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Title: Leveraging Delta Smelt Data for Juvenile Chinook Salmon Monitoring in the San Francisco Estuary

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Abstract

Monitoring is an essential component in ecosystem management and leveraging existing data sources for multiple species of interest can be one effective way to enhance information when making management decisions. Here we analyzed juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) bycatch data that has been collected by the recently established Enhanced Delta Smelt Monitoring program (EDSM), a survey designed to estimate the abundance and distribution of the San Francisco Estuary's (estuary) endangered Delta Smelt (*Hypomesus transpacificus*). Two key aspects of the EDSM program distinguish it from other fish surveys in the estuary: a stratified random sampling design and the spatial scale of its sampling effort. We integrated the EDSM dataset with other existing surveys in the estuary and used an occupancy model to assess detection probability differences across gear types. We saw no large-scale differences in size selectivity, and while detection probability varied among gear types, cumulative detection probability for EDSM was comparable to other surveys due to the program's use of replicate tows. Based on our occupancy model and sampling effort in the estuary during spring of 2017 and 2018, we highlighted under-sampled regions that saw improvements in monitoring coverage due to EDSM. Our analysis also revealed that each sampling method has its own benefits and constraints. Although the use of random sites with replicates as conducted by EDSM can provide more statistically robust abundance estimates relative to traditional methods, the use of fixed stations and simple methods such as beach seine may provide a more cost-effective way of monitoring salmon occurrence in certain regions of the estuary. Stronger inference on salmon abundance and distribution can be made by leveraging the strengths of each

survey's method. Careful consideration of these trade-offs is crucial as the management agencies of the estuary continue to adapt and improve their monitoring programs.

Introduction

Estuaries are among the most important, heavily impacted, and degraded ecosystems on Earth. The majority of the human population lives in coastal areas around estuaries in part because estuaries are some of the most biologically productive areas in the world (Kennish 2002) and provide valuable ecosystem services (Lotze et al. 2006; Borja et al. 2010). The San Francisco Estuary (hereafter referred to as "the estuary") is the largest estuary on the West Coast of North America and provides important habitat and migratory pathways for over 40 freshwater, estuarine, euryhaline, marine, and anadromous fish species (Moyle 2002). However, human modifications related to flood risk management, water supply to major urban and agricultural areas, as well as urbanization, have resulted in large-scale impacts to the landscape, hydrology, and ecology of the estuary (Nichols et al. 1986; Moyle et al. 2010; Castillo et al. 2018). Today, the majority of the estuary's historical wetlands have been drained, tidal rivers have been channelized, and many reservoirs have been constructed on rivers that flow into the estuary. These system alterations have had profound impacts on a number of endemic aquatic species and their habitats in the estuary (Stevens and Miller 1983; Nichols et al. 1986; Cloern et al. 2016).

Monitoring is crucial for understanding how species and ecosystems respond to anthropogenic impacts and the subsequent management actions to mitigate them. The estuary is one of the most studied and monitored estuaries in the world. Our understanding of this highly complex estuarine ecosystem has been advanced over the years by multiple long-term monitoring programs (Brown and May 2006; Kimmerer et al. 2009; Thomson et al. 2010; Cloern et al. 2017), some of which span over five decades and have captured roughly a million fishes since their inception. These monitoring programs can be costly and time intensive. As such, natural resource agencies are often asked to allocate limited funds and maximize the value of each monitoring program (Joseph et al. 2009). One simple way to gain value in monitoring is to leverage data on non-target species to better understand ecosystem changes and inform management actions. A substantial portion of the monitoring efforts in the estuary were designed for a single species. For example, the California Department of Fish and Wildlife's (CDFW) 20-mm and Spring Kodiak Trawl (SKT) surveys target the endangered Delta Smelt (*Hypomesus transpacificus*) (Dege and Brown 2004; Polansky et al. 2018), while the Delta Juvenile Fish Monitoring Program (DJFMP)'s primary objective is to monitor juvenile Chinook Salmon (*Oncorhynchus tshawytscha*) rearing and migration through the estuary (IEP et al. 2019a). Despite the focus of these monitoring programs on single species, their datasets can still provide valuable insights on other members of the fish community (Brown and May 2006; Mahardja et al. 2017; Castillo et al. 2018).

One of the most recently established monitoring programs in the estuary is the Enhanced Delta Smelt Monitoring program (EDSM). The EDSM is a spatially and temporally intensive sampling effort for the endangered and endemic Delta Smelt that was initiated late in 2016 to better assess the abundance and distribution for all life stages of this species (USFWS et al. 2019). Delta Smelt is a highly important species to the estuary due to its recent precipitous decline and impact on California's water management (Moyle et al. 2018). The intensity and breadth of EDSM's sampling effort requires a large investment of resources and the scientific and management value of this monitoring program can be increased by leveraging its bycatch data for other species of concern such as Chinook Salmon.

The estuary supports fall-, late fall-, winter-, and spring-run Chinook Salmon named after the timing of the adult upstream migration. Of the four runs of Chinook Salmon, two are listed under the federal Endangered Species Act (NMFS 2009; NMFS 2019): winter-run as endangered and spring-run as threatened. A recent review of the winter-run Chinook Salmon monitoring network in the estuary (Johnson et al. 2017) highlighted key information gaps that preclude accurate assessment of the status and trends of this endangered and endemic run of Chinook Salmon. However, the potential use of information from non-salmon focused surveys was not considered in Johnson et al.'s (2017) review, likely because monitoring effort at the scale of EDSM did not exist at the time.

The EDSM dataset could offer an opportunity to supplement existing monitoring data on Chinook Salmon because it differs fundamentally from most of the estuary's long-running fish surveys. EDSM uses a stratified random sampling design (Stevens and Olsen 2004) whereas other fish monitoring programs in the estuary sample at fixed stations. Additionally, EDSM collects replicate samples at each location to account for imperfect detection (i.e., false zero catch), a relatively uncommon procedure for monitoring programs in the estuary. Here we aim to explore how the methods used by EDSM can be leveraged to improve inferences drawn from the existing salmon monitoring network in the estuary. Our objectives were to: 1) compare the overall capability of EDSM in detecting juvenile Chinook Salmon relative to other surveys currently used to monitor the species in the estuary, and 2) assess the value that EDSM adds to the estuary's salmon monitoring network. Note that our investigation is not meant to be a comprehensive analysis of Chinook Salmon capture probability, nor is it a re-evaluation of the overall Central Valley salmon monitoring network. This paper highlights new information that EDSM contributes to Chinook Salmon monitoring. Consequently, our geographic range is also largely limited to the tidal freshwater and brackish portion of the estuary monitored by EDSM.

Methods

Study System

The estuary's watershed spans about 40% of California, carrying runoff produced in the 163,000 km^2 area bounded by the Cascade and Sierra Nevada mountains (Cloern and Jassby 2012). It is of major socioeconomic importance as a cornerstone of the California water infrastructure, supplying water to a multi-billion dollar national and international agribusiness, and for approximately one third of California's population (Lund et al. 2008; Lund 2016). The estuary is largely influenced by natural tidal cycles and flows from two main tributaries within the California's Central Valley; the Sacramento River to the north and the San Joaquin River to the south (Figure 1). The Sacramento and San Joaquin rivers converge to form the Sacramento-San Joaquin Delta (Delta). Once a mosaic of river channels, tidal wetlands, floodplains, and riparian forest, the Delta now consists mainly of islands reclaimed for agriculture, separated by a network of leveed channels (Whipple et al. 2012). The tidal freshwater Delta is generally considered the uppermost extent of the estuary (Figure 1). Freshwater exits the Delta, then enters the Suisun Bay region before flowing through Carquinez Strait into San Pablo Bay, and finally passing under the Golden Gate Bridge at the exit of the San Francisco Bay to meet the Pacific Ocean.

Habitat alteration is of great concern for Chinook Salmon, especially at this southern end of Chinook Salmon's natural range where water diversions, predation, and temperature increase due to climate change pose additional conservation challenges (Yoshiyama et al. 2000; Williams 2006; McLain and Castillo 2010). Historically, salmon populated the entire drainage area of the estuary's watershed (Whipple et al. 2012). Currently, impassable dams reduce available upstream habitat to approximately 5% of the historically available river mileage (Reynolds et al. 1993). Juvenile Chinook Salmon use the estuary for rearing and migration and are thought to enter the estuary as early as October with residence time ranging from 41 to 117 days (del Rosario et al. 2013).

Four different runs of Chinook Salmon inhabit the California's Central Valley. However, properly identifying these distinct runs during the Chinook Salmon's juvenile life stage has been difficult. The California Department of Fish and Wildlife developed length-at-date criteria in 1989 to assign juvenile Chinook Salmon into the different runs based on timing and size (Fisher 1992); however, the inaccuracy of run assignment for Chinook Salmon based on this length-at-date criteria has been recognized for many years (Hedgecock 2002; Harvey et al. 2014). Yet, length-at-date criteria remains the primary method for identifying spring and winter-run Chinook Salmon for near-real time management in the system due to the time and cost currently associated with genetic analysis. Chinook Salmon management in the estuary further requires distinguishing wild-origin fish from hatchery-origin fish, which can also be challenging. Millions of hatchery-reared Chinook Salmon are released each year in the Delta and upstream (Sturrock et al. 2019). Hatcheries contribute substantially to Chinook Salmon populations within the system (Barnett-Johnson et al. 2007; Huber and Carlson 2015; Willmes et al. 2018), but while a considerable number of hatchery fish can be readily identified by the presence of adipose fin clip and coded-wire-tag, many are released unmarked. Given our inability to identify the different runs and natal origin of Chinook Salmon with high accuracy, we chose to analyze the species collectively rather than by run-timing or natal origin.

