# LONGFIN SMELT SCIENCE PLAN

# 2020 – 2030


Developed Collaboratively by California Department of Water Resources, California Department of Fish and Wildlife, State Water Contractors, and the United States Fish and Wildlife Service

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# EXECUTIVE SUMMARY

Longfin Smelt science has continued to progress since the species listing under the California Endangered Species Act (CESA) in 2009. However, there are substantial gaps in our understanding of the biology of this species, including management activities needed to prevent further decline of Longfin Smelt in the San Francisco Estuary. On March 31st, 2020, the California Department of Fish and Wildlife (CDFW) issued the California Department of Water Resources (DWR) an Incidental Take Permit (ITP) under CESA for the operations of the State Water Project. Within this ITP, Condition of Approval 7.6.3 requires DWR, in collaboration with CDFW, the State Water Contractors, and the US Fish and Wildlife Service, to develop and support the Longfin Smelt Science Program. The first step in implementation of this new program is to develop a Longfin Smelt Science Plan to address some of the major science and management priorities identified within the ITP.

This Longfin Smelt Science Plan, and the science program as a whole, is intended to serve two purposes: the first is to fulfill the requirement of the ITP described above, and the second is to provide a framework for Longfin Smelt scientific investments over the next 10 years. This program follows a similar approach to the recently completed 2014 Longfin Smelt Settlement Agreement (CDFW 2014), but with a broader, open format, and is linked to the ITP Adaptive Management Program. Our hope is that this format will encourage other partners to align their research with the Longfin Smelt Science Plan and the Longfin Smelt Science Program. Towards this goal, the Longfin Smelt Science Plan has identified seven Priority Areas where scientific investments that can produce valuable information for resource managers. These Priority Areas include:

1. Life Cycle Modeling
2. Factors Affecting Abundance, Growth, and Survival
3. Improved Distribution Monitoring
4. Improved Larval Entrainment Monitoring (i.e. ITP Condition of Approval 7.6.2)
5. Longfin Smelt Culture
6. Fish Migration and Movements
7. Spawning and Rearing Habitats for Longfin Smelt

The seven Priority Areas represent a suite of topics which cover uncertainties and assumptions identified in the development of the ITP, inform the science priorities in Condition of Approval 7.6.3, while also covering broader topic areas that are of management relevance. For the purposes of the new Longfin Smelt Science Plan, a multi-agency team of biologists developed detailed information for each of the Priority Areas. Specifically, the Longfin Smelt Science Plan describes how each study element provides: a connection to science priorities identified in the ITP; key background information; management relevance; possible approaches to informing that topic; and additional considerations, such as coordinating with other processes (e.g. Interagency Ecological Program annual workplan).

The Longfin Smelt Science Program will be implemented by the Longfin Smelt Technical Team, who will prioritize, develop, and execute studies that inform one or more identified priority areas. To do this, the technical team will develop a team charter as a first step in implementation of this plan. The charter will establish the team's goals and objectives as well as determine appropriate decision-making processes for selecting and prioritizing science investments.

Since one of the purposes of the Longfin Smelt Science Plan is to provide a framework for new scientific investments over the next 10 years, our hope is that this document will be informative to other partners (e.g. universities, consulting firms, public water agencies) who want to conduct management relevant science. The Longfin Smelt Technical Team will also serve as an information conduit for the ITP's Adaptive Management Program, where findings and results will help inform the adaptive management process.

In summary, the Longfin Smelt Science Plan outlines priorities for management relevant science during the 10-year duration of the new ITP. The information produced from this process is expected to inform future permitting efforts as well as improve our general understanding of the species and its habitat needs.

## STATUS OF LONGFIN SMELT

Longfin Smelt (*Spirinchus thaleichthys*) were once one of the most abundant species within the San Francisco Estuary (SFE) (Rosenfield and Baxter 2007). However, the long-term surveys have shown a precipitous decline in the abundance of the species over time and throughout the SFE (Rosenfield and Baxter 2007; Nobriga and Rosenfield 2016), with notable drops following the introduction of invasive clams in the late 1980s (Kimmerer 2002) and as part of the Pelagic Organism Decline in the early 2000s (Thomson et al. 2010).

Based on concerns about the population status of the species, Longfin Smelt was listed as threatened under the California Endangered Species Act (CESA) in 2009 (CDFG 2009). The U.S. Fish and Wildlife Service (USFWS) has found the San Francisco Bay-Delta Distinct Population Segment of Longfin Smelt warrants protection under the federal Endangered Species Act (ESA), but the listing was precluded at the time (USFWS 2012). However, almost a decade later, their numbers remain low, highlighting the need for continued management efforts and to establish a refuge population (Hobbs *et. al* 2017, Pollard and Flagg 2004). As the San Francisco Estuary population serves as the southernmost reproductive population for the species (Garwood 2017), continual declines would likely result in the extirpation of this population from the San Francisco Estuary (SFE).

## INCIDENTAL TAKE PERMIT

On March 31, 2020 the Department of Water Resources (DWR) and the California Department of Fish and Wildlife (CDFW) signed incidental take permit number 2081-2019-066-00 (ITP) for long-term operations of the State Water Project (SWP) in the Sacramento-San Joaquin Delta (Delta). The ITP authorizes incidental take of Delta Smelt, Longfin Smelt, and winter-and spring-run Chinook Salmon as a result of operations of SWP facilities in the Delta and Suisun Marsh through March 31, 2030. The ITP includes Condition of Approval 7.6.3, Longfin Smelt Science Priorities, to improve understanding of SWP and CVP impacts on Longfin Smelt and build upon the current understanding of Longfin Smelt ecology. This Condition of Approval requires DWR to establish the Longfin Smelt Science Program, develop this Longfin Smelt Science Plan (LFSSP) by December 1, 2020, and implement all elements of the plan during the term of the ITP.

Components of the Science Plan described in the ITP include:

- Develop a Longfin Smelt life cycle model. DWR, CDFW, and SWC will work collaboratively using the best available science to develop a mathematical life cycle model for Longfin Smelt, verified with field data collection, as a quantitative tool to characterize the effects of abiotic and biotic factors on Longfin Smelt populations.
- New and ongoing monitoring that:
    - Revises existing IEP monitoring programs to expand the spatial distribution of Longfin Smelt sampling to ensure equal sampling effort throughout the Delta, Suisun Bay, and San Francisco Bay regions.
    - Characterizes the distribution and abundance of adult, larvae, and juvenile life stages and changes in these estimates across a range of hydrologic conditions
    - Facilitates estimates of survival probabilities among life stages
    - Identifies factors that influence abundance growth, survival, and distribution
- Complete the Longfin Smelt life cycle in captivity at the Fish Conservation and Culture Laboratory (FCCL)
- Characterize Longfin Smelt spawning substrate and spawning microhabitat requirements
- Studies to improve the understanding of adult migration behavior and juvenile outmigration behavior including transport mechanisms for out-migrating larvae and juveniles

The Longfin Smelt Science Program includes members from CDFW, DWR, USFWS and the State Water Contractors (SWC). Each of the participating agencies may suggest additional science priorities to be added to the Science Plan to expand on the requirements of the ITP.

## PURPOSE OF THE LONGFIN SMELT SCIENCE PLAN

There are two primary purposes of this document. The first is to create a pathway for DWR to fulfill their requirements as part of Condition of Approval 7.6.3 in the ITP (CDFW 2020), and the second is to create a framework which emphasizes topic areas for other Longfin Smelt science investments occurring through 2030.

The seven Priority Areas described below were identified to address the priorities of the ITP but are also expected to inform broader management strategies within the SFE, such as those related to improved monitoring, restoration, and aquaculture. Because of this, the detailed sections for each element (below) includes key background information about the topic, its relevance to management, and potential approaches for research.

In implementation, this document serves as a framework for the Longfin Smelt Technical Team (LFSTT) to guide in the development and review of research proposed as part of the ITP's Longfin Smelt Science Program. This is similar to the structure of the previous version of the Longfin Smelt Science Program as part of the Longfin Smelt Settlement Agreement, with a key difference being that this plan does not pose explicit management questions, nor does it identify researchers to answer those questions. Instead, this process will occur through the LFSTT as part of LFSSP implementation. This is, in part, to prevent unnecessary challenges regarding the State of California's contracting process as part of DWR's requirement under the ITP, but to also promote science investments into broad topics that are important for advancing our knowledge of the species, and allowing for iteration and learning over the next 10 years.

Our goal with this plan is to build a systematic and transparent approach to new and ongoing Longfin Smelt science between years 2020 and 2030 which will address and prioritize key uncertainties related to the ITP and general species ecology, as well as report progress and findings. We also hope that other parties such as stakeholders, universities, other agencies, and consultants can use this framework as a tool for prioritizing research needs for Longfin Smelt. We anticipate that work from other entities within these Priority Areas will substantially complement the work funded by DWR as part of the ITP's Longfin Smelt Science Program.

## LONGFIN SMELT TECHNICAL TEAM

Implementation of the LFSSP is primarily done through the Longfin Smelt Technical Team (LFSTT). The role of the LFSTT is to facilitate the development of new or ongoing research efforts as they relate to the priorities identified within Condition of Approval 7.6.3 of the ITP (CDFW 2020) and the Priority Areas of this plan. To do this, the LFSTT will develop or solicit research projects to fund as part of DWR's requirement within the ITP (CDFW 2020) and ensure that selected projects fit within the framework of this plan.

The LFSTT will also be responsible for synthesizing findings and submitting them to the adaptive management team as part of the ITP's Adaptive Management Program (AMP). The LFSTT will be a small group, composed of scientists from CDFW, SWC, DWR, and USFWS. The LFSTT may consult additional experts outside of the team as needed.

**Key roles and Responsibilities**:

**Team Chair:** CDFW

**Meeting Frequency:** Quarterly

**Funding of Elements identified in ITP**: DWR

**Funding of Additional Research:** Because the Plan includes seven broad areas of research, it is possible that other partners may want to prioritize their funding based on this Plan. The LFSTT is anticipated to work with these partners and funding groups to ensure these projects fit within the framework of the Plan as needed, however these projects are not included as part of DWR's ITP requirement.

**Technical Input:** All group members.

**Connection to Plan:** The LFSTT is expected to develop or review and modify research proposals to ensure all work proposed in connection with the Plan will inform at least one or more Priority Areas.

**Contract Management:** DWR will be contract managers for projects selected by the LFSTT and funded by DWR, which is anticipated to be a large component of the work. However, some elements of this plan may be funded through other contract mechanisms (e.g. Prop 1) and may not be managed by DWR specifically.

**Reporting:** DWR and other contract managers will forward interim and final project reports to the full LFSTT promptly after receipt so that they may be discussed at the next team meeting. DWR with input from the full team, will synthesize the findings from all work related to the LFSSP. This can include work from stakeholders, other agencies, and academia as well as work conducted as part of the DWR's ITP requirement; with the condition that this work contributes to one or more Priority Areas. These reports will be both made available online and submitted to the ITP's adaptive management team on an annual basis.

**Outreach**: DWR will be the lead on outreach regarding plan milestones and development, however, it is expected that all team members will work to promote communication with the broader scientific and resource management community. For example, DFW may take a major role in communication since they will chair the LFSTT.

**Team Charter:** The LFSTT will begin convening in December of 2020 and develop a team charter as well as begin planning and developing goals and objectives for phase 1 Priority Areas based on the *Longfin Smelt Science Plan Timeline* discussed below. The team charter will establish the goals and objectives for the team, determine an appropriate decision-making process, as well as provide guidelines for membership and participation. Once the LFSTT charter is completed, the initial phases of project implementation can begin.

## LONGFIN SMELT SETTLEMENT AGREEMENT

CDFW, DWR and the State Water Contractors (SWC) entered into an agreement in 2014 to implement a multiyear Longfin Smelt Science Program. This earlier effort was based on a 2009 challenge by the SWC's to CDFW's Longfin Smelt incidental take permit for SWP operations. Specifically, the Settlement Agreement represented a collaborative effort to resolve some of the major scientific issues raised in the SWC's legal challenge, improve management of Longfin Smelt, and ultimately inform CDFW in development of the 2020 ITP. This effort lasted approximately five years and the study direction was adaptively managed based on results from the initial year. Information resulting from the Settlement Agreement proved to be valuable (see Lewis et al. 2018, 2020), helping to inform the current ITP. However, one of the more notable features of this effort was the function and efficiency of the technical team created as part of the process, as it was a venue of high value to Longfin Smelt experts within the representative agencies. While the LFSSP will be implemented across a longer period and have a broader scope, it will continue to adopt the same technical forum framework going forward. Thus, while the 2020 ITP's Longfin Smelt Science Program will be a new and different approach to addressing Longfin Smelt science needs than the Settlement Agreement, it will continue to function at a similar technical level.

