days. We generated watershed production estimates, 95% Confidence Intervals (CI), and coefficient of variation (CV) estimates for Chinook (0+), Coho (0+), and Chum salmon. Because of catchability issues we did not generate estimates for any large-bodied smolts from this site in 2025, however those estimates were made at the lower river trap. We estimate a total of 480,744 (176,291-1,062,659) Chinook salmon subyearling outmigrants for the Elwha River in 2025. This represents the fifth highest number of Chinook salmon out-migrants (0+) to date. Chinook salmon productivity, expressed as the number of smolts/female, was also the fifth highest observed to date at 323 smolts/female. Estimated egg to subyearling survival for Chinook salmon has steadily improved over the life of the project and averaged 9.6% in 2025, the third highest recorded. The lower mainstem trap fished 73% of the potential days and we generated estimates of 38,667 (19,797-68,345) Coho smolts and 21,610 (14,355-31,272) Steelhead. The Coho estimate was the 4th highest number of out-migrants since dam removal was initiated. The Steelhead estimate is the second highest recorded over the life of the project.

At the tributary sites, we fished 99% and 100% of potential fishing days at Indian Creek and Little River, respectively. For Indian Creek and Little River, we estimated Coho salmon (age 0+ and smolts), Chinook salmon subyearlings, and Steelhead out-migrants. At Indian Creek, we estimated 163,057 (98,446-254,655) Chinook subyearlings salmon in 2025. We estimated 17,083 (13,232-21,705) Coho salmon smolts, 35,003 (20,203-56,598) Coho salmon 0+, and 2,755 (788-7,048) Steelhead. Based on 14 years of continuous trapping at Indian Creek, there is no empirical evidence that an anadromous sockeye life history has expressed from the kokanee population in Lake Sutherland or by natural reoccupation. For Little River, we estimated a total outmigration of 8,202 (4,871-12,976) Chinook subyearlings. Coho salmon smolts were estimated at 3,071 (1,575-5,423) out-migrants, while Coho salmon 0+ were estimated at 13,642 (6,280-25,989). Steelhead smolts were not estimated as only 15 were captured in 2025. Pacific lamprey populations also continue to expand throughout the watershed as thousands of juveniles (ammocoetes) and out-migrating macrophthalmia were captured at all sites in 2025.

Introduction

Removal of two mainstem hydroelectric dams on the Elwha River was completed in 2014. This action was authorized by the Elwha River Ecosystem and Fisheries Restoration Act of 1994 (PL 102-495) and represents the second largest dam removals conducted 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 scientists in assessing 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 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). EMAM (and closely related biological opinion for Elwha hatchery operations¹) provides quantitative performance targets that can be used to influence management actions necessary to achieve recovery of the populations. EMAM uses performance indicators coupled with management triggers to guide project managers through the recovery process. 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 metrics were chosen because they are predictors of extinction, reflect general processes important to salmon, and are measurable. Fundamental questions regarding the recovery and trajectory of Elwha salmon populations can in part be addressed through smolt enumeration. These include not only abundance and productivity trends, but life history traits such as the timing and size.

The Lower Elwha Klallam Tribe (LEKT) established a smolt enumeration program on the Elwha River beginning in 2006 using methods described in Volkhardt et al. 2007. The 2025 trapping season represents the nineteenth year of mainstem Elwha monitoring. Three discrete periods of monitoring are relevant in relation to dam removals on the Elwha: 1) pre-project (2006-2012), 2) dam-removal and peak sediment transport (2013-2018), and 3) post-project (2019-present). The post-dam removal period is a significant project benchmark and metrics associated with smolt outmigration are important for assessing rates of recovery for Pacific

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salmon. The objectives of this document are to provide abundance and timing for natural origin salmon and report on the ecological significance of those changes.

Methods

In 2025, LEKT commenced trapping operations in the upper mainstem on January 15 and ceased efforts on June 30 and we fished for 95% of the possible fishing days (Figure 1). The lower mainstem trap was deployed on February 5 and was fished until July 8. The lower trap fished 73% of possible days and was not fished during the primary hatchery release periods in April and June. At Indian Creek, trapping commenced on December 17 and ceased operations on July 8, with a total of 99% of the potential fishing days (Figure 2). At Little River, trapping was initiated on February 21 and was concluded on July 8 with a total of 100% of the possible fishing days (Figure 2). Tarp fishing summaries are depicted for all sites in Figure 3.

To evaluate catch efficiency (proportion of total outmigrants captured), we conducted a total of 39 mark-recapture tests at all four trap sites using both small and large-bodied smolts in 2025. We used caudal clips in tandem with bio stains Bismarck Brown Y and Neutral Red for trap efficiency tests (Arnold 1966). Rotating combinations of immersion stains and caudal clips were used to distinguish between test release locations and dates. Upstream test recaptures caught in downstream traps were recorded separately from downstream test recaps and not used in the calculation of reported efficiency percent. For each test we marked a group of natural origin fish, released them upstream of the trap and then counted the number of marked fish recaptured in the trap. Fish were marked using bio stains or fin clips, then held at the release site for at least 24 hours to recover prior to release. Each marked sample group represented the natural species migrating at any given time (i.e. Chinook subyearlings, Coho salmon smolts, and Steelhead smolts), and tests occurred weekly during outmigration periods. Trap efficiency tests for all sites are summarized in Tables 1 & 2 and Figure 5.

On the tributaries, fish were marked and released approximately 100 m upstream of the trap sites. A total of 17 and 10 recapture trials were completed for Indian Creek and Little River, respectively. Recapture rates for small-bodied fish averaged 14.8 and 10.9% at Indian Creek and Little River, respectively. For large-bodied fish, recapture rates averaged 20.4% and 11.2% for Indian Creek and Little River, respectively. In general, the tributary sites had higher mean recapture rates in comparison to the mainstem sites.

We conducted a total of 14 efficiency tests at the mainstem traps. Fish were marked and released approximately 500 m upstream of the upper mainstem trap, and 1500 m upstream of the lower mainstem trap. For the upper mainstem, we conducted 4 separate trials between late January and mid-April using releases of 222-296 small-bodied smolts (Chinook subyearlings). The average recapture rate was 1.08% (range 0.45-1.77%). At the lower trap we

conducted 10 mark-recapture trials using 15-151 large-bodied smolts (Coho/Steelhead) and the recapture rate averaged 12.7% (range 4.0-30.0). For all sites, fish were typically recaptured within 1-4 days.

Data Analysis

The daily catch data along with efficiency trials were used to estimate total numbers of fish migrating past the traps for the season. We calculated estimates for all fish/trap combinations where 10 or more fish were captured. In 2025 there were some issues with the efficiency data that motivated a different estimation procedure. We used a state space model implemented in the R package RTMB. This allows for large gaps in the efficiency and catch data, while propagating the necessary uncertainty (Appendix C). We summarize the results with the estimate and 95% confidence interval for total passage. We also include the geometric coefficient of variation (which is more appropriate for skewed distributions).

For Chinook subyearling outmigrants, we first estimated the number of outmigrants to the individual trap sites. Because the tributary traps are located upstream of the confluence with the Elwha River and the mainstem traps are upstream of the mouth of the Elwha River where it flows into the Strait of Juan de Fuca, we expanded the estimates to include Chinook salmon production downstream of the traps. To do so we assessed the geospatial distribution of redds on the Elwha River collected during 2024 Chinook peak spawning ground surveys (McHenry et al. 2024). At each trap site the number of redds distributed upstream of each trap site was divided by the estimated number of outmigrants collected in 2024 to generate an average number of smolts produced per redd. To account for redds produced downstream of each trap site we multiplied the number of redds counted in 2024 downstream of each trap by the average number of smolts produced per redd. This product was added to the estimate at the trap.

We calculated the number of smolts/female Chinook by dividing the smolt estimate by the number of females from the outmigration brood year. We used the SONAR estimates generated by Denton et al. (2024) for total in river escapement, subtracting the number of fish taken for broodstock by the WDFW hatchery. This number is multiplied by the sex ratio of sampled carcasses from the carcass sampling program (Weinheimer et al. 2021).

$$\text{Smolt/female} = \# \text{ 2025 Chinook Outmigrants} / (\text{2024 Sonar Adult Estimates} - \text{Hatchery Broodstock Removed}) * \text{proportion of females}$$

To generate Chinook salmon egg to outmigrant survival, we divided the outmigration estimate by the product of the total number of redds observed during peak Chinook surveys (McHenry et al. 2024) multiplied by the average fecundity of females (5,800 eggs) used in the broodstock program (Weinheimer et al. 2018; WDFW Unpublished Data).

$$\text{Egg to Outmigrant Survival} = \frac{2025 \text{ Outmigration Estimate}}{2024 \text{ Redd Count}} * \text{Average Female Fecundity}$$

Results

During the 2024-2025 Chinook salmon incubation season only one minor peak flow of ~14,000 cubic feet/second (cfs) occurred with several smaller flood events (<5,000 cfs). Flow conditions were mostly benign during the 2025 trapping season and fishing was nearly continuous at the upper trap (Figure 4). Releases of hatchery fish resulted in lost fishing time at the lower site and that trap fished 73% of the total days.

In 2025, Chinook subyearling salmon were the most numerous species captured in the mainstem trap with a total of 4,247 captured. We estimated a total Chinook subyearling salmon smolt outmigration of 430,840 (157,991-952,348) to the trap. Using the number of Chinook salmon redds (777) counted upstream of the trap in 2024, we calculated that each redd produced an average of 491 smolts. To account for the number of Chinook salmon redds constructed below the trap (90) we used the average Chinook salmon smolts/redd value multiplied by the number of redds below the trap to account for an additional 49,295 Chinook subyearling salmon. Therefore, the total Chinook subyearling salmon estimate for the Elwha River in 2025 is 480,744 (176,291-1,062,659) (Table 3). Chum salmon out-migrants were estimated at 22,335 (6,192-58,132) and 26,675 (6,090-76,885) at the upper and lower mainstem traps, respectively (Table 4).

We fished the lower mainstem trap to estimate large-bodied Coho salmon and Steelhead smolt abundance as well as Chum salmon. The trap again proved successful at capturing large-bodied smolts including 3,466 Coho salmon and 2,284 Steelhead and fishing 89% of the possible days due to intermittent hatchery releases precluding sampling in April and June. Based on these catches we generated estimates of 38,667 (19,797-68,345) Coho salmon smolts and 21,610 (14,355-31,272) Steelhead smolts (Table 4). A Chum salmon estimate of 26,675 (6,090-76,885) was generated which is likely an underestimation from the number of lost fishing days due to hatchery releases overlapping with peak outmigration at the lower trap.

We estimated adult and juvenile Chinook salmon abundance and productivity in the Elwha River, Indian Creek and Little River over the period of record using outmigration estimates along with annual redd counts (2005-2023) and SONAR escapement estimates (2011-2023). For the mainstem site, the production of Chinook subyearling salmon averaged 50,400 during the pre-dam removal (2005-2012) period. During dam removal period (2013-2018) the number of subyearling Chinook salmon out-migrants was almost identical and averaged 50,477. During the post-dam removal period (2019-2025) natural Chinook salmon estimates increased

dramatically and averaged 518,336. The 2025 estimate is the fifth highest on record and all five have occurred in the post-dam removal period (Table 5).

We assessed Chinook salmon productivity by calculating the number of smolts produced per female over the period of record (2005-2025). In general, the productivity of Elwha Chinook salmon has exhibited two trends over period of record: low or declining levels prior to and during dam removal followed by increasing productivity as channel conditions stabilized following dam removal. During the pre-dam removal period (2005-2012), productivity averaged 118 (range 44-295²) smolts/female. During dam removal Chinook salmon smolts/female further declined and averaged 51 (13-113) smolts/female. During the post-dam removal period Chinook salmon productivity increased dramatically to 317 (108-511) smolts/female. The 2025 outmigration year was the fifth highest on record at 323 smolts/female. The four-year geometric mean for the period from 2021-2025 was 281 smolts/female. Trends in Chinook salmon sub-yearling productivity over time are summarized in Figure 6.

The Indian Creek and Little River traps were fished nearly continuously in 2025. We generated an estimate of 163,057 (98,446-254,655) for Chinook subyearlings, 35,003 (20,203-56,598) Coho 0+, 17,083 (13,232-21,705) Coho salmon smolts, 3,262 (1,603-5,937) Chum salmon, and 2,755 (788-7,048) Steelhead smolts at Indian Creek (Table 6). In Little River, estimates were generated for Chinook subyearlings, Coho salmon 0+ and Coho salmon smolts (Table 7). The Chinook subyearling estimate of 8,202 (4,871-12,976) was low reflecting the relatively low number of redds above the trap (22) in 2024. For Coho salmon we estimated a total of 3,071 (1,575-5,423) smolts and 13,642 (6,280-25,989) 0+ outmigrants. For estimates we plotted daily estimated abundance, catch and efficiency, along with observed catch and efficiency trial data (Appendix A & B).

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 (*Salvelinus confluentus*), Brook trout (*Salvelinus fontinalis*), plus all non-salmonids (Table 8). 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 *O. mykiss* 0+, 1+ and 2+ age classes that were captured at Indian Creek and Little River in 2025. The number of cutthroat encounters is significantly higher in Indian Creek. Two cutthroat smolts were captured at Indian Creek and none in Little River. Two Bull trout were captured in Little River and 4 were encountered at Indian Creek. Four non-native brook trout were captured at the trap and were removed from the system.

² 295 smolts per female appears to be an outlier for the pre-dam removal period. If this value is removed the pre-dam removal average is 69.

For non-salmonids we report two results: 1) the continued expansion of Pacific lamprey (*Entosphenus tridentatus*) in the Elwha River, and 2) the rapid increase in sculpin populations encountered at the mainstem trap. In 2025, total Pacific lamprey captures declined slightly for the first time since the project began (Figure 7). At Little River we caught 426 juvenile lamprey, the highest to date. For sculpin, the number of encounters at the mainstem were generally less than 700/year (19-700). During the pre-dam removal period that number dropped precipitously (16-17). During dam removal period but has averaged between a hundred to over two thousand since 2016 (range 116-2031) (Figure 8). In 2024 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 in Indian Creek. Prickly sculpin at Indian Creek are exceptionally large, likely due to the high availability of food sources within the watershed.

Discussion

The outmigration estimates for Elwha Chinook subyearling smolts in 2025 was 480,744, which represents the fifth highest outmigration over the period of record. The 2025 outmigration estimate is on the high end as compared to the annual estimates from other Puget Sound rivers. For example, the Dungeness and Nisqually Rivers averaged 58,205 and 146,641 naturally produced Chinook subyearling smolts respectively for the period from 1999-2018 (Weinheimer et al. 2022; Klungle et al. 2017; Unpublished Data, WDFW). In contrast, the Skagit River, the largest Chinook salmon river in Puget Sound (8.4 times as large as the Elwha), has averaged 3,455,290 Chinook sub-yearling smolts for the period 1993-2018 (Zimmermann et al. 2015; Unpublished data, WDFW).

Juvenile Chinook salmon productivity as expressed as the number of smolts produced per female has increased on the Elwha following dam removal and the stabilization of channel spawning habitat over time (Figure 6). The pre-project, dam removal and post-project averages are 118, 51, and 317 smolts/female (Table 5). Additionally, the four-year geometric mean productivity for the period from 2021-2025 is 281 smolts/female. The low productivity values prior to dam removal are explained by the combination of low numbers of natural spawners, limited habitat area for spawning, and degraded spawning habitat conditions (sediment starvation). Before dam removal, the river had incised and its bed coarsened to the point there were only a handful of areas where Chinook salmon could construct nests (Pess et al. 2008). Additionally, low numbers of returning Chinook salmon adults resulted in most fish being cycled into the hatchery program as brood stock. 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 through at least the

2017 brood year. 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 2025 Chinook salmon estimate, while similar to the two previous years, is still approximately nine times the pre-project average (Table 5). In 2024, adult Chinook salmon escapement to the Elwha River was moderate (4,156 adults) and a total of 867 redds were enumerated during spawning ground surveys (McHenry et al. 2024). Those eggs were subjected to a benign flow year with the largest flood a ~14,500 cfs event during the incubation period (Figure 5). It was previously hypothesized that egg-to-emergence survival of Chinook salmon that spawned during the dam removal period was low because of unstable streambed incubation conditions due to the high sediment supply associated with dam removal. This was corroborated by low Chinook salmon production through the 2018 trapping season along with the highest egg to outmigrant survival rates recorded between 2019-2025 (Figure 8). A negative correlation between peak flows and Chinook salmon survival has been reported in Puget Sound (Pess et al. 2024; Greene et al. 2005; Waples et al. 2008). Unstable bed conditions, particularly in the areas affected by peak sediment transport (downstream of former Glines Canyon dam) during dam removal has also likely limited the survival of incubating embryos on the Elwha River to date (Pess et al. 2024). The index of flow and suspended sediment concentrations are negatively correlated with Chinook survival (McHenry et al. 2019, Pess 2024). During the 2024 incubation period there were 11 “bedload” moving flow events (Ritchie et al. 2018) of greater than 2,000 cfs, one of which was greater than 10,000 cfs.

Based on estimates of adult Chinook abundance obtained by SONAR (Denton et al. 2024) combined with an average fecundity of 5,800 eggs/female (WDFW, Unpublished Data) we estimated the survival of Chinook salmon eggs to the outmigrant stage over time (Figure 8). In 2025 the survival of Chinook salmon eggs to the outmigrant stage was 9.5%; the third highest over the project. This metric has generally tracked the recovery of the river from dam removal (Figure 9). The pre-project (2005-2012) average was 2.9%. During dam removal (2013-2018) the average declined to 1.2%, likely from impacts during peak sediment transport. During the post-project period (2019-2025) the survival of Chinook outmigrants increased to an average of 8.7%, and the 4-Year geometric mean (2012-2024) has averaged 8.2%.

The large number of Chinook salmon subyearling out-migrants produced between 2019-2025, while encouraging, will need high survival rates to produce significant numbers of adult Natural Origin Recruits (NOR). Based on weekly samples of fish length and weights measured at the mainstem trap (2015-2024), most out-migrating Chinook salmon were small (<45 mm) (Figure 9). For Puget Sound Chinook salmon, size at outmigration may be related to survival to adulthood. Using otolith analysis, Campbell & Claiborne (2017) have shown that small

outmigrants exhibit different degrees of survival to adults. The authors found that small Chinook salmon outmigrants contributed up to 35% of returning adults in northern Puget Sound watersheds (Skagit, Nooksack). In contrast, southern Puget Sound watersheds (Cedar, Green, Puyallup) small Chinook salmon contributed to <5% of the returning adults. These differences were attributed to estuary conditions that are mostly intact in northern Puget Sound and severely degraded in South Puget Sound (with exception of Nisqually). While dam removal on the Elwha has resulted in a temporarily expanded estuary, it appears that feature is being eroded over time as sediment supply balances with high energy nearshore environments.

The estimated number of Chinook subyearling salmon produced from Indian Creek (163,057) was significant. Indian Creek had moderate numbers of Chinook spawners in the 2024 brood year with 71 redds counted. Because Chinook spawning ground surveys are conducted only in the lower 1.5 miles of the system, it is probable that redds are undercounted, which would overestimate productivity and bias expansion made for production below the trap. In contrast, Little River produced an estimated 8,202 Chinook out-migrants based on a redd count of 24 in the 2024 brood year. Little River has had five of twelve years where few or no Chinook salmon entered the system. This is due to the combination of low attraction flows and that the thalweg of the mainstem was located on the west side of the valley (opposite of the mouth of Little River) in those years. Based on redd counts, along with an estimation of out-migrating Chinook salmon smolts, the overall productivity of the two tributaries is very high (Figure 10) as compared to the mainstem. We hypothesize that this is because the tributaries are much more resistant to scour impacts than the mainstem Elwha River. Over the life of the project the number of smolts/female has averaged 2,472 and 1,480 for Indian Creek and Little River respectively.

We compared the total outmigration estimates between tributaries and found some noticeable differences in abundance and timing over time (Appendix A & B). In past seasons, large numbers of Coho 0+ salmon parr outmigrants were detected moving downstream through PIT antenna arrays in Little River and to lesser extent Indian Creek, presumably to rear in other habitats or emigrating to the Strait of Juan of de Fuca as parr (Liermann et al. 2017). Coho parr emigration during the fall has been documented in other nearby Strait of Juan de Fuca watersheds and has been shown to result in survival to adulthood (Bennett et al. 2014). In 2025 we estimated the total outmigration of Coho 0+ salmon at 35,003 and 8,202 for Indian Creek and Little River, respectively. Indian Creek produced an estimated 17,083 Coho salmon smolts, which is the fourth highest since monitoring began. For Little River we estimated a total of 3,071 Coho smolt outmigrants, the highest over the period of record.

Steelhead smolt production in the Elwha River has generally increased since the LEKT was able to generate its first production estimates in the mid to later 2010's. Prior to 2015 (and

2020-2021) we encountered so few Steelhead smolts (less than 50/year) that we were unable to generate a valid estimate at the upper mainstem trap. In 2025 we captured 2,284 Steelhead smolts at the lower trap generating an outmigration estimate of 21,610. Steelhead smolts are also capable of avoiding capture in some screw traps and even if caught can escape by swimming out of the holding box. Other Puget Sound smolt trapping programs also struggle with Steelhead estimation in some years (Personal Communication, Joe Anderson, WDFW). In 2021 LEKT conducted trap efficiency testing using Steelhead smolts on the upper mainstem. We conducted three separate trials using a total of 882 Bismarck brown Steelhead smolts and only recaptured three individuals (0.34%). As a result, LEKT added an additional screw trap in the lower river beginning in 2022 to target larger bodied smolts.