Data Sources

Enhanced Delta Smelt Monitoring Program

The EDSM program is a year-round weekly sampling program conducted by the U.S. Fish and Wildlife Service (USFWS) that provides: 1) fine-scale temporal resolution of Delta Smelt abundance and distribution, 2) early warning of potential adult and juvenile Delta Smelt entrainment events to the Delta's water pumps (Smith et al. 2019), and 3) supporting data for life cycle and entrainment modeling efforts (USFWS et al. 2019). Pilot sampling began in November 2016, with full-scale sampling starting in January 2017. Sampling year is divided into three phases of implementation that correspond with Delta Smelt life stages and management goals. Phase 1 samples adults using Kodiak trawls from approximately December through March, corresponding to the Delta Smelt spawning season. Phase 2 samples post-larvae and small juveniles using larval tow nets from approximately April through June. Phase 3 samples juveniles and sub-adults using Kodiak trawls from approximately July through November. The initiation and duration of phases can be dynamic depending on contemporary environmental conditions, catches, and management needs, but remained constant throughout the first two years of EDSM implementation and will likely stay static for years in the future. In this study, we only used Kodiak trawl data from Phase 1 of the first two years of EDSM (December 2016 − March 2017, December 2017 – March 2018). Juvenile Chinook Salmon are not captured effectively by the gear used during April–June (Phase 2) targeting larval and small juvenile Delta Smelt, and Chinook Salmon are present in low numbers within the estuary in Kodiak trawl samples during July–November (Phase 3).

Surface-oriented Kodiak trawls are used during Phase 1 to sample juvenile, sub-adult, and adult Delta Smelt based on their capability to retain Delta Smelt (Mitchell et al. 2017; Mitchell et al. 2019). The Kodiak net is composed of five panels, each decreasing in mesh size towards a live box at the cod end. The mesh size for each panel ranges from 5.1 cm stretch at the mouth to 0.6 cm stretch just before the live box. The live box (30.5 cm wide by 30.5 cm tall by 45.7 cm long) is composed of 0.18 cm thick aluminum perforated with 0.46 cm diameter holes. The live box contains internal baffles intended to minimize fish mortality and stress caused by flow pressure. The fully extended mouth size of the Kodiak net is 1.96 by 7.62 m. The Kodiak net is towed approximately 31 m behind two boats sitting approximately 4.5 m apart. At the front of each wing of the net is a 1.83 m metal bar with floats at the top and weights at the bottom to keep depth constant while sampling. The Kodiak net is connected to the boats using a 2.3 m rope bridle attached to a 30.5 m tow rope, which is attached to the metal bar on each side of the net. Starting in 2018, all Kodiak tows were standardized to 10 minutes in length under normal conditions. Before this, the duration of tows ranged between 2.5 and 10 minutes. All fish ≥ 25 mm fork length (FL) are identified to species or run and then measured to the nearest 1 mm FL. If more than 50 individuals of a juvenile Chinook Salmon run are captured within a single haul, a random subsample of 50 individual fish is measured for FL and the rest of the captured fish are counted but not measured.

The sampling region of EDSM is dynamic as it varies with Delta Smelt life stage and expected distribution. In general, the study area is defined as waters of the estuary occupied by Delta Smelt (Figure 2). The study area is divided into spatially defined, temporally dynamic strata. During Phase 1 of 2016−2017 there were four spatial strata corresponding to perceived risk of Delta Smelt entrainment into the South Delta water export facilities (see Figure A1, USFWS et al. 2019). As the program evolved, strata were modified to better reflect geographic boundaries or historical Delta Smelt distribution. Within each stratum, sampling locations are selected each week using a generalized random-tessellation stratified (GRTS) design (Stevens and Olsen 2004). The GRTS sampling procedure yields random samples that are spatially well-distributed across a stratum. Field crews sample 3–5 days per week for a total of 24–37 sites per week (2–15 sites per stratum). To account for false zeroes, at least two replicate tows are generally conducted at each site. From the beginning of the survey in December of 2016 through Phase 3 of 2017 (July 2017 – November 2017), if no Delta Smelt were caught at a site after the second replicate tow, up to five total tows were completed at sites within strata of (presumed) high Delta Smelt density, and up to eight total tows were completed at sites within strata of (presumed) low Delta Smelt density (Figure A1). In Phase 1 2017–2018, the maximum number of tows per site in low density strata was reduced from eight to six. EDSM applies a “stopping rule” to the number of tows conducted at each site to reduce potential impact to the Delta Smelt population from sampling take. Sampling with replicate tows at a site stops after at least one Delta Smelt is observed and at least two full tows are completed, unless 25 or more Delta Smelt are capture in the first tow. Generally, if 3–24 Delta Smelt are captured in the first tow, the duration of the second tow is reduced. If approximately 25 or more Delta Smelt are captured in the first tow, no replicate or additional tows are conducted.

Delta Juvenile Fish Monitoring Program

The USFWS DJFMP has used a combination of surface trawls and beach seines to evaluate the relative abundance and distribution of juvenile fishes in the estuary since 1976 (IEP et al. 2019a). Since 2000, three fixed trawl sites and 58 beach seine sites have been sampled weekly or every two weeks within the estuary and the lower Sacramento and San Joaquin rivers. Beach seines are used to assess the spatial distribution of juvenile Chinook Salmon in the Delta and upstream by targeting the shallow (≤ 1.2 m depth) near-shore habitats where small juvenile Chinook Salmon can typically be found. Beach seine sites are sampled with a single haul using a 15.2 m by 1.3 m beach seine net with 3 mm mesh. Beach seines are deployed along the shoreline by two crew members within unobstructed habitats (e.g., boat ramps, mud banks, sandy beaches) starting from the downstream portion of each site to limit disturbance (e.g., displacement of sediment into the site).

DJFMP trawls are used to examine the relative abundance of juvenile Chinook Salmon migrating in and out of the Delta: Sacramento and Mossdale trawl sites for entry points into the Delta at the Sacramento River and San Joaquin River, respectively, and Chipps Island trawl site for the exit point of the Delta at the confluence between Sacramento and San Joaquin rivers (Figure 2). The DJFMP samples the Chipps Island trawl site using a midwater trawl and the Mossdale trawl site using a Kodiak trawl. At the Sacramento River trawl site, a Kodiak trawl is used from October to March, while a midwater trawl is used for the remainder of the year with the thought that it would maximize the capture of larger Chinook Salmon and provide a more robust catch index for juvenile winter-run Chinook Salmon (McLain 1998). While the Kodiak trawls share identical dimensions among EDSM and the Sacramento and Mossdale trawl sites, the midwater trawl dimensions vary between the Chipps Island and Sacramento trawl sites (Table 1). Regardless of the site or type of trawl, a total of ten 20-minute tows are attempted Monday, Wednesday, and Friday each week to maximize temporal coverage. At the Sacramento and Chipps Island trawl sites, effort was increased from 5 to 7 days per week sampling in 2017 and 2018 for a separate study aimed at estimating gear efficiency and producing absolute abundance estimates for juvenile winter-run Chinook Salmon. Fish processing procedures at all DJFMP beach seine and trawl locations are identical to those followed by EDSM.

Spring Kodiak Trawl

The SKT survey was established by CDFW in 2002 to monitor the distribution and relative abundance of spawning Delta Smelt in the estuary (Souza 2002; Polansky et al. 2018). The core SKT survey samples from January to May with a single tow each month at 40 fixed stations that cover the range of adult Delta Smelt (Figure 2). The SKT survey is conducted with a Kodiak trawl net almost identical to that used by EDSM for 5 or 10 minutes at near-idle speed. Although Delta Smelt is the target species for the SKT, this survey has caught a substantial number of Chinook Salmon over the years (Castillo et al. 2018), and the similarity of its gear with EDSM is useful for comparison between randomized and fixed stations.

Yolo Bypass Fish Monitoring Program

Since 1998, the California Department of Water Resources has conducted fish monitoring in Yolo Bypass, a floodplain-tidal slough complex in the northern part of the Delta (IEP et al. 2019b). The Yolo Bypass Fish Monitoring Program (YBFMP), has included year-round beach seining at two week increments for roughly nine locations beginning in 2011. Beach seining is conducted by a single haul of an 8 x 1.2 m pole seine with 3 mm^2 mesh. Because the bank at many of the locations within the Yolo Bypass is steep, the seine is often pulled parallel instead of perpendicular to the shoreline (which differs from the DJFMP beach seine survey). In addition to the beach seine survey, YBFMP operates a rotary screw trap to sample out-migrating juvenile fishes, such as Chinook Salmon (Table 1). The screw trap is deployed near the downstream end of the Yolo Bypass Toe Drain (Figure 2) typically around January and is fished during the weekdays through June.

