Summary of Enhanced Delta Smelt Monitoring for LOBO Independent Review Panel

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The Enhanced Delta Smelt Monitoring (EDSM) program, which began in November 2016, is a year-round weekly sampling program administered by the US Fish and Wildlife Service (USFWS) that samples nearly all life stages of Delta Smelt and produces weekly estimates of abundance for several spatially-defined, and temporally dynamic, strata. The original motivation for the survey was to acquire finer temporal resolution information than existing surveys provided about the spatial distribution and abundance of adult Delta Smelt during the December through March period when State Water Project (SWP) and the federal Central Valley Project (CVP) are exporting water that leads to the entrainment[2] of Delta Smelt and other fish species. The objectives of the EDSM, which are listed in Section 2, have grown considerably since then.

The sampling locations of the EDSM change from week to week and are randomly selected using a probabilistic procedure aimed at providing a spatially dispersed sample. This is in contrast to existing long-term fish monitoring programs, such as the USFWS's Beach Seine Survey and the California Department of Fish and Wildlife's 20mm Survey (20mm), Summer Townet Survey (STN), Fall Midwater Trawl Survey (FMWT), and Spring Kodiak Trawl Survey (SKT), that sample the same non-randomly selected locations[3] over and over. Another key difference from existing surveys is the use of a stopping rule for sampling of life stages that can be readily identified at the time of capture, which includes all life stages but small larvae that require a microscope to identify. Tows are repeated until a fish is caught or an upper limit on the number of tows is reached. The motivation behind the stopping rule is to lower the probability of a "False Zero", i.e., failing to catch fish when fish are present, while aiming to minimize the "take" of a threatened species.

Section 1 is a discussion of the historical events that led to the establishment of the EDSM, and Section 2 lists the objectives of EDSM. The sampling and estimation procedures are briefly sketched in Section 3 with the more technical details found in various technical notes. Section 4 summarizes some results to-date and what has been learned. We conclude with Section 5, which covers potential changes and unresolved issues.

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[1]With contributions from Leo Polansky, Julie Day, and Matt Nobriga.

[2]The term entrainment as used here is the number of fish that die directly or indirectly as a result of water operations at the SWP and CVP. Mortality occurs when fish are pulled into the canals leading into the export pumps, and thus removed from their habitat. It also occurs when fish are drawn into, or somehow attracted, to areas where they would not ordinarily go, which have higher mortality risks, e.g., higher concentrations of predators.

[3]The sites in these historical surveys were presumably judgment samples, "those in which researchers, usually familiar with the resource, make a judgment or decision regarding the best places to locate sample sites" (McDonald 2012). As these are not probability samples, "there is no statistical basis by which inferences can extend beyond the sampled sites".

1 Background and Recent Developments

The origins of the EDSM program arose from concerns regarding implementation of the 2008 Biological Opinion (BiOp) for Delta Smelt, in particular the Reasonable and Prudent Alternatives (RPA) of the BiOp related to reducing the entrainment of both adult and juvenile Delta Smelt. After a 2010 court hearing it was thought that a life cycle model (LCM) for Delta Smelt could be fit using data from existing surveys and that the LCM could be used to both predict the results of RPA actions aimed at limiting entrainment as well as help guide water operations during the entrainment period. Early in the subsequent development of the Delta Smelt LCM, however, its utility for providing timely enough predictions of adult entrainment was questioned. That concern combined with recognition that existing surveys did not necessarily provide data at the desired temporal frequency, or quality, for some management actions, as well as what had been learned by the Early Warning System (EWS, Polansky, et al. 2014) stimulated efforts that led to the EDSM. The EDSM not only replaced the EWS but aimed to compensate for some of the limitations of the EWS as well as extended the scope to include most of the life stages, not just adults. Additional details on this history are provided below along with remarks about recent and highly relevant legislation.

1.1 Delta Smelt Life Cycle Model Effort

Several experts testifying at the April 2010 Delta Smelt Consolidated Cases legal proceedings, as well as the subsequent decision from the presiding judge Oliver Wanger, argued that there was a need for a Delta Smelt LCM that could be used to predict the effects of proposed USFWS management actions. Soon after, staff at the USFWS, with input from several Delta Smelt experts outside the USFWS, began to formulate such an LCM, organizing relevant input data, and attempting to fit an LCM to the data. In October 2014 a workshop, which included participants from USFWS, CDFW, California Department of Water Resources, US Geological Survey, and academia, was held to discuss the status of the LCM, in particular its structure and components. Several workshop participants expressed skepticism about the utility of the LCM to help guide water management recommendations aimed at limiting the entrainment of adult Delta Smelt during December through March. The general concern was that for making weekly management decisions on water operations during the adult entrainment period, the spatial-temporal resolution of the LCM, which had four spatial regions and a monthly time step, was perhaps too spatially inflexible and coarse, and was definitely too temporally coarse, for averting potentially damaging entrainment events.

1.2 Early Warning System

A primary data source that has been historically used as an index of entrainment, *after-the-fact*, is fish salvage data. Salvaged fish are those fish that are more or less continuously collected by USBR and CDFW at facilities near the CVP and SWP export pumps, respectively. While the temporal resolution of salvage data is relatively fine, samples are typically taken for 30 minutes of every 2 hour block, and temporal changes and possible trends in fish densities can be quickly noted, the major drawback of those data is that they only provide a measure of the entrainment *that has already occurred*. In contrast EWS survey was designed to provide a warning of potential *future* entrainment.

The EWS began January - March 2014, and was repeated during the same months in 2015 and 2016. The EWS focused on the lower San Joaquin River and, as its name implies, aimed to provide an early warning of upstream movement of adult Delta Smelt prior to and during the spawning season. It was the most temporally frequent open water sampling effort directed at Delta Smelt ever conducted with up to 15 tows at a single location. It also used what is thought the most efficient gear and deployment method for catching adult Delta Smelt, namely, a Kodiak trawl towed parallel to the water surface. Existing CDFW surveys (FMWT Survey, which takes monthly samples at 100^{+} locations from September through December, and SKT Survey, which takes monthly samples at about 40 locations) were not providing data at the necessary time resolution, e.g., weekly, for assessing entrainment risk. A further concern was that given the relatively low fish densities, the probability of a "False Zero" could be quite high with existing surveys. Data from the EWS was examined on a near daily basis to determine if and when there was a significant increase in adult Delta Smelt densities at the edge of the zone of influence of the SWP and CVP water export pumps, e.g., Jersey Point, which suggested movement upstream of maturing adults, and subsequent potential entrainment (Polansky, et al. 2014).