Production of Steelhead smolts from Indian Creek had been generally increasing over time, from 85 in 2013 to 7,773 (5,880-7,754) in 2021 (Figure 11). Little River Steelhead smolt numbers have been consistently low over the period of record (1-799) and 100 were estimated in the 2025 outmigration. This has been despite the moderate number of Steelhead redds that are observed in annual redd surveys (McHenry et al. 2024). Like Coho parr, large numbers of juvenile *O. mykiss* out-migrate as parr in the fall when the screw trap is not operating in Little River (Unpublished data, LEKT). The ultimate location of these outmigration's is unknown. We have documented this movement since 2012 through the PIT antenna array near the mouth of Little River.

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) well before Steelhead colonized these habitats following dam removal in 2013. These outmigrants were likely the progeny of resident rainbow trout populations that had retained anadromous life histories. This strategy has been previously documented in the Elwha during downstream fish passage studies in the late 1980's (Hiss & Wunderlich 1994) and in a previous genetic analysis of Elwha wild Steelhead (Winans et al. 2017) from 2013-2015. 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.

Coho salmon smolt production in the Elwha River has varied over time since dam removal and estimates have been affected by inconsistent catch rates at the upper mainstem site. Estimates from the lower trap site appear viable, but are likely minimums given the often-high number of lost days due to hatchery releases. The mainstem Coho smolt numbers increased dramatically in 2019 (69,874), but declined to 8,470 in 2020, and 6,082 in 2021. Estimates increased in 2022 to 45,270. These reductions may be partially attributed to very weak adult Cohorts in 2018 and 2019 and the historically inconsistent catch rates at the upper

trap of outmigrants due to trap avoidance. The 2024, the Coho smolt estimate from the lower trap was 21,993 and was like the 2023 estimate of 23,995. In 2025 we estimated a total Coho smolt outmigration of 38,667.

Indian Creek has consistently produced larger numbers of Coho smolt outmigrants relative to Little River over the period of monitoring (Figure 11). The larger numbers of Coho smolt outmigrants from Indian Creek are likely due to the amount and quality of habitat within the basin as previously discussed. Indian Creek also includes Lake Sutherland, a mesotrophic lake, at the headwaters of the system. Coho salmon adults were first documented spawning in Falls Creek (Sutherland tributary) in 2018. Outmigrant trapping in Sutherland's outlet in 2018-2021 has determined that Sutherland is producing Coho smolts that on average are very large in size, including those that are up to 320 mm in length. Those trapping operations were discontinued in 2023.

The total number of Chum salmon out-migrants has been low since dam removal. The population entered dam removal at low levels, had minimal hatchery support, and were negatively impacted during peak sediment transport. The 2025 Elwha Chum salmon estimate (22,335) was well below the pre-dam removal average of 141,802 (2006-2012). In contrast, the Elwha Pink salmon population has shown positive signals beginning in brood year 2021. Prior to this, the abundance trend had been a steady decline (Figure 12). Prior to 2021, neither Indian Creek nor Little River had been colonized by significant numbers of returning adult Chum or Pink salmon. However, in 2025, record numbers of Pink salmon adults were observed spawning in the tributaries as well as mainstem sites. Denton et al. (2026) estimated an escapement of ~35,000 Pink salmon adults to the Elwha River in 2025. Chum and Pink salmon are thought to be critical to the overall Elwha salmon recovery primarily for their contribution of marine derived nutrients to the river. The empirical evidence suggests that these populations, already at very low abundance prior to dam removal, were further impacted by dam removal and the transport of millions of tons of sediment stored behind the dams. Historically abundant, Pink and Chum salmon likely returned large amounts of marine derived nutrients to the Elwha River. Those nutrients contributed to aquatic food webs that support wildlife and other Pacific salmon of the Elwha.

Smolt trapping operations have documented several ecologically significant events that suggest the "reawakening" of anadromy or natural reoccupation events and the successful results of hatchery programs and relocation efforts. Those include the rapid recovery of Steelhead and Coho salmon in the tributaries, the first large outmigration of naturally produced Chinook salmon, the natural reoccupation of Indian Creek by Pacific Lamprey, the early signs of Pink salmon recovery and the continued presence of eulachon in the lower river. However, other species including Chum and sockeye salmon show little or no signal of recovery to date.

The Elwha Fisheries Recovery Plan (Ward et al. 2008) indicates that natural recovery is the preferred means of rebuilding sockeye populations. Because Elwha sockeye salmon were 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 low. Most appear to be riverine spawners and the analysis of 45 adult sockeye from the Elwha River collected since dam removal found that none were of local origin (Lake Sutherland kokanee), and only one was from the proximal Fraser River. Roughly half were strays from the West Coast Vancouver Island and the other half were from northern regions including the Stikine River, British Columbia, and Alaska (Quinn et al. 2021).

Based on eleven consecutive years of smolt trapping on Indian Creek, there is no evidence that Sutherland kokanee population is producing sockeye smolts. This mechanism has been previously documented in the Coquitlam and Allouette Rivers in British Columbia where Sockeye salmon were extirpated by dams constructed in the early twentieth century and anadromous life history recovered following fish passage improvements (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 has 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.

Natural recovery is successfully occurring for Pacific Lamprey in Indian Creek and Little River, where adults were first documented in 2013 and subsequently again in later years at the smolt trap (Hess et al. 2021). These adults were the early colonizers to Indian Creek. Ammocoetes (juveniles) were first encountered at Indian Creek in 2013, one year following the initial reoccupation event by adults in 2012. Pacific lamprey appear to be expanding rapidly in Indian Creek (Figure 7). 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 3,914 were captured, and in 2020 1,954 were captured. In 2021 we had a raw catch of 3,919 ammocoetes, a new record. The 2022 total was 3,716. In 2023 the total was 3,534. We expected that downstream migrating macrophthalmia from Pacific Lamprey would eventually be encountered at Indian Creek, because of their prolonged freshwater residency estimated at 5-6 years (Scott & Crossman 1973). Between 2016-2025 we encountered a total of 71, 600, 649, 546, 441, 675, 654, 1,160, 1976 and 789 Pacific Lamprey macrophthalmia. We report that Pacific lamprey

continues the early reoccupation of Little River with the first captures of 44, 34, 400, 58, 97 and 283 juveniles during trapping operations in 2020-2025 and the first recorded catch of macrophthalmia (143) in 2025.

We assessed trap efficiency by site for all sites over time for small and large bodied trials (Figure 13). In general, the tributary sites have a much higher recapture rate of marked fish (both small and large bodied) than mainstem sites. This is likely because of the larger cross-sectional area being sampled in the tributaries versus the mainstem sites. For the mainstem sites it is apparent that catch efficiency has increased for large bodied smolts at the lower mainstem site, while conversely trap efficiency has dropped for small bodied smolts at the upper mainstem site. This likely directly related to changes in river morphology and flow between the sites. The upper site is shallow with very slow river velocities, while the lower site contains deeper higher velocity conditions. The later has lead to increased catches of large bodied smolts and better abundance estimates for those species.

Acknowledgements

We are indebted to the technicians and biologists of the Lower Elwha Klallam Tribe operating the traps through difficult conditions. Those personnel include Ernest Sampson, Kim Williams, mckenzi Taylor, Wilson Wells, Raymond Moses, Allyce Miller, Vanessa Castle, Gabe Ritchie and Justin Stapleton. Washington Department of Fish and Wildlife have provided hatchery juvenile Chinook for trap testing. Keith Denton provided technical review of the report.

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Tables

Table 1. Results of 0+ mark-recapture efficiency trials for Upper Mainstem, Indian Creek and Little River traps for the 2025 smolt outmigration season. Some trials represent the aggregation of multiple smaller tests.

Site	Date	Species	Age	Number	Recaptures	Percentage
Mainstem	Jan 23	Chinook	0+	296	2	0.68
Mainstem	Jan 28	Chinook	0+	222	1	0.45
Mainstem	Mar 12	Chinook	0+	279	4	1.43
Mainstem	Mar 18	Chinook	0+	283	5	1.77
Mainstem average						1.08
Indian	Jan 14	Chinook	0+	230	15	6.52
Indian	Jan 21	Chinook	0+	305	78	25.57
Indian	Jan 28	Chinook	0+	493	91	18.46
Indian	Feb 2	Chinook	0+	500	26	5.20
Indian	Feb 12	Chinook	0+	313	40	12.78
Indian	Feb 26	Chinook	0+	300	5	1.67
Indian	Mar 5	Chinook	0+	223	53	23.77
Indian	Mar 5	Chinook	0+	223	51	22.87
Indian	Apr 9	Chinook	0+	82	12	14.63
Indian	Apr 9	Chum	0+	47	8	17.02
Indian average						14.85
Little	Feb 26	Chinook	0+	175	33	18.86

Site	Date	Species	Age	Number	Recaptures	Percentage
Little	Mar 5	Chinook	0+	223	19	8.52
Little	Mar 5	Chinook	0+	223	16	7.17
Little	Mar 18	Chinook	0+	283	26	9.18
Little average						10.3

Table 2. Results of 1+ mark-recapture efficiency trials for Lower Mainstem, Indian Creek and Little River traps for the 2025 smolt outmigration season. Some trials represent the aggregation of multiple smaller tests.

Site	Date	Species	Age	Number	Recaptures	Percentage
Mainstem Lower	Apr 15	mykiss	smolt	34	5	14.71
Mainstem Lower	Apr 22	Coho	smolt	18	0	0.00
Mainstem Lower	Apr 22	mykiss	smolt	97	10	10.31
Mainstem Lower	Apr 30	Coho	smolt	15	3	20.00
Mainstem Lower	Apr 30	mykiss	smolt	20	6	30.00
Mainstem Lower	May 6	Coho	smolt	100	9	9.00
Mainstem Lower	May 7	mykiss	smolt	72	10	13.89
Mainstem Lower	May 14	Coho	smolt	151	19	12.58
Mainstem Lower	May 14	mykiss	smolt	71	4	5.63
Mainstem Lower	May 28	Coho	smolt	149	6	4.03
Mainstem Lower	May 28	mykiss	smolt	67	5	7.46
Mainstem Lower average						12.76
Indian	Apr 27	Coho	smolt	56	10	17.86
Indian	May 7	Coho	smolt	249	72	28.92
Indian	May 15	Coho	smolt	80	20	25.00
Indian	May 29	Coho	smolt	84	29	34.52
Indian	Jun 4	Coho	smolt	50	11	22.00
Indian	Apr 30	mykiss	smolt	102	4	3.92

Site	Date	Species	Age	Number	Recaptures	Percentage
Indian	May 15	mykiss	smolt	46	5	10.87
Indian average						20.44
Little	May 15	Coho	smolt	41	5	12.20
Little	May 29	Coho	smolt	84	8	9.52
Little	May 15	Coho	smolt	50	6	12.00
Little average						11.24

Table 3. Total catch, estimated outmigrants, 95% confidence interval (C.I.) and the geometric coefficient of variation (CV) for smolt outmigration from the mainstem Elwha River (Upper trap site), 2025 outmigration year. NE=Not Estimated.

Species	Catch	Estimated Outmigrants	95% C.I.	gCV
Chinook Salmon(0+)	4,247	480,744 ³	176,291 - 1,062,659	0.48
Chinook Salmon(1+)	8	NE	NE	NE
Coho Salmon(0+)	292	27,611	8,245 - 68,946	0.58
Coho Smolt	84	NE	NE	NE
Chum Salmon	162	22,335	6,192 - 58,132	0.62
Pink Salmon	1	NE	NE	NE
Steelhead	11	NE	NE	NE

³ Expanded estimate accounting for redds below trap.

Table 4. Total catch, estimated outmigrants, confidence interval (C.I.) and geometric coefficient of variation (CV) for smolt outmigration from the mainstem Elwha River (Lower trap site), 2025 outmigration year. NE=Not estimated.

Species	Catch	Estimated Outmigrants	95% C.I.	gCV
Chinook Salmon(0+)	3,667	NE	NE	NE
Chinook Salmon(1+)	8	NE	NE	NE
Coho Salmon(0+)	99	NE	NE	NE
Coho Smolt	3,466	38,667	19,797 - 68,345	0.32
Chum Salmon	1,359	26,675	6,090 - 76,885	0.72
Pink Salmon	37	NE	NE	NE
Steelhead	2,284	21,610	14,355 - 31,272	0.20

Table 5. Estimated number of Chinook salmon subyearling outmigrants and productivity (smolts/female) for the Elwha River, Indian Creek and Little River (2005-2025).

Year	Elwha 0+ Outmigrants	Elwha Smolts /Female	Indian 0+ Outmigrants	Indian Smolts /Female	Little 0+ Outmigrants	Little Smolts /Female
2005	106,348	109				
2006	44,256	113				
2007	16,228	50				
2008	18,352	103				
2009	14,533	66				
2010	125,772	295				
2011	11,808	44				
2012	65,901	165				
Pre-Project Average	50,400	118				
2013			118,109	1,845	38,601	
2014	93,981	113	35,822	607	10,628	443
2015	16,200	13	84,318	3,243	8	
2016	45,818	30	112,074	7,472	21,863	429
2017	73,152	60	3,024	108	3	
2018	23,236	40	3,916	112	5,205	578
Dam Removal Average	50,477	51	59,544	2,231	12,718	483
2019	571,817	350	236,523	1,643	125,585	1,993
2020	1,057,329	379	176,355	844	356,327	2,874
2021	292,418	236	95,170	1,286	21,963	3,138
2022	111,454	108	141,193	1,502	22,103	553
2023	507,766	312		6,457	15,215	
2024	606,823	511	373,126	4,723	29,742	2,974
2025	480,744	323	163,057	2,297	8,202	342
Post-Project Average	518,336	317	197,571	2,679	82,734	1,979
4YR GeoMean	414,946	281	170,522	2,203	29,371	1,384

Table 6. Total catch, estimated outmigrants, 95% confidence interval (C.I.) and Coefficient of Variation (CV) for smolt outmigration from Indian Creek, 2025 outmigration year. NE=Not estimated.

Species	Total Catch	Estimated Outmigrants	95% C.I.	CV
Chinook Salmon(0+)	14,375	163,057 ⁴	98,446 - 254,655	0.25
Chinook Salmon(1+)	5	NE	NE	NE
Coho Salmon(0+)	4,816	35,003	20,203 - 56,598	0.27
Coho Smolt	4,550	17,083	13,232 - 21,705	0.13
Pink Salmon(0+)	0	NE	NE	NE
Chum Salmon(0+)	437	3,262	1,603 - 5,937	0.34
Steelhead	169	2,755	788 - 7,048	0.61

⁴ Estimated number of smolts to trap.

Table 7. Total catch, estimated outmigrants, 95% confidence interval (C.I.) and geometric coefficient of variation (CV) for smolt outmigration from Little River, 2025 outmigration year. NE=Not estimated.

Species	Total Catch	Estimated Outmigrants	95% C.I.	gCV
Chinook Salmon(0+)	870	8,202 ⁵	4,871 - 12,976	0.25
Chinook Salmon(1+)	1	NE	NE	NE
Coho Salmon(0+)	1,389	13,642	6,280 - 25,989	0.37
Coho Smolts	336	3,071	1,575 - 5,423	0.32
Pink Salmon(0+)	0	NE	NE	NE
Chum Salmon(0+)	1	NE	NE	NE
Steelhead	15	NE	NE	NE

⁵ Expanded estimate accounting for redds below the trap.

Table 8. Total catch of miscellaneous fish encountered at Elwha River, Little River and Indian Creek smolt traps, 2025. For trout the first entry is Rainbow and the second is Cutthroat (*mykiss/clarkii*).

Site	0+ Trout	1+ Trout	2+ Trout	Bull Trout	Brook Trout	Cutthroat Trout (Smolts)	Cottids (P/CR) ⁶	Redside Shiner	Ammocoete	Macrophthalmia	Adult Pacific Lamprey
Elwha (Upper)	43/0	31/0	0/0	0	0	0	8/347	0	152	9	4
Elwha ⁷ (Lower)	22/0	342/5	11/0	13	0	15	331/140	7	283	143	4
Little	21/1	404/0	35/0	2	0	0	0/0	0	177	1	0
Indian	117/16	718/60	86/5	4	0	2	54/34	240	2665	789	0

⁶ Prickly/Coast Range Sculpins

⁷ Additional catch of 26 Eulachon

Figures

Figure 1. Top Elwha River 8' rotary screw trap fishing at Rkm 4.0 during the post-project period. Bottom 5' rotary screw trap fishing at Rkm 0.6. The traps fishing locations were reversed in 2024.



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



Figure 3. Elwha mainstem, Little River and Indian Creek smolt trap fishing effort for 2025. Line segments showing when the traps were fishing. Green=fishing and checked, Black=not fishing, Blue=fishing but not checked Gray=fished less than 12hrs. The segments under the bars represent a 4-day period from the beginning of the efficiency trials. Black bars represent trials with 0+ fish, and orange bars represent 1+ and 2+ trials. Dotted vertical lines represent the 1st of each month.

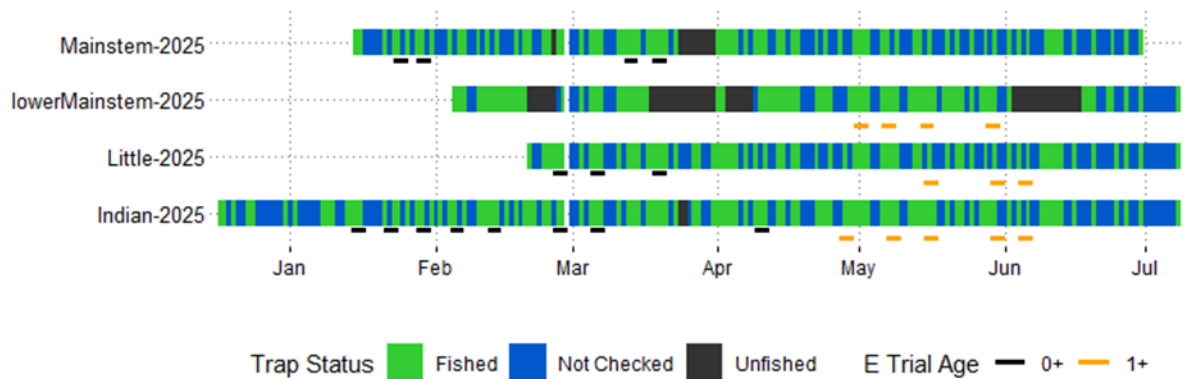


Figure 4. Elwha River flows (cfs) measured at the McDonald Gage Site, September 15, 2024 to February 1, 2025 (top-Chinook salmon incubation period) and January 5, 2025 to July 10, 2025 (bottom-smolt outmigration period).

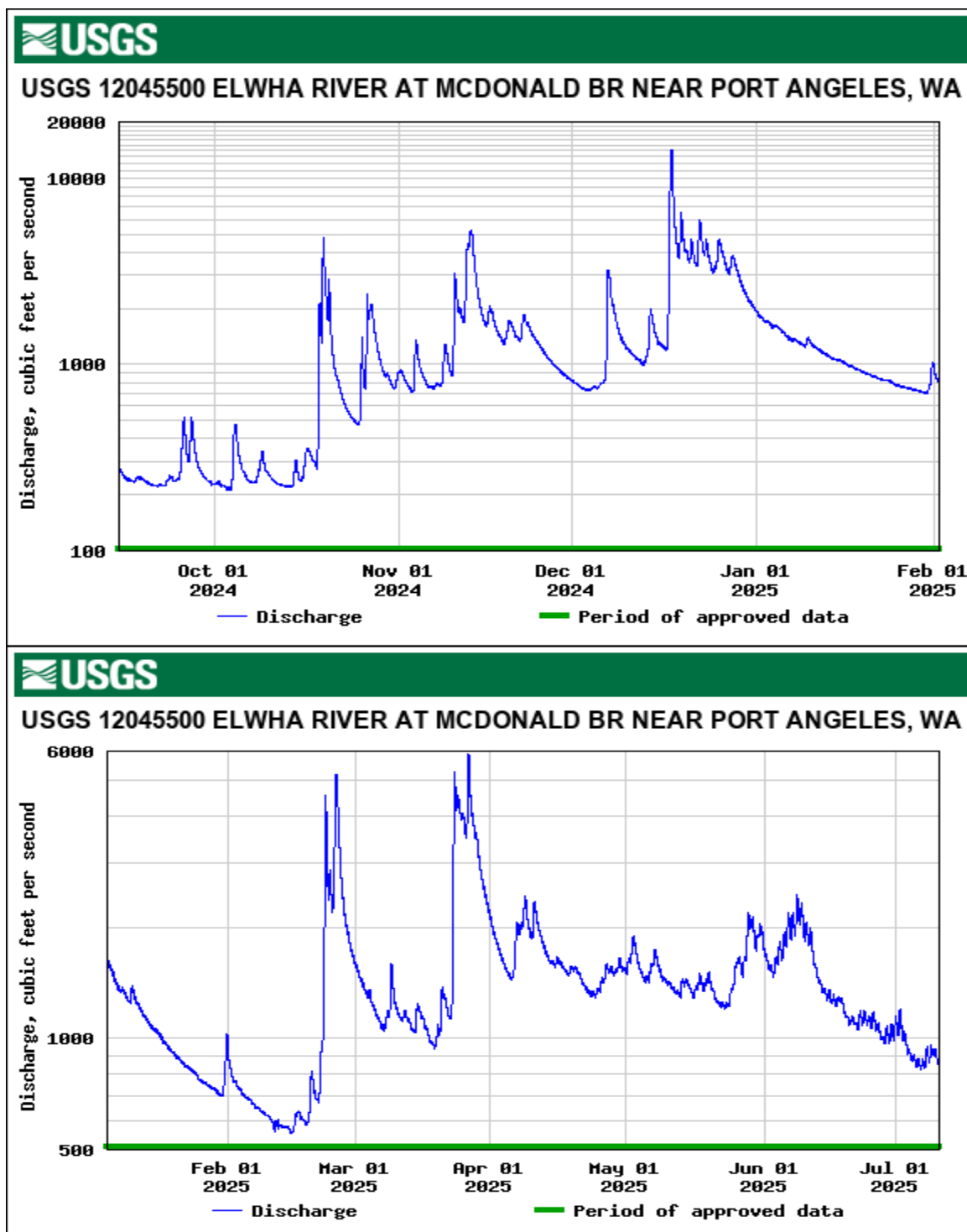


Figure 5. Efficiency estimates with 95% confidence intervals by date for the different traps and age classes. The dashed line at 0.04 is to assist with between group comparisons.