Questions examined in the Settlement Agreement included the following (see CDFW 2014):

*Longfin Smelt distribution and regional contribution to overall abundance:*

1. Quantify the relative abundance of early life stages and adult Longfin Smelt in Bay tributaries (e.g. Napa River, Sonoma Creek, Petaluma River, Alameda Creek and Coyote Creek) during the spawning and rearing seasons occurring during wet and dry years.

2. Determine if geochemical signatures of Bay tributaries vary to the extent that otolith geochemistry could be used to determine the relative contribution of Bay tributaries to recruited juvenile and adult fish collected in IEP-DFW surveys in the San Francisco Bay.

3. Determine the extent to which initial rearing in different salinity zones and geographic areas contribute to the Longfin Smelt population and compare these contributions between wet and dry years.

4. Determine if geochemical signatures of the ocean environment can inform the extent to which Longfin Smelt use the near-shore ocean environment using otolith geochemical signatures.

*Longfin Smelt vertical migration behavior*

5. Determine the extent to which Longfin Smelt exhibit regular vertical movements within the water column during the day-night cycle, and whether these behaviors vary among different regions of the estuary or seasonally.

6. Determine the relationship between water transparency and the Longfin Smelt catch in the Bay Study midwater trawl and otter trawl sampling.

7. Determine whether changes may be needed in current Longfin Smelt survey index calculation methods, and whether the new information provides better insight into the proper formulation of quantitative population estimates

# COORDINATION

As in previous years with the Settlement Agreement Process, suitable elements of the ITP's Longfin Science Program will be incorporated into the Interagency Ecological Program (IEP) Annual Work Plan, providing assistance which includes oversight, proposal review, permitting and take authorization, and coordination of staff and equipment resources. The former Longfin Science Program has been a recurring element in IEP's Annual Work plan, and we anticipate that the 2020 ITP Longfin Smelt Science Program will continue in its place and that IEP will continue to provide a major coordination forum.

Another venue for coordination will be the Collaborative Science and Adaptive Management Program (CSAMP), along with the Collaborative Adaptive Management Team (CAMT). These are high-profile coordination teams that include water agencies, fisheries agencies, water regulators, water users, and environmental groups. We therefore anticipate that that these forums will be a primary venue to discuss collaborative science for Longfin Smelt.

In addition to these coordination opportunities, there are other important ongoing efforts which will be informed by the LFSSP.

First, the USFWS is currently writing a Species Status Assessment (SSA) document for the Bay-Delta Distinct Population Segment of the Longfin Smelt. The SSA, which will consist of the species life history, species needs, current condition, and future condition, is a tool based on the best available science that the USFWS may use to inform decisions such as listing. The SSA Core Team, which is tasked with drafting the overall SSA document, includes experts from USFWS and CDFW some of whom are also involved in the Longfin Smelt Science Plan. The SSA and USFWS's listing process is separate and distinct from the LFSSP, although science and information produced from the LFSSP may be included in the SSA. In addition, any proposed regulatory measures which are based on work conducted as part of the LFSSP, will be cited in the SSA.

Second, the Longfin Smelt conceptual model – which is being developed by the IEP Management Analysis and Synthesis Team (MAST) – was not available for use in the development of this plan. However, this conceptual model may be integrated into the science plan in the future once its complete.

## RELATIONSHIP TO ADAPTIVE MANAGEMENT PROGRAM

Throughout implementation of the ITP, DWR, CDFW, and SWC will convene regular meetings of the Adaptive Management Team (AMT) as part of the ITP's Adaptive Management Program (AMP) to consider and address scientific uncertainty regarding the Bay-Delta ecosystem and covered species ecology. The AMP is a separate process that will be informed by the LFSSP and is intended to improve understanding of take of covered species, impacts of the taking, and minimization associated with operating criteria in the ITP. After reviewing results from ongoing monitoring, science, and syntheses the AMP may recommend amendments to the operational components of the ITP. The Longfin Smelt Science Program is a significant part of the new science and monitoring requirements included in the ITP that will inform the AMP process (ITP Attachment 2, Section J.2.1).

The Draft Adaptive Management Plan (ITP Attachment 2) defines adaptive management as "a science-based approach to evaluate management actions and address uncertainties associated with those actions to achieve specific objectives and to inform subsequent decision making. When correctly designed and executed, adaptive management provides a means to evaluate management actions and their underlying scientific basis using formal science programs to assess their efficacy in achieving conservation objectives by comparing the outcomes to predicted responses, and providing the scientific basis for continuing, modifying, or abandoning the action or implementing an alternative action." As of December 2020, the Draft Adaptive Management Plan was in the process of being finalized by the AMT. After a final draft is approved within the AMT, the plan will be a "living document" that could be changed in response to future needs.

The December 2020 draft AMP anticipates that the results of science and monitoring initiated as a result of this Longfin Smelt Science Plan would be synthesized and submitted to the AMT for review and consideration on a multi-year time scale. These syntheses may result in recommendations to change Longfin Smelt science, monitoring, and/or actions initiated as part of the ITP.

Throughout the term of the ITP the AMP will convene to review syntheses of science required by the ITP and other science, as available, to consider and address scientific uncertainty regarding the effect of the management actions. The AMP may also convene symposia to communicate results from science and monitoring initiated under the Longfin Smelt Science Plan to a wide audience. Over time, the AMP may expand to incorporate or collaborate with adaptive management and science efforts being conducted as a part of the Interagency Ecological Program, the Delta Science Program, Voluntary Agreements or the Collaborative Science and Adaptive Management Program (CSAMP).

## LONGFIN SMELT SCIENCE PLAN TIMELINE

### Ten Year Timeline

Implementation of this plan will occur over a 10-year period beginning in 2020 and lasting through 2030. Over this 10-year period, each of the seven priority areas described below are expected to be informed through work funded by DWR. To better facilitate this process, this plan has categorized each of the Priority Areas into one of two phases. These phases are intended to serve two purposes, the first is to provide some order for implementation of this plan over the next 10 years, and second is to comply with the requirement of Condition of Approval 7.6.3 of the ITP. Beginning in 2021, the LFSTT is expected to begin implementing Priority Areas identified in Phase 1 of this plan. To the extent possible, these phases will be conducted in series. However, it is likely that projects will overlap across phases and that resource availability (e.g. staffing, equipment) will affect the specific timing of each element. For example, it is likely that Longfin Smelt Culture activities will occur throughout all 10 years of the plan.

**Phase 1:**

- Longfin Smelt Life Cycle Modeling
- Longfin Smelt Culture
- Improved Distribution Monitoring

**Phase 2:**

- Factors Affecting Abundance, Growth, and Survival
- Larval Entrainment Monitoring[1]
- Fish Migration and Movements
- Spawning and Rearing Habitats for Longfin Smelt

Once the LFSTT has identified projects for DWR to fund, those projects and their reporting deadlines will be integrated into this plan and become part of the LFSSP timeline over the next 10 years. Since this timing structure is specific to DWR's funding requirement of the ITP, other members of the LFSTT with available funding are encouraged to invest in any of these Priority Areas at any time during implementation of this plan.

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[1] This element is identified as a separate Condition of Approval within the ITP (7.6.2) and is being addressed by a separate team. See *Larval Entrainment Monitoring* section below.

### Annual Timeline

Implementation of this plan at the annual level is anticipated to occur in coordination with other important annual deadlines, such as those associated with the state contracting process as well as coordination with the IEP workplan. For example, several potential study elements are likely to be incorporated into the IEP work plan and therefore would need to follow IEP's planning process. The key dates for IEP's proposal review process are as follows:

**March:** Start of IEP workplan process with request for concept proposals.

**Mid-June:** Full proposals due and review process begins.

**End of August**: Draft IEP Workplan complete for discussions with Agency Directors.

**December:** Director approval.

To the extent possible, the relevant Longfin Smelt study elements would try to align with this timeline. Hence, the LFSTT will generally work to develop, review, or solicit work in the fall of each year to begin drafting concept proposals for March of the following year. However, there may be an initial period (e.g. 2021) when projects are initiated before fall.

For each project there will be additional deadlines for deliverables. Our general goal is that each project would be expected to prepare an annual report and provide progress updates to the LFSTT twice a year. In addition, there would be draft and final reports, the exact deadlines of which would depend on the term of the contract.

## REPORTING

The ITP requires DWR to submit the draft Longfin Smelt Science Plan to CDFW for review and approval no later than December 1, 2020. After the plan is approved by CDFW, DWR is required to fund and implement required science and monitoring according to the timelines included in the final science plan. DWR is also required to convene the Longfin Smelt Technical Team quarterly each year throughout the duration of the permit to review progress implementing the plan, share data and interim reports, discuss methods used to implement required monitoring, and review draft results from science required as part of the plan.

The specific approach to Data Management remains to be determined. However, many elements of the Longfin Smelt Science Plan will likely follow IEP's data management guidelines, with an emphasis on transparency and open data.

## FUNDING

DWR's ITP Project Description proposed an annual budget of $2 million a year to support the Longfin Smelt Science Plan. However, the exact level of support at any given time will vary substantially depending on which contracts are active and the priorities of the Longfin Smelt Technical Team. As noted above, DWR will have primary contracting responsibilities. The specific funding approach may also vary depending on the composition of the team for each project (e.g. agency, university, consultant, public water agency).

## OTHER SCIENCE PRIORITIES

The previous sections provide information about science priorities that were specifically identified in the ITP. However, the Longfin Smelt Science Plan drafting team recognizes that there are likely other high value science topics that we did not identify. Hence, we emphasize that the current Longfin Smelt Science Plan is not intended to deter researchers from pursuing other research topics. To the contrary, additional research is encouraged since it may be relevant to the science gaps identified within the Longfin Smelt Science Plan and could lead to new innovations in Longfin Smelt science and management. Moreover, it is likely that at least some of the science projects funded by the Longfin Smelt Science Program will include smaller elements that were not specifically identified above. For example, the Life Cycle Modeling effort may identify critical information gaps that can only be addressed with new monitoring or focused research.

To help stimulate additional research, the Longfin Smelt Science Plan drafting team identified some important science topics that were not included in the ITP:

- Contaminant effects
- Invasive species effects
- The possible role of diseases in Longfin Smelt population dynamics
- Identifying the food web for Longfin Smelt
- Development of new tools (e.g. monitoring, health)
- Measurement of vital rates (growth, survival, reproduction)
- Climate change effects (e.g. hydrology, temperature)

This list is not intended to be comprehensive; rather, it is provided to show a continued interest in broader topics about Longfin Smelt science. Proposed additions to the science priorities identified in the plan should be brought to the Longfin Smelt Technical Team for review. After unanimous approval by CDFW, DWR, USFWS, and SWC, they would be incorporated as an addition to the Plan.

# LONGFIN SMELT AREAS OF SCIENCE PRIORITY

# LIFE CYCLE MODELING

## Introduction

One of the most important tools for the management of at-risk species is a suitable life cycle model and Longfin Smelt is no exception. While field monitoring and research can be a useful approach to measure the responses of species to natural or managed changes in the environment, life cycle models can help to integrate the effects of multiple factors operating at different life stages, evaluate different management scenarios, and provide insight into overall population effects. For this reason, one of the highest priority science needs for Longfin Smelt identified in the ITP is the development of a life cycle model.

## Connection to Condition of Approval 7.6.3: Longfin Smelt Science Priorities

Work conducted within this priority area is expected to inform the following priorities identified in 7.6.3 of the ITP (CDFW 2020):

- Develop a mathematical life cycle model for Longfin Smelt, verified with field data collection, as a quantitative tool to characterize the effects of abiotic and biotic factors on Longfin Smelt populations.

## Key background information

There have been several approaches to model Longfin Smelt life history. One example includes IEP's development of a conceptual model for the species, known as the Longfin Smelt MAST. Although the IEP product will not be sufficient to meet the needs of this Longfin Smelt Science Plan element, a conceptual model represents an important first step in the development of mathematical models.

Other examples include basic statistical models based on one or more drivers of abundance. The simplest of these examples are relationships between Longfin Smelt abundance and outflow or X2 position (e.g. Jassby et al. 1995; Kimmerer 2002; Sommer et al. 2007). This approach was recently improved by incorporating a classical spawner-recruitment framework, allowing the authors to examine alternative conceptual models for drivers of abundance (Nobriga and Rosenfield 2016).

Maunder et al. (2015) used an innovative state-space approach to develop a demonstration life cycle model for Longfin Smelt. The model was designed to allow for hypothesis testing; for example, the effects of introduced clams, predators, and ammonia inputs. Two of the authors of the Longfin Smelt state-space model had previously used a similar framework for Delta Smelt (Maunder and Deriso 2011).