1.3 Genesis of EDSM

A key limitation of the EWS data, however, was that it did not provide information about the proportion of the population at risk. In other words, the densities observed by the EWS might suddenly spike upwards, but the densities in the Sacramento River, presumably at low risk of entrainment, might suddenly spike upwards, too, and the relative numbers at risk of entrainment may or may not be deemed high.

In late 2014, during a briefing of the Region 8 Director about the status of the LCM and feedback from the October 2014 workshop, a suggestion was made to develop a sampling plan focused on collecting data that would not only be an early warning system but could also be used to estimate proportional entrainment of adult Delta Smelt during the December through March period. Proportional entrainment was defined as the ratio of number of fish entrained[4] to the total abundance at that time. For example, if there were 100,000 fish and 1000 were entrained, then proportional entrainment was 0.01 or 1%. This idea was further developed over the next six months and a draft report titled Delta Smelt Entrainment Monitoring-Delta Smelt Entrainment Estimation (DSEM-DSEE) was completed in June 2014. The DSEM component advocated for continuing to use the efficient gear used by the EWS, namely Kodiak Trawls, as well as making multiple tows at sample locations to lessen the chance of False Zeros. In contrast to the EWS, however, samples

[4] In this context entrainment refers to the number of fish estimated to be in a specific region of the Delta that we have labeled as a "High Risk" zone. Figure 1 shows the region defined as High Risk during July 2017.

would be taken at multiple locations throughout the Bay Delta region and the locations would be chosen randomly using a spatially regular sample design (e.g., Generalized Random Tesselation Stratified, or GRTS, design). The DSEE component included a Baranov catch equation type formulation, based on comparing densities in a so-called High Risk Zone (HRZ) and a Low Risk Zone (LRZ), at the beginning and the end of a period of entrainment when movement between Zones was assumed minimal (this will be shown mathematically later).

The DSEM-DSEE proposal was reviewed internally and discussed informally with other agencies over the next year. The DSEM evolved into a more detailed and ambitious plan, namely the EDSM program. The most significant change from the DSEM-DSEE was that the EDSM was a year-round monitoring program. Thus the EDSM samples most life stages of Delta Smelt (currently excluding eggs and larvae). It aims to not only assess entrainment risk and estimate entrainment, but to also provide information about the temporal changes in spatial distribution and estimate the density of post-larvae, juveniles, sub-adults, and adults. A further departure from the DSEM proposal was the introduction of stopping rules for the number of tows. In particular, for life stages that could be easily identified at the time of capture as Delta Smelt, if a Delta Smelt is caught during the first two tows (or in some situations, caught after the first tow), towing stops. Otherwise additional tows are made until a fish is caught, or until some maximum tow count is reached, e.g., 8 tows.

1.4 Three phases of EDSM

The EDSM expanded, after a pilot start in November 2016 with a single field crew to three crews in January 2017, and is now viewed as having three phases. We note the initiation and duration of the phases are dynamic depending upon environmental conditions, catches, and fish lengths, and the periods given below are approximate, particularly for the cessation of Phase 2 and initiation of Phase 3.

Phase 1. This phase focuses on adult Delta Smelt just prior to and during the spawning season, runs from December through March, and uses Kodiak trawl sampling gear deployed with a surface orientation, and includes a stopping rule. During 2016-2017 there were four spatial strata, two falling in a High Risk Zone (high risk of entrainment) and two falling in a Low Risk Zone. In future years, this phase could extend into April if catches were considered relatively high.

Phase 2. This phase focuses on post-larvae, runs from approximately April through June, and uses a fixed frame larval sampling gear towed behind the boat with an oblique tow path from a point several meters below to the surface (quite similar to the gear and deployment method used by CDFW for their 20mm survey). Instead of a stopping rule, exactly two tows are made per sample location as the smaller fish cannot be readily identified in the field.

The initiation of Phase 2 depends on when the post-larvae are large enough to be caught with a non-negligible probability by this gear, e.g., at least 15mm long. Termination of this phase could also be a function of length, e.g., assuming a dome-shaped selectivity curve for the larval gear, when the probability of catching fish longer than 40mm is considered too low, and the Kodiak trawl gear used for Phase 3 is considered more effective. Another factor affecting this phase's duration is the maturity of the majority of the fish and how their location in the water column may be affected by size and environmental conditions, e.g., if the swim bladder is not well developed the fish may be distributed too low in the water column for the surface oriented Kodiak trawl gear to work well.

During April 2017, there was a three week halt in data collection to facilitate this first-time transition to the different sampling gear. The strata boundaries changed significantly between Phase 1 and Phase 2. While there were still four primary strata, the two strata that had been viewed as locations having relatively high risk of entrainment were merged, and a stratum that had two geographically separated portions was turned into two separate strata. Also, the crews experimented with a custom-made fixed frame larval gear that was about 1/3 the size of the other gear that was deployed from the side of the fishing vessel and in shallow waters nearer to shorelines. This had the effect of creating a second layer of stratification during Phase 2 corresponding to deep or shallow water.

Phase 3. This phase focuses on juveniles and sub-adults, runs approximately from July through November, and similar to Phase 1, uses Kodiak gear and a stopping rule. However, during 2017, in contrast to Phase 1 a slightly more restrictive sampling rule (stopping after catching a Delta Smelt during the first tow) has sometimes been carried out if the initial catch was deemed "large" – more than 24 fish.

The number of strata was increased from four to eight. The increase provided more location-specific information, particularly for portions of the Delta with less area that had been infrequently sampled within large strata, and it was thought to improve the precision of estimates of densities of Delta Smelt across strata. The new strata also allowed EDSM to accommodate a request from the US Bureau of Reclamation (USBR) to use EDSM to provide additional information for its assessment of the effects of a management action called the Directed Outflow Project (DOP) whereby flows through the Yolo Bypass are manipulated in late summer and early fall to increase freshwater flow into Suisun Bay.

1.5 WIIN Act

Nearly coincident with the initiation of the EDSM program was passage of the Water Infrastructure Improvements for the Nation Act or the WIIN Act[5] in December 2016. Embedded in the WIIN Act, amongst hundreds of sections, is a single mandate that Delta Smelt be monitored: "(Sec. 4010) The bill requires Interior to conduct, with respect to Delta smelt, increased monitoring and a distribution study."