Knights Landing Rotary Screw Trap

The CDFW established the Knights Landing rotary screw trap sampling site on the upper Sacramento River in 1995 to provide an early warning of juvenile salmonids emigrating into the Delta and trigger water operation modifications (Figure 2). Out-migrating salmonids are sampled using two 2.4 m diameter rotary screw traps that are fished daily from approximately October through June. Captured Chinook Salmon are measured to the nearest 1 mm FL and weighed to the nearest 0.1 g. Detailed sampling procedures are outlined in various reports produced by CDFW (Snider and Titus 2000; Julienne 2016).

Data Analysis

Size Distribution Comparison

We constructed a series of bean plots illustrating size-frequency distributions of Chinook Salmon catch over time to explore differences between sampling programs. Bean plots provide a convenient way to characterize the distribution shape of continuous data, which is given by a kernel density estimate computed within the "beanplot" function and library in R (Kampstra 2008; R Core Team 2018). We limited data to those that overlap with the EDSM data used in this study (*i.e.,* December 2016 – March 2017, December 2017 – March 2018). For this size distribution comparison, we further limited the data by excluding catch without length measurements and catch of known hatchery-origin Chinook Salmon that were identified by a clipped adipose fin. Sample locations from all monitoring programs were spatially joined in ArcGIS (version 10.6.1) by geographic proximity to EDSM region (Figure 2) to ensure comparisons were made with the same or nearby EDSM region. We also summarized these data to quantify the differences in catch and size distributions of juvenile Chinook Salmon in the estuary (see Table 2).

Occupancy Model

To assess large-scale relative differences in detection probability of juvenile Chinook Salmon between surveys, we used an occupancy model framework (MacKenzie et al. 2002). An occupancy model uses replicate samples conducted within each site in a set of sites to simultaneously estimate occupancy (the probability that a randomly selected site in the study area is occupied) and detection (the probability of detection at a site conditional on occupancy) for a species of interest. A site's detection history consists of a series of 1's (indicating detection) and 0's (indicating non-detection) reflecting the outcomes of the replicate samples (e.g., 011 for non-detection, detection, detection). Detection histories can be used to construct a likelihood for estimating occupancy and detection probabilities. It is generally assumed that the occupancy status (occupied or not occupied) of a site remains constant throughout the period during which replicate samples are collected; this is known as the closure assumption (MacKenzie et al. 2002).

We defined our study area as the San Francisco Estuary (Figure 1), our study time frame as December through March, and our species of interest as juvenile Chinook Salmon. We divided the estuary into 39 geographic subregions (edited slightly from EDSM subregion cutoffs to be more applicable for Chinook Salmon; see Figure 2), defined a site as a unique combination of subregion and date, and treated samples collected by EDSM, DJFMP, SKT, and YBFMP in a given subregion–date as replicates. We modeled occupancy probability, Ψ, and detection probability, p, in terms of three categorical variables, Region, Month, and Gear:

$$\Psi(\text{Region} + \text{Month}) \quad (1)$$

$$p(\text{Region} + \text{Month} + \text{Gear}). \quad (2)$$

Region reflects a coarse spatial partitioning of the Estuary, with each of the 39 subregions falling into only one of the 11 regions (Figure 2), and Month reflects the month (December, January, February, or March) during which a sample was collected. We included Region and Month to account for spatiotemporal variability in abundance that can affect occupancy and detection, but our primary interest was in Gear, which we used to assess relative differences in detection probability of juvenile Chinook Salmon between surveys. We divided Gear into six categories: EDSM Kodiak trawl, DJFMP Sacramento Kodiak trawl, DJFMP Chipps Island midwater trawl, DJFMP Mossdale Kodiak trawl, CDFW Spring Kodiak trawl, and beach seine (DJFMP and YBFMP combined). We kept the various Kodiak trawls separate in order to implicitly account for design differences between surveys (e.g., differences in tow durations, fixed vs. random site selection methods). We did not include common habitat predictor variables such as water quality parameters as they are beyond the scope of our study.

For further clarification on how we structured the data, suppose two EDSM samples and one beach seine sample were collected in a given subregion on a given date (i.e., a given site). Then the detection history for this site would be a vector of length three, for example (0,1,1), and the Gear covariate vector would be (EDSM, EDSM, seine). The Region vector would consist of the region value (corresponding to the given subregion) repeated three times. Similarly, the Month vector would consist of the month value (corresponding to the given date) repeated three times.

We fit separate models for the December 2016 – March 2017 time period and the December 2017 – March 2018 time period. The former corresponds to water year 2017, which was a record wet year with fairly high juvenile Chinook Salmon abundance, while

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the latter corresponds to water year 2018, which had below average precipitation and modest juvenile Chinook Salmon numbers. (We note that water year in California begins in October and ends in September). The two years provide good contrast, and running separate models allowed us to account for inherent differences between these two years while avoiding a great reduction in degrees of freedom through interaction terms. We fit both models using the “unmarked” package (Fiske and Chandler 2011) in R (R Core Team 2018).

Occupancy Model Interpretation

Our analysis represents the novel application of an occupancy model framework to data that were not collected as part of a dedicated occupancy study. Because of this, further discussion of model interpretation is warranted. With traditional occupancy models, individual locations are surveyed multiple times over the course of the study and the occupancy state (i.e., occupied or unoccupied) at a given sampling location does not change over the study (see Kéry 2010). Using this survey design, the interpretation of occupancy is the proportion of locations sampled in which at least one fish was present. This differs from our survey design and interpretation of occupancy. Based on how we defined a site (i.e., a subregion sampled on a given date),, occupancy represents the proportion of subregion-date combinations during which at least one fish was present in the subregion on that date. Thus, occupancy for a given region and month is then the proportion of subregion–date combinations (within the given region–month combination) that are occupied. It should be noted that this is different from—and more abstract than—the interpretation of occupancy as the proportion of days during which a given subregion was occupied.

Each tow or seine haul constitutes a subsample of a subregion. It can be argued that even temporal replicates (like those conducted by EDSM Kodiak Trawl, Sacramento Kodiak Trawl, Chipps Island Midwater Trawl, and Mossdale Kodiak Trawl) equate to spatial subsamples since water in the Estuary is constantly moving and a gear cannot realistically sample the exact same “patch” of water multiple times. This introduces the concept of local occupancy, i.e., occupancy at the sample level conditional on occupancy at the subregion level (Kendall and White 2009; Guillera-Arroita 2011). In our model, what we refer to as detection probability (Equation 2) is therefore an *effective detection probability* equal to the product of the probability of local occupancy and the probability of detection at the site level. Among other variables, local occupancy probability is a function of the proportion of subregion water volume sampled, with the probability of occupancy increasing from zero to one as the proportion sampled increases from zero to one. From this perspective, local occupancy can change from sample-to-sample. Here, however, we are attempting to capture large-scale relative changes in both local occupancy and sample-level detection through the Gear variable.

Defining site at the subregion–date level allowed us to have replicate samples while minimizing variability in occupancy and detection. For modeling, however, we used region and month covariates to keep the number of parameters relatively low while still accounting for changes in abundance that can affect detection regardless of which gear is used. The model would have a different interpretation if all samples from a given region or month were treated as replicates, and in that case, occupancy and detection estimates would be higher.

Cumulative Detection Probability

In addition to the single-sample detection probability estimates provided by the model, we investigated the ability of a given gear to detect at least one Chinook Salmon across "replicate" samples in a given month and region. We calculated gear-specific cumulative detection probability $\gamma_{r,m,g}$ as:

$$\gamma_{r,m,g} = 1 - \left(1 - \hat{p}_{r,m,g}\right)^{n}$$

where $\hat{p}_{r,m,g}$ is the model-estimated detection probability for gear *g* in month *m* and region *r*, and $n = 1, \ldots, 10$ is a hypothetical number of replicate samples.

We summarized the benefits of EDSM to Chinook Salmon monitoring efforts through a synthesis of our understanding of salmon biology, the use of existing surveys, and our modeling results. However, in order to provide a quantitative assessment of such benefits, we calculated the probability of detecting Chinook Salmon at least once in a given month and subregion conditional on the species' presence and on a particular level of sampling effort across gear types. We used 39 subregions (Figure 2), each of which falls into a single region, to examine detection differences during the study period on a finer geographic scale. We calculated the across-gear cumulative detection probability $\Gamma_{s,m}$ for subregion *s* and month *m* as

$$\Gamma_{s,m} = 1 - \prod_{g_{s,m} \in G_{s,m}} \left(1 - \gamma_{s,m,g}\right)$$

where $\gamma_{s,m,g}$ is the gear-specific cumulative detection probability for gear *g*, month *m*, and subregion *s* and the product is across the set of all gears $G_{s,m}$ that were used to sample subregion *s* and month *m*. Here we calculated $\gamma_{s,m,g}$ as

$$\gamma_{s,m,g} = 1 - \left(1 - \hat{p}_{r,m,g}\right)^{n_{s,m,g}}$$

where $n_{s,m,g}$ is the actual number of "replicate" samples taken by the gear and $\hat{p}_{r,m,g}$ corresponds to the region containing subregion *s*. We calculated $\Gamma_{s,m}$ under two scenarios, one with EDSM samples excluded and one with EDSM samples included, and subsequently calculated the increase in detection probability resulting from the inclusion of EDSM samples.