For fish and other species, one of the more sophisticated approaches to life cycle modeling is the development of individual based models (IBM). This approach is widely-used for multiple species and has been successfully applied to Delta Smelt (Rose and Kimmerer 2013a,b; Kimmerer and Rose 2018), for evaluating different management actions. Due to its spatial and bioenergetic components the IBM allowed for an evaluation of the effects of changes to food supply and spatially explicit actions on the population. Currently, there is not yet a published IBM for Longfin Smelt; however, Loboschefsky (2013) used the general Delta Smelt framework to put together an IBM for Longfin Smelt as part of a PhD dissertation.

## Primary Management Issues That This Area Will Address

It is expected that the development of a life cycle model will be a key tool to help understand the effects of ITP management actions on Longfin Smelt, as well as other related resources planning activities. Examples of some of the management applications of life cycle modeling for Longfin Smelt include the following:

- Estimating entrainment of individuals and the population level effects of entrainment.
- Understanding the effect of winter and spring outflow on population trends.
- Assessment of the potential effects of habitat restoration on population trends.
- Determine the effects of new projects (e.g. conveyance) and processes (voluntary settlement agreements) on individuals and population trends.
- Understanding the effects of climate change on individuals and population trends.
- Providing valuable feedback for adaptive management processes.

## Potential Scientific Approaches

Two of the primary potential approaches include additional refinement of an IBM and/or a state-spaced model, as illustrated by the review above of progress to date. It is anticipated that either approach will build on previous work on Longfin Smelt and Delta Smelt, described above. An advantage of the IBM is that it can be coupled to hydrologic and hydrodynamic models, allowing the evaluation of focused water management changes and habitat projects. However, the state-spaced model also has significant attributes as illustrated by recent progress in the application of this approach to Delta Smelt (Polansky et al 2019; 2020). This work has produced useful products like more refined life-stage specific abundance indices, habitat relationships with vital rates, and completion of population viability analyses.

Note that the review above is not meant to constrain the choice of a particular modeling platform. The ultimate choice of a modeling approach will be based on multiple factors including the breadth of management applications, development time, PI qualifications, availability of input data, and user-friendliness (see below). Moreover, it is possible that other effective life cycle modeling approaches (not described above) will be identified.

## Additional Considerations

Unlike many of the other elements of the Longfin Science Program, development of a life cycle model will not directly require new permits or take authorization. However, it is likely that the performance of the model will depend on the availability of high-quality input data, such as that described in a related section on Longfin Smelt monitoring needs. Some of the associated data collection activities, if necessary, may need to be approved by permitting agencies.

Another consideration is that these models will be most useful if they can be run by multiple staff within the resource agencies. While significant progress has been made in hydrodynamic and biological modeling in the San Francisco Estuary, some of these models are so complex and specialized that relatively few staff are capable of running the models. For this reason, our goal is to generate a model (or models) that will be useable by a broader spectrum of scientists and staff in the region. To achieve this goal, there will have to be substantial coordination with potential users and experts during model development, and a commitment to a model structure and documentation that is relatively user-friendly.

# FACTORS THAT AFFECT LONGFIN ABUNDANCE, GROWTH, AND SURVIVAL

## Introduction

Understanding the factors that affect abundance, growth and survival can be important in managing Longfin Smelt. Long term monitoring and targeted studies have provided key information on some of the important factors known to affect Longfin Smelt over time. However, there are likely other under-studied factors which influence growth, abundance, and survival and merit further exploration. Understanding these factors will not only improve management tools but will also increase our understanding of species needs when it comes to life stage specific habitat suitability as well as increasing the accuracy and precision of predictive modeling tools. These factors represent a core component of Longfin Smelt ecology and therefore are identified as a Priority Area in the LFSSP for further research.

## Connection to Condition of Approval 7.6.3: Longfin Smelt Science Priorities

Work conducted within this priority area is expected to inform the following priorities identified in Condition of Approval 7.6.3 of the ITP:

- Develop a mathematical life cycle model for Longfin Smelt, verified with field data collection,
  as a quantitative tool to characterize the effects of abiotic and biotic factors on Longfin Smelt
  populations.
- Complete Longfin Smelt lifecycle in captivity at the FCCL.
- New and ongoing monitoring that:
    - Facilitates estimates of survival probabilities among life stages.
    - Characterizes changes in abundance and distribution of life stages across a range of hydrologic conditions, including different water year types.
    - Addresses factors that influence Longfin Smelt population abundance, distribution, and catchability, including vertical migration behavior, water transparency, and other factors that support growth and survival.

## Key Background Information

*Abundance*

A number of analyses have documented the positive correlation between Longfin Smelt abundance in the fall and freshwater flows or position of X2 in winter-spring (Stevens and

Miller 1983, Jassby 1995). Kimmerer (2002) later detected a step decline in this relationship that corresponded with the establishment of the introduced clam *Potamocorbula amurensis* after 1987. Another step decline was attributed to the Pelagic Organism Decline after 2002 (Thomson et al 2010). The Thomson et al. (2010) also found water clarity was an important covariate explaining Longfin Smelt abundance step changes in addition to the spring position of X2. Mac Nally et al. (2010) included covariates of prey availability and predator abundances as well as abiotic factors from Thompson et al. (2010) and found strong support for the spring X2 effect, but also identified a potential link between flow and prey abundance with Longfin Smelt abundance. An important prey item, *Eurytemora affinis* was found to be correlated with spring X2 (Kimmerer 2002) suggesting the mechanism underlying the fall abundance to flow relationship may be driven, at least in part, by increased food and feeding, may promote rapid growth and survival in the early life stages. However, the effects of food may be complex as there is no simple relationship between flow and larval abundance, as measured by the 20 mm survey. An analysis by Maunder et al (2015) determined that ammonia, temperature, and Napa River Outflow were highly correlated with abundance suggesting alternative factors should be explored. More recently Nobriga and Rosenfield (2016) tested several models that included the influence of adult stock and density dependence on Longfin Smelt population dynamics. All models indicated winter-spring flow was an important predictor of recruitment to age-0 in the fall but did not find support for a relationship between flow and survival from age-1 to age-2. Furthermore, recruits-per-spawner had not declined over time suggesting the food web changes from invasion of the overbite clam did not impact the flow to fall recruitment relationship, but a cyclic pattern in the residuals from this model implicated an ocean influence on recruitment.

A number of mechanisms have been identified to explain the flow-recruitment relationship which include, (1) transport away from points of diversion to nursery habitat, (2) increased retention with flow in nursery habitat, (3) feeding in productive nursery habitats, (4) nursery habitat extent, (5) increased nursery habitat complexity that occurs in wetter years and (6) increased spawning and nursery habitat in bay-tributaries (Rosenfield and Baxter 2007, Grimaldo et al 2017, Lewis et al 2020)

*Growth*

Understanding the factors that affect individual growth can be important in managing Longfin Smelt. Growth during the early life stage of fishes is a critical vital rate that can have large impacts on recruitment success. Larger fish are relatively less susceptible to stressors such as predation, thus fish exhibiting faster growth are more likely to survive the early life predation. Another key vital rate metric is size-at-maturity since larger individuals are more fecund, which in turn can improve population growth (Chigbu and Sibley 1994, CDFW 2009).

Longfin Smelt larval and small juvenile growth rates in the SFE have been assessed using apparent growth (changes in mean length over time), (Baxter et al. 2005, CDFW 2009) and ongoing studies are using otoliths (Dr. Levi Lewis *pers. comm*). Longfin Smelt growth as larvae is generally slow (~0.15mm/day) which is much slower than Delta smelt (Baxter et al 2005).

There are several abiotic and biotic factors that may impact the growth of Longfin Smelt, which may in turn ultimately influence survival and abundance. Many of the factors described above for abundance may also apply to growth. For example, abiotic factors include temperature, salinity, turbidity, and contaminants. Biotic factors include prey type and abundance, toxic algae, aquatic weeds, and predation (Hobbs et al 2017). Greater prey densities have correlated with larger larvae (Hobbs et al 2006).

The landlocked population of Longfin Smelt in Lake Washington was found to have alternating annual variation in growth, correlated with an odd/even pattern of corresponding high and low densities suggesting growth may be density dependent (Moulton 1974). In the same study by Moulton (1974), it was determined that males were larger than females suggesting males may grow faster than females. Although the odd/even year densities correlated with growth in the Lake Washington study, no such consistent alternating pattern has been observed in the Longfin Smelt population within the SFE, and species densities were determined to be low enough to warrant listing (CDFW 2009, USFWS 2012). Some evidence of density dependence has been found for Longfin Smelt in the SFE (MacNally et al 2010, Maunder et al 2015, Nobriga and Rosenfield 2016) suggesting that density dependence in growth rates should be evaluated in any lifecycle model that is developed as part of the LFSSP.

*Survival*

Several factors are expected to affect survival of Longfin Smelt. Those factors include direct effects such as entrainment and predation as well as indirect effects such as poor food availability or suboptimal water quality habitat (Hobbs et al 2017). Understanding the population level impacts of entrainment is one of the many questions regarding survival for Longfin Smelt. Loss due to entrainment at the water projects is further detailed in the Entrainment section. Low prey availability may be related to low survival of juveniles to adults (Nobriga and Rosenfield 2016) and survival from year 1 age class (Rosenfield and Baxter 2007). Predation studies in the SFE documented predation by Sacramento Pikeminnow (*Ptychocheilus grandis*) and Striped bass (*Morone saxatilis*) (Grossman 2016). A study of the California Current found that Longfin Smelt were also preyed upon by birds and mammals (Szoboszlai et al 2015). Another factor that influences the probability of Longfin Smelt survival is condition, such that poor condition due to increased stress or poor nutrition can reduce survival.

*General list of factors affecting Abundance, Growth, and Survival*

- Hydrology (Delta outflow, inflow, water year, bay tributary outflow)
- Water quality (temperature, salinity, turbidity, contaminants)
- Prey (copepods, mysids, other zooplankton)
- Harmful Algal blooms (dinoflagellates, toxic diatoms)
- Aquatic Weeds (habitat encroachment, herbicides)
- Predation (fish, birds, and mammals)
- Competition/ invasive species (marine, estuarine, and freshwater competitors and/or invasives)
- Anthropogenic effects include Entrainment (Urban and agricultural syphons, CVP and SWP operations), dredging, wetland habitat loss, water depletion, and in-water construction.

## Primary Management Issues This Topic Will Address

Understanding the drivers of abundance, growth and survival is a critical need to understand the effects of management actions including flow and habitat restoration on Longfin Smelt in the SFE. Hence, these metrics are all critical for effectiveness monitoring for ITP actions, and to develop new approaches for Longfin Smelt management. A related factor is that these measurements of vital rates are essential to inform population modeling, an essential tool for the management of imperiled species.

Increased research in these areas can lead to new management opportunities for the species, such as the use of habitat proxies (in addition to observed distribution data) for real-time operations management. Additionally, understanding these factors can also inform and improve new and ongoing monitoring programs to ensure that important factors are incorporated into sampling design and collected over the long term. Improving our understanding of life-stage specific needs related to growth and survival can also aid in establishing a successful captive population of Longfin Smelt in culture.

## Potential Scientific Approaches

*Laboratory studies*

- Tolerance studies. Some initial studies have already been conducted (see Culture Section). Additional studies can be conducted where multiple factors are evaluated at the same time (see Jeffries et al 2016). The information can be used to develop habitat suitability indices, predictive mapping, and improve lifecycle modeling.
- Bioassays: Acute and Chronic toxicity studies. Studies on Delta Smelt and other SFE species can be used as a reference (see Foott and Stone 2007, Hobbs et al 2010,

Jefferies et al 2016, Connon et al 2019, Hasenbein et al 2019). It may be necessary to conduct toxicity testing on Longfin Smelt instead of relying on surrogate studies as there may be species specific impacts (e.g., differences in temperature tolerance).

- Nutritional studies: Nutrient optimization, ration studies. These studies can improve culturing of the species which will provide a valuable resource of test subjects for further laboratory studies. These studies when combined with tolerance studies and bioassays can improve predictions of modeling for the effects of management actions on Longfin Smelt vital rates.
- Behavioral studies: Swimming Behavior (Swanson et al 2000), Predation studies, Prey selection. Behavioral studies have been useful for evaluating the interactions of multiple stressors. The studies can inform actions like habitat restoration and fish screen design.