That the EDSM is potentially the means of fulfilling that particular mandate has been reinforced

[5] The Act is available at `https://www.congress.gov/bill/114th-congress/senate-bill/612`.

by letters to the USFWS Regional Director from Senator Diane Feinstein, the Coalition for a Sustainable Delta, and the Metropolitan Water District. To be fair, these letters voiced concerns that to fulfill the WIIN Act mandate the EDSM needed to expand the spatial extent of the sampling frame to include shallower waters and other "meso-habitats" and to consider alternative types of sampling gear for fishing such waters. Our objectives (listed next) have been modified slightly in light of these concerns.

2 Objectives

Before listing the objectives of the EDSM program we note that there is a broader USFWS objective that underlies EDSM and that is to protect and restore the Delta Smelt population. The EDSM program should be viewed as a means of achieving that larger objective. Below is our current statement of objectives along with italicized comments. We note that the objectives of the EDSM have evolved as we have gained experience since November 2016.

1. To estimate the total abundance of Delta Smelt, along with standard errors or confidence intervals, on a weekly to bi-weekly basis for various life stages (post-larvae, juveniles, subadults, adults) throughout the year.

   While some existing surveys, e.g., CDFW 20mm survey, do provide information on a bi-weekly basis, other surveys, e.g., CDFW FMWT and SKT surveys, have a monthly time step. Also sites in these other surveys were not selected using probability sampling methods. We note that there are concerns about the need to sample some additional "meso-habitats" not currently sampled by existing surveys, i.e., expanding the study area, and these concerns are discussed later.

2. To estimate the spatial distribution of Delta Smelt at a management relevant temporal and spatial resolution, including weekly to bi-weekly estimates of the proportion of adult fish at risk to entrainment from December through March.

   The Smelt Working Group (SWG) often meets weekly throughout this time period and providing updates on spatial distribution at the same time resolution is thought useful.

3. To provide early warning of potential adult Delta Smelt entrainment events during the spawning period and help inform how Old and Middle River flows(OMR) and turbidity could be managed to balance entrainment risk and water supply using our existing management strategies.

   EDSM can be viewed as a continuation and extension of the now defunct Early Warning Survey, which was deemed useful by the USFWS Regional Manager and the SWG.

4. To provide data for estimating adult entrainment and for modeling adult entrainment as a function of environmental conditions and water operations.

These were primary objectives of the Delta Smelt Entrainment Estimation proposal. Mathematical details, e.g., the Baranov catch equation-based model, are provided in the DSEM/DSEE proposal (Newman, et al. 2015), and brief mention is made in Section 5.

5. To compare EDSM-based estimates of abundance and spatial distribution, arising from probability-based site selection procedures, to those based on existing surveys such as SKT, 20mm, STN, and FMWT, to determine the degree of site-selection bias, and to compare the precision of parameter estimates based on EDSM with estimates based on the overlapping long-term surveys.

   If site-selection bias is found negligible, then it may be possible to combine data from EDSM and co-occurring surveys to yield even greater precision. We note that the gear used for some of the co-occurring surveys, namely the townet gear of the STN survey and the midwater trawl gear of the FMWT survey were not selected with Delta Smelt in mind, in contrast to the fixed frame larval gear and the Kodiak trawl, and the former gears are considered much less efficient for catching juvenile and sub-adult Delta Smelt. Gear deployment methods, however, affect efficiency, too, and a mid-water trawl towed parallel to the surface is far more effective than a mid-water trawl dropped to a depth several meters below the surface and towed to the surface.

6. To provide data that can be used to independently evaluate predictions from Life Cycle Models (LCMs) that were fit using data from other surveys. In particular, to assess LCM predictions of recruitment (post-larvae per adult), survival of post-larvae to juveniles, of juveniles to sub-adults, and sub-adults to adults. To supplement data for updating LCM parameter estimates.

   One intended use of LCMs is to serve as a decision support tool for managers considering various management actions, e.g., adjusting water outflows to locate the 0.2% salinity line (X2) at 61km upstream of the Golden Gate Bridge during April and May to increase reproductive success. Estimates of abundance and spatial distribution before and after such actions could provide insight as to the effect of such action.

7. To potentially assist the USBR DOP study with its data collection needs during the August through October 2017 period, and possibly to extend into November 2017.

   USBR's recognition of the utility of EDSM for monitoring the effects of management actions is similar to the motivation for assessing the 2008 BiOp RPAs.

3 Methods

There are four broad components to EDSM: monitoring design, data collection, data analysis, and reporting out of the results of data collection and analysis.

3.1 Monitoring Design

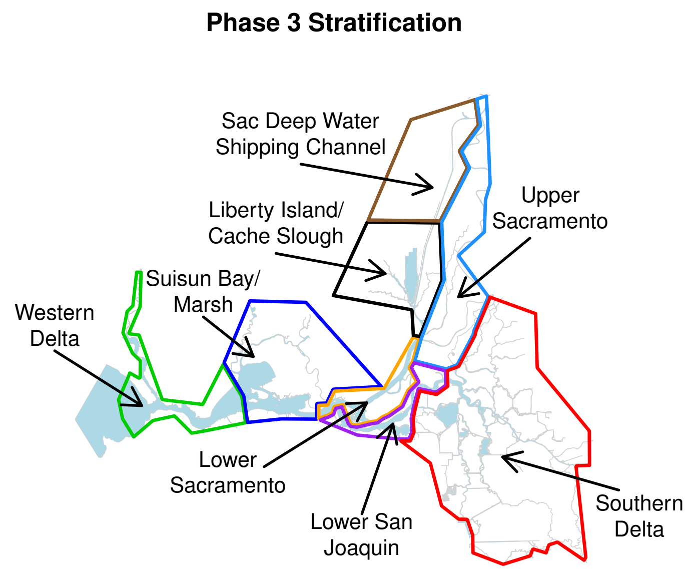
Monitoring design includes (a) definition of the study area, (b) the sample frame, (c) spatial stratification, (d) temporal sampling frequency, (e) sample selection procedure, (f) definition of sampling units. The attributes that are measured is also part of the design and relevant comments are included in the sample unit discussion and a later section.