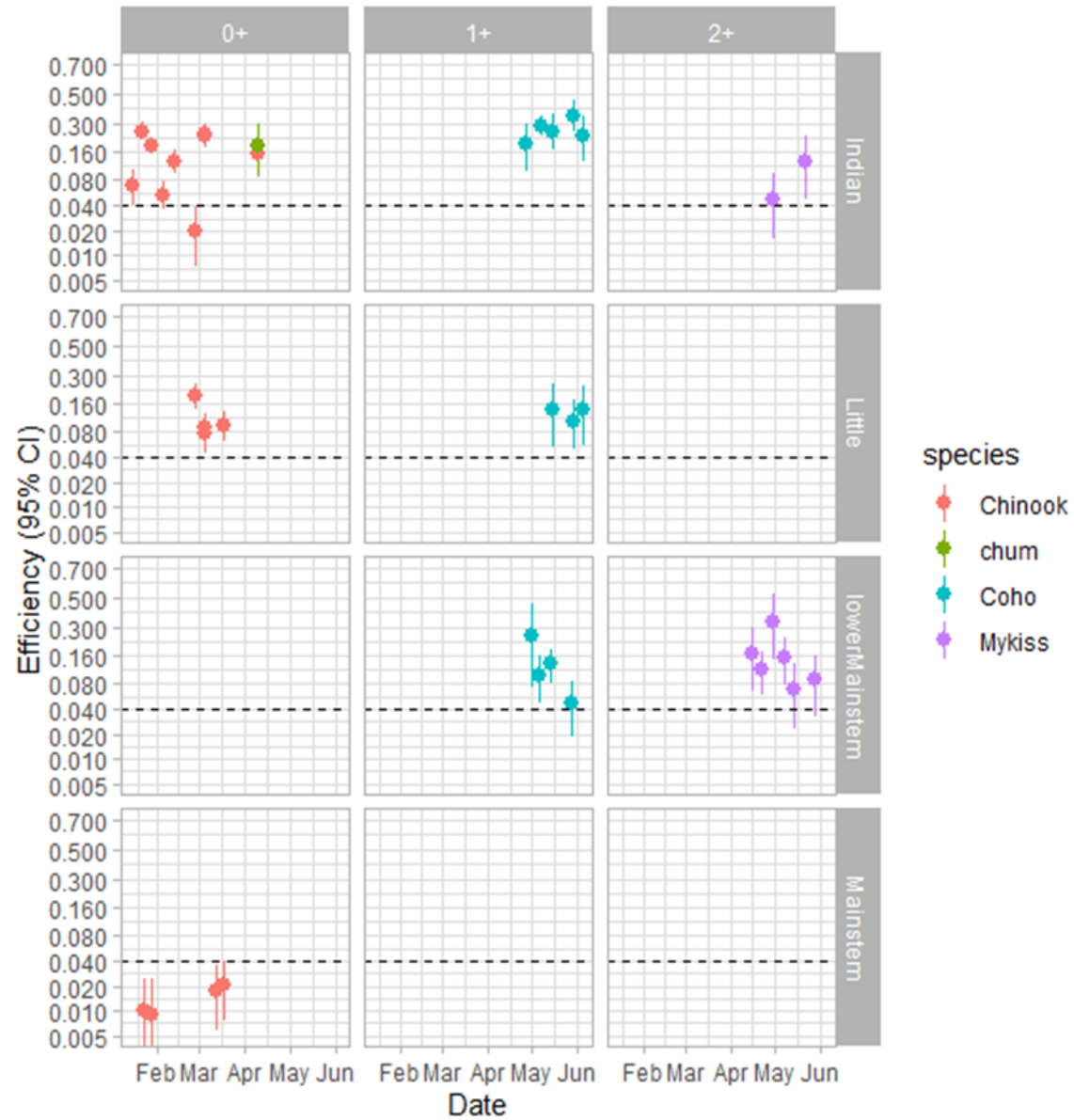


Figure 6. Elwha subyearling Chinook abundance and productivity (2005-2025).

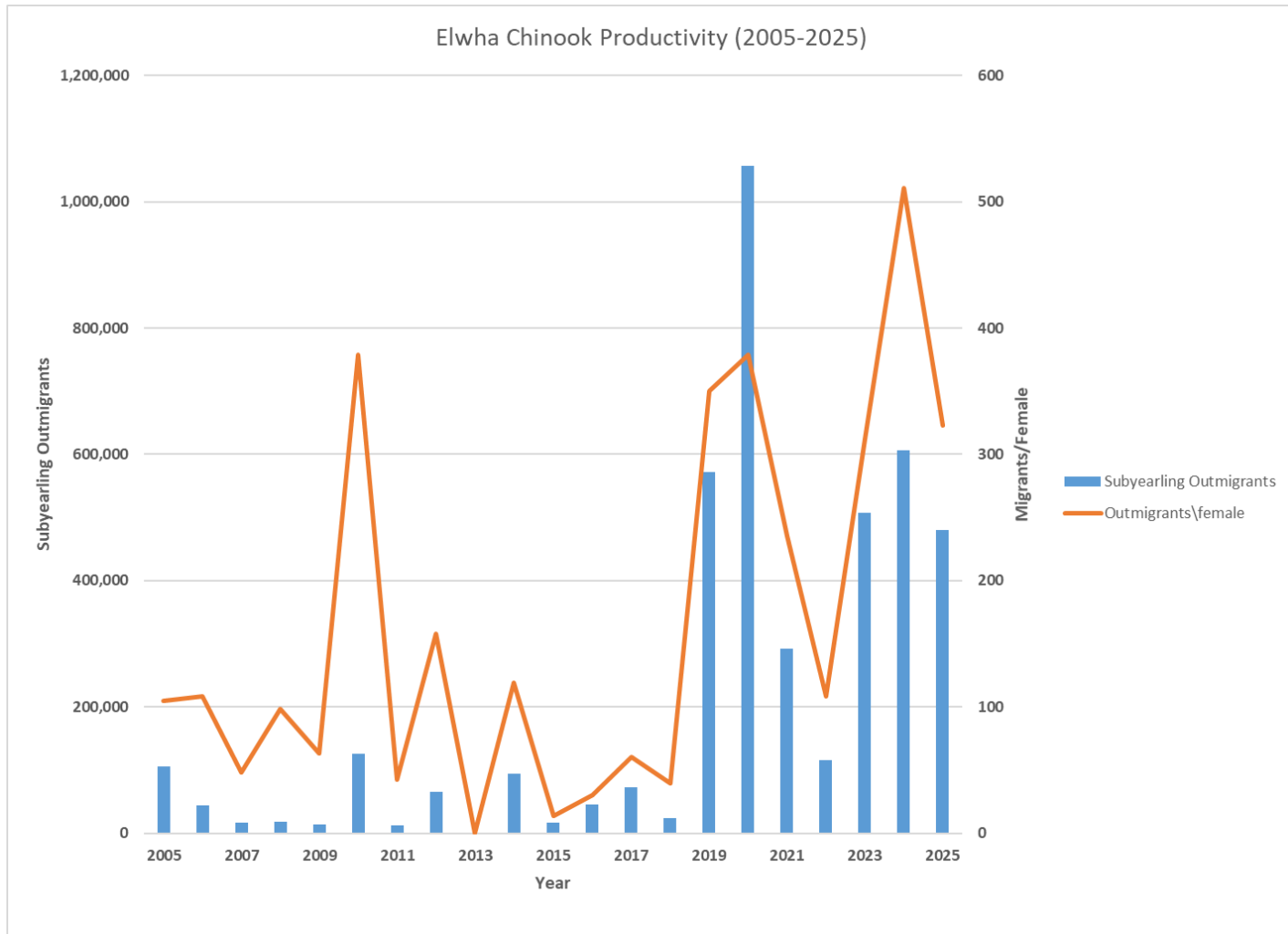


Figure 7. Juvenile Pacific Lamprey captures at the Indian Creek Smolt trap (top) and sculpin (bottom) at the mainstem Elwha trap (2005-2025).

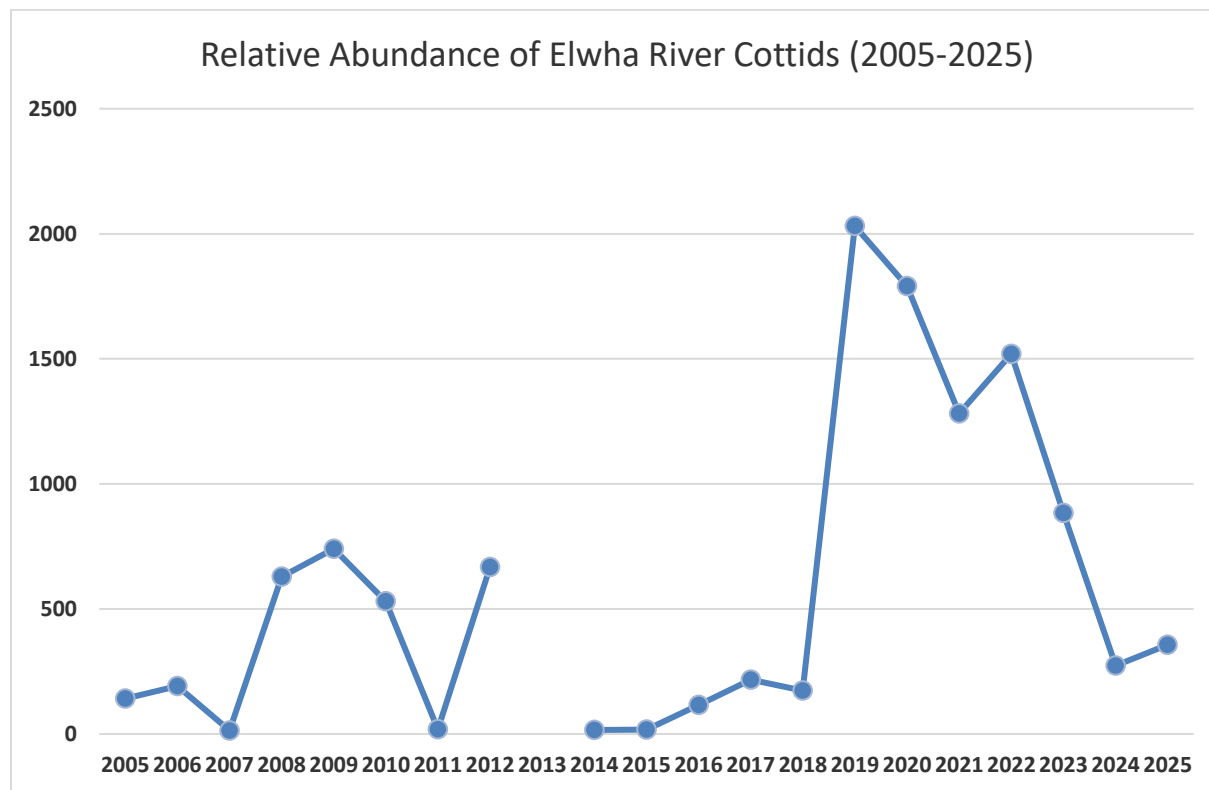
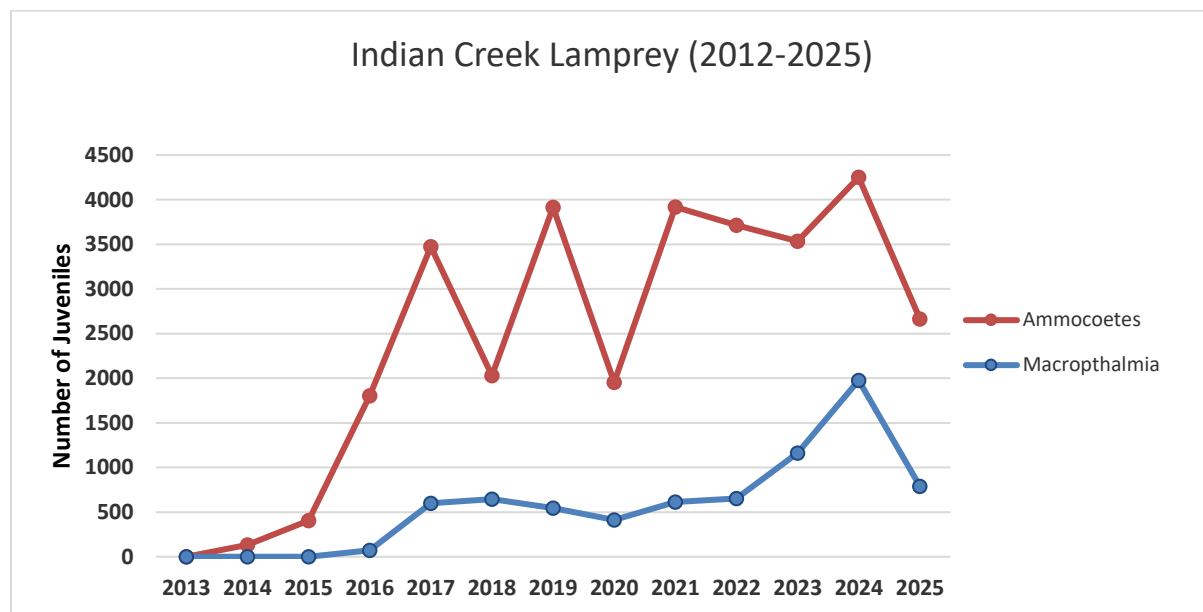


Figure 8. Egg to outmigrant survival rate for Elwha Chinook salmon (2005-2025).

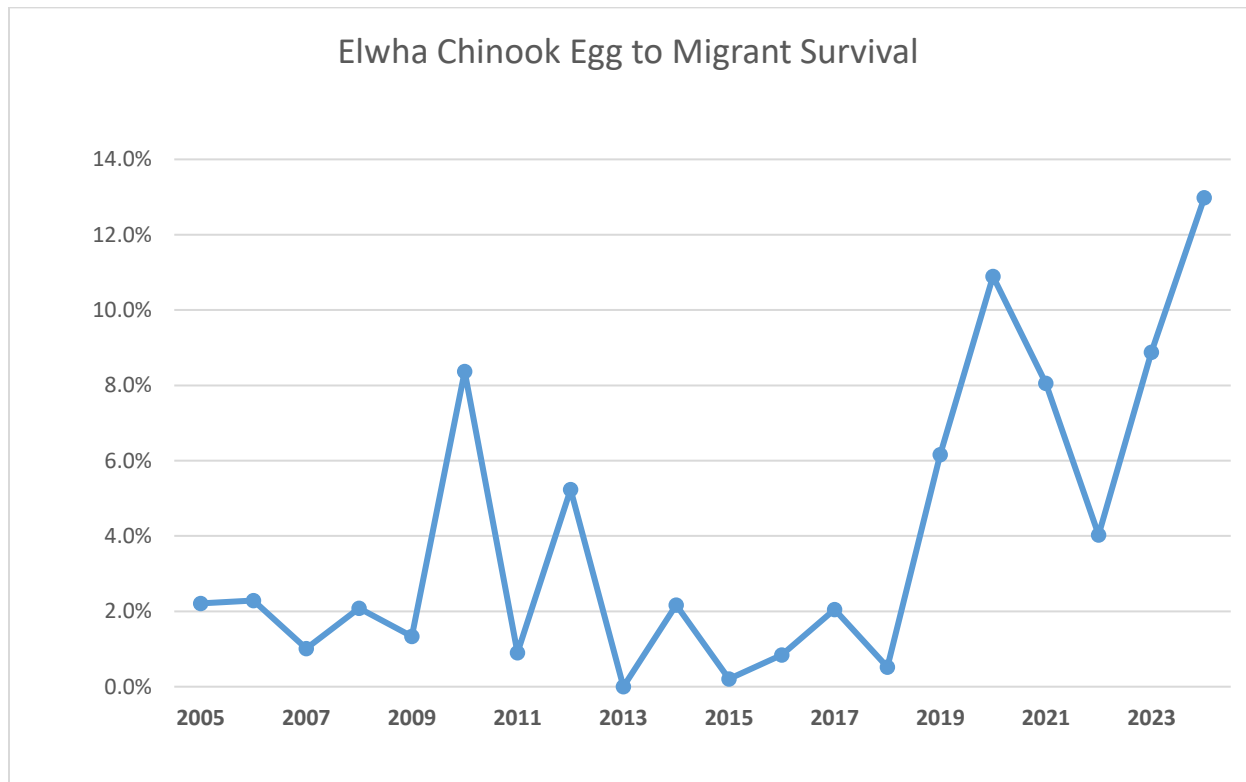


Figure 9. Chinook outmigrant timing and sizes for the Elwha River screw trap during the period when length data was available (2016-2024). The three vertical lines represent three dates that could be used to separate fry and parr migrants. The horizontal line at 45 mm represents a common cutoff used to separate fry and parr. The dotted lines at 80 mm and June 1st provide references for assessing changes in growth over time.

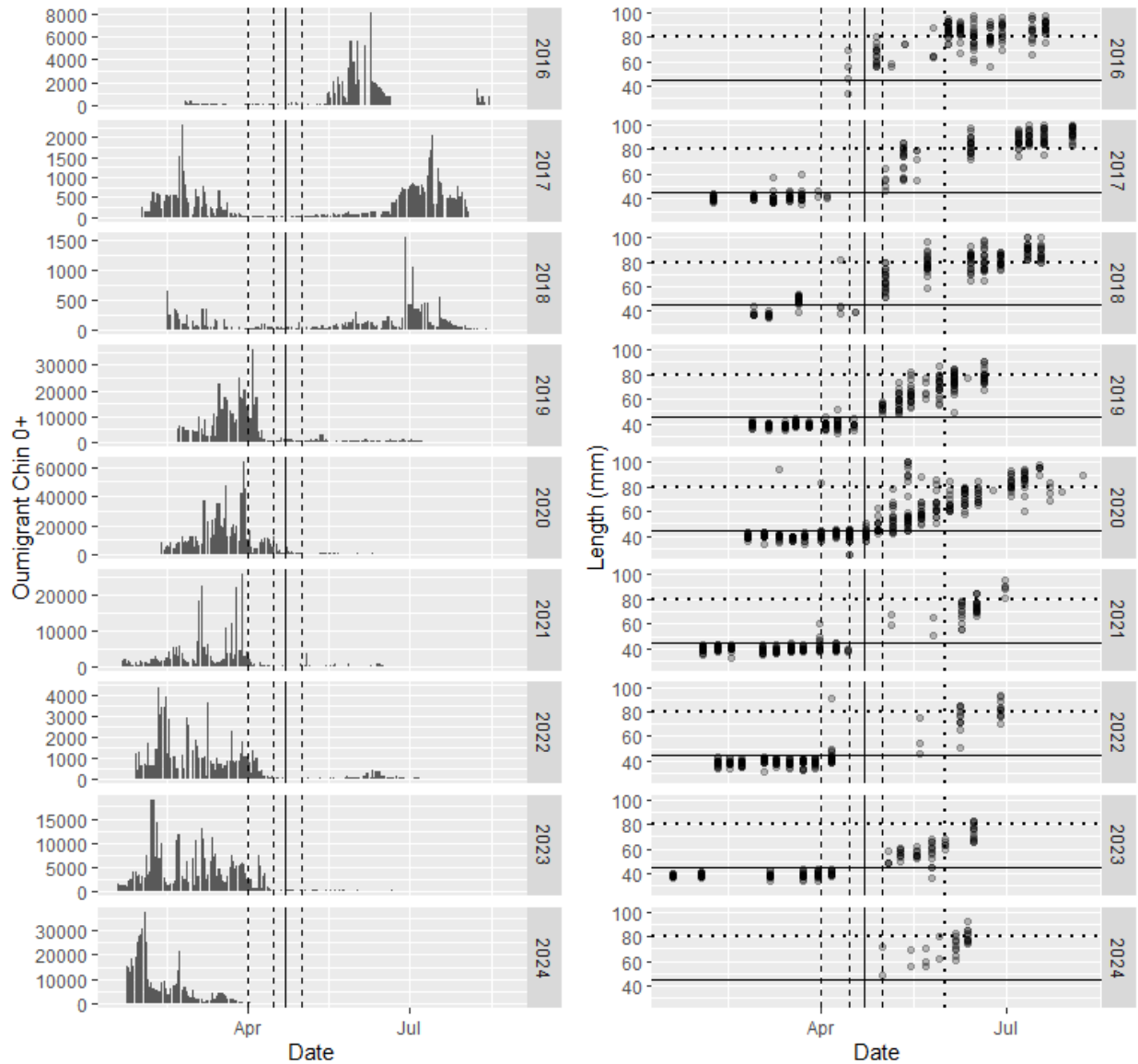


Figure 10. Chinook subyearling productivity for Indian Creek and Little River (2013-2025).