*Field Monitoring and Investigations*

- Surveys: Trawls, eDNA, telemetry, acoustics, bioassays (see Dryfoos 1965, Gold et al 2011, Connon et al 2019). These would include both ambient monitoring (which would be good for trend analyses and relative effects) and special studies monitoring which would be short-term surveys designed to evaluate a short-term management action.
- Targeted field experiments: BACI, Cage studies, Comparative/Reference studies such as those conducted by the Tidal Wetland Monitoring group. Targeted studies would be appropriate for addressing specific questions and uncertainties of a management action. The regular surveys may not be appropriate to use therefore a targeted field experiment would be better.

- Condition and health studies: combining otolith age and growth information with somatic condition indices, diets and isotope markers can be used to further understand abiotic and biotic drivers of health, growth and survival.

*Modeling*

- Multivariate analysis (see Mahardja et al 2020, Kimmerer et al 2018) for initial exploration of simple relationships and hypothesis testing. Results can guide future syntheses and lifecycle model development.
- Lifecycle modeling as mandated by the ITP
  - Utilization or improve the current lifecycle model, Maunder et al (2015, see Hanson 2014) and/or develop a new model (See Lifecycle Model Section)
- Synthesis analysis:
  - Review of prior multivariate and univariate analyses to identify and prioritize gaps in knowledge to inform management of the species.

    - Risk Assessment using toxicology studies on Delta Smelt and other fish from the SFE as surrogates
- Update previous synthesis efforts using current data (see Tamburello et al 2019). This will check for any changes in relationships or further validate relationships to reduce potential for relying on spurious or outdated relationships.

## Additional Considerations

As for all other elements of this study plan, there are other factors to consider when addressing what is needed to generate more information on Longfin Smelt growth, abundance, and survival for management. Survey limitations, permitting, and culture limitations may be factors. In addition, there are larger scale issues that may require being more adaptive to changing conditions such as water year, the status of restoration sites, and climate change.

Increasingly, long-term survey data is being used beyond the original purpose of the surveys. However, long term survey datasets are a wealth of information and should be utilized as appropriate (Stompe et al 2020). Biases are present in all types of monitoring and should be identified and accounted for where possible and practical (Latour 2016). Moreover, long-term surveys are often not sufficient for evaluating the effects of a specific management action or questions to inform a management action. In such cases, modification or special studies will need to be considered, which will require new permits and impose logistical limitations that will need to be addressed. If permits are not available, alternative monitoring techniques or methodologies will need to be considered, such as monitoring of fish related factors including food density, composition, and availability or using no or low take methods such as fish cameras, bioacoustics, and eDNA. In addition, there may be some significant resource limitations such as staff, equipment, and the availability of cultured fish. As has been noted by the IEP Fleet Resiliency Strategy, there are a limited number of boats and crews available for use. Alternative sources of boats and crews may need to be developed or identified from existing programs using outside staff (e.g. sister agencies, consulting biologists).

# IMPROVED DISTRIBUTION MONITORING

## Introduction

Longfin Smelt are sampled in many of the monitoring programs implemented within the SFE. However, these monitoring programs are often limited in their ability to match the temporal and geographic distribution of Longfin Smelt. For this reason, the ITP identified several priorities regarding the development or modification of monitoring programs for Longfin Smelt. In this Priority Area, we describe the current suite of monitoring programs which collectively provide the long-term datasets for Longfin Smelt, their limitations, and potential approaches to filling key data gaps.

## Connection to Condition of Approval 7.6.3: Longfin Smelt Science Priorities

Work conducted within this priority area is expected to inform the following priorities identified in Condition of Approval 7.6.3 of the ITP:

- New and ongoing monitoring that:
    - Applies equal effort throughout the known spawning and rearing distribution in the Delta, Suisun Marsh, Suisun Bay, Napa-Sonoma Marsh and Alviso Marsh in South Bay.
    - Characterizes the distribution and abundance of adult, larvae and juvenile life stages.
    - Facilitates estimates of survival probabilities among life stages
    - Characterizes changes in abundance and distribution of life stages across a range of hydrologic conditions, including different water year types.
    - Considers revisions to existing IEP monitoring programs to expand the spatial distribution of Longfin Smelt sampling.
    - Addresses factors that influence Longfin Smelt population abundance, distribution, and catchability, including vertical migration behavior, water transparency, and other factors that support growth and survival (i.e., prey density).

## Key background information

Eight long-term fish monitoring surveys effectively capture one or more Longfin Smelt life stages annually and are listed below in order of targeted life stage, starting with those targeting larvae. Except for eggs, all Longfin Smelt life stages are collected by one or more of the current agency fish-monitoring surveys described below and in Honey et al. (2004).

Longfin Smelt produce demersal, adhesive eggs, which have not been collected in the SFE and no sampling study exists to address this gap (*see section on spawning and rearing habitats*).

Current fish-centric surveys vary in their temporal and geographic coverage of targeted life stages. For each survey listed below, the sampling period and frequency are described as well as the sampling range, the target fish sizes and original intent of the sampling. The list below also includes limitations that pertain to survey's ability to comprehensively collect targeted life stages (size ranges) of Longfin Smelt. The Spring Kodiak Trawl collects some juvenile and adult Longfin Smelt, but not enough to warrant inclusion. Similarly, neither the historical CDFG Resident Fishes shoreline electrofishing survey nor the current USFWS beach seine survey sampling (Honey et al. 2004) capture sufficient numbers of Longfin Smelt to warrant inclusion in this discussion either.

1. **Smelt Larva Survey** (initiated 2009): Samples biweekly January- March, single oblique tow per station; range includes the Delta and downstream to eastern San Pablo Bay;
    - **Target:** Newly hatched larvae – small juveniles (5-10 mm best, up to 25 mm); preserved in formalin and processed in the lab.
    - **Original intent**: Provide density and proximity information for larval Longfin Smelt in relation to south Delta export pumps and density information within low-outflow range of larval Longfin Smelt.
    - **Limitations**: Misses larvae hatching in December and April (rarely May) and habitat in San Pablo and southern South San Francisco Bays, as well as in tributaries in those regions. Single tow per station doesn't allow for detection probability.

2. **20-mm Survey** (initiated 1995): Samples biweekly late March – early July, three oblique tows per station; range includes the Delta and downstream to eastern San Pablo Bay;
    - **Target:** Medium-sized larvae – small juveniles (10-30 mm); preserved in formalin and processed in the lab.
    - **Original intent**: Provide density and proximity information for larval and small juvenile Delta Smelt in relation to south Delta export pumps.
    - **Limitations**: Misses recruitment to gear beginning in February and misses habitat in San Pablo, Central and South San Francisco Bays, as well as in tributaries in those regions.

3. **Summer Townet Survey** (initiated 1959): Samples biweekly June—August, 1-3 oblique tows per station; range includes the Delta and downstream to eastern San Pablo Bay;
    - **Target:** small juveniles (20-50 mm); many <25 preserved in formalin and processed in the lab; others processed in the field and released.
    - **Original intent**: Produce an abundance index for Striped Bass at 38 mm mean size for use in survival estimation.

- **Limitations**: Misses recruitment to gear beginning in April and misses habitat in San Pablo, Central and South San Francisco Bays, as well as in tributaries in those regions, though tributary use is likely temperature limited at some point between April and June.

4. **Fall Midwater Trawl Survey** (initiated 1967): samples monthly September—December, 1 oblique tow per station, which samples throughout the water column, but a maximum depth of about 40 ft (DFG unpublished); range includes the Delta and downstream to western San Pablo Bay;
   - **Target:** Juveniles- small-sized adults (50-150 mm) processed in the field and released.
   - **Original intent**: Produce an abundance index for age-0 Striped Bass in fall.
   - **Limitations**: Juveniles don't fully recruit to gear until 60-70 mm (Longfin Smelt are slimmer than Delta Smelt of the same length and Delta Smelt recruit at 60 mm, Mitchell et al. 2017) and omits habitat in Central and South San Francisco Bays (tributary use is delayed until temperatures drop in late November or December). Single tow per station does not allow for detection probability, but stations are in close proximity thus spatial binning could be conducted to assess detection.

5. **Bay Study Survey** (initiated 1980): Samples monthly year-round, 1 tow per station each with an otter trawl (OT) which samples along the bottom, and a midwater trawl (MWT) which samples throughout the water column with a maximum depth of about 40 ft (DFG unpublished); range includes lower rivers in western Delta throughout the SFE to southern South San Francisco Bay;
   - **Target**: Juveniles- small adult fishes (25-250 mm, varies by net) and invertebrates. Fish and crabs mostly processed in the field and released; shrimps preserved in formalin and processed in the lab.
   - **Original intent**: Provide data to monitor the distribution and abundance trends for a suite of invertebrate and fish species.
   - **Limitations**: Juveniles don't fully recruit to OT gear until about 40-50 mm and MWT-gear until 60-70 mm and covers open water habitat only. Fewer stations per embayment compared to FMWT. Single tow per station doesn't allow for detection probability estimation. Does not sample tributary marsh habitats to San Pablo Bay and South San Francisco Bay and has limited sample stations in the Central, South, and North Delta.

6. **Enhanced Delta Smelt Monitoring** (initiated 2016): Samples weekly to biweekly year-round, with up to 2 surface larval-net tows or 4 surface Kodiak trawl tows per randomly selected sampling location (high catches of Delta Smelt will reduce tow number); range sampled includes the Delta and downstream through the eastern half of San Pablo Bay.

- **Target:** 20-mm trawl (larval net) used April – June to target medium-sized Delta Smelt larvae – small juveniles (10-30 mm) preserved in the field and processed in the lab, and a Kodiak Trawl used July- March to target Delta Smelt juveniles-adults (40-150 mm) processed in the field and released;
- **Original intent**: Sample in a probabilistic fashion to estimate absolute abundance of Delta Smelt late stage larvae in spring and older life stages through remaining seasons. **Limitations**: 20-mm sampling is limited to only 3 months in spring, sampling distribution doesn't cover recruitment region in wet years; Kodiak Trawl samples the top surface (~3.5 m) and Longfin Smelt juveniles and adults while are more common at mid-depths and toward the bottom, and the sampling effort does not cover Longfin Smelt habitat south of the San Joaquin River in the Delta, western San Pablo, South or Central San Francisco bays or their tributaries. Has been in operation only a few years.

7. **Chipps Island Trawl** (initiated 1976): samples 3-7 days per week, year-round, using a MWT fished near the surface to conduct ten 20-min tows per sampling day; range sampled – three trawl lanes (north, middle and south) in channel adjacent to Chipps Island only.
    - **Target:** Juveniles – small adult fishes (40-150 mm) most processed in the field and released; tagged fish processed in the lab;
    - **Original intent**: Estimate percent passage or survival of emigrating juvenile Chinook Salmon and Steelhead.
    - **Limitations:** Samples only a single location, gear samples near surface only and likely misses some benthic oriented individuals, fraction of the population reaching and passing Chipps Island between late fall and late spring likely varies with outflow: maximum passage likely occurs when X2 is > 81 and drops as X2 moves downstream. Nonetheless, sampling during the winter-spring spawning period appears sufficient to detect the presence of Longfin Smelt migrating into the Delta, a precursor to entrainment in the south Delta export pumps.

8. **Suisun Marsh Survey** (initiated 1980): Samples monthly year-round, using a single OT tow at each sampling location within sloughs in Suisun Marsh;
    - **Target**: Juvenile and small adult fish and invertebrates (25-250 mm) processed in the field and released.
    - **Original intent**: Track trends in distribution and abundance of invertebrate and fish communities in Suisun Marsh.
    - **Limitations:** Samples fish and inverts only within Suisun Marsh. Single tow per station doesn't allow for detection probability.

**Limitation of all surveys:** None of the listed surveys sample the local coastal waters believed to provide habitat July -September for Longfin Smelt in their second year of life (Rosenfield and Baxter 2007), if not longer (CDFG 2009). This information gap is therefore is substantial limitation in our understanding and management of Longfin Smelt.

## Primary Management Issues This Topic Will Address

Understanding the distributions of Longfin Smelt at various life stages is key to understanding the habitat needs and movements of the species, and its vulnerability to entrainment under different conditions. Specifically, effectively sampling the entire distribution of each key life stage will improve the ability to calculate important population metrics and vital rates (e.g., abundance, survival, etc.) and improve their accuracy (e.g., a shift in distribution to outside the sampling frame will reduce accuracy of abundance calculations). Moreover, effective and geographically comprehensive sampling during the larval and early juvenile stages is important to successful investigation of the mechanisms underlying the Longfin Smelt outflow-abundance relationship. Similarly, knowledge of where important Longfin Smelt habitat exists through different life stages and through varied environmental conditions (ex. outflow, temperature) will be necessary to plan and execute effective habitat restoration.