Study area. The study area (terminology from McDonald 2012), sometimes referred to as the target universe (Overton and Stehman 1996), is dynamic as it varies with Delta Smelt life stage and time of year. In general the study area is defined to be the waters of the Bay Delta occupied by Delta Smelt. Figure 1 is a coarse display of the areal extent of the study area for Phase 3 starting July 3 2017, where the water bodies within the polygons are the study area. That areal extent was reduced for about eight weeks (all of August and part of September) with the area labeled South Delta removed due to the perception that water temperatures were too high for Delta Smelt to be present. There is a vertical component to the study area as well, and the depth varies between life stages with the depth extending from the surface to 10m depth during Phase 2 but between -0.5m and -4.5m during Phases 1 and 3 (see Section 5.4 for further discussion on strata volumes). The depths used for Phases 1 and 3 are based largely on assumptions about a general surface orientation for older fish but an avoidance of the very top layer (surface to 0.5m depth), while the Phase 2 depths are meant to reflect varying degrees of swim bladder development and limited ability to control vertical position.

Sample frame. The sample frame is the area and volume where samples are potentially taken. Due to limitations on where fishing gear can be deployed the sampling frame is smaller than the study area. While this is another dynamic aspect of the design, the spatial frame includes waters that are at least 2m in depth, thus excluding some of the near shore portions of the study area and very shallow open water regions (e.g., Grizzly Bay and Franks Tract). Volumes within these physical dimensions of the study area have been calculated using GIS. Various issues and concerns regarding the study area and sample frame are discussed in Section 5.

Spatial stratification. Figure 1 also shows eight strata that were used starting July 3, 2017. Like the study area, the stratification scheme is also dynamic. For example, as mentioned previously the stratum labeled South Delta was removed for about eight weeks due to warm water temperatures.

Figure 1: Areal extent of study area and eight strata for Phase 3. (What is currently labeled South Delta has been labeled "High Risk" in earlier maps and the Sacramento Deep Water Shipping Channel stratum has been reduced in size from what is shown in this map.)



The size of the Sacramento Deep Water Shipping Channel was recently reduced, too, with a northern portion of the channel removed from the stratum due to the failure to ever catch Delta Smelt there.

Sampling schedule. The temporal sampling frequency is weekly with field crews on the water four or five days of the week.

Sample selection procedure. Within each stratum, different sampling locations are randomly selected for each week using the Generalized Random Tesselation Stratified (GRTS; Stevens and Olsen 2004) sampling procedure. The sampling locations, which are points, are drawn with equal inclusion densities. The GRTS scheme yields samples that are "well-distributed" spatially and the probability of two adjacent points both being chosen decreases as the distance between points decreases, i.e., the joint inclusion densities are inversely proportional to distance between points[6].

[6]Spatially systematic samples are another way to achieve spatially well-distributed samples; e.g., sampling locations are chosen by randomly superimposing a grid on a map. However, variance estimation for systematic samples is

The current weekly total sample size is around m=24 sites per week with at least two sites being sampled per stratum. See Section 5 for more discussion on sample sizes.

Sampling units. In classic finite population sampling the sampling frame is partitioned into N discrete, mutually exclusive sampling units and a probability sample of size n is drawn. The way the GRTS procedure is being applied to the study area, single points are being randomly selected within each stratum within the study area[7] and there is, in essence, an infinite population. When applying GRTS to continuous areal resources, Stevens and Olsen (2005) divide the area into discrete non-overlapping polygons (using a method called recursive partitioning). Within each polygon, sample units are identified, in some cases the entire polygon is the sampling unit, while in other cases there are multiple non-overlapping sampling units and there is a further random selection of sampling units within the selected polygons. In effect an infinite study area (in terms of number of points) has been partitioned into a finite sample frame. When a point is randomly selected in the study area, measurements are made on the sample unit that contains that point.

However, due to the way that the data are collected (discussed later), the EDSM design does not have such a finite partition, and the sampling units are not well-defined, and this indeterminacy of the sample unit is at odds with standard GRTS sampling of a linear or areal, hence infinite, resource.

Comment.

- Monitoring taxonomy. McDonald (2003) developed a classification system for monitoring designs. At one extreme the same (randomly chosen) sampling locations are visited on every sampling occasion, what is called a single panel design. At the other extreme, on every sampling occasion a new set of randomly selected sampling locations are visited, an "independent" monitoring design, and this is the EDSM design. In between these two extremes are various types of multiple panel designs where selected subsets of sampling locations that are always visited at the same time are called panels.

  The single panel design is generally considered "good" or "best" for detecting trends in abundance, while the independent design is "good" for assessing population status (McDonald 2003). While we are interested in both the status and trends of abundance, given that fish are continually moving, with spatial distribution a function of salinity, water temperature, turbidity, and prey, at least, it is not clear whether trends could be detected any more readily with a single panel or multiple panel designs.

problematic as they are probability samples of size 1, i.e., the joint inclusion probabilities for all chosen points is 1 and any other pair of points such that one is in the sample and one is not are the joint inclusion probabilities equal 0, and this complicates variance estimation. GRTS can be viewed as a probability-based sampling procedure that yields spatially well-distributed samples such that each point has its own inclusion probability and joint inclusion probabilities are between 0 and 1.

[7] The `R` function `grts` in the package `spsurvey` is used to select the sample locations. The sampling frame for EDSM is defined by two-dimensional GIS *shapefiles*. Other options with `grts` are zero-dimensional (a finite set of objects, e.g., 30 lakes) and one-dimensional (a collection of line segments).

3.2 Data collection

At each chosen sample location, at least two tows (typically) are made around each sample point. For Phases 1 and 3, if a Delta Smelt is caught in at least one of the first two tows, no further tows are made. However, if no Delta Smelt are caught, further tows are made until either a Delta Smelt is caught or an upper bound on the number of tows, q_{max}, is reached. As mentioned previously, in situations where more than 24 Delta Smelt are caught in the first tow, the rule is to stop after one tow. For Phase 2 sampling, where Delta Smelt are too small to be readily identified in the field, only two tows are made. Tow duration can be dynamic as well with the general guideline being to make a 10 minute tow, but that time can be shortened for areas thought to potentially have high densities of Delta Smelt. The Delta Smelt caught are counted, either on the boat for Phases 1 and 3 or later at a lab for Phase 2, and their lengths are recorded.

The volume that has been sampled for each tow is estimated (based on flow meter measurements and net dimensions) and recorded. Counts of other species are also made along with various physical measurements including water temperature, conductivity, turbidity, and tide stage. The EDSM Standard Operating Procedures manual (EDSM_SOP_2017_0808.pdf) provides additional details on the data collection procedures used by the field crews. Data QA/QC procedures are also discussed in the manual.