Results

Catch Summary

A total of 20,412 Chinook Salmon were sampled across the monitoring programs in December 2016 – March 2017 and December 2017 – March 2018 (Table 2). Out of this total, we observed the highest catch counts in January (n = 9,261) followed by February (n = 5,705), March (n = 4,790), and December (n = 656). Approximately 53.6% of the total Chinook Salmon catch was sampled from the Knight's Landing rotary screw trap (n = 10,946; Table 2). Beach seine monitoring programs consistently captured a large percentage of the monthly catch (Table 2) with DJFMP and Yolo Bypass sampling accounting for approximately 16.1% and 7.2% of the total salmon catch, respectively. Juvenile Chinook Salmon sampled by EDSM represented approximately 4.3% of the total catch. The Mossdale Kodiak trawl captured the least number of salmon with 0.6% of the total catch. We note however that some of the variation in catch statistics reported above are likely due to differences in sampling effort, survey location, and differences in salmon production from the Sacramento and San Joaquin basins (Carlson and Satterthwaite 2011; Table 1).

Size Distribution Comparison

Despite substantial differences in total catch across monitoring programs, the size frequency distributions of captured Chinook Salmon were relatively consistent (Figure 3; Table 2; Figure A2). The contrast between EDSM and Chipps Island Trawl was a notable exception. The Chipps Island Trawl captured larger salmon on average between December and March (Figure 3; Table 2). It may also be worth noting that size distribution differences between EDSM trawl and other surveys appear to differ more in the month of March (Figures 3 and A2). Variation in fish size was greatest in December (mean coefficient of variation [CV] = 0.412) and March (mean CV = 0.251) across monitoring programs (Figure 3; Table 2). We observed the least amount of variation in fish size in February (mean CV = 0.152; Figure 3; Table 2).

Occupancy Model

The data set used to fit the model for water year 2017 consisted of 698 sites (subregion–date combinations), with the number of replicate samples per site ranging from 1 to 32. Seventy-nine percent of sites had 1, 2, 5, 8, or 10 replicate samples (Table A1). The data set used to fit the water year 2018 model consisted of 903 sites, with replicate sample sizes ranging from 1 to 25. Eighty percent of sites had 1, 2, 5, 6, or 10 replicate samples (Table A1).

Overall occupancy probabilities were higher in water year 2017 than water year 2018 (Table 3). Occupancy was highest in the Sacramento River, Sacramento Deep Water Shipping Channel, Yolo Bypass, and Suisun Marsh regions in 2017 and in the Sacramento River, Suisun Bay, and Suisun Marsh regions in 2018. With the exception of February 2017, overall occupancy generally increased between December and March (Table 3; Figure A3). Detection probability for the beach seine was consistently higher than for any other gear (with the exception of Mossdale Kodiak Trawl), while detection probability for EDSM was consistently lowest (Figure A4). SKT detection probability was similar to that of Sacramento Kodiak trawl and Chipps midwater trawl except in water year 2018 when detection at Chipps Island was higher than SKT. In a given water year, temporal detection patterns were similar for all gears. For example, in water year 2017, detection increased from December to February and decreased in March.

Cumulative Detection Probability

Although EDSM had the lowest single-sample detection probability, as few as two or three replicate EDSM samples resulted in cumulative detection probability similar to a single-sample detection probability by SKT in both years, Sacramento Kodiak trawl in both years, and Chipps midwater trawl in 2017. Because EDSM conducts between 2 and 10 tows per site, typically with multiple sites per subregion, the cumulative detection probabilities for EDSM were generally comparable to single-sample detection probability of the other gears (Figure 4). The primary gains in cumulative detection probability from the addition of EDSM occurred in the lower estuary (*i.e.,* San Pablo Bay/Napa River, Suisun Bay, and Suisun Marsh), the lower San Joaquin River, the Sacramento River, and Cache-Slough Liberty Island, with the most dramatic increases occurring in March of each year (Figures 5 and A5).

Discussion

Effective management in a dynamic estuarine system can be challenging given the number of species in decline, limited resources, various interacting environmental drivers that continually change the system, and imperfect information to guide management and conservation actions. Monitoring is a crucial component of ecosystem management and leveraging existing data sources for multiple species can be one effective way to enhance information when making management decisions. Here we explored juvenile Chinook Salmon bycatch data collected by the recently established EDSM program (USFWS et al. 2019). Our examination of juvenile Chinook Salmon size frequency distribution indicates that, in general, fish surveys in the estuary capture similar sizes of juvenile Chinook Salmon from December to March (Figure 3). However, around Chipps Island, Kodiak trawls (as used by EDSM and SKT) appear to be under-sampling larger-sized salmon while DJFMP midwater trawl seems to be under-sampling smaller-sized salmon. This is in contrast to a previous study showing that Kodiak trawls catch larger salmon than midwater trawls on the Sacramento River (McLain 1998). The DJFMP midwater trawl used at Chipps Island has a larger net opening and mesh size compared to the DJFMP midwater trawl used on the Sacramento River (Table 1), which may explain this discrepancy (IEP et al. 2019a). If absolute abundance estimation for the various salmon runs in the estuary is the goal (Perry et al. 2016), then a relative gear efficiency assessment using existing data (Walker et al. 2017) or an additional side-by-side gear comparisons for juvenile salmon may be warranted to better understand the fish size bias associated with net and mesh dimensions (Mitchell et al. 2019).

The spatiotemporal patterns in occurrence and detectability we observed in our occupancy model were aligned with our understanding of Central Valley salmon life history. We expect to see detection probability increase with salmon density (*i.e.*, number of salmon available to be caught). As such, both occupancy and detection probability estimates were at their highest in February and March−the months in which we would expect higher catch of salmon within our December−March study period (Yoshiyama et al. 1998; Sturrock et al. 2015). Occupancy and detection probability estimates also tend to be higher in regions that are within the migratory pathway of salmon (*e.g.,* Sacramento River, Suisun Bay), whereas backwater areas such as the Sacramento Deep Water Shipping Channel had low cumulative detection probability estimates despite the amount of sampling that occurred (Figure 2). The wet water year of 2017 (December 2016–March 2017) saw considerably higher occupancy and detection probabilities (Table 3), consistent with previous studies that demonstrated a positive relationship between outflow and salmon occurrence in the estuary (Kjelson et al. 1982; Brandes and McLain 2001; Munsch et al. 2020). One potential reason for the higher occurrence of juvenile salmon in the estuary during high flow years (Figure A3) is floodplain inundation such as that observed in Yolo Bypass during 2017, which can increase habitat and create additional migratory pathways (Sommer et al. 2001). In the drier water year of 2018 (December 2017–March 2018), moderate to high occupancy probability estimates were primarily restricted to the Sacramento River and downstream (Table 3), likely reflecting the well-documented low survivorship of juvenile salmon along the San Joaquin River and the interior Delta (Newman and Brandes 2010; Perry et al. 2010; Buchanan et al. 2013; Perry et al. 2018).

We found considerable differences in detection probability among gear types and these differences remained consistent between the two years. In general, given a single sampling event, beach seines had the highest probability of detecting juvenile Chinook

Salmon in a region if the species is present, followed by the fixed station trawl, and then by the EDSM random-station trawl. Multiple factors likely led to this result. Beach seines occur in shallow-water, nearshore habitat, whereas the trawls take place in open water. Juvenile Chinook Salmon may rear in higher density in nearshore habitat than open water (Kjelson et al. 1982). The fixed station trawls that DJFMP conducts (Figure 2) are set in the migratory path of juvenile Chinook Salmon by design, therefore, we can expect these stations to have higher detection probability than randomly chosen sites. It is less clear why fixed sites for a Delta Smelt monitoring program such as the SKT would have higher detection probability for juvenile salmon than those selected at random. However, fixed stations are typically determined based on their higher fish catch and may be comprised of higher quality habitat for fish in general (McClelland and Sass 2012). Random sites as sampled by EDSM are meant to provide a snapshot of the estuary and may inadvertently survey microhabitats not used by juvenile salmon in a particular region.

It is also important to consider the assumptions of our model and how they may affect our results. We defined a site as any sub-region with at least a single sample on a given day. Based on this definition, a subregion can become occupied or unoccupied with little consideration for temporal correlation aside from the month variable. However, the occupancy of a subregion–date is naturally correlated with the occupancy of the same subregion on the previous date and subsequent date. In particular, if Chinook Salmon are present on the adjoining dates, it is more likely they will have been present on the intervening date. This lack of independence in occupancy between subregion–date combinations can lead to biased parameter estimates, overdispersion in the model, or both. A potential solution would be to incorporate extinction and colonization probabilities into the model (e.g., MacKenzie et al. 2003) to account for local exodus and re-occupancy of subregions, but this was beyond the scope of our objectives.

Our model also assumed that temporal and spatial replicates are exchangeable. EDSM and DJFMP trawls had temporal replicates, while the SKT and DJFMP beach seines had only spatial replicates (due to the lack of temporal replicates in their original survey designs). Spatial replicates may induce bias in occupancy estimates depending on sampling design (e.g. with or without replacement), the system, and species dynamics (Kendall and White 2009; Guillera-Arroita 2011; Charbonnel et al. 2014). The discrepancy in replicate types may have also contributed to some of the differences in the gear detection probabilities we observed. Having spatial replicates may lead to higher detection probability estimates merely because samples from multiple locations within the same subregion and day would likely have more independence (*i.e.*, lower correlation with one another) than multiple samples taken from a single location within the same subregion and day. Teasing apart the different factors that affect detection probability is outside the scope of our study. However, we expect that the relatively low detection probability of EDSM is partly due to differences in the number of spatial and temporal replicates.