Understanding the impact of loss to the population from entrainment into the south Delta and CVP/SWP facilities and other diversions is important for establishing management strategies to minimize entrainment (*see Improved Entrainment Monitoring* section). Current annual larva sampling within the Delta and Suisun Bay by the SLS provides information on hatch timing, proximity of larvae to the export pumps, the magnitude of flow through the lower San Joaquin River needed to help guide locally hatched larvae beyond the range of entrainment, and potentially the fraction of the larval population vulnerable to entrainment. Production of young from areas not effectively sampled by long-term monitoring (e.g. SF Bay and tributaries) is therefore important for understanding the proportion of young life-stages vulnerable to entrainment.

Effective sampling of all Longfin Smelt life stages can provide the data needed to populate a life cycle model (see *Life Cycle Modeling* section). As noted previously, life cycle models are essential tools for the management of special status fishes in the Bay-Delta.

## Potential Scientific Approaches

As noted previously, several of the existing surveys do not have sufficient geographic or temporal scale to cover the range of Longfin Smelt. This is particularly true for the SLS and 20-mm Survey, which would need to be expanded in time and geography to cover the periods larvae recruit to the gears and the range of these larvae through small juveniles. The same may also apply for the Summer Townet Survey, but that program is less useful for entrainment management given its timing. It is conducted at a time of year when south Delta temperatures typically exceed maximum tolerance for juvenile Longfin Smelt (June or July).

Additional sampling considerations and decisions to be made include:

- Consideration of whether and how to sample smaller tributaries (Sonoma Creek, Petaluma River, Coyote Creek/Alviso Slough). The number of larvae originating from these tributaries are limited by small geographical area of these habitats, but surviving larvae may provide disproportionally important contributions to subsequent life stages.
- Consideration of the need to expand the spatial sampling of early life stages equally across the SFE in all years. The bay tributary sampling conducted during the Longfin Smelt Settlement Agreement found very few larvae in bay tributaries in dry years, while in wet years, most larvae were found outside the current sampling footprint.
- Development of "sampling strata" for expanded sampling for all gear types. Such sampling strata will be needed to estimate water volume and calculate absolute abundance (i.e., strata volume and area are needed for strata density expansions).
- Consideration of whether expanded sampling should continue to use fixed sampling locations, employ an assumption of random sampling and design-based estimation (e.g., Newman 2008), or attempt to randomize sample site selection.
- Determine whether to include replication of tows at each sampling location.
- Evaluate the value of adding zooplankton sampling to expanded survey sampling and to surveys that do not currently collect zooplankton.
- Assess whether current SF Bay Study sampling effort per embayment should be increased.
- Assess whether local coastal distribution should be monitored at some frequency annually or investigated at some frequency annually for several years -- to estimate the proportion of the population that uses this habitat and during what seasons – and then stop, either permanently or for some period of time prior to repeating the process to see if use has changed.
- Develop a study plan to investigate size of complete gear retention for Longfin Smelt; some data for retention exists for SLS and 20-mm Survey.
- Develop a study plan to investigate the depth distribution of Longfin Smelt and the factors that affect what strata of the water column is used.

## Additional Considerations

*Logistics*

Expanded sampling described above will require additional resources including boat(s), personnel, and sampling gear to account for added locations. Expansion of sampling into new regions will also add several days of field work to each sample period and additional sample intervals will need to be added for many surveys. Expansion of SLS and 20-mm Survey will require additional laboratory staff and space (Stockton CDFW lab space will be surpassed), or an alternate sample processing pipeline (e.g. using genetic tools) to process samples in a timely manner.

In contrast to expanding the sampling, survey evaluation with the idea of reducing redundancy could be considered. Several of the surveys overlap temporally and spatially and reducing redundancy can provide additional flexibility in resources to address other needs such as reducing detection bias or expanding to under-sampled regions or life-stages. This of course would require a broad evaluation to make sure that any increase in efficiency does not sacrifice components of a monitoring enterprise that are vital for management needs for other species of management concern.

Adding other factors like additional zooplankton sampling or water quality measurements like contaminants will come with additional resource needs regarding additional materials, storage capacity, and staff. For example, lab space limitations will be exacerbated if zooplankton sampling is added to expanded surveys. Current vessel resources are sufficient for existing sampling but will likely need to be expanded to take on additional sampling (i.e., added sampling will put more hours on vessels and require more maintenance/repair and more back up vessels).

*Permits and Approvals*

Any addition to survey sampling panels will require assessment of potential for take of species listed under the ESA or CESA, and time for new take permitting. Moreover, substantial expansion of existing surveys may require review and approval by IEP, which has an annual approval cycle with specific deadlines.

## IMPROVED LARVAL ENTRAINMENT MONITORING

### Introduction

Condition of Approval 7.6.2 in the ITP requires the development of larval entrainment monitoring to better understand larval entrainment into Clifton Court Forebay. Because entrainment of larval Longfin Smelt is not currently quantified at the SWP salvage facilities, and its importance as factor affecting Longfin Smelt abundance is uncertain, it was included as a Priority Area within the LFSSP. In this section, we describe the current process and anticipated goals for developing and testing different approaches.

### Connection to Condition of Approval 7.6.3: Longfin Smelt Science Priorities

Work conducted within this priority area is expected to inform the following priorities identified in Condition of Approval 7.6.3 of the ITP:

- New and ongoing monitoring that:
    - Addresses factors that influence Longfin Smelt population abundance, distribution, and catchability, including vertical migration behavior, water transparency, and other factors that support growth and survival

### Key Background Information

Condition of Approval 7.6.2 in the ITP requires the implementation of a new Smelt Larval Entrainment Program with the goal of quantifying larval Delta Smelt and Longfin Smelt entrainment into Clifton Court Forebay. A draft monitoring plan will be developed by March 31, 2022, then a pilot program will be conducted for one year, leading to final monitoring plan by March 31, 2023. For the purposes discussed here, "larval" refers to the life-stage of post-hatch Longfin and Delta Smelt with a length less than 20mm.

A team of scientists from CDFW, CDWR, NMFS, and USFWS has been convened and is currently developing the draft monitoring plan. As the first step in this process, the team drafted three goals for the project:

1) Develop a quantitative estimate of larval smelt entrainment.
2) Further the understanding of environmental conditions and mechanisms leading to Delta Smelt and Longfin Smelt larval entrainment events.

3) Achieve better resolution, in real time, of the magnitude and duration of Delta Smelt and Longfin Smelt larval entrainment events.

Prior to the issuance of the ITP, larval smelt entrainment monitoring was conducted via a variety of long-term monitoring programs in the channels leading to the export facilities and within the fish salvage facilities themselves. Existing larval monitoring consists of:

- CDFW's Smelt Larva Survey: Started in January of 2009 with the expressed goal of informing assessments of larval Longfin Smelt vulnerability to entrainment. This program samples biweekly from the beginning of January to mid-March every year (see above; Chorazyczewski 2019). The geographic coverage of this survey's 44 stations extends from the lower Napa River and Carquinez to the freshwater portions of the Delta. At each station, a single tow is completed with a sled mounted 500 µm net, with samples preserved in 10% formalin for later analysis in DFW's lab.
    - Condition of Approval 7.6.1 in the ITP provides the Smelt Monitoring Team the ability to request up to two additional SLS sampling events in December each of year, which are based on adult Longfin Smelt catch in the Chipps Island Trawl. This condition provides a tool for understanding larval entrainment risk for the month of December. Because of this specific purpose, these sampling events will only include tows at central and south Delta stations.

- CDFW's 20mm Survey: Started in 1995 with the goal of informing assessments of risk for larval Delta Smelt entrainment to the south Delta export facilities. This program samples biweekly from March to June annually (see above; Mahardja et al. 2017, Tempel and Damon 2018). The 20mm survey samples 47 stations from Carquinez (and west to San Pablo Bay and the Napa River during high outflow years) to the freshwater portions of the Delta. At each station, triplicate tows are conducted using a sled mounted 1600 µm net, with samples preserved in 10% formalin for later analysis in DFW's lab.

- Larval Fish Monitoring at the Skinner and Tracy Fish Facilities: Every year since 2009, the fish salvage facility staff conduct larval fish sampling to monitor for the presence of larval Longfin and Delta Smelt (Reyes 2020). This sampling varies in its start and end dates based upon recommendations from the Smelt Monitoring Team, but typically occurs from February/March to early June. For each 30 min fish count the facility conducts, typically four per day, the standard fish screen (2.4 mm opening) is overlain with a larval screen (0.5 mm opening) and a sample is collected from the basin using a fine mesh dip net. The sample is preserved in 10% formalin for analysis on site. It is important to note that this sampling is considered by the Smelt Monitoring Team to be highly inefficient and the data produced are treated as presence only, not as quantification of larval entrainment. One of the goals of this element is to increase the sensitivity and quantification of larval smelt monitoring at the salvage facilities. This program will work with the Smelt Monitoring Team to produce information that is useful and actionable with respect to making recommendations on OMR levels (ITP Conditions of Approval 8.4.2 and 8.5.2).

### Primary Management Issues This Area Will Address

This element will improve the accuracy and sensitivity of larval smelt monitoring and increase understanding of larval smelt entrainment dynamics in the south Delta, particularly into Clifton Court Forebay. Increased sensitivity and quantification of larval smelt presence in the south Delta is critical to informing the real-time operations of the SWP, minimizing the entrainment of larval smelt into the south Delta and CCF per Conditions of Approval 8.4.2 and 8.5.2, improving our ability to analyze patterns of larval entrainment and environmental parameters that may correlate with entrainment events, and informing the creation of a robust Longfin Smelt life cycle model. Ultimately, this information will allow scientists and managers to adaptively manage south Delta operations to minimize impacts to smelt populations while maximizing water export capacity.

### Key Scientific Approaches

To meet these needs, the larval entrainment monitoring team, as of this writing, has compiled a list of approximately 19 direct and indirect candidate sampling methods, ranging from environmental DNA sampling (Brandl et al. 2015, Baerwald et al. 2020) to expanding existing net surveys, to new direct methods like light traps and pump sampling (Bennett et al. 2002). These methods also include potential applications both in south Delta channels and within the infrastructure of the SWP and Skinner Fish Salvage Facility. All of the methods will be evaluated in an iterative process, with an initial red flag review to remove methods that are prohibitive in some sense, then a second round of evaluation to examine how each method could assist in meeting the project goals. These evaluations will include the scientific merit of the method (gear selectivity, sensitivity, utility, etc.), the feasibility and logistics of carrying out the sampling (effort required, reliability of method, etc.), and the management relevance of the data produced (sample processing time [data available in near-real-time for entrainment management decisions], data utility for modelling, benefits for monitoring other species, etc.).

Once candidate methods are chosen, a draft monitoring plan will be created, and a pilot evaluation study will be conducted to further refine the methods. This one-year pilot field effort is targeted for the spring of 2022. Based on the results of the pilot study, following the aforementioned timeline, a final monitoring plan will be created and implemented to codify the new monitoring into the suite of long-term ecological monitoring conducted by IEP. The specific elements chosen for the final monitoring plan will be selected by the larval smelt entrainment monitoring team, in consultation with the Smelt Monitoring Team and Longfin Smelt Technical Team, coordinated with the IEP Science Management Team, and with final approval by CDFW.

## Additional Considerations

All methods being evaluated would increase the resource needs of the agencies undertaking the sampling. Depending on the methods included in the pilot and final monitoring plans, there may be a need for new permits authorizing additional take of listed species. As with the expansion of any long-term monitoring program, there will be considerable logistical hurdles, from staffing and vessel needs, to increasing capacity of the sample processing pipeline, to creating a robust data management and quality assurance program. It is anticipated that these new or expanded monitoring elements will undergo periodic review, synthesis, and adaptive management to ensure that they continue to produce valuable and actionable information well into the future.

# LONGFIN SMELT CULTURE

## Introduction

The effort to establish Longfin Smelt in culture started in the early 2010 and has been steadily progressing since. The importance of establishing a captive population of Longfin Smelt is twofold: 1) to buffer against extinction and 2) increased opportunity for research. Because of this, completing the Longfin Smelt life cycle in captivity was identified as a science priority within the ITP and is a core component of this Priority Area within the LFSSP.

## Connection to Condition of Approval 7.6.3: Longfin Smelt Science Priorities

Work conducted within this priority area is expected to inform the following priorities identified in Condition of Approval 7.6.3 of the ITP:

- Complete Longfin Smelt lifecycle in captivity at the FCCL.

## Key Background Information

Attempts at culturing Longfin Smelt were first initiated at the UC Davis Fish Conservation and Culture Lab (FCCL) during the 2010-2011 Longfin Smelt spawning season. Adult brood stock have since been collected annually whenever available from the U.S. Fish and Wildlife Service (USFWS) Chipps Island Trawl, the UC Davis Otolith Geochemistry & Fish Ecology Laboratory, and DWR.