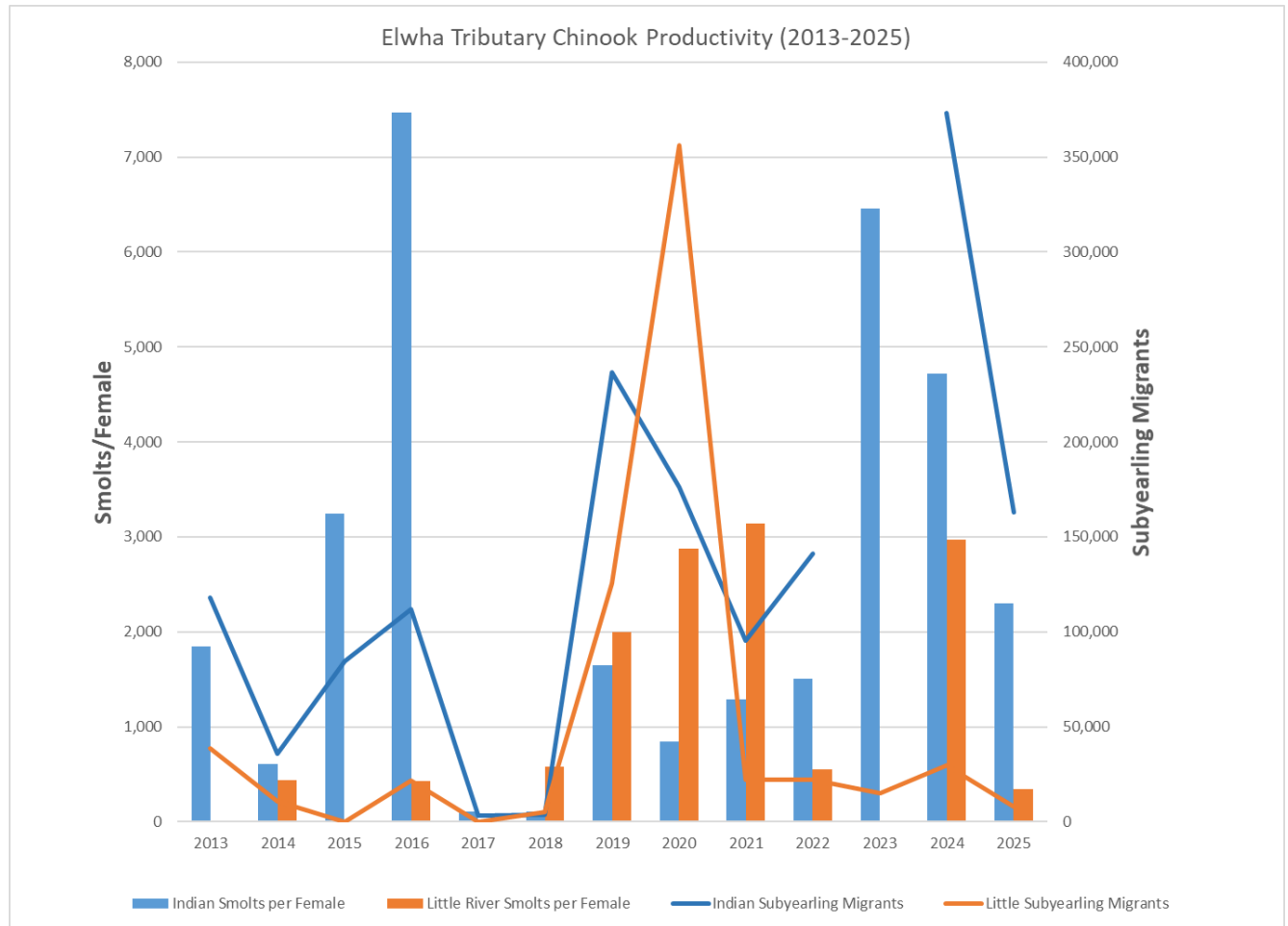


Figure 11. Estimated Steelhead and Coho smolt production for Indian Creek and Little River (2012-2022).

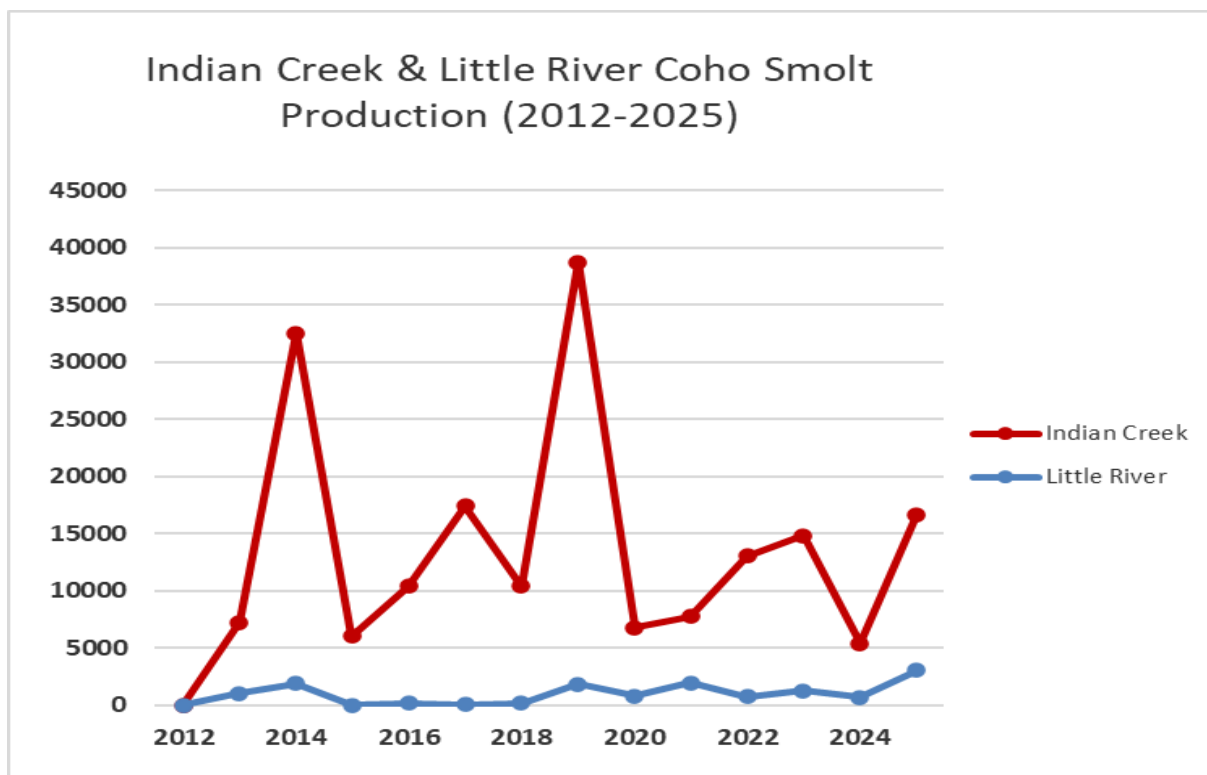
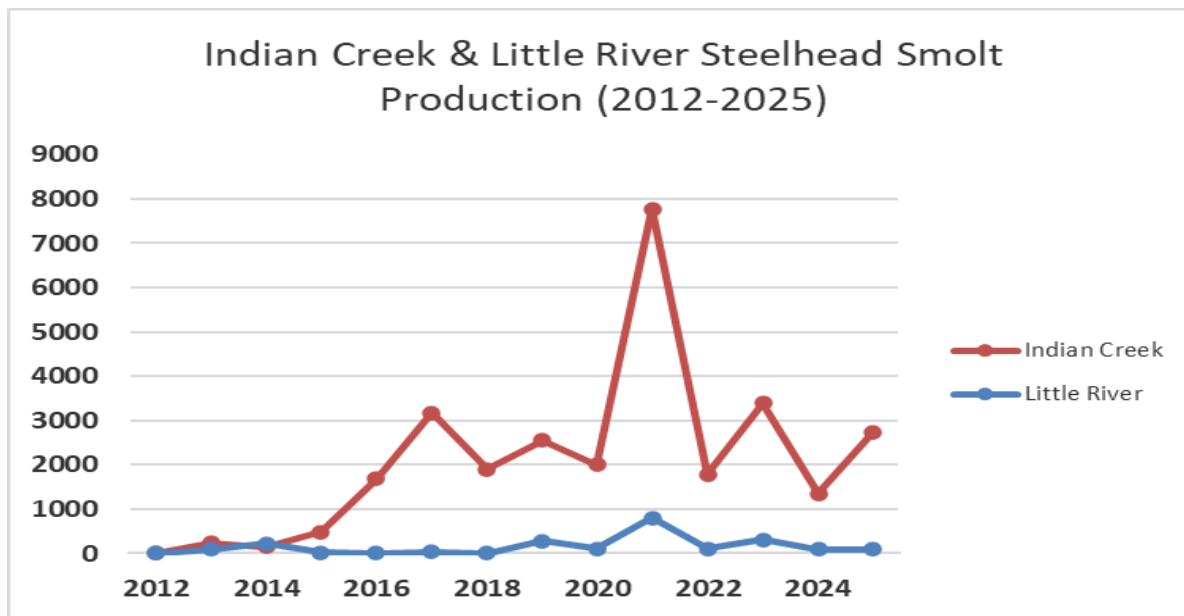


Figure 12. Estimated Pink and Chum salmon outmigration for the Elwha River (2005-2025).

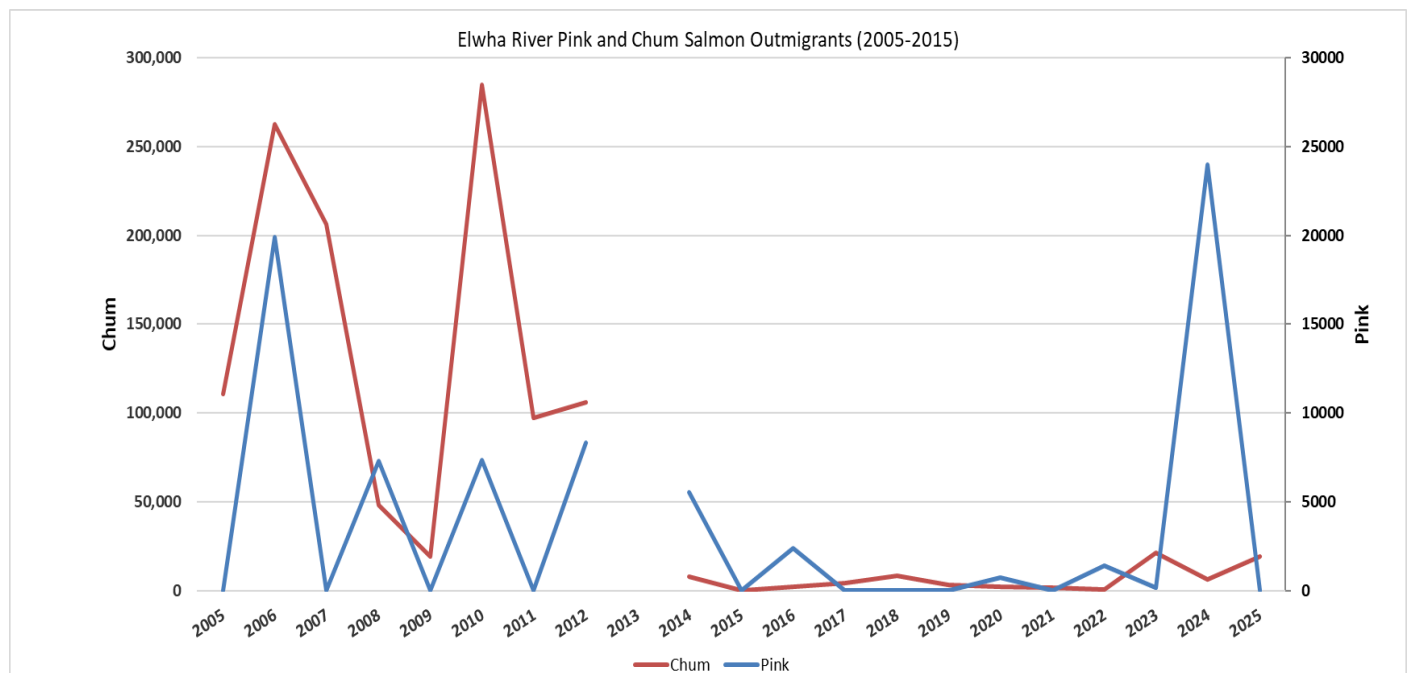
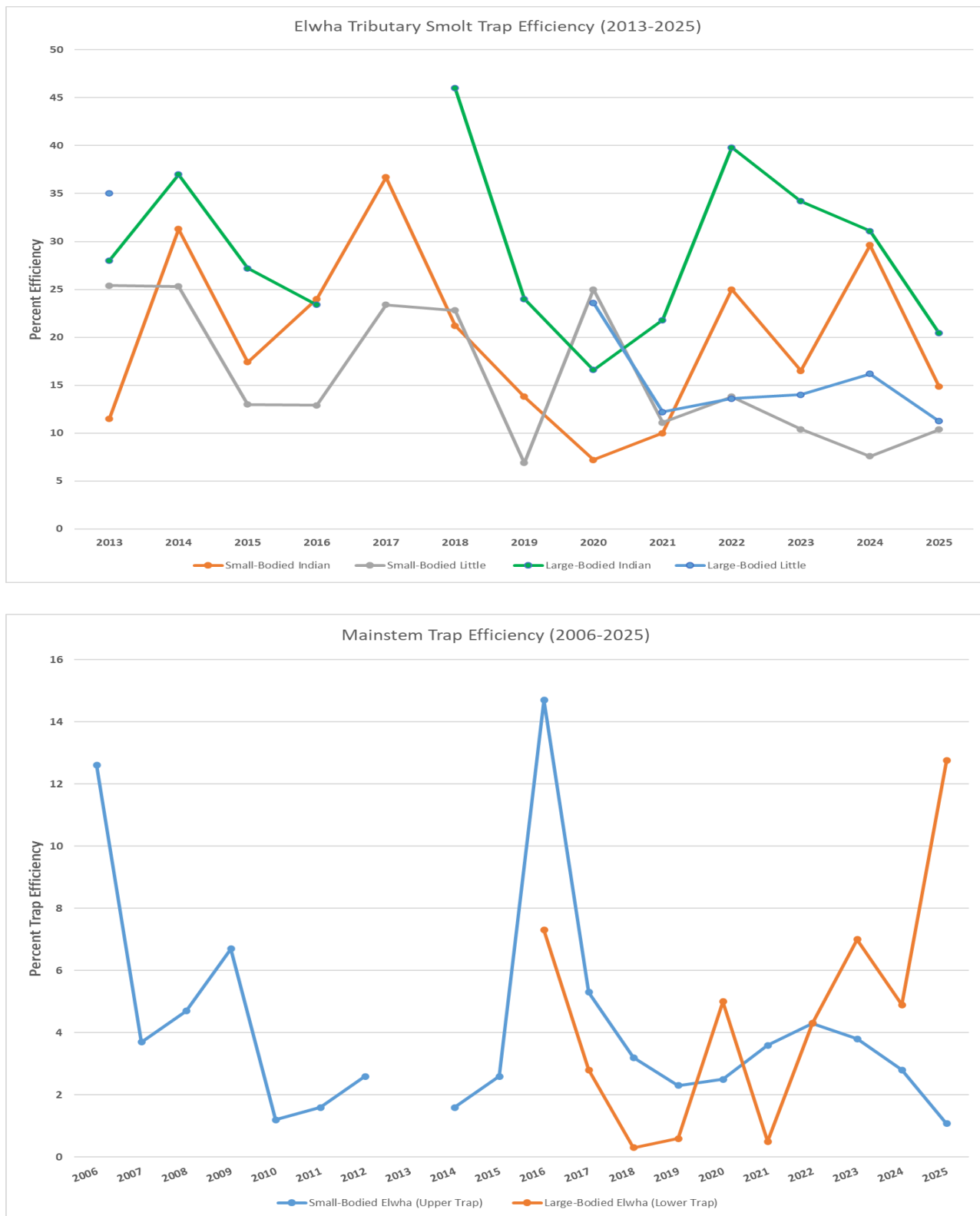
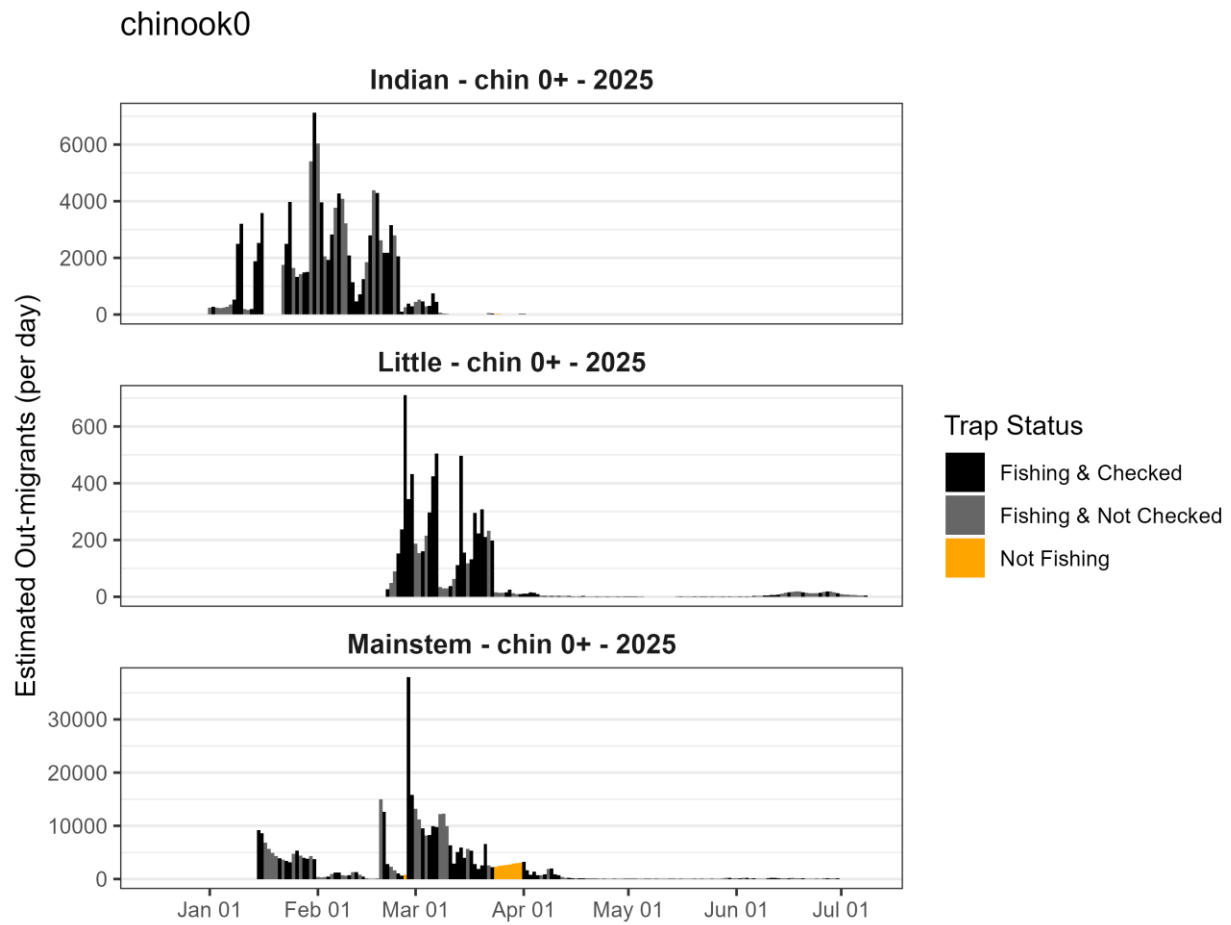


Figure 13. Long-term trap efficiency for small-bodied and large-bodied smolts for Elwha River tributaries (2013-2025) and mainstem Elwha River (2006-2025).