Despite the relatively low detection probability of the EDSM trawl, we found substantial improvements in our juvenile Chinook Salmon monitoring coverage for water years 2017 and 2018 (Figures 5 and A5). This is largely owed to the wide geographical scope of EDSM and the frequency at which it conducts its sampling. At a single location, EDSM would typically conduct anywhere between two and ten replicate tows, which would increase the program's cumulative detection probability to levels comparable with other surveys (Figure 4). This was done four days per week throughout December to March in our study period across a large portion of the estuary, resulting in improved cumulative detection probability for juvenile salmon in regions that were generally under-sampled by other surveys (provided that salmon are present in detectable numbers). This added information was notable downstream of the Delta (Figures 5 and A5), where EDSM has observed fish that were winter-run and spring-run length-at-date sizes (Figure 6).

Having information in these key regions of the salmon migratory pathway can help better understand the species' life history variability (Sturrock et al. 2015; Goertler et al. 2018; Sturrock et al. 2020) and how they interact with environmental drivers such as water year type (Figure 6). Moreover, fixed stations are not likely to be representative of the estuary as a whole (IEP SAG 2013; Peterson and Barajas 2018) and may bias abundance estimation (McClelland and Sass 2012; Kiraly et al. 2014; Li et al. 2015). Incorporating random station data from EDSM can potentially aid the estimation of absolute abundance for juvenile Chinook Salmon through the proper calibration of fixed station random effects. Data from EDSM can also be used to better account for imperfect detection (*i.e.*, observation error), as the program's replicate tows are conducted within a fairly short timeframe and should not violate the closure assumption excessively (Peterson and Barajas 2018). However, there are aspects of the EDSM data that could limit its use for Chinook Salmon monitoring under the current state. The juvenile Chinook Salmon outmigration window in the estuary extends into the early summer months, and the larval fish gear that EDSM uses in these months does not capture juvenile salmon efficiently. The EDSM program also currently uses length-at-date criteria instead of genetic analysis, which may lead to erroneous assignments for the various Central Valley Chinook Salmon runs (Hedgecock 2002; Harvey et al. 2014).

For all fish monitoring programs, there will inevitably be trade-offs in temporal and spatial scales of measurement due to limited resources and at times, multiple objectives (Radinger et al. 2019). Recommendations have been made to adjust the estuary's salmon monitoring network, such as the addition of new gears, collection of fish condition information, or transition into randomized stations (IEP SAG 2013; Johnson et al. 2017). Stratified random sampling design offers many advantages and is generally preferable for estimating the abundance of a species given unlimited resources (IEP SAG 2013; Kiraly et al. 2014; Peterson and Barajas 2018). However, results from our model indicate that certain methods (*i.e.*, fixed station beach seines) are more cost-effective at detecting juvenile Chinook Salmon if the species is present in some areas (as it generally involves less staff and gear). For fixed station surveys, such as the DJFMP beach seine, modifying protocol to include some form of random station selection could provide similar benefits (*e.g.,* high detection probability, cost-effective) while allowing for better abundance estimation. Plans are currently being developed to implement a stratified random sampling design for the DJFMP beach seine survey in accordance with these recommendations (IEP SAG 2013), and it would be prudent to assess how detection probabilities change once this new design is implemented. However, for some aspects of juvenile Chinook Salmon management that focus on their occurrence at certain regions, such as the Delta Cross Channel gate operations (NMFS

2009; NMFS 2019), having higher detection probability at specific regions may be more desirable than a proper estimation of abundance.

This study serves as a first step in leveraging Delta Smelt monitoring data collected by EDSM to better understand juvenile Chinook Salmon monitoring in the estuary. Our results indicate that using EDSM data along with the traditional salmon surveys can improve our monitoring of under-sampled regions of the estuary and increase the spatial resolution of surveys within each region of the estuary. With data collected under a stratified random design, we can also make better inference on the true proportion of the estuary occupied by salmon at a given time period. Lastly, we demonstrated that trade-offs exist between various sampling designs undertaken by the fish monitoring programs we analyzed. By leveraging the strengths from each program, we can make stronger inferences about juvenile Chinook Salmon abundance and distribution patterns. Each survey design (*e.g.,* fixed station vs. random station) offers advantages that are tied to specific monitoring goals. Careful consideration of these trade-offs and the overall monitoring objectives is crucial as management agencies of the estuary continue to adapt and improve their monitoring programs.

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Figure Captions and Tables

Figure 1. An overview map of the San Francisco Estuary (estuary), showing the estuary's downstream extent at San Francisco Bay and its upstream extent at the Sacramento-San Joaquin Delta (Delta). Black outline indicates the boundaries of the legal Delta.

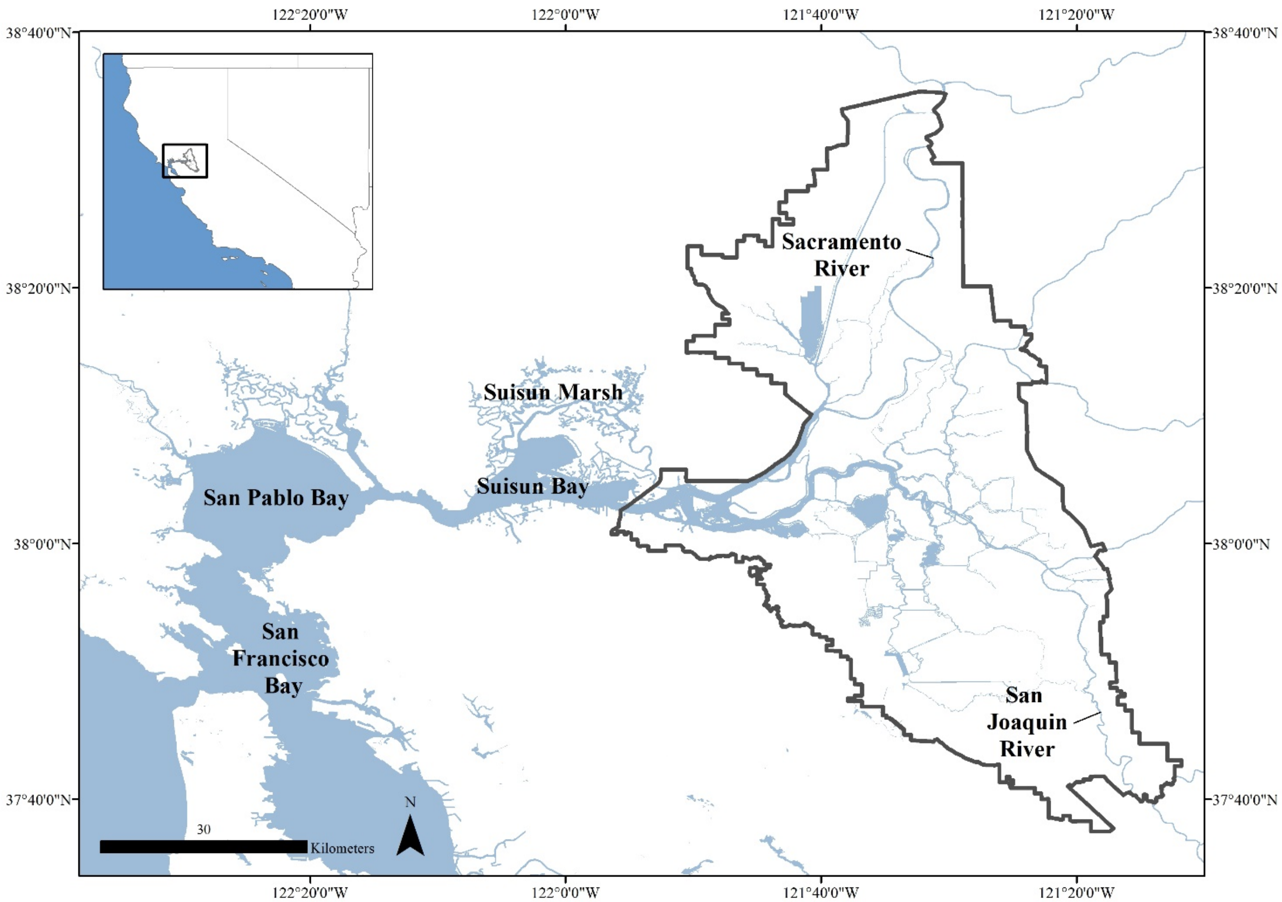

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Figure 2. Map of the study area including random sites sampled by EDSM during the study period (December 2016 – March 2017 and December 2017–March 2018), fixed stations sampled by other monitoring programs used in this study, the 11 regions used for occupancy modeling (in dark blue lines), and the 39 subregions (in grey lines) used to calculate across-gear cumulative detection probability.