3.3 Data analysis

Point estimates The parameters estimated include abundances within each stratum each week. Letting $n_{h,w}$ denote the abundance in stratum h during week w, the estimate of abundance is the product of estimated density, $\hat{\psi}_{h,w}$, and the volume of the stratum, V_h:

$$\hat{n}_{h,w} = \hat{\psi}_{h,w} V_h \tag{1}$$

For Phase 1 the proportion at risk of entrainment is estimated simply by using the ratio of the estimated abundance in a so-called High Risk Zone (HRZ) to the estimated total abundance:

$$\hat{p}_{HRZ,w} = \frac{\hat{n}_{HRZ,w}}{\sum_{h=1}^{H} \hat{n}_{h,w}} = \frac{\sum_{k=1}^{K} \hat{n}_{HRZ,k,w}}{\sum_{h=1}^{H} \hat{n}_{h,w}} \tag{2}$$

where H is the total number of strata in the study area and K is the total number of strata in the HRZ.

Estimation procedures The procedure for estimating $\psi_{h,w}$ is involved, with different procedures used for Phases 1 and 3 which have the stopping rule and Phase 2 which does not have a stopping rule. Details for the stopping rule case are provided by Newman and Mitchell (2017) and here we sketch the basics. For all Phases, the number of fish present in a single tow volume is assumed to follow a zero-inflated negative binomial (ZINB) probability distribution. The ZINB distribution is a two component mixture distribution where with probability π_0 there are no fish present in the volume sampled,and with probability $1 - \pi_0$, the number of fish follows a negative binomial distribution, NegBin($\alpha\beta v$, α), where v is the volume sampled and α and β are unknown parameters. The expected density in volumes where fish are present is $\alpha\beta$. The probability distribution for the total number of fish caught at a sampling location after multiple tows is further complicated by the stopping rule. Numerical methods are required to calculate maximum likelihood estimates of π_0, α, and β (the log likelihood is eq'n 11 in Newman and Mitchell, 2017).

Given estimates of these three parameters, the average density for stratum h during week w, $\psi_{h,w}$, is estimated as follows.

$$\hat{\psi}_{h,w} = (1 - \hat{\pi}_{0,h,w})\hat{\alpha}_{h,w}\hat{\beta}_{h,w} \tag{3}$$

Thus the abundance estimate (eq'n 1) can be rewritten as:

$$\hat{n}_{h,w} = (1 - \hat{\pi}_{0,h,w})\hat{\alpha}_{h,w}\hat{\beta}_{h,w}V_h \tag{4}$$

Assumptions. There are several crucial assumptions underlying the estimation procedure:

- The Kodiak trawl, used in Phases 1 and 2, is assumed to be 100% efficient, i.e., all Delta Smelt in the water volume swept by the gear are caught.
- The 20mm gear is not 100% efficient and its efficiency is a function of fish length. We are currently using a sigmoid (logistic) curve as the gear efficiency model. This efficiency curve is a work in progress, and pending completion of an analysis of side-by-side gear comparisons, the final curve may be much different than this curve, e.g., it may be dome-shaped, and this will likely affect the estimates of abundance for Phase 2.
- During Phases 1 and 3, Delta Smelt are assumed to occupy just the horizontal layer of [-4.5m, -0.5m] below the surface and the vertical density at a given location is assumed to be homogeneous, i.e., there is no gradient to the density in that dimension. This means that the volume used to estimate abundance is based on this 4m depth band of water.
- During Phase 2, Delta Smelt are assumed to occupy the horizontal band from the surface to a depth of 10m (or to the bottom if shallower than 10m) and the volume used to estimate abundance is calculated accordingly[8].

Standard errors and confidence intervals. The optimization program used to find the maximum likelihood estimates also provides estimates of the standard errors of $\hat{\pi}_0$, $\hat{\alpha}$, and $\hat{\beta}$. We then use the so-called Delta method, which is based on a first order Taylor series approximation of a

[8]Initial drafts of weekly Phase 2 reports calculated abundance estimates using volumes from a depth of 1.7m to the estuary bottom. This was a mistake and the latest revision of the 3 July 2017 Phase 2 report used the surface to 10m depth volumes.

function, say $f(x)$, for calculating the variances of $\hat{n}_{h,w}$ and $\hat{p}_{HRZ}$. This procedure, however, is assuming that simple random samples have been drawn from the study area and does not recognize that a spatial sampling method (GRTS) was used (more on this in Section 5).

Approximate confidence intervals for the abundances are calculated based on an assumption that the estimated abundances have a lognormal distribution. Suppressing subscripting for strata and time:

$$\hat{n} \sim \text{Lognormal}\left(\mu = \ln(n), \sigma = \sqrt{\ln(CV^2 + 1)}\right), \tag{5}$$

where CV is the coefficient of variation of the estimate of n. Assuming a lognormal distribution assures that the interval estimates remain above zero. We have been doing some ancillary work to assess just how reasonable, or not, the lognormal assumption is (Leo Polansky, personal communication).

4 Results to Date and Lessons Learned

4.1 Real-time reporting

Throughout its first year, EDSM successfully met its commitment to real-time reporting. At the end of each sampling day during Phases 1 and 3 the daily effort and catch of species of concern was compiled, distributed to stakeholders, and uploaded to the USFWS website. During Phase 2, daily summaries were distributed within 4872 hours of sample collection to account for lab processing time of larval catches. Since processing of larval fish requires extensive time, resources, and expertise; reporting larval catches in nearly real-time limited the amount of effort possible during Phase 2. This may have in turn impacted the ability to effectively estimate population abundances within sufficient confidence intervals. Relaxing the real-time reporting deadline during Phase 2 could potentially allow EDSM to increase its effort and provide more robust abundance estimates.

4.2 Weekly reports

At the end of each week of sampling, on Friday or the following Monday, a report is produced on the weekly results, in particular abundance estimates and confidence intervals, as well as the number of sites sampled in each stratum, the volumes sampled, and the number of fish caught. Three examples of these reports are included in the supplemental materials: one is the final 2017 summary of Phase 1, a second is the 2017 summary of Phase 2, and the third is a recent report from Phase 3.

4.3 Comparisons with existing CDFW surveys

This is work in progress and has not been completed in time for this report. The aim is to provide some side-by-side comparison with existing surveys, in particular SKT, 20mm, TNS, FMWT, at, say, a monthly time step.