*Adult Brood stock*

In recent years, the wild adult brood stock have been held in 10 ppt salinity water at 12˚C (Hung 2019) in 86-L tanks (Hung pers. comm.) and fed with cultured mysids and adult and newly hatched artemia (Hung 2019). During the 2015-2016 season, the adults showed early signs of fin rot at salinity 0.2 and 2 ppt. The 2016-2018 Longfin Smelt Culture and Marking Study found that increased salinity (7.5 ppt) and the addition of Delta Smelt to the Longfin Smelt tanks doubled the length of wild Longfin Smelt survival (Tigan et. al 2018a). The co-culturing with Delta Smelt likely encourages feeding and improves schooling behavior (Hung et al. 2020). In almost every year, adult survivorship has been highly correlated to their size, with >111-mm adults surviving an average of 37 days post-capture and <80-mm adults surviving an average of just 9 days (Hung 2019, Tigan et. al 2018a and 2018b).

Adult feeding has been one of the many issues faced in the culturing process. The adults have not accepted dry feed but have shown a preference for cultured mysids and live Artemia. However, most adult broodstock die due to unknown reasons within a month after arrival, which highlights the continuing challenge in maintaining adult survivorship in captivity (Afentoulis 2019).

*Spawning*

Strip spawning and crossing of wild adult Longfin Smelt has made significant progress over the years. Adult female fecundity is mostly correlated with size, with overall average fertilization rates of approximately 50% and average hatching rates of approximately 90% (Hung et. al 2020). Eggs are spawned in freshwater at 12˚C, and the embryos are incubated for 16 days (Hung et. al 2020). Although fertilization and hatching rates have improved, the FCCL's ability to obtain ripe adults has been a challenge throughout the years (Afentoulis 2019, Tigan et. al 2018a and 2018b). Many of the adult sized fish are immature, already spawned out, or of low quality due to injuries related to catch and transport. In addition, the FCCL does not have the physical capacity to provide rearing space for excess fertilized eggs (Hung 2019).

*Larvae*

Larval culture has remained a bottleneck for Longfin Smelt culture at the FCCL (Hung 2019). The average survival rate of larvae, which are held in 86-L tanks at the FCCL, to 40 dph (days post hatch) has been only 19.5%, with no clutch averaging over 50% survival until the 2019-2020 spawning season, which saw a remarkable 68% survival rate (Hung et. al 2020). In addition, survival to 120 dph has never been above 1% until the 2019-2020 season, which attained a survivorship of over 50% (Yanagitsuru et. al 2020, preliminary). Rearing the 2020 clutch is ongoing, and the FCCL hopes to continue this positive survivorship trend.

The recent larval survivorship success for the 2020 progeny has been a collaborative effort between the FCCL, Dr. Nann Fangue and Dr. Richard Connon's labs at UC Davis, and the Otolith Geochemistry & Fish Ecology Laboratory. Significantly increased survivorship has been attributed to the use of elevated water salinity levels at 2 ppt instead of freshwater (0.4 ppt), which has been used in all the previous years. Laboratory experimental treatments showed that yolk-sac larvae were able to maintain water balance similarly between 0.4-10 ppt, but growth and survival was greater at 5-10 ppt, and 0.4 ppt treatments experienced stalled yolk resorption (Yanagitsuru et. al, in prep). In addition, survival within 0.4 ppt treatments was under 40% 200 hours post-exposure, whereas survivorship at 5 and 10 ppt was nearly 100%. Due to saltwater discharge restrictions, the FCCL was limited to rearing the larvae at 2 ppt instead of 5 ppt. Nevertheless, larvae survivorship in 2020 was at a historical high, and could potentially be even higher with the use of 5-10 ppt treatments. The 2020 progeny have been feeding successfully on Rotifers until 40 dph, and then transitioned over to newly hatched Artemia (Hung pers. comm.) However, as the live Artemia is not enriched, the feed is inadequate for proper growth and development (Hung pers. comm.). Rotifers, *Brachionus plicatilis* (Reed Mariculture Inc., Campbell, CA), are enriched with rotifer feed (*Nannochloropsis*) to improve the nutrients they provide to larvae. The enrichment improved larval culture for Delta Smelt and is expected to do the same for Longfin Smelt.

## Primary Management Issues This Area Will Address

As noted previously, Longfin Smelt are listed as threatened under CESA and there is a management need for a refuge population to allow for the possibility of supplementing the wild population to prevent extinction. Unlike Delta Smelt and salmonids, the San Francisco Bay-Delta Distinct Population Segment (DPS) of the Longfin Smelt lack a refugial population to buffer against the stressors that the species continues to face. In addition to potential future supplementation, successfully culturing Longfin Smelt would provide a more thorough understanding of the species life history, thereby improving its management. For example, significant progress has recently been made on understanding the species embryonic and larval needs by exploring salinity and temperature requirements for the 2019 and 2020 progeny year classes (Connon et. al 2020, unpublished data). Cultured fish could also provide further information on reproduction, growth, response to stressors such as suboptimal water quality, and feed preferences. This type of information is a critical need for the development of life cycle models, and to identify habitat requirements that could be addressed through management actions (e.g. flow, restoration, etc.)

Longfin Smelt captive propagation would also allow for further field and lab studies to support management. One of the bottlenecks in evaluating the effects of management actions on Longfin Smelt is that their numbers are low and take authorization could limit the implementation of additional field sampling. Cultured fish therefore allow us to use laboratory and field approaches (e.g. enclosures) to understand how the species' physiology, ecology, and genetics respond to different environmental variables and management actions.

## Potential Scientific Approaches

With the recent progress on cultured Longfin Smelt, research should be focused on how to rear the species throughout its entire lifecycle. Establishing the appropriate salinity and temperature requirements at the embryonic and larval life stages has been instrumental, so developing similar metrics for the juvenile and adult life stages will be essential. The salinity requirement for the species can be determined by way of salinity tolerance (Critical Salinity Maxima, loss of equilibrium, performance curves, etc.) and common garden tests, where individuals are acclimated to either freshwater or specific salinity conditions, and then challenged with alternate salinity regimes to evaluate salinity tolerance. Similarly, temperature requirements can be determined by way of temperature susceptibility tests (critical thermal maximum, loss of equilibrium, etc.) as well as begin to inform valuable Longfin Smelt physiology metrics, such as metabolic rates. A number of these experiments are currently under way at UC Davis for the 2020 progeny year class (Connon pers. comm.). As both Longfin and Delta Smelt are known to prefer more turbid environments (Mahardja et. al 2017, Moyle et. al 2016), more research is needed on the effects of turbidity. Potential factors that could be examined include the effects of turbidity on growth, survival, feeding, and predation.

In addition to basic water quality variables, there are many other factors to consider including the development of optimal diets for each life stage, and optimization of tanks and other culture systems (e.g. vessel design, potential habitat features, substrate). The current use of live, unenriched Artemia is not sufficiently nutritious (Dabrowski and Rusiecki 1983, Payne and Rippingale 2000, Shields et. al 1999), so additional live feeds such as cultured copepods may be needed to maintain juveniles and older fish. Recent lab studies have also shown that larvae do not transition from rotifer to Artemia when turbidity is lower than 10 NTU (Yanagitsuru et. al, in prep) suggesting that food preferences may be linked to water clarity. Longfin Smelt may also require a specialized formulated feed to improve growth, development, reproduction, and survival. Another critical element will be the development of genetic management methods to reduce the potential effects of inbreeding and domestication.

In summary, attempts to close the Longfin Smelt lifecycle in captivity would require intense focus on the favorable conditions for the species at every life stage to maintain survivorship. Many of these parameters have been identified at FCCL for Delta Smelt, another Osmerid native to the SFE (Maunder and Deriso 2011, Moyle 2002, Moyle et. al 2016). Given that Longfin Smelt are anadromous with a lifecycle of up to 3 years (Merz et. al 2013, Moyle 2002, Rosenfield and Baxter 2007), a more adaptive scientific approach may be necessary to discover the requirements at every life stage.

## Additional Considerations

As much of the overall behavior of Longfin Smelt remains unknown, successful captive propagation is likely to require extensive personnel. In addition, a broad range of equipment and facilities capable of obtaining and discharging fresh, brackish, and saltwater may be required due to the species' anadromous lifecycle. Even if adults are successfully housed in freshwater, rearing in this environment may cause artificial selection and altered migratory behavior if ever released into the wild for supplementation, as has been observed for hatchery-reared salmonids (Brenner et. al 2012, Jonsson et. al 1991, Knudsen et. al 2006, Pascual and

Quinn 1994). As excessive discharge of saline water is not permitted at the FCCL, additional facilities may need to be considered, as well as development of a closed, recirculating system.

Since Longfin Smelt are listed as threatened under the CESA, scientific collection permits will be required whenever collecting broodstock. Culturing will require ample adult numbers, so it will likely be necessary to attain adults from sources in addition to the existing collections from Chipps Island Trawl, South Bay study, and DWR. As Longfin Smelt catch numbers from field surveys have substantially decreased over time, balancing sufficient collection numbers while preventing over-harvesting of the fish will be a challenge to assess.

This research element is not intended to directly support a full supplementation program, which would open up a substantial range of other issues. For example, supplementation programs for anadromous fish species have resulted in reduced genetic adaptation due to founder effects, domestication selection, inbreeding depression, and overall decreased long-term fitness on wild populations (Araki and Schmid 2010, Attard et. al 2016, Christie et. al 2016, Janowitz-Koch et. al 2019, Wapples 1991). Even if the proposed effort remains focused on culture research, perhaps including the development of a refuge population, there is a need to ensure effective genetic management of the fish.

The genetic makeup of Longfin Smelt in the SFE has recently been analyzed (Saglam et. al, submitted), but further genetic fingerprinting will be required to ensure that the SFE population gene pool is maintained. For example, the geochemical and genetic makeup of Longfin Smelt from multiple regions (e.g. South Bay, Suisun Bay, etc.) should be analyzed for distinction and continuity. Field surveys and geochemical analysis of Longfin Smelt otoliths suggest that the SFE population may be expressing multiple life history strategies (Lewis et. al 2020), and it remains unclear if crossing adults from various regions with different life histories would result in genetic drift or reduced long-term fitness. Sufficient funding and personnel for comprehensive genetic and geochemical analysis will be necessary to compare captive reared Longfin Smelt to wild broodstock and conserve the SFE population gene pool in a captive refugial population.

# FISH MIGRATION AND MOVEMENTS

## Introduction

Longfin Smelt are a small fish species within the SFE that are assumed to move considerable distances for spawning and rearing, however research into the species' migration behavior has been limited, see Rosenfield and Baxter (2007). By enhancing our understanding of movement and migration strategies for Longfin Smelt, we can improve our understanding of entrainment risk and develop new tools for managing the species. Because of this, migration behavior was identified as an important science priority for Longfin Smelt within the ITP. In this Priority Area, we hope to research a broad category of topics, such as larval swimming behavior and egg drift, in addition to the priorities identified in the ITP.

## Connection to Condition of Approval 7.6.3: Longfin Smelt Science Priorities

Work conducted within this priority area is expected to inform the following priorities identified in Condition of Approval 7.6.3 of the ITP:

- Improve understanding of adult migration behavior and review the current conceptual model that assumes adult staging is followed by rapid migration into lower salinity water and spawning soon thereafter.

- Improve the understanding of juvenile Longfin Smelt outmigration behavior and transport mechanisms for out-migrating fish, as it relates to the potential for miscuing resulting in increased entrainment at the south Delta facilities.

## Key Background Information

Longfin Smelt are known to be anadromous and therefore have at least two major population scale movements within the SFE each year; upstream migration of maturing adults from more saline habitat to low salinity and freshwater habitats for spawning, and downstream emigration of juveniles for rearing (Rosenfield and Baxter 2007). However, it is unclear how Longfin are able to navigate through the SFE, where they contend with tidal forces and changes in salinity during migrations which can span from the ocean to fresh water reaches of the Sacramento and San Joaquin rivers. Observations from Lake Washington, where distinct migration behaviors have been documented (Brocksmith and Sibley 1995; Dryfoos 1965; Martz et al. 1996; Moulton 1974), provide some insight into migration behaviors used by Longfin within the SFE.