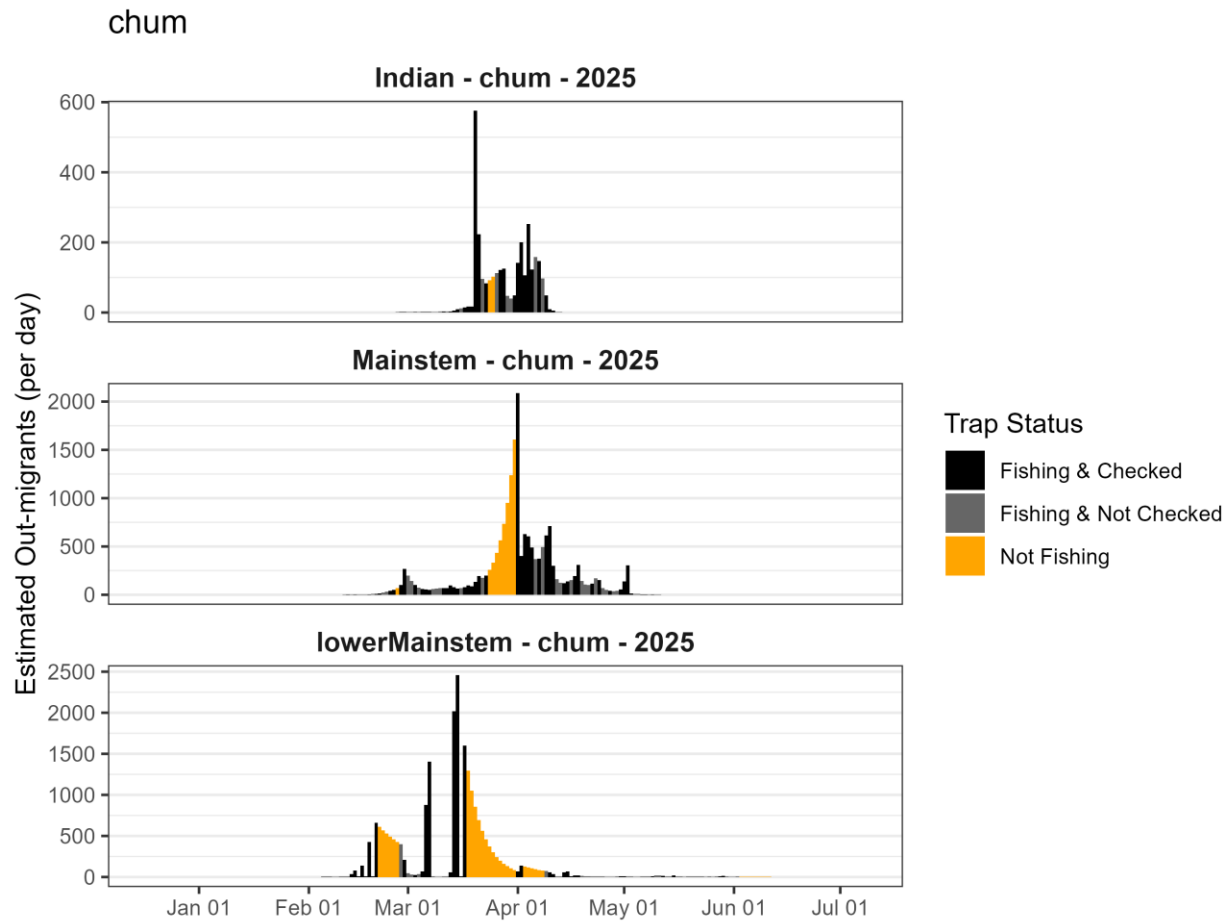


Appendix A.

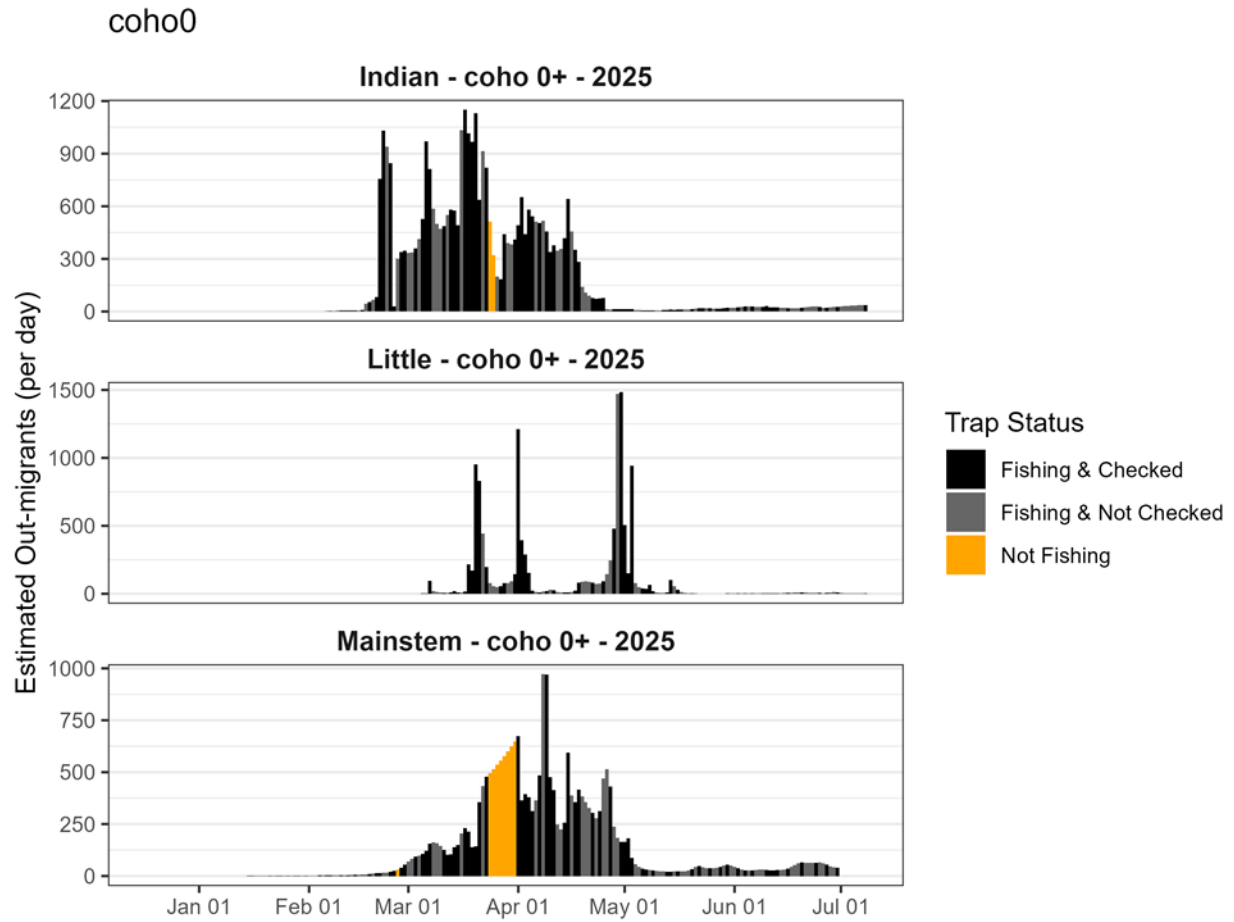
Estimated number of Coho 0+, Chinook subyearlings, Pink and Chum outmigrants at the Upper mainstem Elwha, Indian Creek and Little River Trap sites by day during 2025.



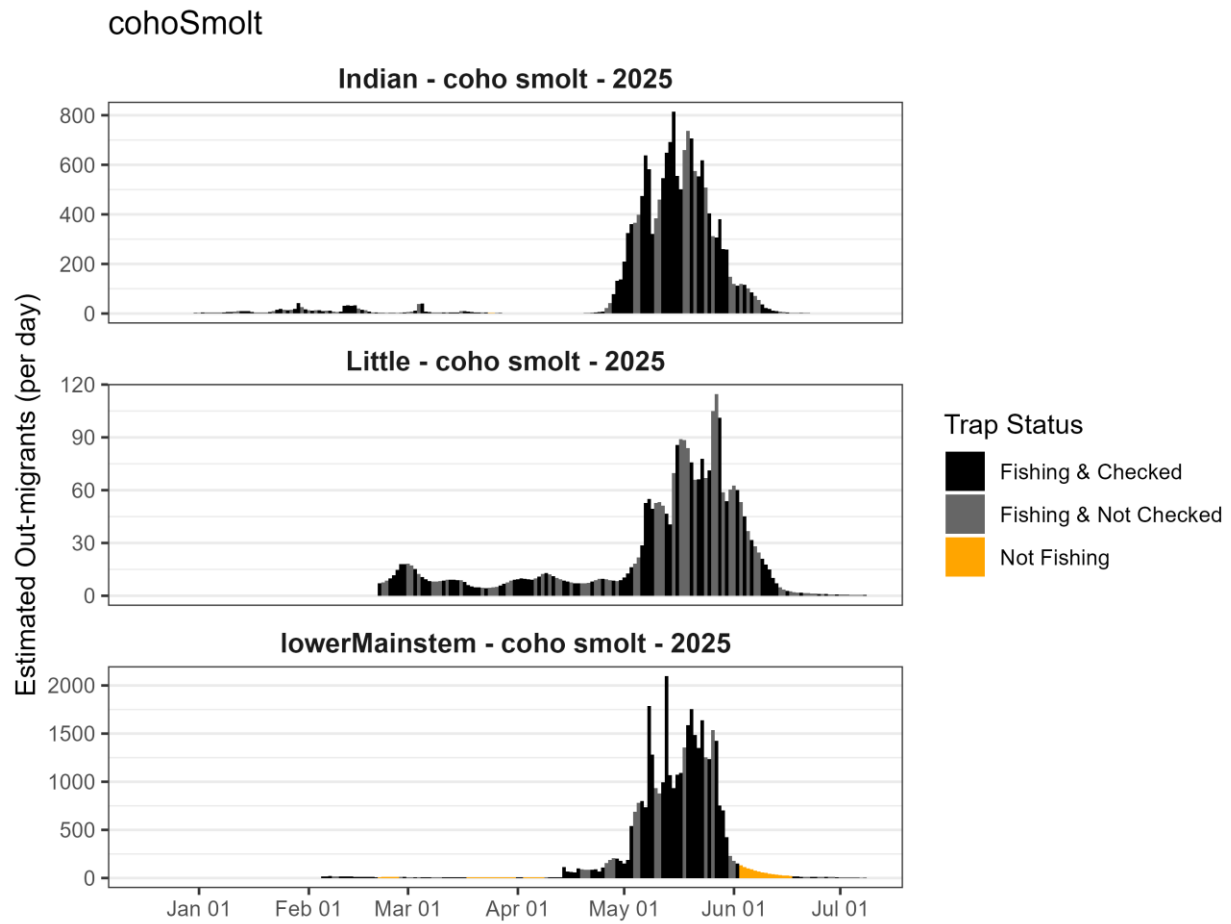
Estimated number of Chum smolt out-migrants at the Indian Creek, Upper mainstem and Lower mainstem Elwha River trap sites by day during 2025.



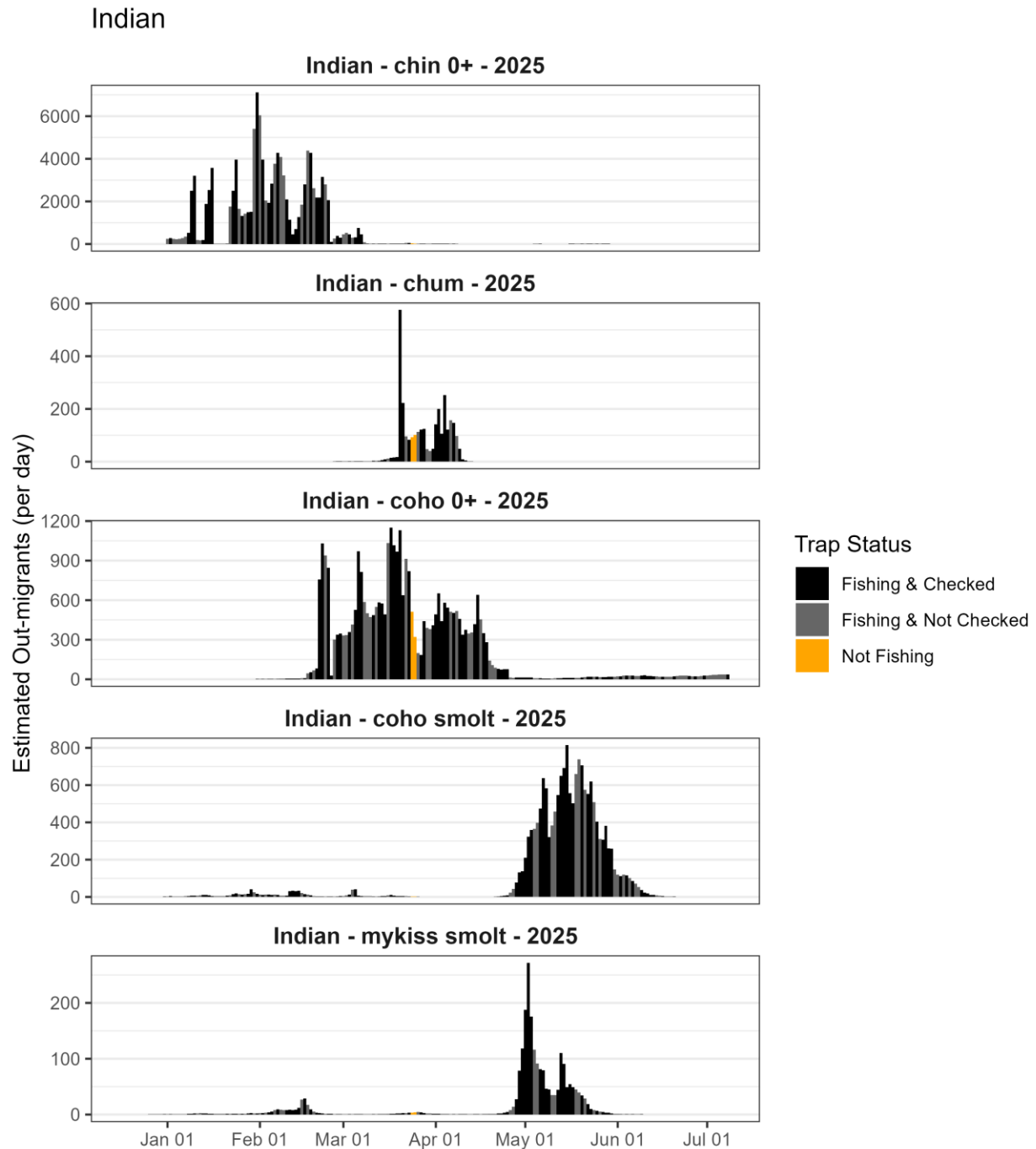
Estimated number of Coho 0+ outmigrants at the Indian Creek, Little River and Upper mainstem trap sites by day during 2025.



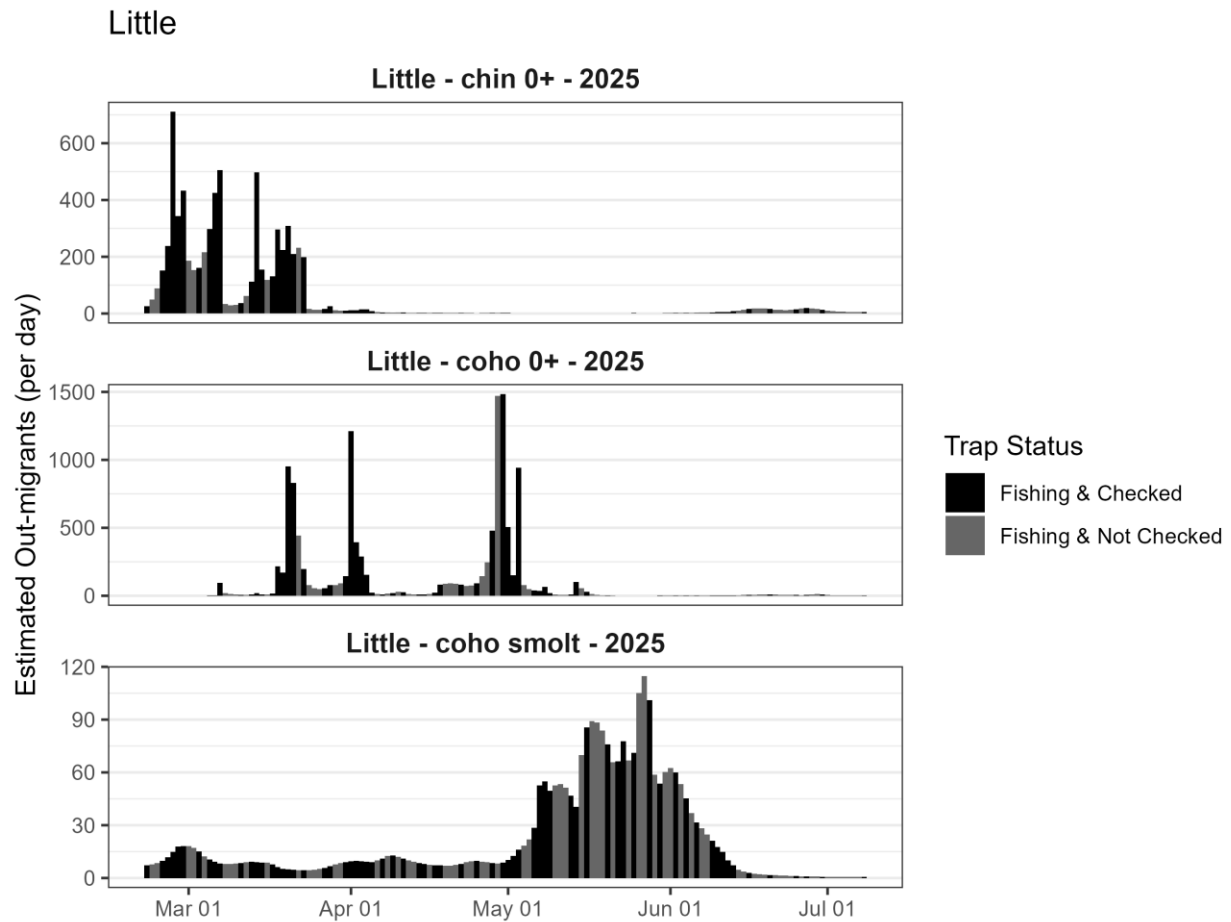
Estimated number Coho smolt outmigrants at the Indian Creek, Little River and lower Elwha mainstem trap sites by day during 2025.



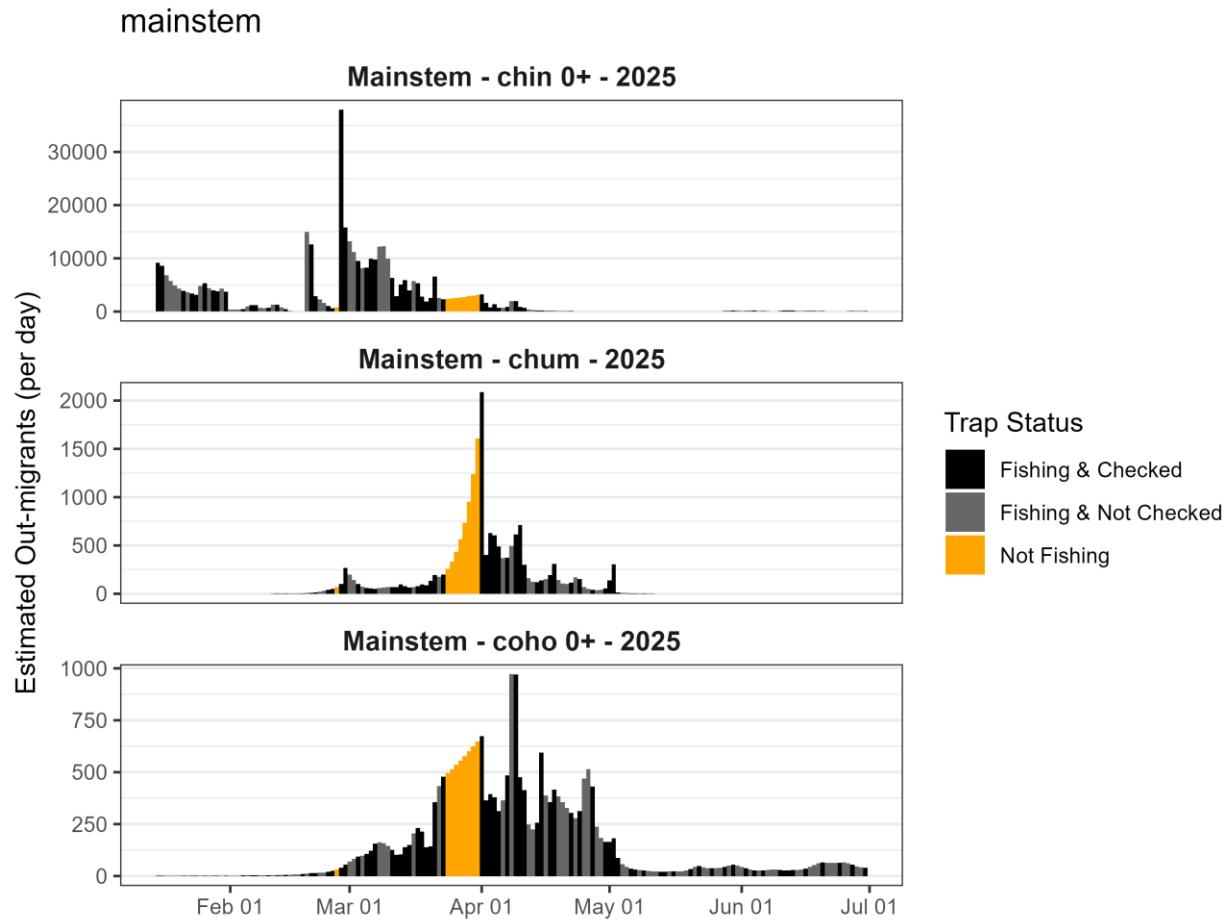
Estimated number Chinook subyearlings, Chum, Coho 0+, Coho smolt and mykiss out-migrants at the Indian Creek trap site by day during 2025.