4.4 Lessons Learned

The first year of EDSM has been largely successful. EDSM has proven to be both feasible and able to effectively sample at least some portion of the Delta Smelt population. The sample design and dynamic nature of EDSM has allowed the project to continually improve and adapt based on feedback, criticisms, and lessons learned. This is a big advancement to historically static surveys. The dynamic nature also allows EDSM to respond to new and specific management concerns. While EDSM is a great tool to answer real-time management questions as they arise and should continue to retain this capability, this responsiveness has sometimes risked the ability to meet EDSMs core objectives. The long-term utility of EDSM may be compromised if too many of its resources are invested in answering secondary questions.

It must also be acknowledged that there are real logistical limitations to sampling fish throughout the extent of the Delta. Sampling Delta Smelt across all possible meso-habitats with all potential types of gear would no doubt yield useful information. However, it may not be possible for any one program to sample in all possible habitats with the amount of weekly effort required to create sufficiently small confidence intervals. During Phase 2 EDSM experimented with shallow water sampling and small larval nets. While this was proven to be feasible and provided some useful information from a new type of stratification, it diluted effort across strata and reduced EDSMs ability to make population inferences. A more efficient strategy might be to foster collaborative efforts across projects rather than rely on EDSM to sample across all possible habitats and gear types. Many projects within the Delta have already developed specializations, expertise, and infrastructure that can complement the information collected by EDSM. Leveraging other existing efforts would allow each project, including EDSM, to focus its resources on collecting the highest quality data where it can make the biggest impact. This may lead to a synthesis of information that could be of significant management value.

5 Concerns and Tentative Changes

5.1 Adequacy of EDSM Results

Whether or not the EDSM-based estimates are adequate for management purposes is an open question. Point estimates of total abundance have varied considerably between weeks with physically impossible increases in abundance from one week to the next. The often quite wide confidence intervals are indicative of the degree of imprecision. One reason for the wide confidence intervals is that the variance estimates are potentially biased high (see Section 5.2) but that is likely a very minor contribution to the wide confidence intervals. The primary cause is the extremely high between site (and even between tow) variation in Delta Smelt densities.

To improve the precision in parameter estimates, we have considered three strategies, that we simply list here and then discuss in more detail below.

1. Alternative model-based procedures, including spatially and/or temporally aggregating across strata and weeks
2. Increase and/or modify the spatial stratification so that densities within the new strata are more homogeneous that the current stratification.
3. Increase and/or modify the sample sizes, including total sample size, maximum tow number (q_{max}), and allocation of the total sample to each stratum

5.1.1 Alternative model-based procedures

The fundamental distinction between design-based and model-based sampling procedures is that the former assumes that variation in the observed sample values is due to the artificially induced randomness in the selection of sites while the latter assumes that variation in sample values is a function of some underlying stochastic process. Given the obvious dynamic nature of fish density (fish densities at a single location can change considerably within a single day due to tidal velocity variation alone), model-based inference seems reasonable. We remark that some statisticians argue that model-based inference procedures do not require random site selection. However, other statisticians, who are in fact advocates of model-based procedures, are more comfortable making model-based inferences when the sample units have been selected using a well-defined probability procedure.

Our estimation procedure is a combination of a design-based procedure and a model-based procedure. It is design-based in the sense that stratified random sampling procedure selects the sample sites, with equal probability GRTS samples being drawn within each stratum. It is model-based in that we assume that the catches at a given location (and given tow) follow a zero-inflated negative binomial (ZINB) distribution. The ZINB explicitly models patchiness in the spatial density field (with probability π_0, there are no fish present) as well as relatively high variation (compared to a Poisson distribution) at the locations that do have fish present (with probability 1-π_0). The parameters of the ZINB have been allowed to vary between spatial strata as well as to vary between weeks. Thus with H strata, up to $H \times 3$ parameters are being estimated each week; e.g., with H=8, that is 24 parameters.

We are currently satisfied with the design-based aspect of EDSM, although the number of strata and the definition of the strata are dynamic (see Section 5.1.2). Stratified sampling is debatable according to Overton and Stehman (1996) and they point out some problems with pre-stratification in monitoring designs and suggest that post-stratification may be preferable.

We are not as satisfied with the model-based aspect of EDSM. One issue is that the estimates of $\pi_{0,h}$ (for stratum h) are quite noisy in a statistical sense, often alternating between values near 0 and values near 1. This is likely a function of the relatively small sample sizes within a stratum, which suggests a need for either larger sample sizes within the strata, or perhaps pooling some strata or assuming a common π_0 value for some subset of strata.

One way to increase the precision and stability of abundance estimates is to combine survey data across weeks (temporally smoothing) and thus increase sample sizes, assuming that the densities have remained relatively static between weeks. A similar idea is to spatially smooth data using something like the spatial generalized additive (non-parametric) model that Polansky, et al. (2017) applied to SKT data. The legitimacy of doing so hinges somewhat on the degree of similarity in densities between the spatial-temporal strata. There may be a technical challenge to do so in a way that accounts for the fact that GRTS samples were drawn within each stratum (although a technique for stratifying after-the-fact (post-stratification) described by Overton and Stehman (1996) may provide ideas on how to properly weight the sample values).

Another model-based alternative is to consider a different underlying stochastic process for the spatial-temporal variation in fish densities. The ZINB process notably lacks any spatial connectivity and the idea of spatially continuous, or spatially-temporally continuous, random processes is attractive, e.g., log-Gaussian Cox processes (Moller et al 1998). The chapter "Model-Based Methods for Global Quantities in Space" in de Gruijter et al. (2006) includes methods from geostatistics that are worth examining, too. Environmental covariates, e.g., salinity or turbidity, could serve as potential covariates in models for spatial-temporal densities (see Polansky, et al. 2017 for an example as well as difficulties in having measurements of the spatial field for such covariates).

5.1.2 Alternate stratification

It is possible that a different stratification would increase precision and improve stability of estimates. As additional field data are collected more insight will be gained about the degree of spatial homogeneity, or lack thereof, and this could guide the stratification design.