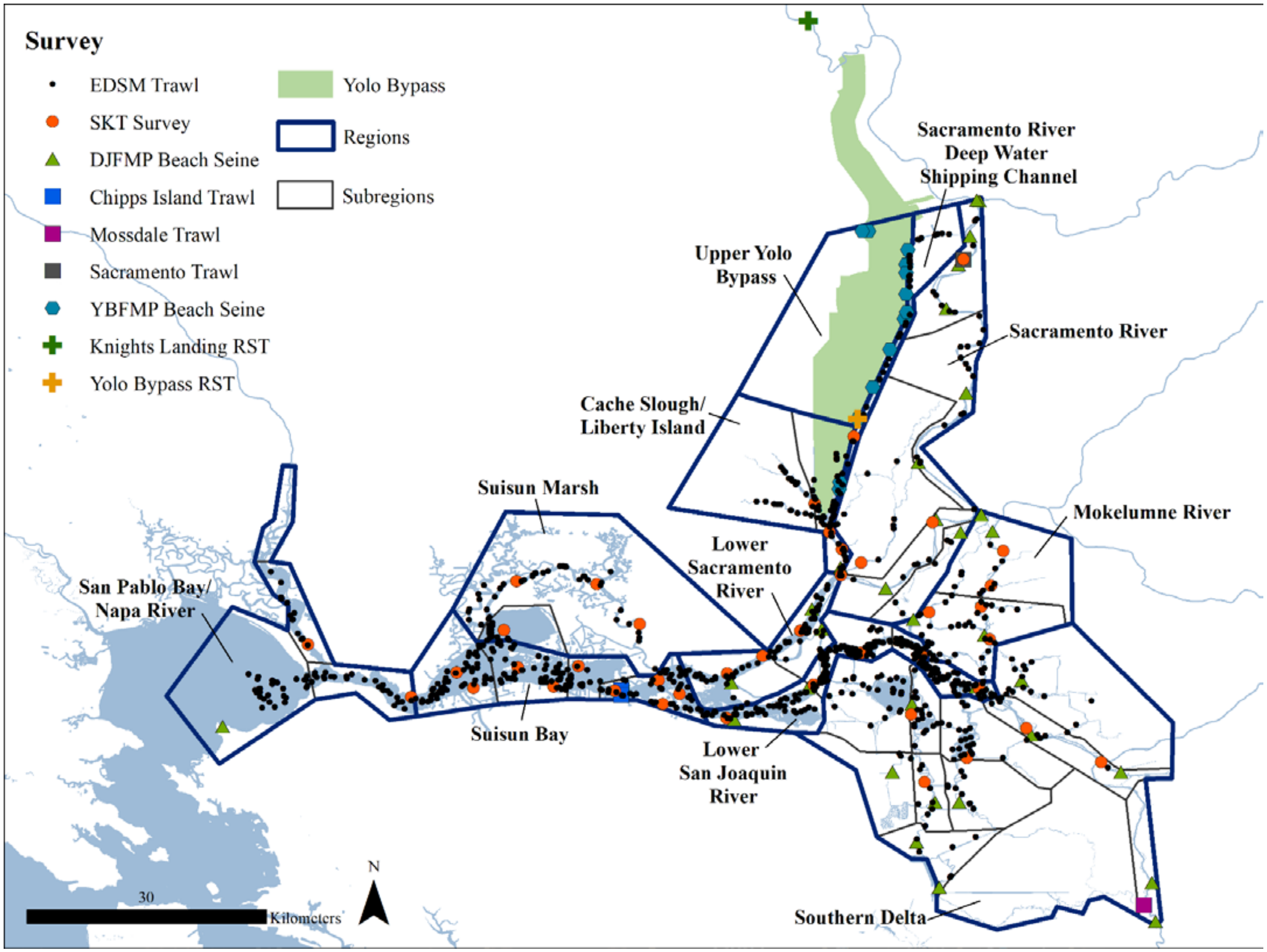

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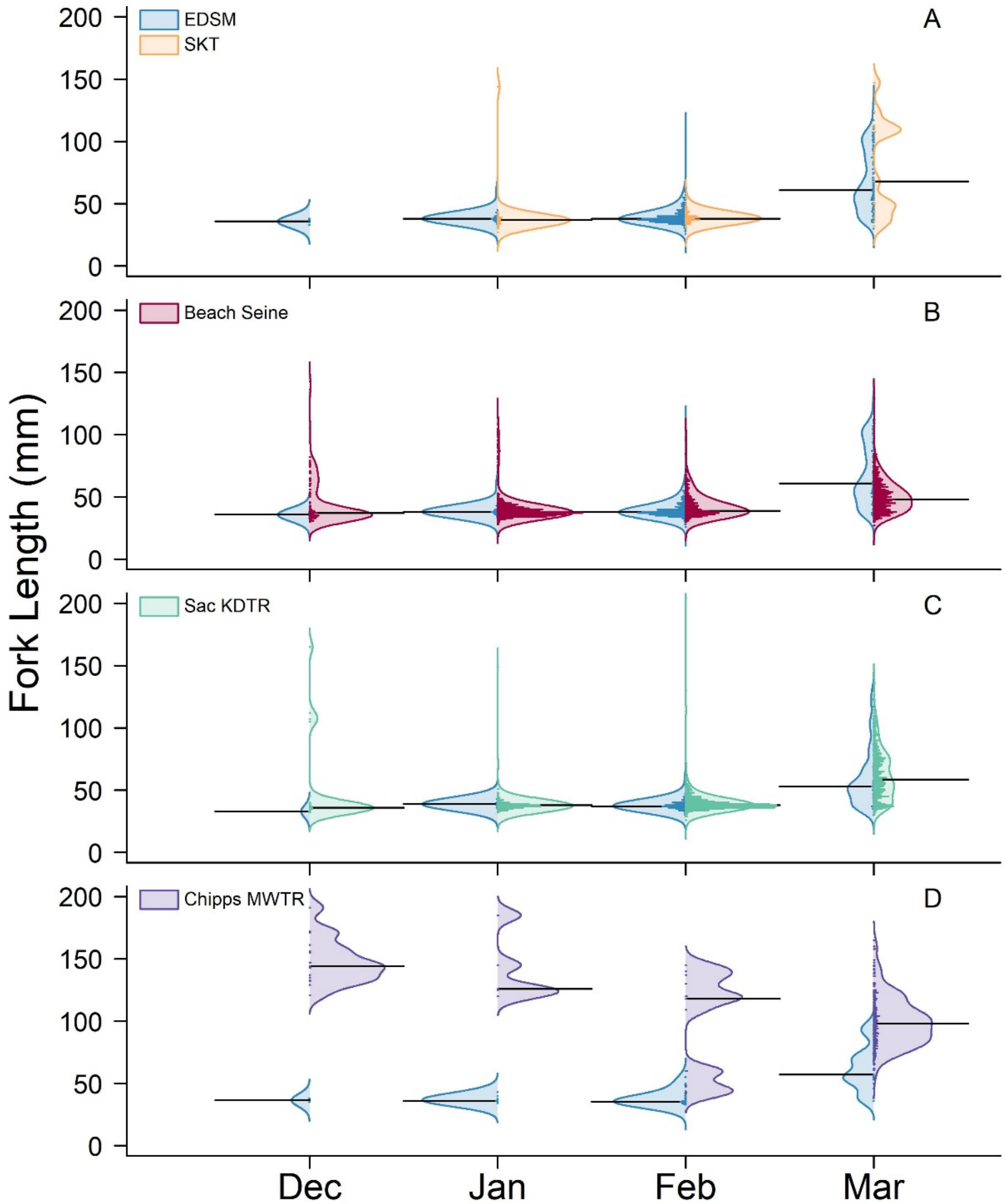
Figure 3. Series of bean plots comparing the size distribution of juvenile Chinook Salmon caught in EDSM Kodiak trawl relative to the SKT survey and three DJFMP methods. The bandwidth for all bean plots was set to 5 and the median fork length highlighted by the solid horizontal black line. Catch counts are illustrated by histograms within each density distribution polygon.



 doi:10.20944/preprints202006.0362.v2

Figure 4. Results from occupancy model demonstrating juvenile Chinook Salmon cumulative detection probability by EDSM Kodiak trawl relative to other gears from the Sacramento River subregion in March of 2018.