In the absence of SFE specific information, and knowing that all ages of Longfin Smelt are absent from the Delta and south San Francisco Bay from mid-summer to late fall (Baxter 1999, CDFG 2009), the effects analysis for the ITP developed a basic conceptual model to provide insight into how adult Longfin Smelt may interact with water exports when spawning (Eakin et al. 2020). This conceptual model had two prevailing assumptions regarding migration behavior. First, it was assumed that Longfin move rapidly upstream once detected in the Chipps Island Trawl. This assumption is based on observations from Lake Washington, where both active spawning and the movement of ripe and spent fish were only observed from the late evening through early morning (Martz et al. 1996, Moulton 1974). These observations also lead to the second assumption for migration behavior in this conceptual model, in that spawning occurs relatively soon after upstream migration. This is in contrast to Delta Smelt (*Hypomesus transpacificus*), which often migrate upstream and "hold" for some time before they spawn (Sommer et al. 2011).

The ability of adult Longfin Smelt to move upstream against substantial flow is another area of uncertainty. In the Delta, tidal surfing is a strategy that Delta Smelt use to work their way upstream by using the power of the flood tide to "surf" their way to spawning grounds (Bennett and Burau 2014). It is not known if Longfin use a similar strategy, as they were observed in Kodiak surface tows on the flood and ebb tides, but unlike Delta Smelt, were absent from shoreline sampling. In Lake Washington, adult Longfin Smelt were observed in the low velocity habitat along channel margins while continuously moving upstream (Martz et al. 1996, Moulton 1974). Martz et al. (1996) also observed fish actively swimming upstream throughout the channel in Cedar River, where flows averaged 400 cfs in the winter, suggesting that Longfin can swim against higher velocity waters to an extent. This may be an important component of swimming strategies in the smaller bay tributaries, where flows are relatively low compared to the Delta.

Swimming behaviors of larval Longfin are another topic of interest within the SFE. Two dimensional particle tracking models, such as the Delta Simulation Model 2 (DSM2), have been used to analyze how hydrodynamics influence larval Longfin distribution (CDFG 2009). However, the ability of these models to accurately represent larval fish movements is somewhat dependent on how the particles are expected to behave. For example, in the absence of known information, particles are often treated as "neutrally buoyant" and will behave more passively in the water column than particles with swimming behaviors.

Fortunately, there is some information regarding larval Longfin swimming behaviors within the SFE. First, Longfin appear to be able to implement vertical migration strategies after developing an air bladder (~10-12 mm) (Bennet et al. 2002). This strategy may explain findings from Baxter (1999) and Dege and Brown (2004) where distribution of larvae was influenced by Delta outflows. In culture, larval Longfin, like other fish species of the Delta, appear to be attracted to light sources (Yanagitsuru pers. comm.) indicating some ability to move around in the water column after hatching. This is further supported by Brocksmith and Sibley (1995) where larvae were hatched in a lab setting and immediately swam to the surface before dying several days later. Additionally, Quinn et al. (2012) documented strong diel vertical migrations in both the spring and fall seasons for Longfin Smelt in Lake Washington, indicating that fish within the SFE may also reposition themselves in the water column based on time of day.

Lastly, the role of egg drift in the downstream dispersion of pre-hatch fish is unknown. Eggs are an under-sampled part of the Longfin life history within the SFE (see monitoring section) and thus it is unknown if egg drift occurs. In Lake Washington, egg collection by passive drift nets accounted for approximately 8% of eggs sampled in the Cedar River (Martz et al. 1996). This same study also documented the highest catch of "eyed up" eggs at the mouth of the Cedar River in May, following peak storm events in April. This anecdotal information suggests that its possible some larvae are hatching in locations that are different from where their eggs are deposited.

### Primary Management Issues That This Area Will Address

Effective management of an imperiled species is improved each time important knowledge gaps are filled. Understanding Longfin Smelt migration and movement strategies presents an opportunity to develop more focused and effective management strategies for the species at multiple life history stages. For example, information on this topic can lead to the development of:

- *Improved real-time monitoring*: By understanding movement behaviors, more effective and targeted monitoring can be developed to inform water operations of fish movements or hatching in the southern Delta.

- *Effective entrainment triggers*: By increasing our knowledge of migration and movement behaviors, managers can develop more reliable and effective triggers for export reductions based on real-time information.

- *Improvements to modeling tools*: Models are used as tools for managing at-risk species and can be improved by incorporating fish movements. Examples of such models include particle tracking and life-cycle models.

In addition to effective entrainment management, this topic can also provide important insight into the ecology of Longfin Smelt and its relationship to other habitat conditions including temperature and flows. By developing a better understanding of transport mechanisms for young larvae and eggs, managers may be able to develop new ways of minimizing and mitigating losses to the water export facilities through manipulation of hydrologic processes.

## Potential Scientific Approaches

There are multiple approaches that could be used to increase our understanding of Longfin Smelt migration and movement behaviors, below are a list of some of the more applicable approaches to filling this data gap.

- *Targeted field studies*: If Longfin Smelt are moving at night, and staying near shore, then daytime, mid-channel trawling techniques are likely missing fish. Targeted studies likely using specialized gear could therefore help to better understand adult movements.
- *Otolith studies*: Otoliths are an important tool that can be used to understand some of the general migration strategies with respect to age, geography, and salinity (Hobbs et al. 2010).
- *Laboratory studies*: Because the establishment of Longfin Smelt in culture is still in development, the opportunity to study these behaviors in a lab setting has only recently become available. These efforts can be useful for understanding behaviors of several life stages.
- *Telemetry methods for adults*: Telemetry technology has been improving over time and may be at a point where its applicable for use on Longfin Smelt adults. This approach can provide greater resolution in movement patterns up and down the SFE by older fish and perhaps hatchery surrogates, once available via improved culture methods.
- *Modeling studies*: Use of 3D particle tracking models to test different swimming behaviors for young fish, and comparisons with observed fish distributions.

## Additional Considerations

Many of the methods described above would require permitting for collection and sampling of wild fish. The number of permits required may depend on the location of sampling. If sampling were to occur in the Delta, then permits for take would be needed under both ESA and CESA due to geographic overlap with Delta smelt and other federally listed fish species.

Laboratory studies are currently limited because Longfin Smelt culture is in early stages of development and wild broodstock is limited. However, it is expected that Longfin Smelt culture practices will continue to improve over time and minimize this limitation in the future.

## SPAWNING AND REARING HABITATS FOR LONGFIN SMELT

### Introduction

Like Delta Smelt, spawning and rearing habitats for Longfin Smelt remain poorly understood. Identification of these core habitats will improve habitat restoration actions aimed at benefiting the species. Characterizing and mapping spawning and rearing habitat throughout the Delta are also important for understanding potential impacts as a result of operations of the SWP. For these reasons, spawning habitat was identified as an area of scientific priority within the ITP and a core component of this Priority Area within the LFSSP.

### Connection to Condition of Approval 7.6.3: Longfin Smelt Science Priorities

Work conducted within this priority area is expected to inform the following priorities identified in Condition of Approval 7.6.3 of the ITP:

- Characterize Longfin Smelt spawning substrate and spawning microhabitat requirements.

- Improve understanding of Longfin Smelt spawning substrate distribution in the Delta, Cache Slough, and Suisun Marsh

### Key Background Information

Longfin Smelt have been described as semelparous, spawning primarily during the second year of life from November through June with most spawning occurring from Late December through February (CDFG 2009). However, a small proportion of young-of-year Longfin Smelt have been observed to reach maturity in their first year (CDFG 2009). Longfin Smelt have generally been thought to spawn in the tidal reaches of the upper SFE (CDFG 2009, Moyle 2002, Wang 1986), though more recent studies have observed spawning in tributaries of San Francisco Bay (Grimaldo et al 2017, Lewis et al 2020). The precise locations and substrates used in the SFE have not been identified.

Longfin Smelt spawn negatively buoyant (demersal), adhesive eggs that are about 1-mm in diameter (Dryfoos 1965, Chigbu and Sibley 1994, Wang 2007), similar to other stream spawning members of family Osmeridae (Hay and McCarter 2000, Martin 2015). While eggs have not been observed in the SFE, observations of yolk-sac staged larvae suggest spawning habitat extends from the tidal reaches of the Sacramento and San Joaquin Rivers to Suisun Bay and Suisun Marsh ( Grimaldo et al. 2017, CDFW 2009; Meng and Matern 2001, Wang 1986;).

However, adult and larval Longfin Smelt have also been found recently in the Napa-Sonoma Marsh, Petaluma River and the Alviso Marsh in Lower South San Francisco Bay as well as in shallow water habitat in Suisun  Bay and San Pablo Bay, indicating the spawning habitats of this species may be distributed over a much broader geographic range than previously known (Grimaldo et al 2017, Lewis et al. 2019).

The Cedar River is the largest tributary entering Lake Washington (45 mi in length) with average discharge of 659 cubic-feet-per-second (cfs) and peak flows up to 10,000-cfs. The stretch of river where Longfin Smelt were found to spawn consisted of a mixture of large gravel and cobbles to smaller gravel and sands near the mouth. Longfin Smelt eggs have been collected from the river mouth to 1.2-km upstream, with the majority of eggs found from the mouth to approximately 300m upstream (Harza Co. 1994, Brocksmith and Sibley 1995, Martz 1996). Eggs were deposited from the river margin to 3.3-m depth with relatively low velocities from 0.7 – 2.7 fps. Most eggs were found on sand-gravel substrates ranging from 0.063 to 32mm in diameter. Martz et al. (1996) combined the data from these studies and found negative correlations between grain size, water velocity and distance from the river mouth with egg abundance. Artificial stream spawning experiments were also conducted in a lab setting and the authors concluded that Longfin Smelt preferred spawning on sand substrates (Martz et al. 1996 Brocksmith and Sibley 1995). The sand grains function to weigh-down the embryos, keeping them on the bottom of the riverbed. However, the embryos are subject to drift if flows are high. In the Cedar River, Martz et al. (1996) collected eggs using drift nets suggesting that some proportion are dislodged by movement of bottom material with high flows.

Longfin Smelt use habitat differently by life stage; larvae have generally been found from the tributaries of San Francisco Bay to the South Delta near the CVP and SWP and the Cache Slough Complex in the North Delta (Merz et al. 2013, Baxter 1999). Larvae can be found from very shallow waters in tidal marsh (Grimaldo et al. 2017, Meng and Matern 2001) to near-bottom of deep channels (Bennett et al. 2002). Recently, larvae have been found in the Alviso Marsh in Lower South Bay expanding the known distribution of larval rearing habitat (Lewis et al. 2019).

While larvae can be found over a wide geographic distribution (Merz et al. 2013) their rearing habitat has been identified to include shallow low salinity marsh habitat (Grimaldo et al 2017). Hieb and Baxter (1993) and Baxter (1999) showed that downstream dispersal of larvae appeared to be a function of outflow during the larval period extending from Suisun Bay into San Pablo and central San Francisco bays during high outflow years. Dege and Brown (2004) analyzed 20-mm Survey data and found the geographic center of distribution of small larvae (< 20 mm FL) was located at or just upstream of X2 during low and below average outflow conditions. They also show that the center of distribution tended to start above and end downstream of X2 through the sampling season in high outflow years.

Suitable rearing habitat is also largely governed by the distribution of low-salinity habitat. Grimaldo et al. (2017) used a Generalized Additive Model to describe larval Longfin Smelt distribution with respect to salinity, Secchi depth, temperature, and depth. Temperature and year were the strongest driver of larval Longfin Smelt explaining 57.5% of the deviance. Salinity was also found to be significant driver at 18.7% of the deviance. Larval densities were found to peak between 3 and 4-psu with an upper threshold of 18-psu for occurrence. Larval densities were negatively related to Secchi depth, peaking at 50-cm and when temperatures were between 8 and 12 °C. Using a similar analytical technique Lewis et al. (2019, Fig 18 for post-larvae to juveniles up to 32-mm FL) found a similar relationship between larva to juvenile life stages (up to 32-mm FL) and salinity and Secchi depths. Although fish were found in higher temperature (12-17 °C) this was likely due to later sampling and older fish occurring when seasonal temperatures were warmer. Using otolith chemistry, Hobbs et al. (2010) examined the natal portion of adult otoliths and found that fish hatched into habitats ranging from freshwater to salinity >4-6-PSU. However, the majority hatched into habitats with salinities from 1 to 3-PSU.

## Primary Management Issues That This Area Will Address

Understanding spawning and rearing habitats is critical for the design and maintenance of habitat restoration projects and could be used to inform entrainment risk assessments. Moreover, this information is important to help understand the effects of local habitat alterations such as pesticide inputs, dredging, water diversions, and aquatic weeds. Unless we have a good understanding of the specific habitats that Longfin Smelt occupy, it is difficult to identify protective measures. Good information on spawning habitats can also help inform overall management of the species, relative to other management issues (e.g. flow, food web, predators). Towards this goal, spawning and rearing habitat information would inform the development of life cycle and hydrodynamic models that could be used as a tool to evaluate the effects of spawning habitat restoration versus other potential management actions.