While we do not know if the following will improve the quality of estimates, a new stratification with 10 strata is proposed when Phase 3 begins again in November 2017. The changes are:

- The Suisun Bay/Marsh stratum is divided into two strata: a northern portion that includes Suisun Marsh (and Montezuma Slough), and a southern portion that covers most of the open water area and extends westward to Carquinez Strait. The Western Low Risk stratum would be reduced accordingly.
- The Southern Delta stratum is divided into two strata where one stratum includes the more northerly portion on the current stratum, namely the Mokelumne and Cosumnes Rivers watersheds.
- The Lower San Joaquin River stratum may be reduced somewhat with the western most

portion either added to the Lower Sacramento River stratum or added to the newly created southern Suisun Bay stratum.

The reasons for the first two changes include evidence for distinctly different Delta Smelt densities, largely due to differences in habitat, within the existing stratum. The reason for the third change is that the influence of SWP and CVP water operations on the western most portion of the Lower San Joaquin stratum is thought slight and estimates of the proportion of the population at risk may be overestimates if and when that stratum is included as part of a "High Risk" zone.

5.1.3 Sample size determination

The simplest but potentially most expensive way to increase precision is to increase the sample size. The sample size of typically 24 sites per week is largely a function of the number of personnel and amount of equipment (e.g., boats) available. If we assume that the ZINB distribution is correct, then the magnitude of the standard errors is not only a function of sample sizes, both total number of sites selected, $m.$ and the allocation of sites to each stratum, say m_1, m_2, ..., m_H, the number of tows (either fixed at 2 for Phase 2, or with upper bounds of q_{max}=5 or 8, say for Phases 1 and 3 with the stopping rules), and volumes sampled, but also the parameters of the ZINB distributions themselves, the $\pi_{0,h,w}$, $\alpha_{h,w}$, and $\beta_{h,w}$. With this structure in mind, the precision of the estimates is a function of the following factors:

- The patchiness of the fish density fields within each stratum, in particular the $\pi_{0,h,w}$ values.
- The magnitude and variation in fish densities at locations where fish are present (with probability 1-$\pi_{0,h,w}$) that depend upon $\alpha_{h,w}$ and $\beta_{h,w}$.
- The total sample size, $m.$, and the sample size per stratum, m_h.
- The number of tows made at a sample location (up to q_{max}, for example).
- The volume sampled per tow.

We have just started examining the sample size issue and are considering a sequence of procedures, starting quite simply and then working our way toward the realistic situation. Here is the sequence.

1. Scenario 1: Examine just one stratum with NegBin(α,β), so using `R` code language: $catch_i$ NegBin($\mu = \alpha * \beta$, $\theta = \alpha$, offset=ln(volume)), $i = 1, 2, .., m$, where α is the overdispersion parameter in this setting.
2. Scenario 2: Examine multiple strata with NegBin(α, β_h, offset=log(volume)), h=1, ..., H, with a total m evenly allocated across H strata. So each stratum has the same overdispersion but different densities.

3. Scenario 3: Examine multiple strata with ZINB(π_0 ,α, β_h), h=1, ..., H. Same sample allocation as for Scenario 2.

4. Scenario 4: Examine multiple strata with ZINB($\pi_{0,h}$, α_h, β_h), h=1, ..., H.

5. Scenario 5: Examine multiple strata with stopping rule-ZINB. This is exactly the situation for EDSM.

The objective of this exercise would be to see how well we can estimate the true densities, per stratum, for a "reasonable" set of π_0, overdispersion parameter α, and densities ($\alpha\beta$), as a function of m and the allocation of m to strata for Scenarios 2-5. And in the case of multiple strata, mimicking EDSM, we'd want to estimate the proportion in a "High Risk Zone". One criterion would be how often the parameters can even be estimated, and then a second would be the precision of estimates.

5.2 Variance estimation is wrong

Our estimation procedures have ignored the fact that GRTS samples were drawn and have instead treated the data as if it came from simple random samples (within each stratum). For point estimates, this is likely fine as equal probability samples were drawn. However, for variance estimation this is wrong, and, ignoring the uncertainty in the gear efficiency estimates, this should lead to erring on the side of producing variances that are too large. A primary motivation of GRTS sampling is to get more precise estimates of attributes measured on a study area than simple random samples will yield. The variance estimation procedure recommended by Stevens and Olsen (2003, 2004) is their neighborhood variance estimator, which we have not yet tried, and frankly, we are not exactly sure how we should use it given the ZINB-based maximum likelihood estimation procedures.

5.3 Indeterminacy of the sampling unit

Continuing discussion of the departure from conventional GRTS procedures (Section 3.1), while a point was randomly selected within a stratum, data collection is necessarily based on measurements made from multiple volumes of water around the point. Thus the sample unit on which measurements are made is that collection of water volumes. For example, suppose three tows are taken at a given point and the volumes of water sampled are 3,000m^3, 2800m^3, and 3100m^3. If the volumes were non-intersecting, ignoring the fact that the water is moving, the sample unit would be the total "block" of water with volume 8900m^3. However, given that water is moving and the volume sampled varies at random, among other things, the sample unit is a dynamic entity. Given that the ultimate attribute of interest is fish density, number of fish per unit volume of water, the effect of a dynamic sampling unit on the estimation procedures (including estimates of variance) is admittedly uncertain and a point for discussion.

5.4 Mismatches between volumes sampled and volumes extrapolated over

There are mismatches between the depths actually sampled, and the volumes, to specific depths, that are used in the V_h calculations. For Phases 1 and 3, the Kodiak trawl with a surface orientation deployment is, on average, sampling from the surface to a depth of 1.8m. An assumption is made that fish are only present between 0.5m and 4.5m below the surface, thus the effective sampled volume used for estimating the fish density is $1.3/1.8 = 0.72$ times the estimated sampled volume. The resulting estimated density is then multiplied by the volume between 0.5m and 4.5m below the surface. Thus this procedure is excluding fish below 4.5m depth and assuming that the density in the [-1.8m, -0.5m] horizontal layer is the same as that for [-4.5m,-1.8m].

For Phase 2, the fixed frame larval gear is sampling from depths typically ranging from 4m and 8m below the surface to the surface. For abundance estimation, strata volumes from the surface to a depth of 10m (or to the bottom if less than 10m deep), which assumed post-larval/juvenile habitat. Thus inferences are being made to depths that are sometimes greater than those actually sampled.

5.5 Too small a study area

There is concern that the EDSM is systematically excluding portions of the Bay Delta where Delta Smelt might be found, i.e., the study area being sampled is too small. Several areas, labeled meso-habitats[9] are not usually sampled by EDSM, nor other long-term surveys, in particular, bodies of water where the historically-used gear cannot be readily deployed.