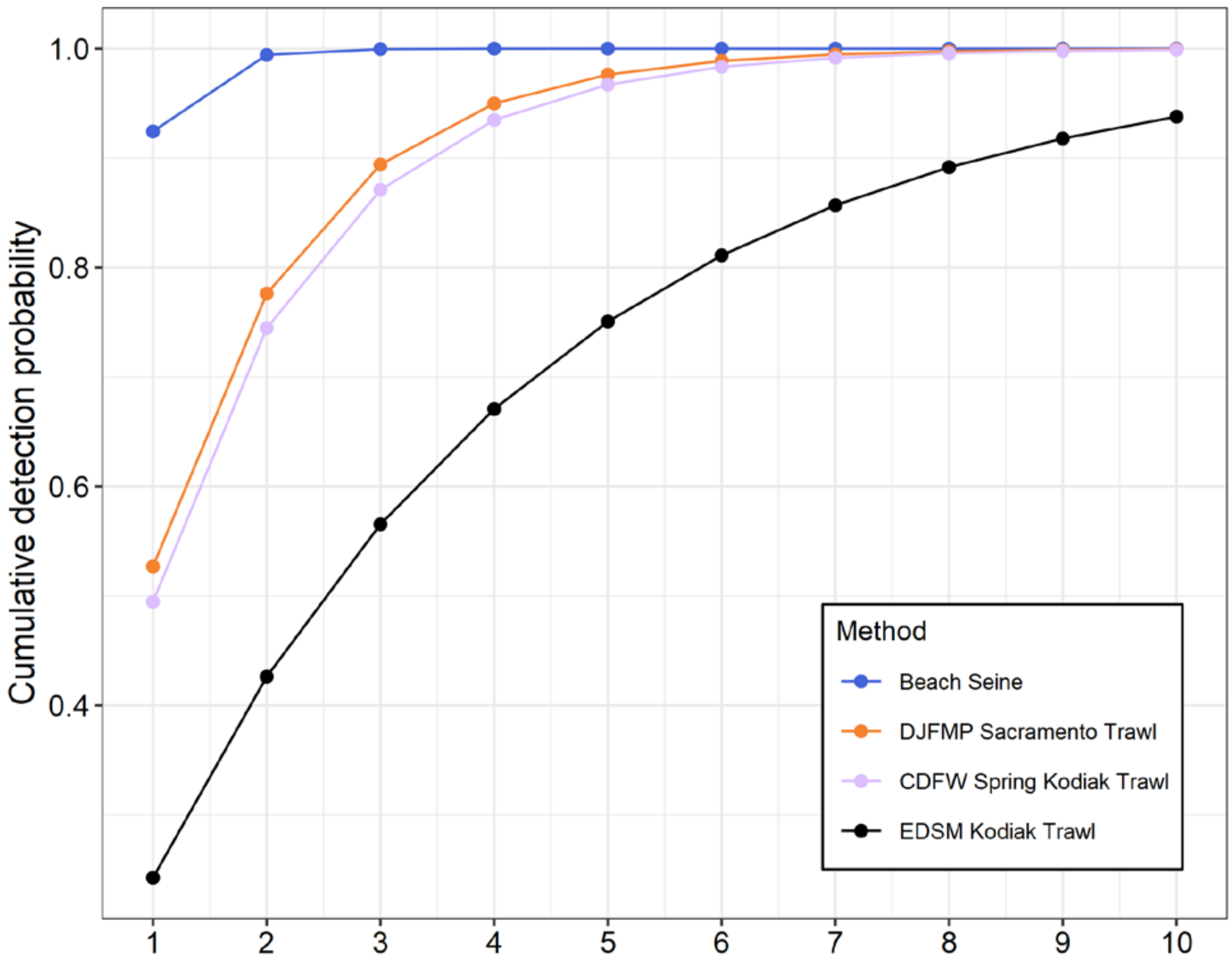


Figure 5. Cumulative detection probability summary (assuming salmon presence) by subregion for March of 2017 and 2018 demonstrating increased spatial coverage for juvenile Chinook Salmon through EDSM for both high (2017) and low (2018) density years. The top and middle rows show cumulative detection probabilities without and with the inclusion of EDSM sampling while the bottom row shows the resulting difference in probability when EDSM is included.

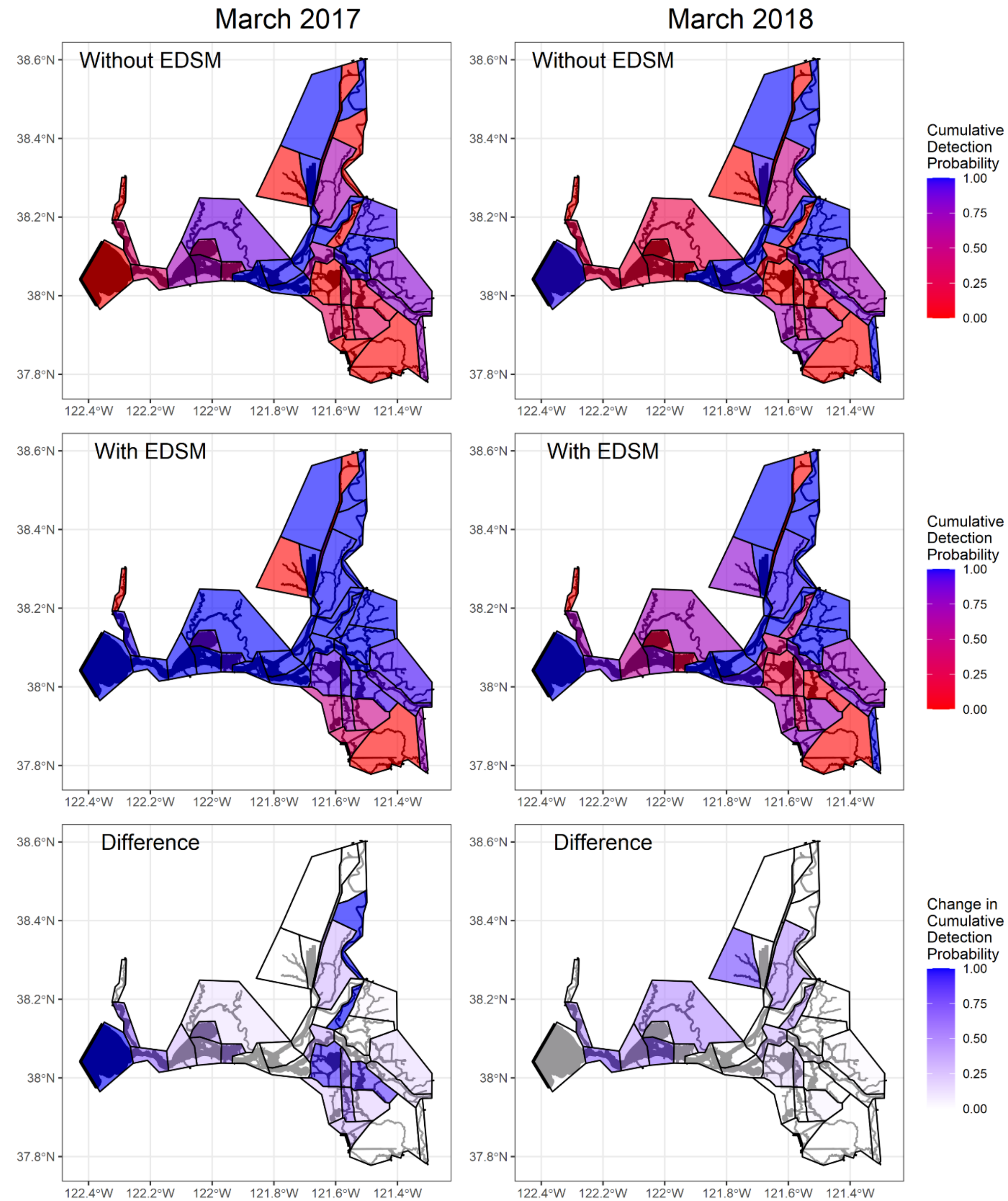


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Figure 6. Size and life stages of Chinook Salmon caught in EDSM Kodiak trawls from Suisun Bay, Suisun Marsh, and San Pablo Bay regions (as seen in Figure 2), demonstrating contrast in numbers and sizes of Chinook Salmon observed within this area between the wet water year of 2017 and moderately dry year of 2018. Only data from measured fish are shown on the figure. Colors denote different life stages of Chinook Salmon as classified by field crew and “n/p” indicates that it was not recorded (generally for adipose fin-clipped, hatchery fish).