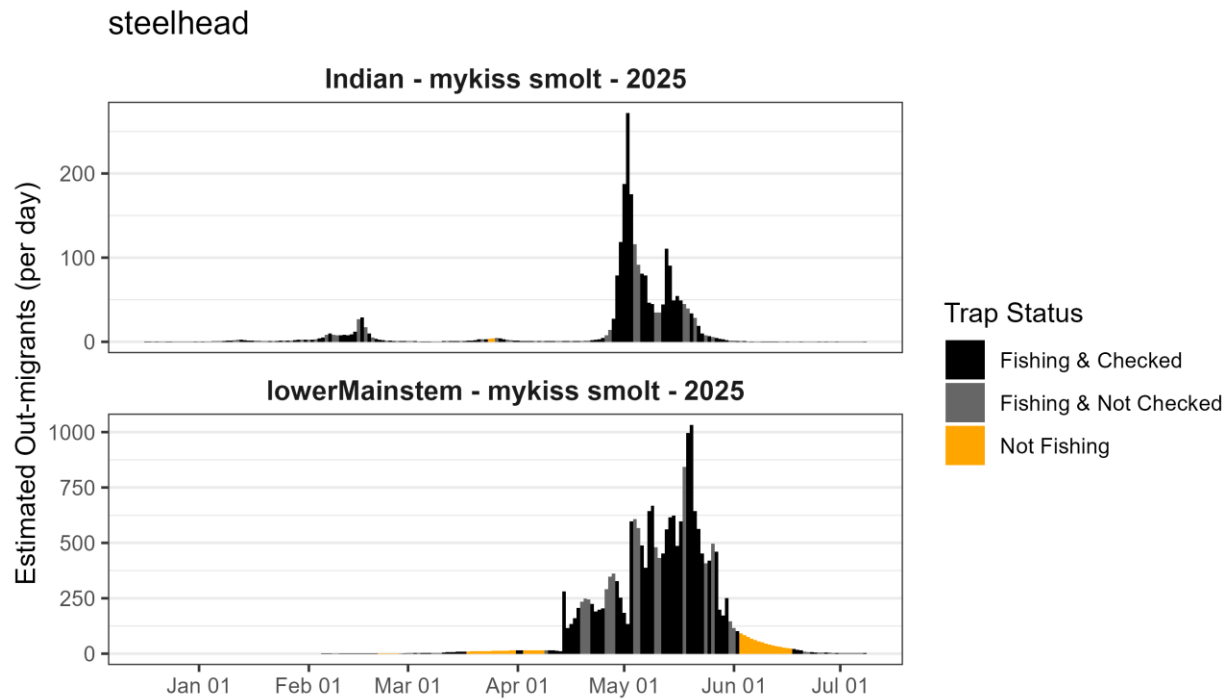
Estimated number of Chinook subyearlings, Coho 0+, and Coho smolt out-migrants at Little River trap site by day during 2025.



Estimated number of Chinook subyearlings, Coho 0+, and Chum smolt out-migrants at Upper mainstem trap site by day during 2025.



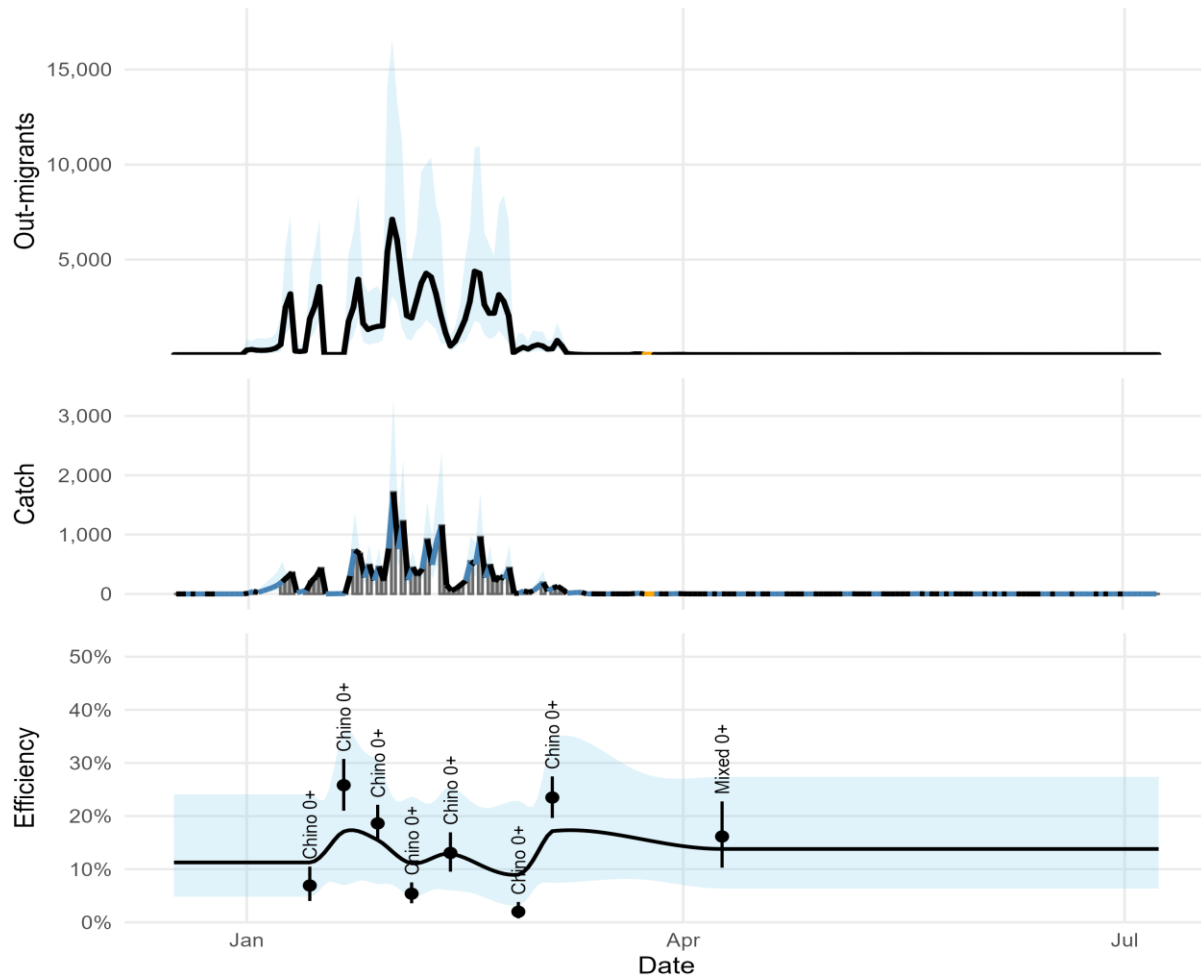
Estimated number of Steelhead smolt out-migrants at Indian Creek and Lower mainstem trap sites by day during 2025.



Appendix B. Here we include plots to visualize the estimation process. Top panel: The black line and blue ribbon represent the current model fit with 95% confidence interval. Orange line segments are for days not fishing, and blue are for days that were partially fished (<24hours fished). Middle panel: Gray bars are observed catch by day. The black line and blue ribbon represent the estimated catch and 95% confidence interval. blue line segments represent days when the trap was not checked, and orange line segments represent periods when the trap was not fishing. Bottom panel: Points with vertical bars represent efficiency estimates with independent 95% confidence intervals. The black line and blue ribbon represent the model based daily efficiency estimates with 95% confidence interval. The text indicates the fish species and age used for the trials.

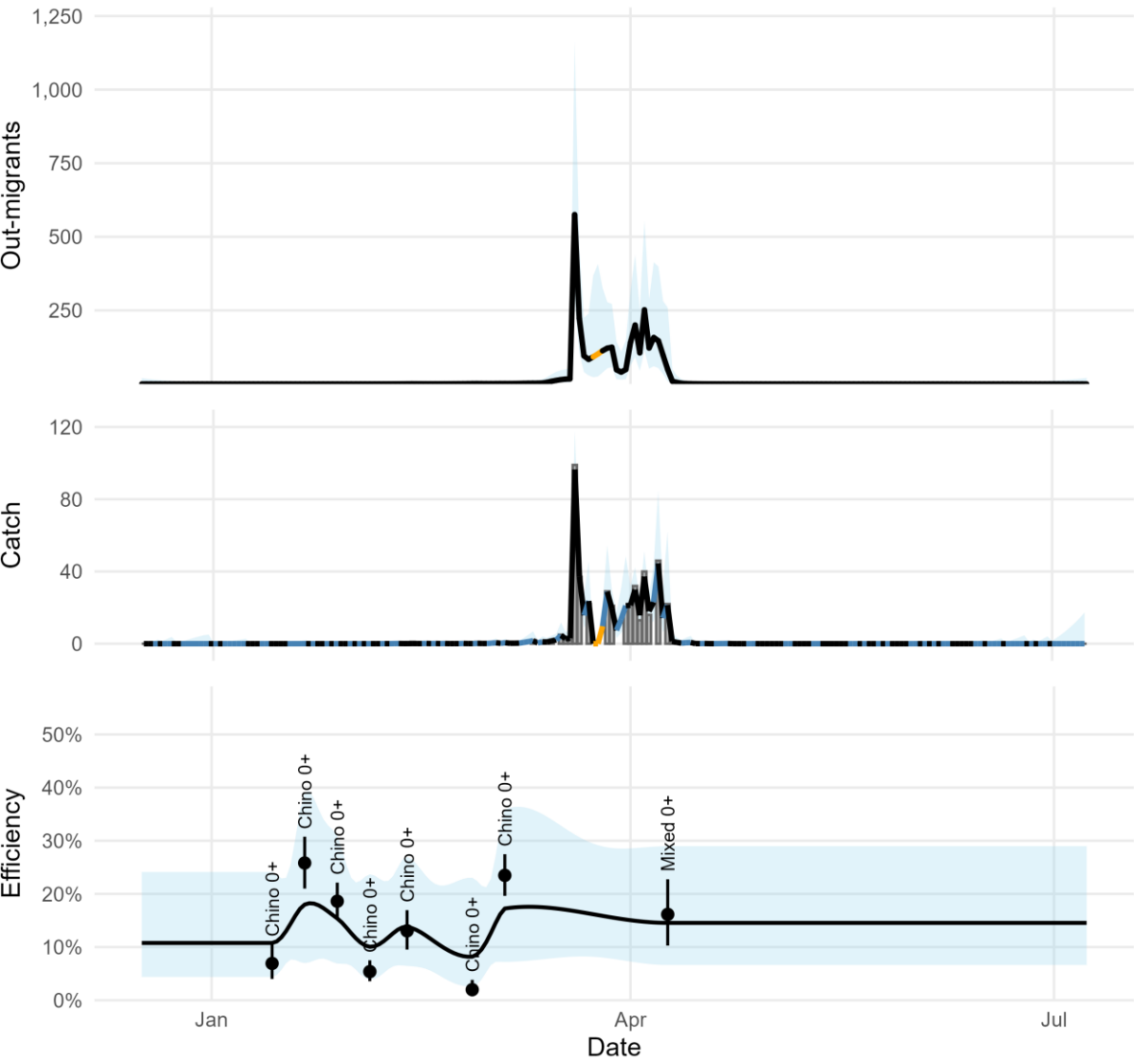
Indian-2025-chin 0+

Total Estimate: 119,422 (72,101 - 186,508)



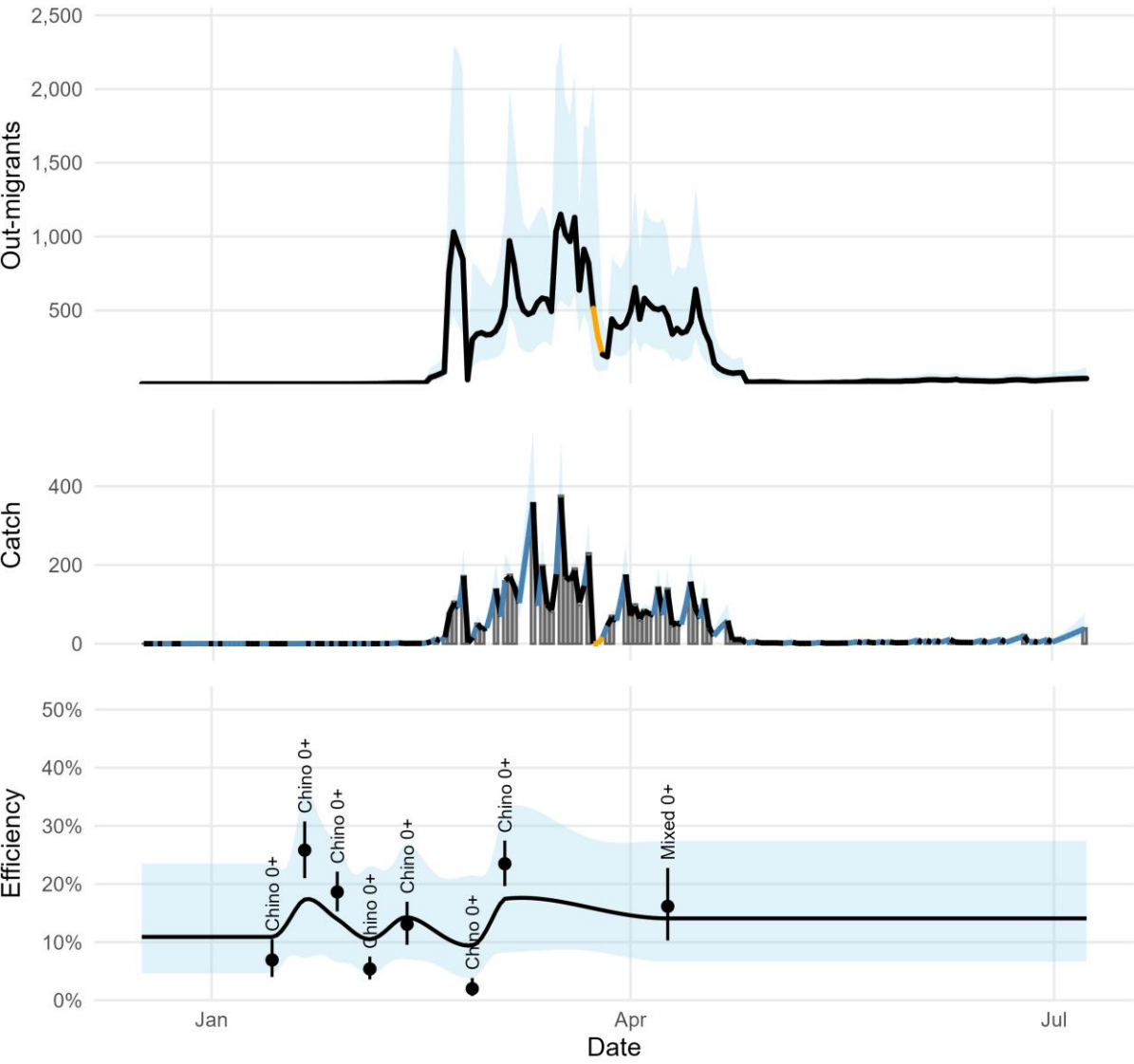
Indian-2025-chum

Total Estimate: 3,262 (1,603 - 5,937)



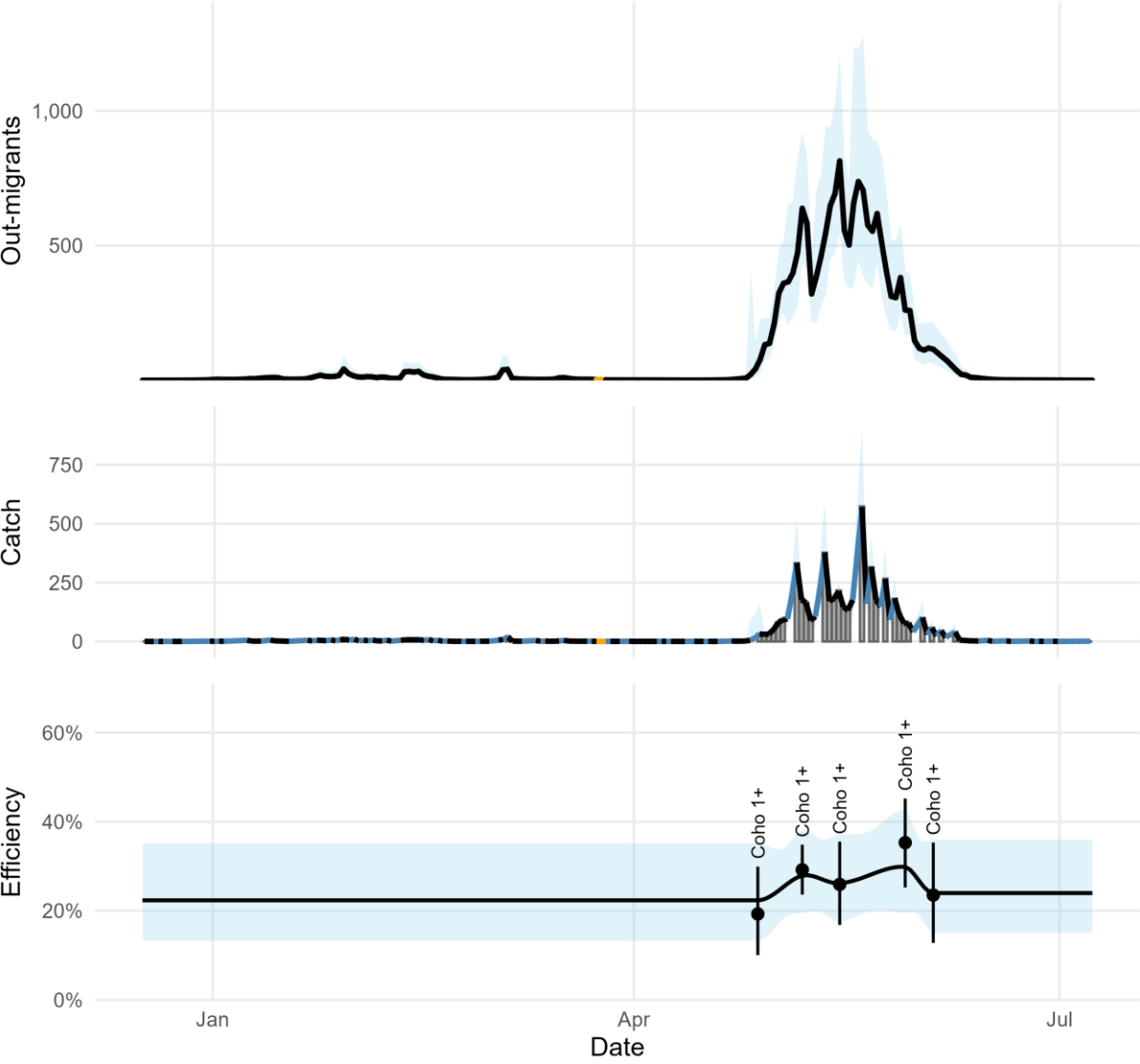
Indian-2025-coho 0+

Total Estimate: 35,003 (20,203 - 56,598)