The most important issue is the magnitude of the negative bias in estimates of abundance when areas occupied by Delta Smelt are systematically excluded from the sample. There are at least three responses to this concern.

- Keep the existing sampling design but enlarge the stratum volumes, V_h, h=1,. . .,H, to include adjacent water bodies and apply the estimated density, $\hat{\delta}_h$, to this enlarged volume, denoted V_h^e: $\hat{n}_h^e = \hat{\delta}_h V_h^e$. If the density in the added water bodies is lower than that in the original volume, then $\hat{n}_h^e$ will be biased high, and the converse if the density is lower.
- Use gear that can be deployed in these unsampled meso-habitats. This will likely increase sampling costs and the gear efficiencies will need to be estimated, or at least calibrated with

[9]Letter dated May 5, 2017 from Coalition for a Sustainable Delta to Paul Souza, Regional Director, Region 8, USFWS. A quote from the letter: "[The EDSM] does not sample the breadth of habitats used by delta smelt as the means of understanding the distribution of delta smelt and obtaining an accurate estimate of the size of its population." Eight meso-habitats were listed: (1) open water situations in bays and channels, in the near-surface, light-penetrating zone; (2) open water in bays and channels, near-bottom and below light-penetrating zone; (3) mid-water locations in dead-ended and inter-connected sloughs; (4) first- and second-order dendritic watercourses feeding channels and sloughs; (5) shoals and shallow areas, absent submerged aquatic vegetation; (6) shoals and shallow areas, with substantial aquatic vegetation; (7) bathymetrically diverse locations in the sub-littoral zone; (8) seasonally inundated floodplains and marsh plains.

existing gear.

- Ignore this concern.

Regarding the third response, an elementary "what if" analysis of the volume of water being excluded by EDSM was carried out. The EDSM only samples bodies of water that are at least 2m in depth, and the volume of the sampled waters relative to all waters, including the shallower waters (<2m in depth) is 94%. Thus 6% of that total volume is systematically excluded. For the body of water that is sampled, namely waters at least 2m deep, the following table shows the percentages of the total volume that four different vertical strata contribute to the total volume (pooled over all strata).

Surface to 2m	2m to 4m	4m to 10m	10m to bottom
36%	22%	32%	10%

Referring to Section 5.4, the portion of the volume excluded from abundance calculations during Phases 1 and 3 is around 40% (assuming that the volume from 4.5m to the bottom is about 2% less than the volume between 4m and the bottom). The consequences of applying the estimated density between 0.5m and 1.8m below the surface (the assumed layer for Delta Smelt in the tow path of the Kodiak trawl) to waters below 4.5m would likely yield overestimates of abundance as the density gradient appears to decline with depth (Mitchell, et al. 2017). On the other hand, excluding depths below 4.5m from V_h could be yielding underestimates of abundance.

The bottom line point is that more information about the vertical density gradient of Delta Smelt for different life stages would be helpful. We know that where and how a Delta Smelt locates itself in the water column at any particular age and place is a very complicated process (Rockriver, 2004; Kimmerer, et al. 1998). Knowledge of general preferences for one vertical location, e.g., the surface, relative to another vertical location, by life stage, to the degree that they exist, or where homogeneous vertical distribution is more likely than a vertical gradient, e.g., density decreasing linearly with depth, could guide the choice of volume for abundance estimation.

5.6 Take

A commonly voiced concern is that the take of fish by the EDSM may be significantly damaging to the population numbers. The impact of sampling on the Delta Smelt population is certainly an important and valid concern. However, without sampling in areas of high fish density it would not be possible to generate realistic estimates of Delta Smelt abundance and distribution. EDSM attempted to balance these concerns by sampling for short tow lengths in areas of high fish density. In many areas the standard tow length has been reduced from 10 to 5 minutes for the duration of the project. Also, after initial tows of high catches the second tow was reduced by half. During the first week of Phase 3 sampling, a single catch of 35 Delta Smelt was captured in a 5-minute tow in the Deep Water Shipping Channel. This incident raised concerns about the potential take generated with finer stratification in areas of high Delta Smelt density during Phase 3. In response, EDSM implemented procedures that further reduced tow lengths, or eliminated replicate tows after extremely high initial catches. Despite these short towing times, Delta Smelt were frequently captured in short tows in high density areas. This indicated that systematically shortening tow lengths was likely an effective strategy to gather information in areas of high fish density while minimizing take.

When considering the impact of take, it is also useful to consider the fraction of the water being sampled. Assuming that 24 locations are sampled each week and that 4 tows with volumes of 3000m3 were taken at each location, the total volume sampled each week is 24*4*3000 = 288,000m^3. Estimates of the volume to 10m depth in the study area is 1,744,080,840m^3. Thus 0.017% of the water volume (to 10m depth) is being sampled each week.

5.7 Estimation of entrainment

As discussed previously, the DSEE portion of the DSEM/DSEE proposal outlined an approach to estimate entrainment using a Baranov-type catch equation. The simplest, and potentially, most controversial estimator assumes that there are two areas, one that experiences entrainment (a High Risk Zone, HRZ) and one that does not (a Low Risk Zone, LRZ), that over some time interval $[t, t+\Delta]$ there is no movement betwen the zones, and that in the absence of entrainment the underlying mortality rates are the same for both zones. A deterministic version of the resulting model for abundances in both zones at time $t+\Delta$:

$$n_{t+\Delta,LRZ} = \exp(-M\Delta)n_{t,LRZ} \quad (6)$$

$$n_{t+\Delta,HRZ} = \exp(-(M+E)\Delta)n_{t,HRZ} \quad (7)$$

Note that given estimates of the abundances in both areas at times t and $t+\Delta$, E and M can be estimated. The number entrained, $n_{t,entrain}$, can be calculated as

$$n_{t,entrain} = \frac{E}{M+E}\left(1-\exp(-(M+F)\Delta)\right)n_{t,HRZ} \quad (8)$$

Polansky (personal communication) has explored the ability to make such estimates in the presence of one-way movement between areas (see also Newman, et al. 2015).

For now we simply note that some work is underway (Lara Mitchell, personal communication) to apply the method to the 2017 Phase 1 data. To accommodate the relatively large observation errors and to constrain abundances such that the total abundance must decline over time, the approach has been nested within a state-space framework. However, the results are too preliminary to report here.

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