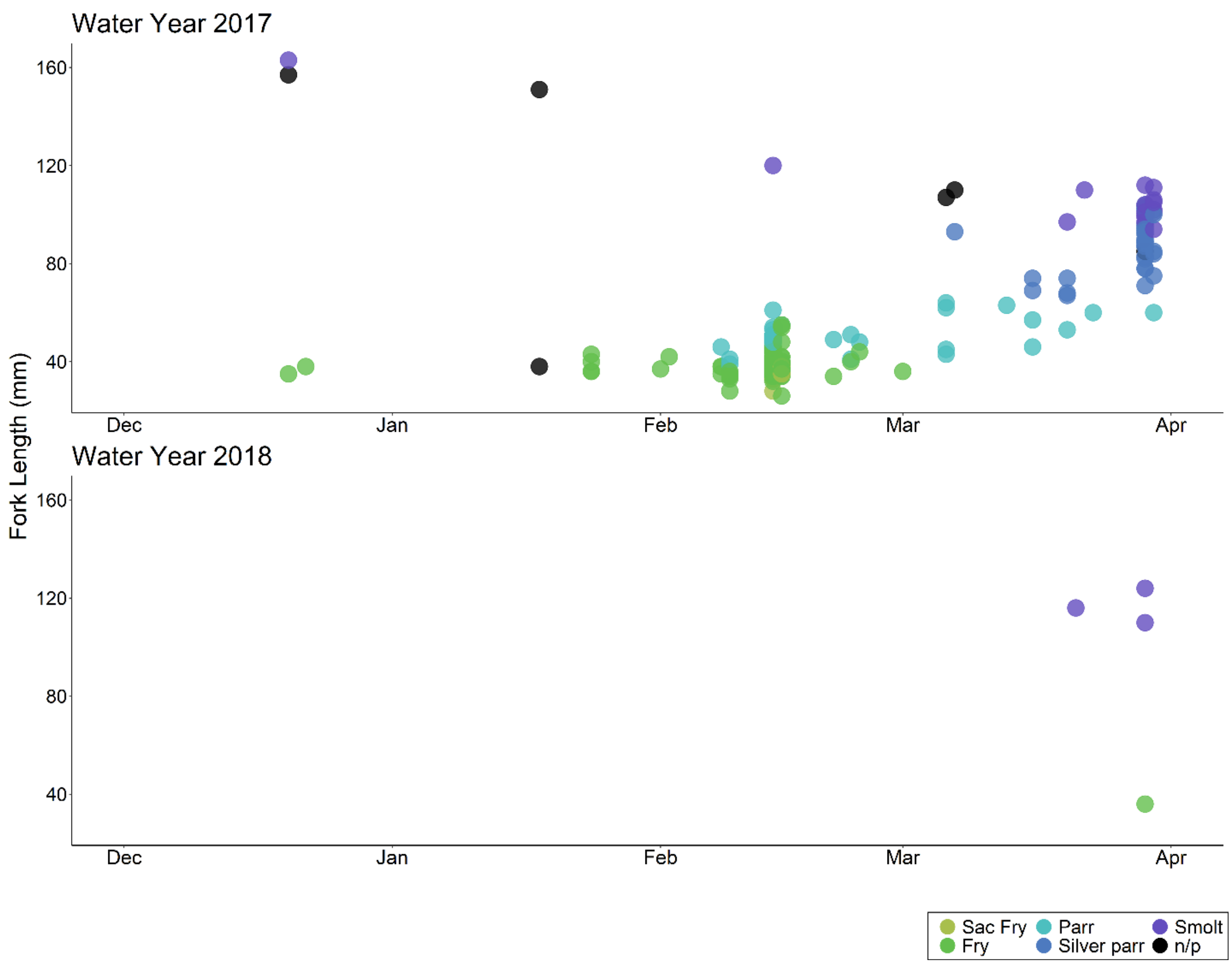

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Table 1. Summary table for this study's data sources

Monitoring Program	Agency	Gear Type	Gear Size	Months Sampled	Year Established	Region(s) Sampled
DJFMP Beach Seine	USFWS	Beach seine	15.2 m x 1.3 m net, 0.3 cm^2 mesh	Year-round	1976	Middle Sacramento River, Tidal Delta, Estuary, and Bays
DJFMP Chipps Island Trawl	USFWS	Mid-water trawl	18.6 m^2 mouth, variable stretch mesh	Year-round	1976	Tidal Delta
EDSM	USFWS	Kodiak trawl	12.5 m^2 mouth, variable stretch mesh	July–March	2016	Middle Sacramento River, Tidal Delta, Estuary, and Bays
DJFMP Mossdale Trawl	USFWS	Kodiak trawl	12.5 m^2 mouth, variable stretch mesh	Year-round	1994	San Joaquin River
DJFMP Sacramento Trawl	USFWS	Kodiak trawl	12.5 m^2 mouth, variable stretch mesh	October–March	1994	Sacramento River
DJFMP Sacramento Trawl	USFWS	Mid-water trawl	5.1 m^2 mouth, variable stretch mesh	April–September	1988	Sacramento River
SKT	CDFW	Kodiak trawl	13.9 m^2 mouth, variable stretch mesh	January–May	2002	Tidal Delta, Estuary, and Bays
YBFMP Beach Seine	DWR	Beach seine	8.3 m x 1.3 m net, 0.3 cm^2 mesh	December–June	1998	Yolo Bypass

YBFMP Rotary Screw Trap	DWR	Rotary screw trap	2.6 m diameter rotary screw trap	January–June	1998	Yolo Bypass
Knights Landing Rotary Screw Trap	CDFW	Rotary screw trap	2.4 m diameter rotary screw trap	October–June	1995	Sacramento River

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Table 2: Total number of Chinook Salmon captured (N), average fork length in mm (FL) and standard deviation (SD), and coefficient of variation of fish fork length (CV) by each survey during our study period (December 2016 – March 2017, December 2017 – March 2018). Surveys included EDSM, DJFMP, Spring Kodiak Trawl (SKT), Yolo Bypass Fish Monitoring Program (YBFMP), and the Knights Landing (Knights Lnd) Rotary Screw Traps (RST). Note: Data exclude adipose-clipped Chinook Salmon.

		December			January			February			March	
Survey	N	FL (SD)	CV	N	FL (SD)	CV	N	FL (SD)	CV	N	FL (SD)	CV
EDSM	4	35.8 (2.2)	0.062	55	38.7 (3.8)	0.099	674	39.3 (6)	0.152	145	67.9 (24.4)	0.359
SKT				47	38.8 (16)	0.413	152	38.7 (3.3)	0.086	15	79.3 (38.6)	0.487
DJFMP Beach Seine	153	44.4 (18.3)	0.412	1312	40.3 (10.9)	0.269	759	42 (8.6)	0.205	1068	50 (11.8)	0.236
Sacramento Trawl	27	49 (32.7)	0.668	420	38.1 (6.4)	0.167	1483	39.3 (7.4)	0.188	958	61.7 (19.6)	0.318
Chipps Island Trawl	17	148.1 (18)	0.121	5	140.2 (26.8)	0.191	13	97.8 (40.4)	0.413	277	99.6 (19.3)	0.194
Mossdale Trawl				48	36 (1.7)	0.047	17	35.5 (1.8)	0.052	55	74.2 (12.9)	0.174
YBFMP Beach Seine	1	34		361	37.7 (4.4)	0.117	797	40.3 (5.2)	0.129	313	56.1 (10.6)	0.189
YBFMP RST				158	38.2 (2.4)	0.062	118	39.9 (4.9)	0.123	14	68.4 (21.7)	0.317
Knights Lnd RST	454	45.3 (24.5)	0.541	6855	38.5 (6.1)	0.157	1692	40.1 (7.2)	0.18	1945	61.9 (15.6)	0.251

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Table 3. Occupancy model parameter estimates for water years 2017 and 2018. The reference levels for the categorical variables Region, Month, and Gear are Cache Slough-Liberty Island, January, and Beach Seine.

			Water Year 2017			Water Year 2018		
	Variable	Categorical Level	Estimate	SE	P(>|z|)	Estimate	SE	P(>|z|)
Occupancy	Intercept		1.338	0.861	0.120	-1.546	0.840	0.066
	Region	Lower Sacramento River	-0.90	0.857	0.294	0.006	0.963	0.995
		Lower San Joaquin River	0.240	0.866	0.782	0.037	1.950	0.985
		Mokelumne River	0.238	1.020	0.816	-0.616	1.065	0.563
		Sacramento Deep Water Shipping Channel	1.851	7.197	0.797	-4.912	4227	0.999
		Southern Delta	-0.62	0.841	0.459	-0.273	0.901	0.762
		Suisun Bay	-0.654	0.751	0.384	1.917	0.869	0.027
		Suisun Marsh	0.288	1.815	0.874	0.160	3.085	0.959
		Sacramento River	2.313	0.934	0.013	2.461	0.869	0.005
		San Pablo Bay/Napa River	-0.662	0.967	0.493	-1.764	1.740	0.311
		Yolo Bypass	0.742	0.966	0.443	-1.390	1.408	0.323
	Month	February	-0.107	0.478	0.823	0.175	0.407	0.667
		March	0.273	0.488	0.575	1.340	0.364	<0.001
		December	-1.953	0.532	<0.001	-0.607	1.181	0.607
Detection	Intercept		1.321	0.602	0.028	0.613	0.802	0.445
	Gear	Chipps Island Trawl	-1.462	0.306	<0.001	-0.281	0.609	0.644
		EDSM Trawl	-2.184	0.243	<0.001	-3.642	0.385	<0.001
		Mossdale Trawl	0.223	0.378	0.554	0.904	0.640	0.158
		Sacramento Trawl	-1.215	0.285	<0.001	-2.395	0.295	<0.001
		SKT	-1.30	0.334	<0.001	-2.524	0.688	<0.001
	Region	Lower Sacramento River	-0.00016	0.658	1.000	0.587	0.874	0.502
		Lower San Joaquin River	-0.873	0.559	0.118	-2.302	1.570	0.143
		Mokelumne River	-1.393	0.614	0.023	0.079	1.290	0.951
		Sacramento Deep Water Shipping Channel	-1.108	0.832	0.182	-7.457	4202	0.999
		Southern Delta	-2.683	0.605	<0.001	-2.375	0.982	0.016
		Suisun Bay	-0.601	0.567	0.289	-1.304	0.828	0.115
		Suisun Marsh	-0.433	0.689	0.530	-1.318	2.131	0.536
		Sacramento River	0.314	0.586	0.592	1.146	0.756	0.130
		San Pablo Bay/Napa River	-1.153	0.605	0.057	-0.170	2.007	0.933
		Yolo Bypass	1.066	0.816	0.191	-0.959	1.835	0.601
	Month	February	0.848	0.158	<0.001	-0.696	0.190	<0.001
		March	0.447	0.146	0.002	0.744	0.140	<0.001
		December	-0.713	0.200	<0.001	-3.608	0.616	<0.001