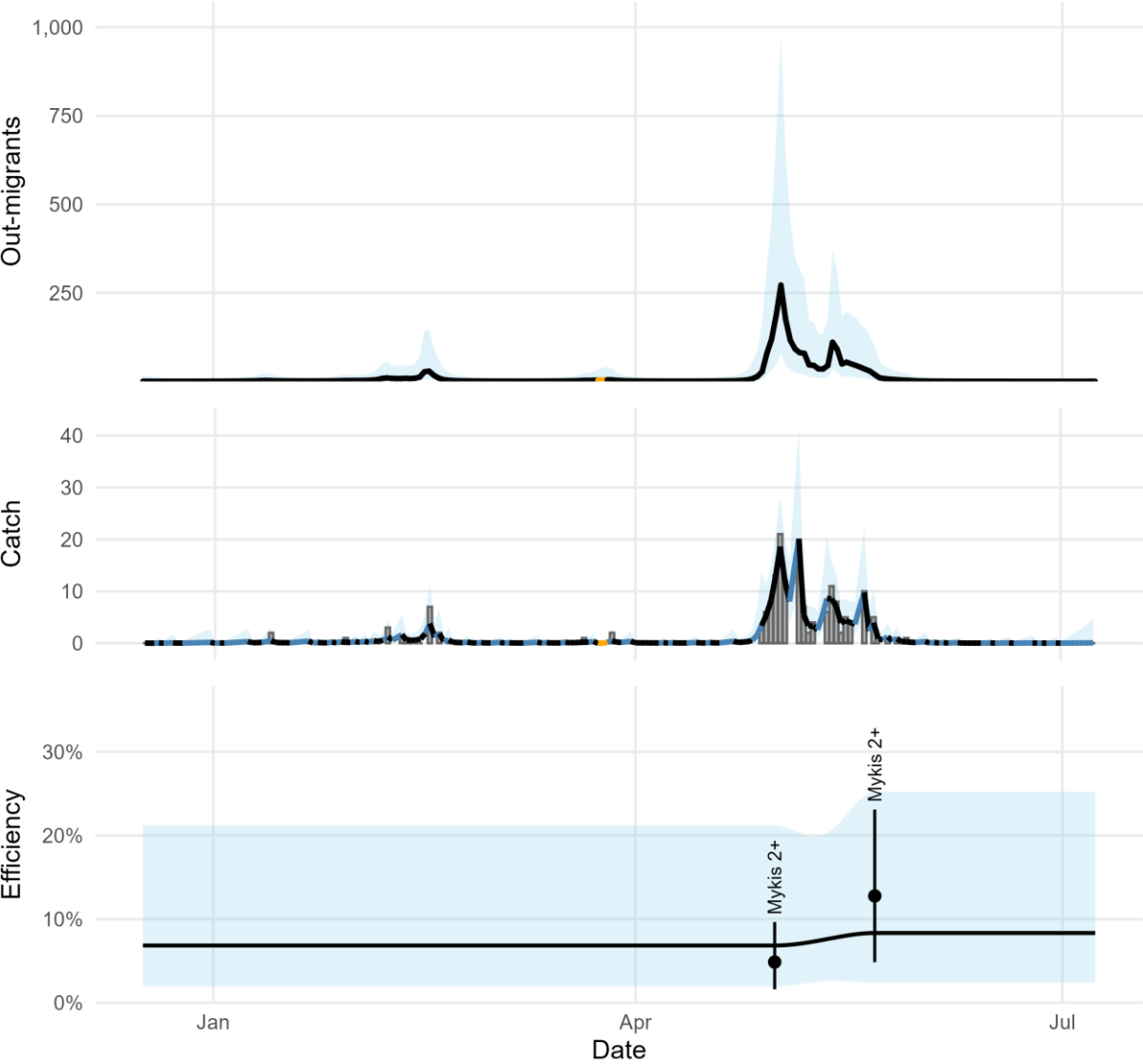
Indian-2025-coho smolt

Total Estimate: 17,083 (13,232 - 21,705)



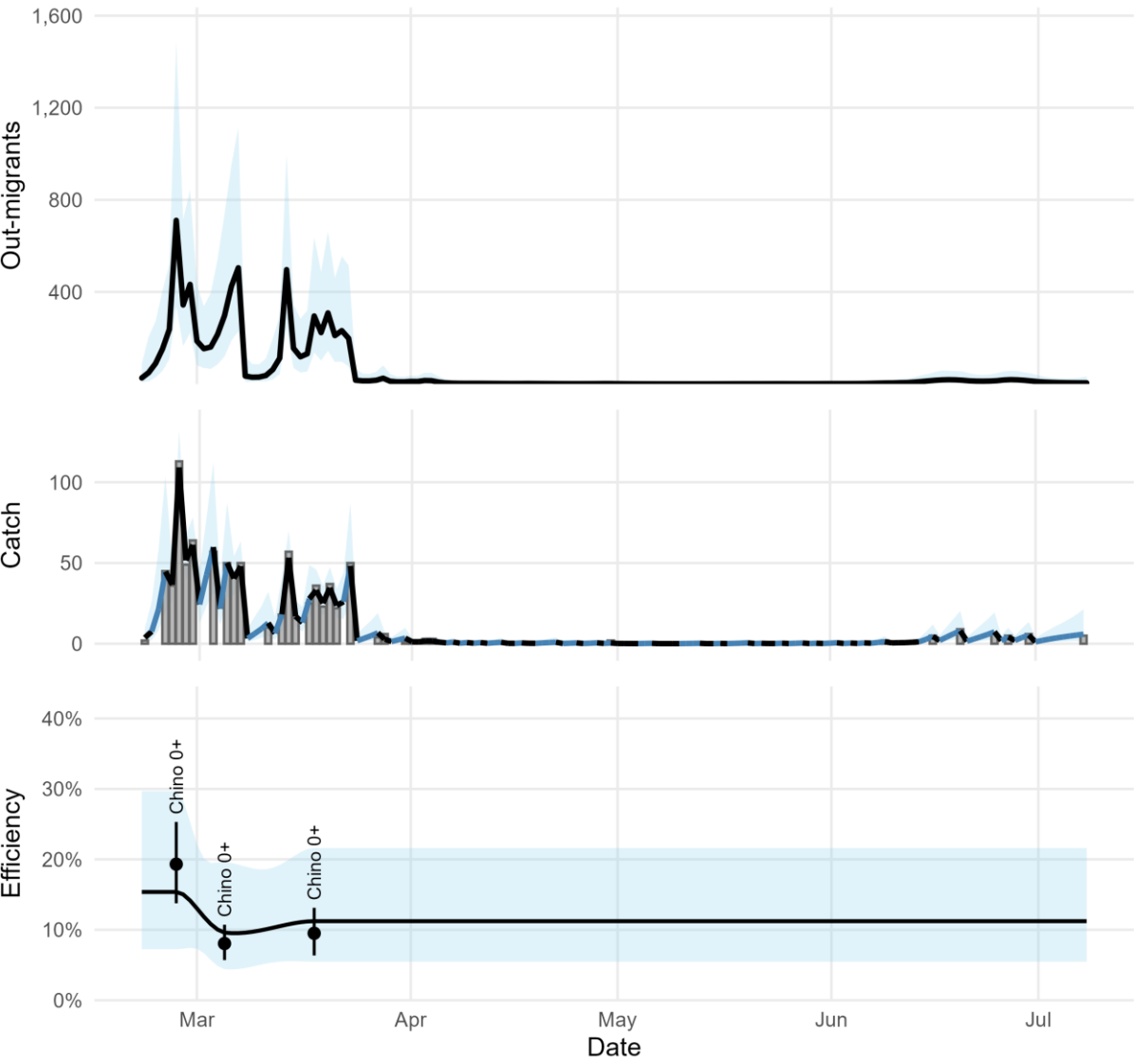
Indian-2025-mykiss smolt

Total Estimate: 2,755 (788 - 7,048)



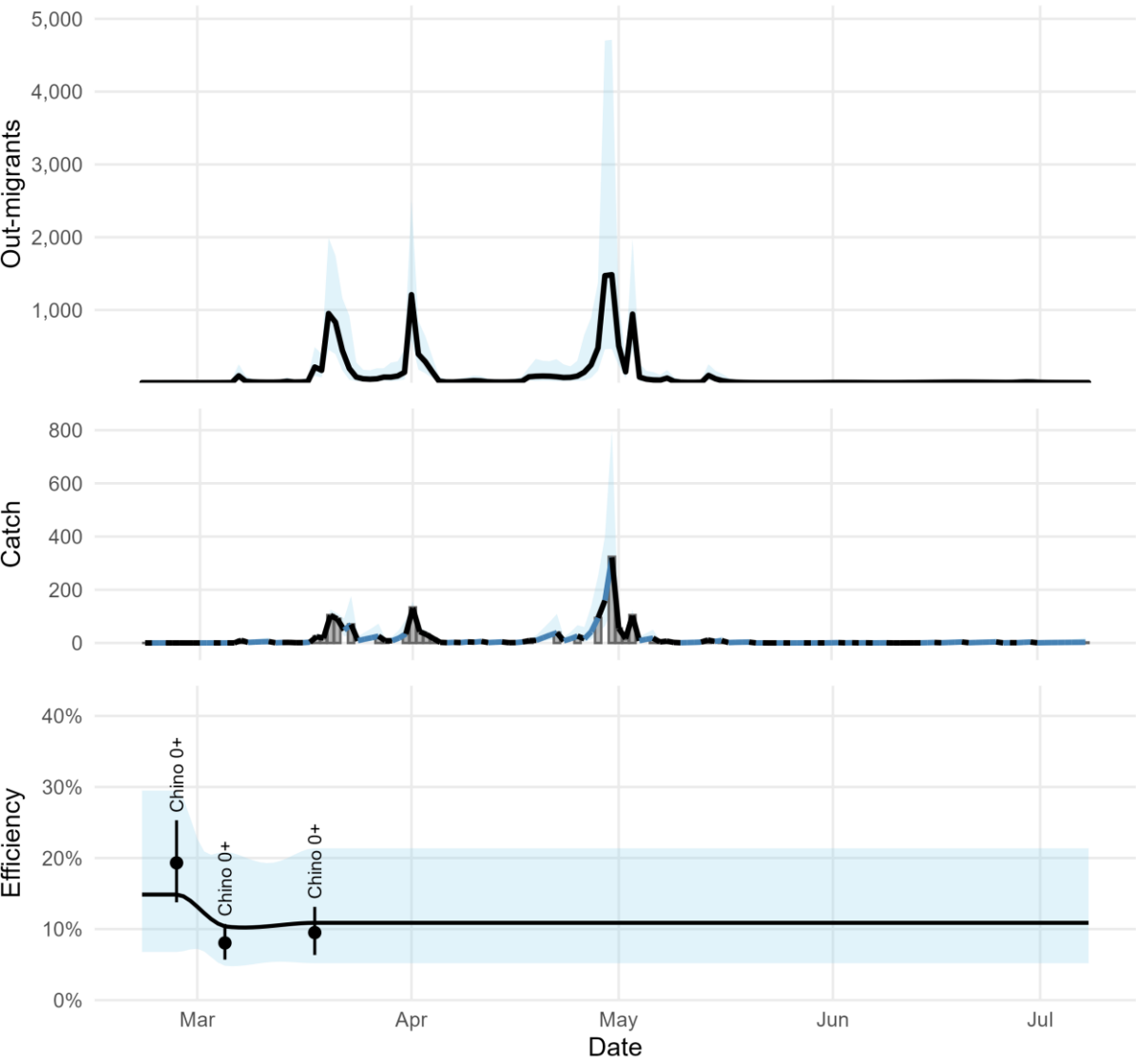
Little-2025-chin 0+

Total Estimate: 7,519 (4,465 - 11,895)



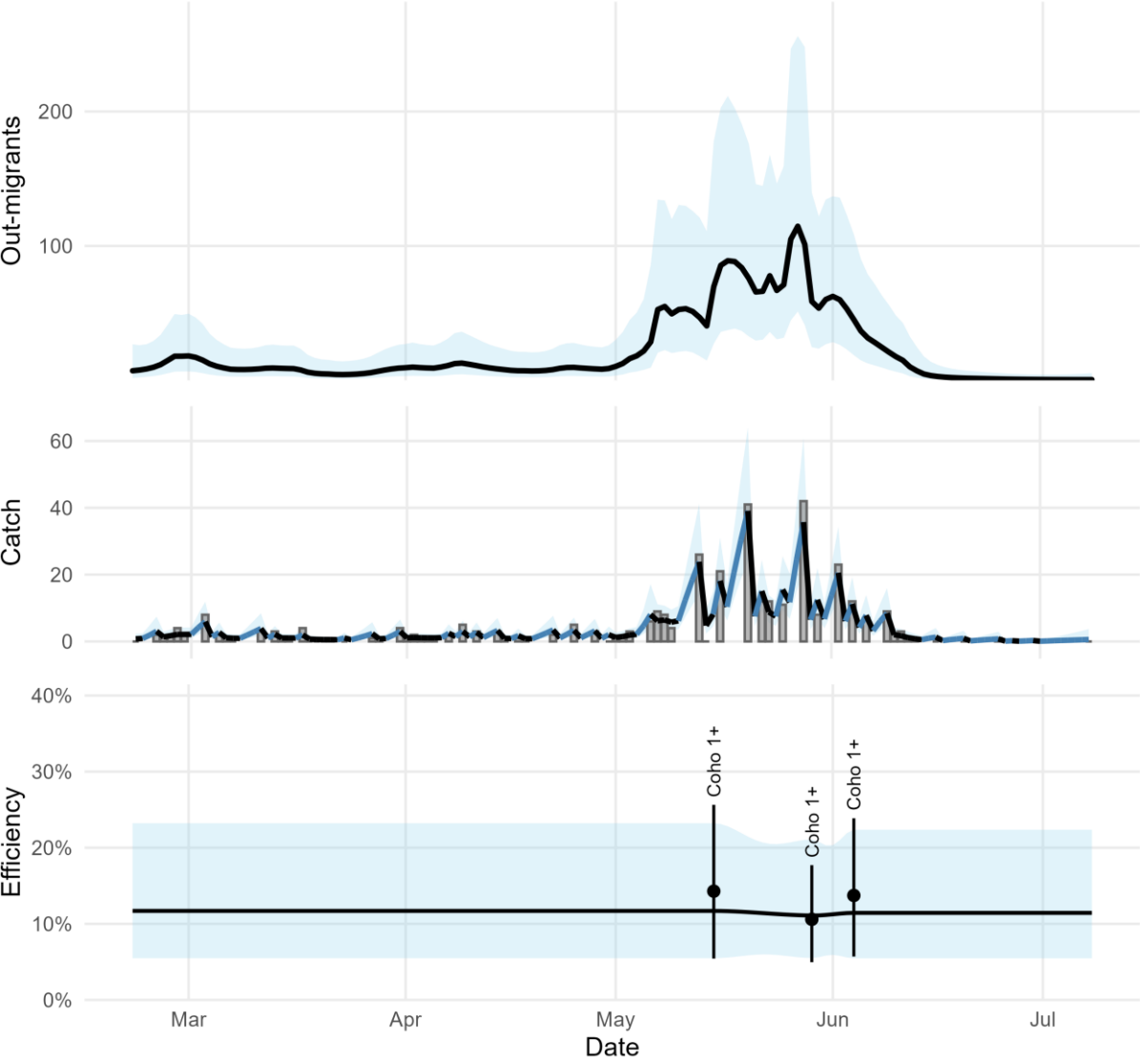
Little-2025-coho 0+

Total Estimate: 13,642 (6,280 - 25,989)



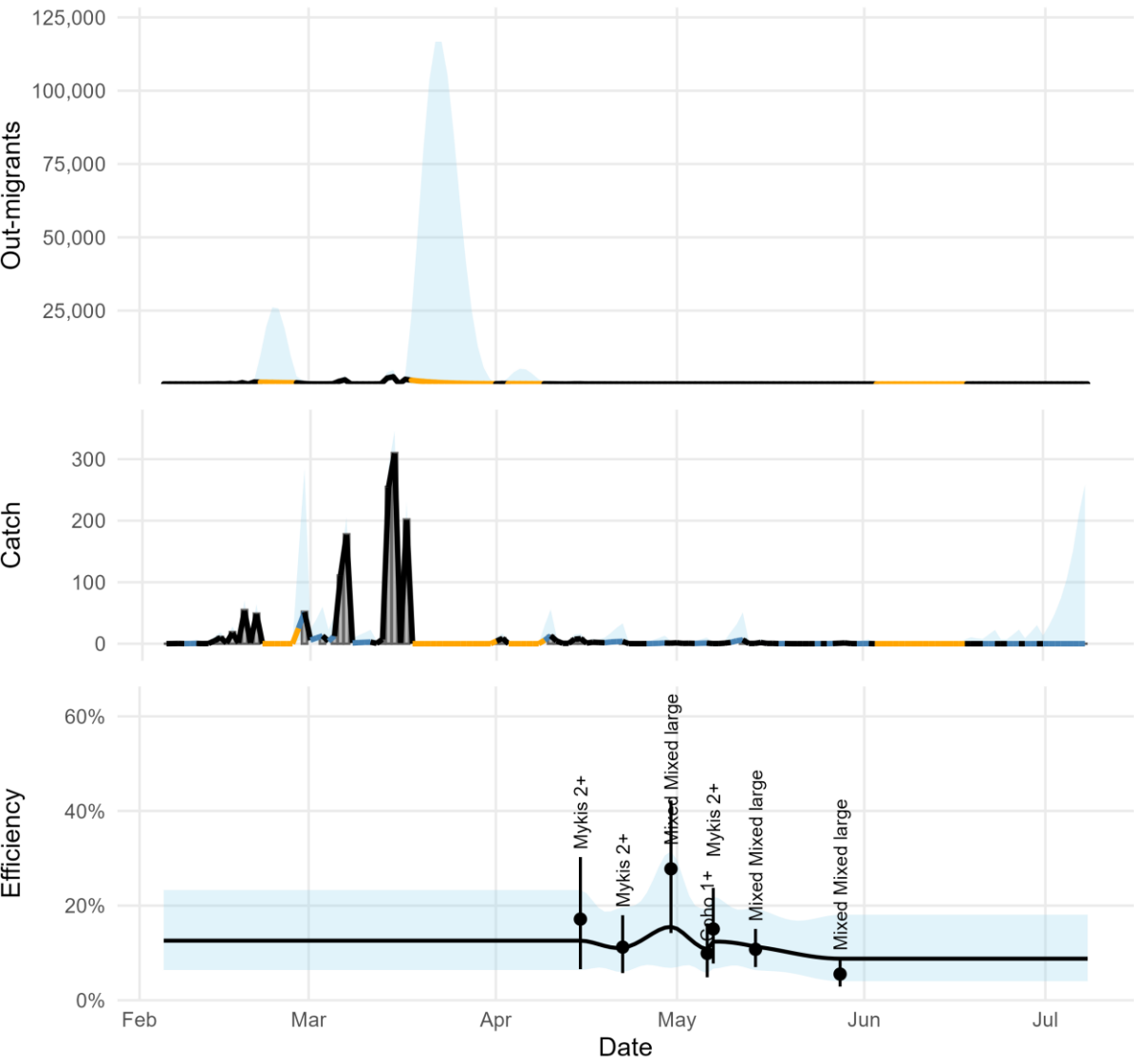
Little-2025-coho smolt

Total Estimate: 3,071 (1,575 - 5,423)



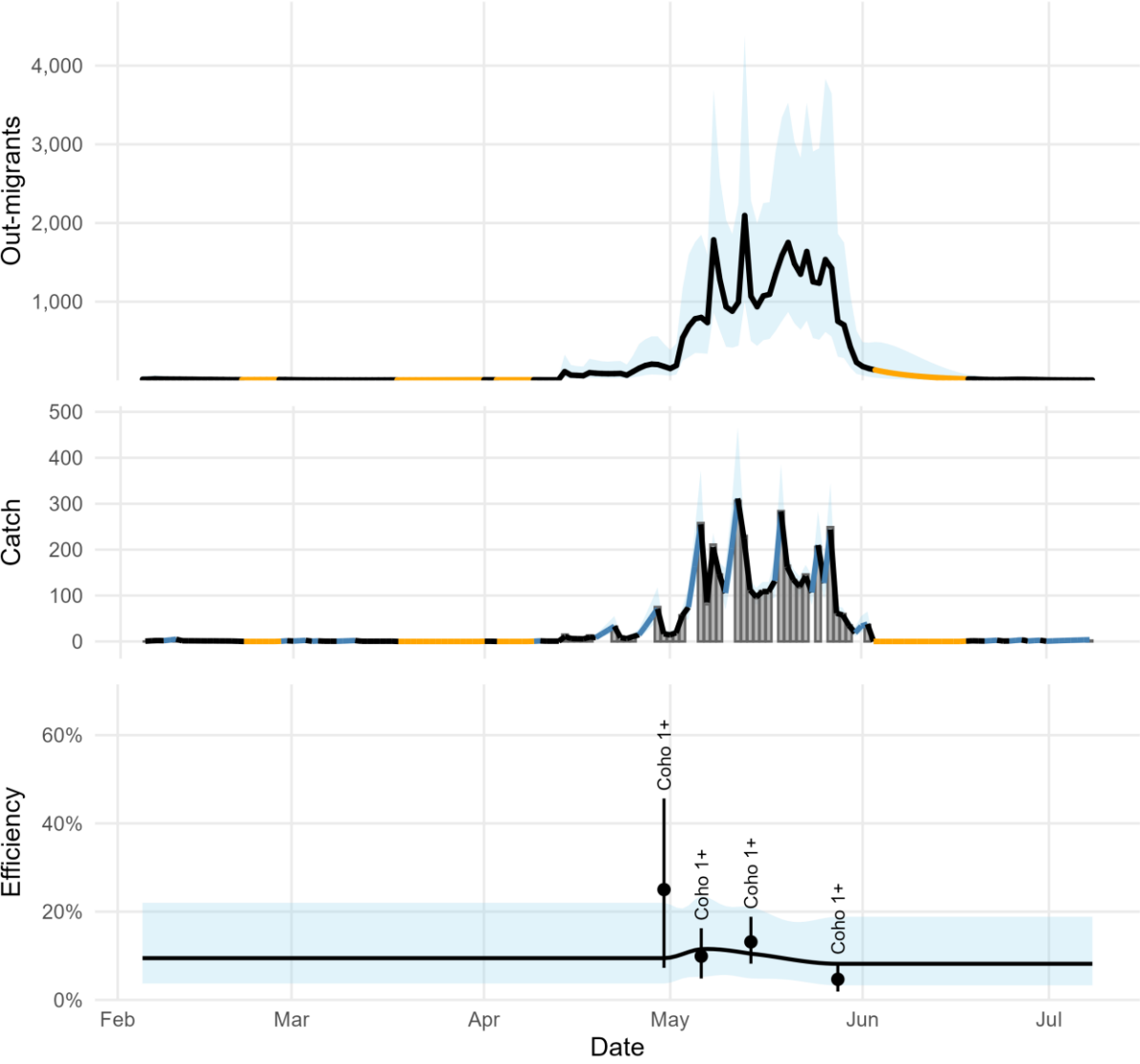
lowerMainstem-2025-chum

Total Estimate: 26,675 (6,090 - 76,885)



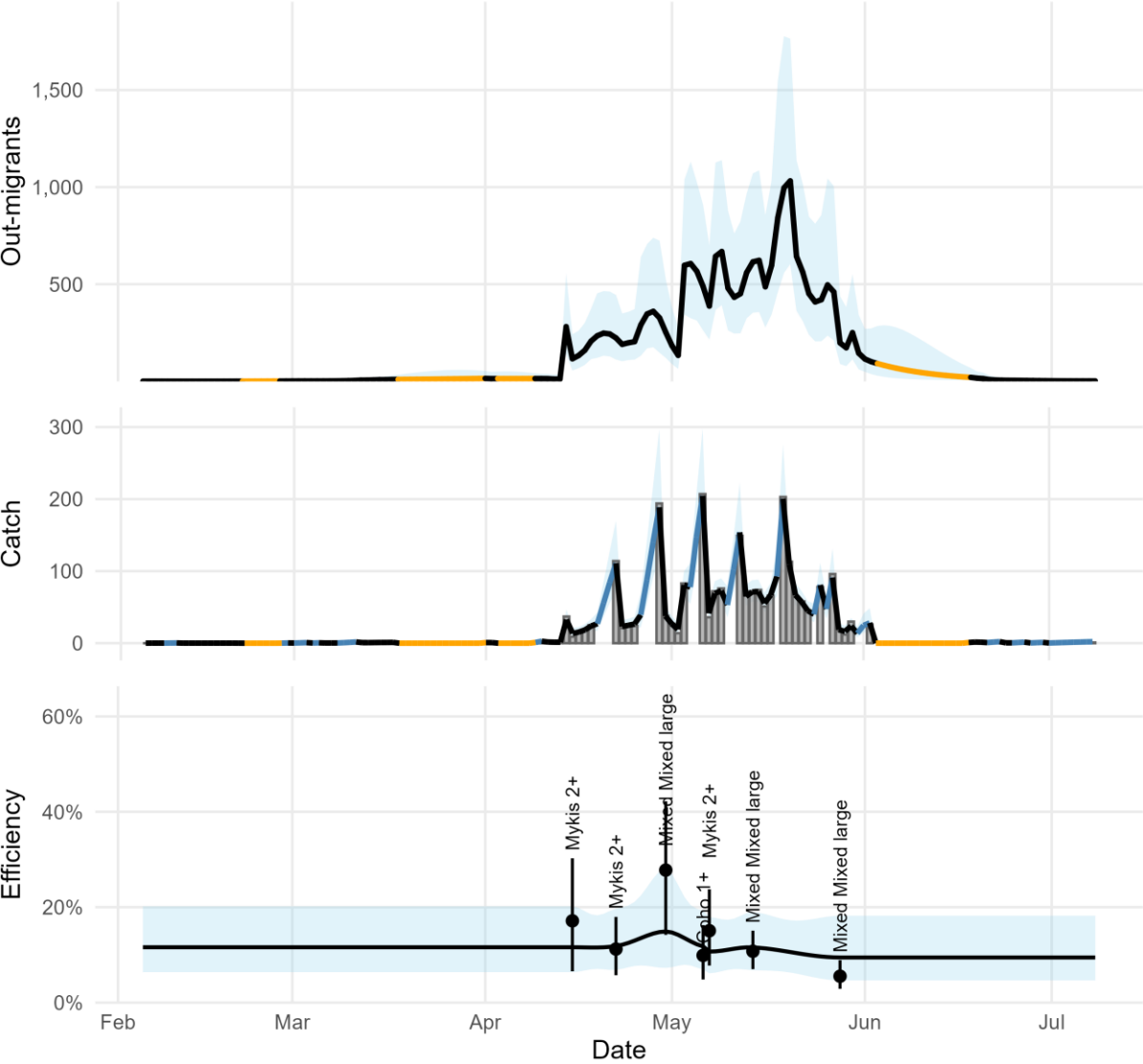
lowerMainstem-2025-coho smolt

Total Estimate: 38,667 (19,797 - 68,345)



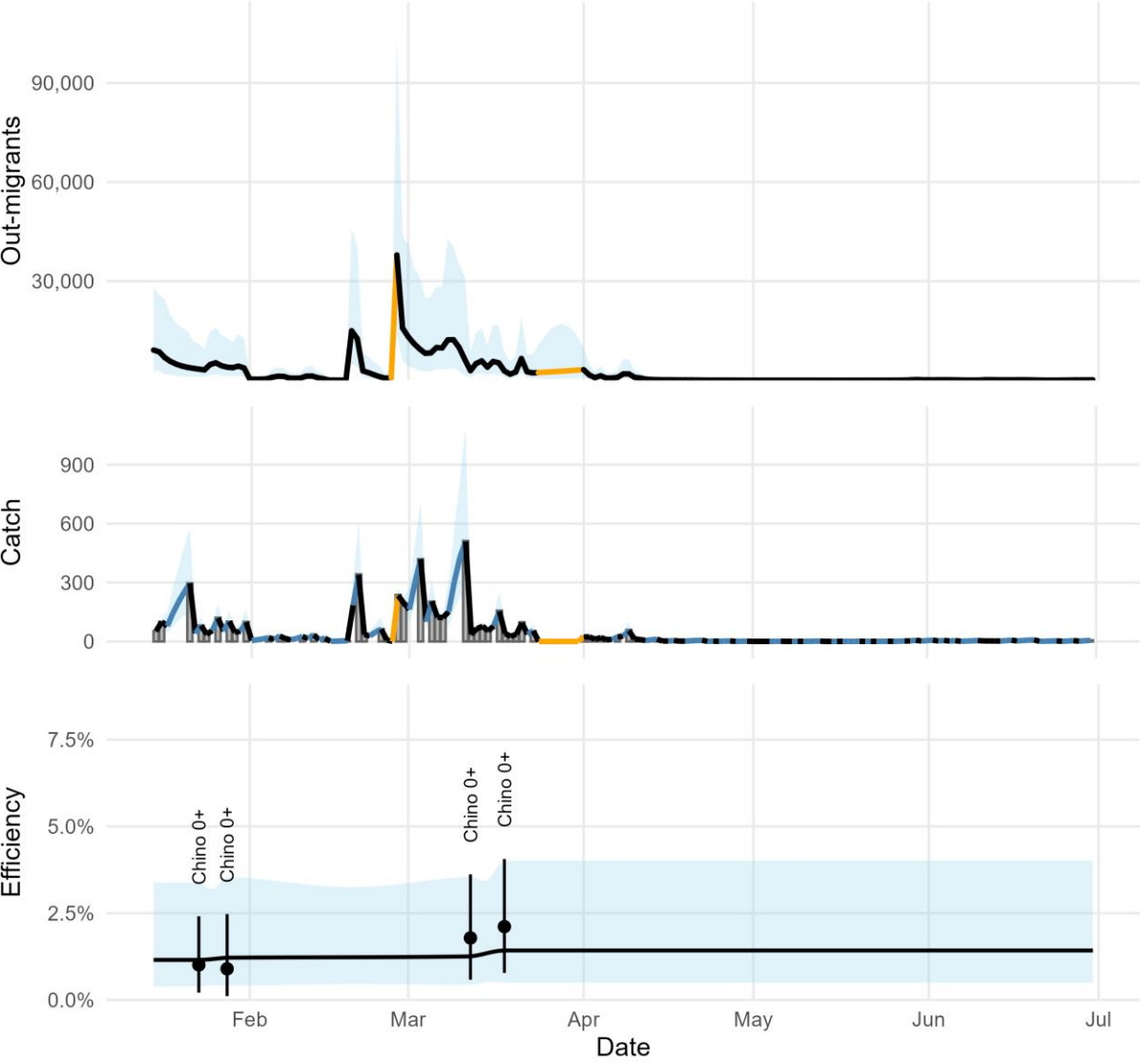
lowerMainstem-2025-mykiss smolt

Total Estimate: 21,610 (14,355 - 31,272)



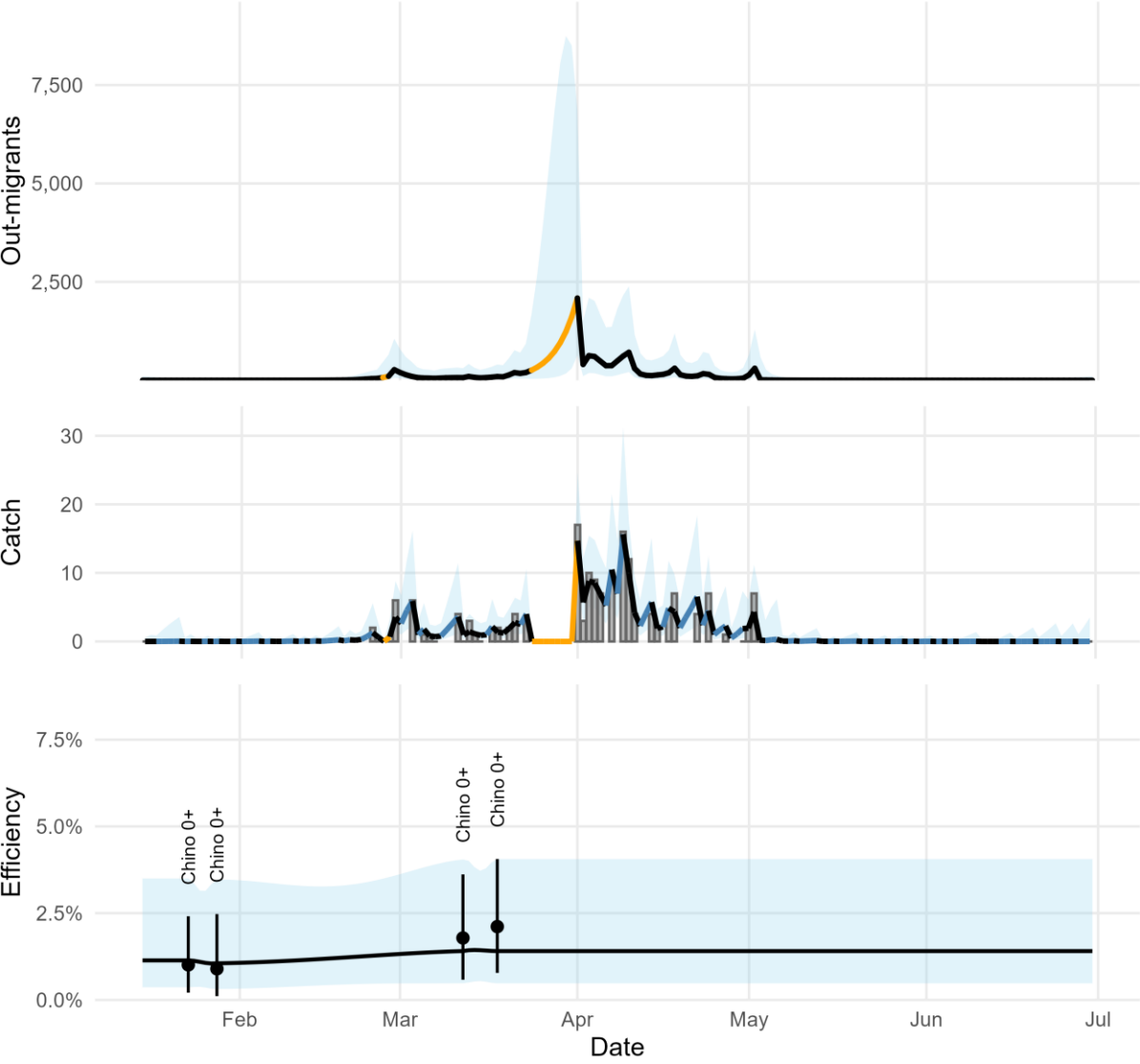
Mainstem-2025-chin 0+

Total Estimate: 430,840 (157,991 - 952,348)



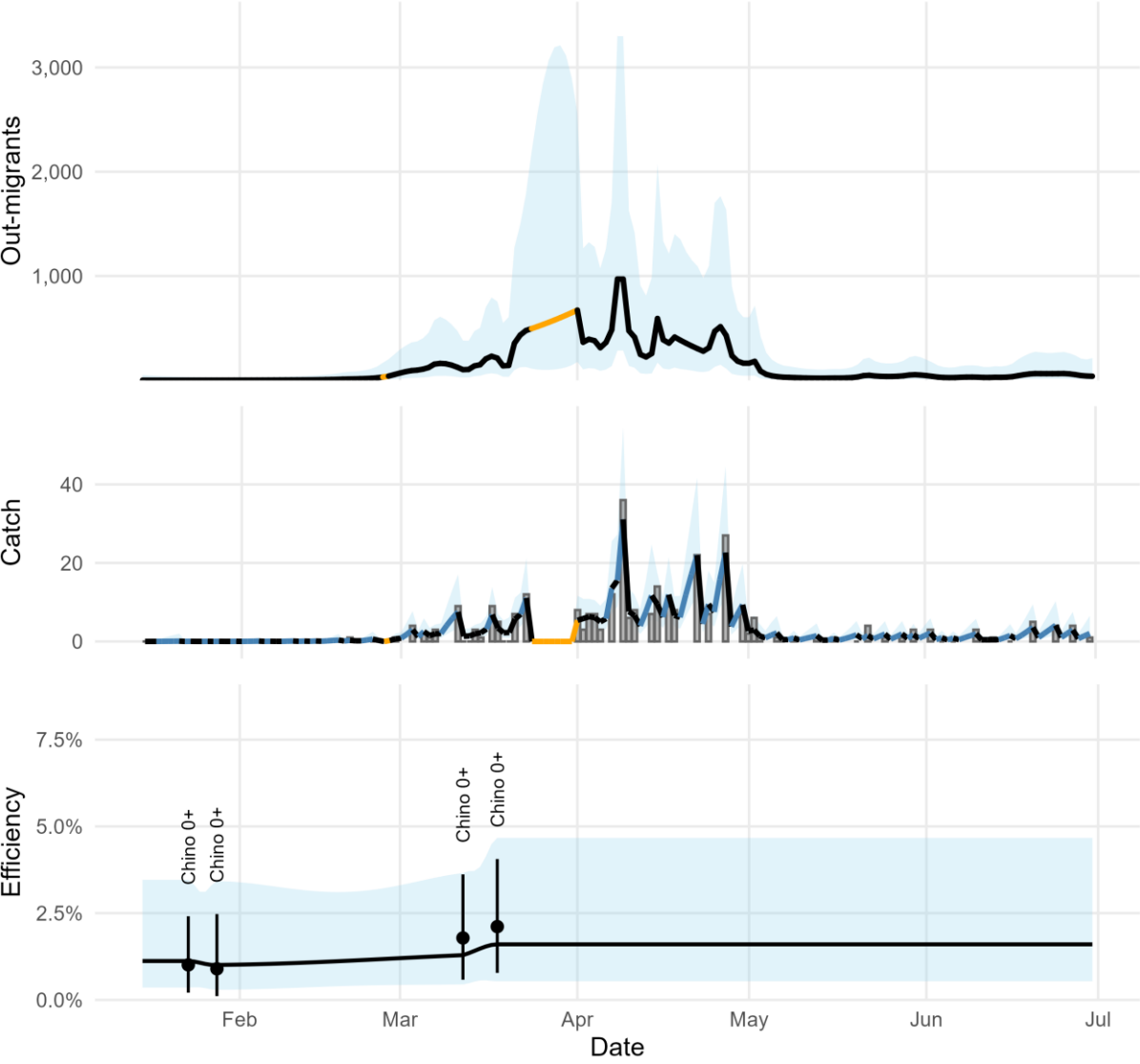
Mainstem-2025-chum

Total Estimate: 22,335 (6,192 - 58,132)



Mainstem-2025-coho 0+

Total Estimate: 27,611 (8,245 - 68,946)



Appendix C: Out-migrant Estimation Model Methods

Process Model: Daily Abundance and Efficiency The true daily abundance of out-migrants (N_t) was modeled as a latent, first-order random walk process in log-space. To accommodate the highly episodic nature of smolt out-migration, the step sizes of the random walk were drawn from a Student's t-distribution with 3 degrees of freedom. This heavy-tailed distribution allows the daily out-migrant abundance to generally follow a smooth temporal trend while permitting occasional, sudden migration pulses without artificially inflating the baseline process variance during periods of stable migration or missing data.

$$\log(N_t) \sim t(\text{location} = \log(N_{t-1}), \text{scale} = \sigma_N, df = 3)$$

Trap efficiency (p_t) was modeled in two stages to capture both global trap performance and seasonal trends. First, the efficiencies for the days on which point-in-time trials occurred (p_j) were modeled hierarchically in logit-space, drawn from a global mean efficiency distribution.

$$\text{logit}(p_j) \sim \text{Normal}(\mu_p, \sigma_p)$$

Second, to continuously estimate daily trap efficiency between these trials, the daily values ($\text{logit}(p_t)$) were derived using a deterministic Cubic Hermite spline interpolation of the trial-level estimates ($\text{logit}(p_j)$). This approach generates a smooth, continuous efficiency curve across the season that naturally flattens (slope of 0) at the first and last trials, preventing erratic extrapolations at the tails of the season.

Observation Model: Daily Catch and Efficiency Trials The expected catch on any given day ($E[C_t]$) is the product of the estimated daily abundance, the estimated daily efficiency, and the proportion of the day the trap was actively fishing.

$$E[C_t] = N_t \cdot p_t \cdot \left(\frac{\text{hoursFished}_t}{24} \right)$$

To account for periods where the trap was fishing but not checked, the expected daily catches were accumulated over the continuous un-checked period. The total observed catch at the time the trap was checked (C_{obs}) was then modeled using a Poisson distribution. Because the process model for abundance natively accounts for heavy-tailed variance (overdispersion in the true number of fish), the observation error of the trap itself is adequately captured by the standard Poisson count process.

$$C_{obs} \sim \text{Poisson}(\sum E[C_t])$$

Information for the efficiency process model was informed by mark-recapture efficiency trials. For each trial, a group of marked fish (M_j) was released upstream, and the number of recaptured fish (R_j) was recorded. To account for overdispersion in recapture rates due to environmental fluctuations or schooling behavior, recaptures were modeled using a Beta-Binomial distribution. This distribution is parameterized by the expected trial capture probability (p_j) and a shared precision parameter (ϕ).

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

Model Implementation The model was implemented in the R programming language using the RTMB package. Unlike standard Bayesian MCMC software, RTMB uses automatic differentiation and the Laplace approximation to efficiently integrate out the daily random effects (abundance and efficiency) and maximize the marginal likelihood via the `nlmminb` optimizer. Model convergence was assessed by evaluating the final maximum gradient of the objective function. Model fit was evaluated through visual inspection of the raw data overlaid with the predicted daily catch, efficiency, and abundance trajectories.

The following R code defines the negative log-likelihood function used to fit the model parameters to the data.

```
f<- function(parms) {
  getAll(parms, dat)

  # Parameter transformations (log to real scale)
  sd_N <- exp(log_sd_N)
  sd_P <- exp(log_sd_P)
  phi  <- exp(log_phi)

  # -----
--
  # PRIORS
  # -----
--
  log_phi  %~~% dnorm(2, 2)
  log_sd_N %~~% dnorm(sd_N_prior_mean, sd_N_prior_sd)
  log_sd_P %~~% dnorm(0, 1)
  mu_P     %~~% dnorm(mu_P_prior_mean, mu_P_prior_sd)

  # -----
--
  # HIERARCHICAL PROCESS MODEL: Efficiency (Trial Level)
  # -----
}
```

```

--
logitP %~~ dnorm(mu_P, sd_P)

# -----
--
# OBSERVATION MODEL: Efficiency Trials (Beta-Binomial)
# -----
--
p_trial <- plogis(logitP)
alpha_bb <- p_trial * phi
beta_bb <- (1 - p_trial) * phi

recaps %~~ dbetabinom(size = releaseSize, shape1 = alpha_bb, shape2 = beta_bb)

# -----
--
# PROCESS MODEL: Abundance (Random Walk)
# used t-dist with fat tails to allow for extreme values without huge standard deviation
# -----
--
#diff(logN) %~~ dnorm(0, sd_N)
diff(logN) %~~ dt2(mu = 0, sigma = sd_N, df = N_df) # fat tailed dist

# -----
--
# INTERPOLATION: Daily Efficiency (Sparse Matrix Multiplication)
# W_interp is a precomputed sparse matrix [nDays x nTrials] passed in 'data'
# -----
--
logit_p_daily <- as.vector(W_interp %*% logitP)

# -----
--
# OBSERVATION MODEL: Catch (Poisson)
# -----
--
p_daily <- plogis(logit_p_daily)
daily_expected <- exp(logN) * p_daily * (hoursFished / 24)

# Map daily expected catch to multi-day trap checks

```

```

expected_per_check <- as.vector(A %*% daily_expected)

# Poisson likelihood for observed catch
obsCatch %~% dpois(expected_per_check + 1e-8)

# -----
--
# ADREPORT
# -----
--
total_N <- sum(exp(logN)); ADREPORT(total_N)
log_total_N <- log(total_N); ADREPORT(log_total_N)
N_daily <- exp(logN); ADREPORT(N_daily)
log_daily_catch <- log(daily_expected + 1e-8); ADREPORT(log_daily_catch)
ADREPORT(logit_p_daily)
ADREPORT(p_daily)

}

```