## Potential Scientific Approaches

There are multiple approaches that could be used to increase our understanding of Longfin Smelt spawning behavior and habitat choice. Here we list approaches for filling this data gap, however this list is not intended to encompass all possible approaches.

Approaches to improve understanding of Longfin Smelt adult migration and spawning behavior:

- Targeted field studies to identify spawning habitat (see *Fish Migrations and Movements*). Longfin Smelt spawn on river, bay, slough bottoms most likely at night requiring target field studies refined to document spawning locations and substrates. Histopathology of gonad and biomarkers to determine spawn timing and refractory period.

Approaches to characterize Longfin Smelt spawning substrate:

- Conduct laboratory-based spawning substrate preference studies.
- Develop methods to detect and quantify eggs (egg drift nets, sieves to find buried eggs.)
- Deploy mats or other artificial substrates in areas likely to have spawning, for example sandy beaches from Rio Vista to the confluence, Lower San Joaquin to Antioch, Roe-Ryer Island sloughs, and other small sloughs around Suisun Bay. Depth variation should also be considered as some evidence suggests hatching can occur in deep water as well.

Mapping of sandy habitat can improve our understanding of potential spawning areas.
Characterize Longfin Smelt rearing habitats

- Synthesis of historical data: Analysis of historical sampling data may provide insights into general habitat associations for young fish (e.g. Grimaldo et al. 2017).

- *Targeted field studies*: Focused field studies in potential rearing habitats could help to identify characteristics and locations of the most suitable rearing areas.

- *Otolith studies*: Otoliths are an important tool that can be used to understand some of the general rearing strategies with respect to age, geography and salinity (Hobbs et al. 2010).

- *Laboratory studies*: Because the establishment of Longfin Smelt in culture is still in development, the opportunity to study these behaviors in a lab setting has only recently become available. These efforts can be useful for understanding rearing behavior and preferences.

## Additional Considerations

Longfin Smelt spawning runs can be rapid, occur overnight during the winter with inclement weather in habitats that are difficult to access. As a result, there are considerable logistical challenges associated with identifying exact spawning locations. Additionally, methods to identify eggs may need to be developed.

Some of the methods described above would require permitting for collection and sampling of wild fish. The number of permits required may depend on the location of sampling. If sampling were to occur in the Delta, permits for take would be need for both the state and federal endangered species acts due to overlap and potential take of Delta smelt or other federally listed fish species. This sampling would need to be coordinated through IEP to ensure proper permit and take coverage.

Laboratory studies are currently limited because Longfin Smelt culture is in early stages of development and wild brood stock is limited. However, it is expected that Longfin Smelt culture practices will continue to improve over time and minimize this limitation in the future.

## LITERATURE CITED


Araki, H., Cooper, B. and Blouin, M.S., 2007. Genetic effects of captive breeding cause a rapid, cumulative fitness decline in the wild. *Science*, *318*(5847), pp.100-103.

Araki, H. and Schmid, C., 2010. Is hatchery stocking a help or harm? Evidence, limitations and future directions in ecological and genetic surveys. *Aquaculture*, *308*, pp.S2-S11.

Attard, C.R., Brauer, C.J., Van Zoelen, J.D., Sasaki, M., Hammer, M.P., Morrison, L., Harris, J.O., Möller, L.M. and Beheregaray, L.B., 2016. Multi-generational evaluation of genetic diversity and parentage in captive southern pygmy perch (*Nannoperca australis*). *Conservation genetics*, *17*(6), pp.1469-1473.

Baerwald M.R., A.M. Goodbla, R.P. Nagarajan, J.S. Gootenberg, O.O. Abudayyeh, F. Zhang, and A.D. Schreier (2020) Rapid and accurate species identification for ecological studies and monitoring using CRISPR-based SHERLOCK. *Molecular Ecology Resources* 20(4): 961-970.

Baskerville, B. and Lindberg, C., 2004. The effect of light intensity, alga concentration, and prey density on the feeding behavior of delta smelt larvae. In *American Fisheries Society Symposium* (Vol. 39, pp. 219-227).

Baxter, R. D. (1999). Osmeridae. Pages 179-216 in J. Orsi (editor). Report on the 1980-1995 fish, shrimp and crab sampling in the San Francisco Estuary. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Technical Report 63, 503 pages.

Baxter, R. Souza, K., Hieb, K., Fleming, K., Bryant, M. (2005). Apparent growth rates of pelagic fishes and relationship to abundance (2. b.). California Department of Fish and Wildlife.

Bennett W.A., W.J. Kimmerer, and J.R. Burau (2002) Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. *Limnology and Oceanography* 47: 1496-1507.

Bennett, W. and J. Burau (2014). Riders on the storm: selective tidal movements facilitate the spawning migration of threatened Delta smelt in the San Francisco Estuary. Estuaries and Coasts. **DOI 10.1007/s12237-014-9877-3**.

Brandl S.C., G. Schumer, B.M. Schreier, J.L. Conrad, B. May, and M.R. Baerwald (2015) Ten real-time PCR assays for detection of fish predation at the community level in the San Francisco Estuary-Delta. *Molecular Ecology Resources* 15: 278-284.

Brenner, R.E., Moffitt, S.D. and Grant, W.S., 2012. Straying of hatchery salmon in Prince William Sound, Alaska. *Environmental Biology of Fishes*, *94*(1), pp.179-195.

California Department of Fish and Game (CDFG) (2009a). Report to the Fish and Game Commission: A status review of the Longfin Smelt (*Spirinchus thaleichthys*) in California. Report to the Fish and Game Commission: 46 pages.

California Department of Fish and Game (CDFG) (2009b). Effects Analysis -- State Water Project Effects on Longfin Smelt, California Department of Fish and Game: 58 pages plus appendices.

CDFW (2014). Longfin Smelt Study Plan: Field, laboratory, and data analyses to investigate the distribution and abundance of Longfin Smelt in the San-Francisco Estuary: 43.

CDFW. 2020 Incidental Take Permit for Long-Term Operation of the State Water Project in the Sacramento-San Joaquin Delta (2081-2019-066-00). California Department of Fish and Wildlife.

Chigbu, P., & Sibley, T. H. (1994). Diet and growth of Longfin Smelt and juvenile sockeye salmon in Lake Washington. Internationale Vereinigung für theoretische und angewandte Limnologie: Verhandlungen, 25(4), 2086-2091.

Chorazyczewski, A. (2019) 2019 Smelt Larva Survey Summary. *Interagency Ecological Program Newsletter* 37(2): 6-8.

Christie, M.R., Marine, M.L., Fox, S.E., French, R.A. and Blouin, M.S., 2016. A single generation of domestication heritably alters the expression of hundreds of genes. *Nature communications*, *7*(1), pp.1-6.

Connon, R. E., S. Hasenbein, S. M. Brander, H. C. Poynton, Erika B. Holland, D. Schlenk, J. L. Orlando et al. "Review of and Recommendations for Monitoring Contaminants and their Effects in the San Francisco Bay– Delta." San Francisco Estuary and Watershed Science 17, no. 4 (2019).

Connon, R., Fangue, N., and Hung. T. 2020. Impacts of salinity and turbidity on early-life stage Longfin Smelt (*Spirinchus thaleichthys*). Preliminary progress report to the U.S. Fish and Wildlife Service for Grant #F18AC00057.

Dege, M. and L. R. Brown (2004). Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco Estuary. Pages 49-65 in F. Feyrer, L. R. Brown, R. L. Brown and J. J. Orsi. (Eds.). Early life history of fishes in the San Francisco estuary and watershed. American Fisheries Society Symposium 39. Bethesda, Maryland.

Dowling, T.E., Marsh, P.C., Kelsen, A.T. and A. TIBBETS, C., 2005. Genetic monitoring of wild and repatriated populations of endangered razorback sucker (*Xyrauchen texanus*, Catostomidae, Teleostei) in Lake Mohave, Arizona-Nevada. *Molecular Ecology*, *14*(1), pp.123-135.

Dryfoos, R. L. (1965). The life history and ecology of the Longfin Smelt in Lake Washington (Doctoral dissertation, University of Washington).

Eakin, M., R. Baxter, J. Hobbs, T. Ngyuen, F. La Luz, T. Tempel, L. Damon, S. Anwar, A. Allison and B. Jacobs (2020). State water project effects on Longfin Smelt and delta smelt. California Department of Fish and Wildlife**:** 136.

Fischer, J. and Lindenmayer, D.B., 2000. An assessment of the published results of animal relocations. *Biological conservation*, *96*(1), pp.1-11.

Foott, J. S., & Stone, R. (2007). Histological Evaluation and Viral Survey of Juvenile Longfin Smelt (*Spirinchus thaleichthys*) and Threadfin Shad (*Dorosoma petenense*) collected from the Sacramento–San Joaquin River Delta, April–November 2007. Delta.

Garwood, R.S., 2017. Historic and contemporary distribution of Longfin Smelt (*Spirinchus thaleichthys*) along the California coast. *California Fish and Game*, *103*(3), pp.96-117.

Gold, J., Novotny, S., & Salop, P. (2011). 2011 Longfin Smelt Monitoring During Dredging By The USACE Hopper Dredge Essayons In The San Francisco Bay Area Contract# W912P7-11-P-0032. Contract, 912(11-P), 0032.

Gregory, R.S. and Northcote, T.G., 1993. Surface, planktonic, and benthic foraging by juvenile chinook salmon (Oncorhynchus tshawytscha) in turbid laboratory conditions. *Canadian Journal of Fisheries and Aquatic Sciences*, 50(2), pp.233-240.

Grimaldo, L., Feyrer, F., Burns, J., & Maniscalco, D. (2017). Sampling uncharted waters: Examining rearing habitat of larval Longfin Smelt (*Spirinchus thaleichthys*) in the upper San Francisco Estuary. Estuaries and Coasts, 40(6), 1771-1784.

Grossman, G. D. (2016). Predation on fishes in the Sacramento–San Joaquin Delta: current knowledge and future directions. San Francisco Estuary and Watershed Science, 14(2).

Hanson, C. H. (2014). Selection of Environmental Covariates for Consideration in Developing a Lifecycle Model for the San Francisco Bay-Delta Population of Longfin Smelt.

Harza Northiwest, Inc. 1994. Distribution of Longfin Smelt *(Spirinchus thaleichthys)* eggs in the Cedar River, Washington. Report to the City of Renton. 13 pp.

Hasenbein, M., Komoroske, L.M., Connon, R.E., Geist, J. and Fangue, N.A., 2013. Turbidity and salinity affect feeding performance and physiological stress in the endangered delta smelt. *Integrative and comparative biology*, 53(4), pp.620-634.

Hasenbein, S., Holland, E. B., & Connon, R. E. (2019). Eyes to the future: approaches to assess pesticide impact on surface waters in a changing climate. In Pesticides in Surface Water: Monitoring, Modeling, Risk Assessment, and Management (pp. 189-214). American Chemical Society.

Hay, D., and P. B. McCarter. 2000. Status of the eulachon, *Thaleichthys pacificus*, in Canada. Canadian Stock Assessment Secretariat Research Document 2000/145:92 pages.

Hieb, K. and R. Baxter (1993). Delta outflow/San Francisco Bay. Pages 101-116 in P. L. Herrgesell (ed). 1991 Annual Report - Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary. Sacramento, California.

Hobbs, J. A., Bennett, W. A., & Burton, J. E. (2006). Assessing nursery habitat quality for native smelts (Osmeridae) in the low-salinity zone of the San Francisco estuary. Journal of Fish Biology, 69(3), 907-922.

Hobbs, J. A., Lewis, L. S., Ikemiyagi, N., Sommer, T., & Baxter, R. D. (2010). The use of otolith strontium isotopes (87Sr/86Sr) to identify nursery habitat for a threatened. Info: Postprints, Multi-Campus.

Hobbs, J., Moyle, P.B., Fangue, N. and Connon, R.E., 2017. Is extinction inevitable for Delta Smelt and Longfin Smelt? An opinion and recommendations for recovery. *San Francisco Estuary and Watershed Science*, *15*(2).

Hobbs, J.A., A. Cooper, C. Parker, M. Bisson, A. Barros, Al. Alfonso, Ab. Alfonso, M. Willmes and L. Lewis. Longfin Smelt Spawning in San Francisco's Bay Tributaries. 2018-19 Annual Report for DWR #4600011196.

Honey, K., R. Baxter, Z. Hymanson, T. Sommer, M. Gingras and P. Cadrett (2004). IEP long-term fish monitoring program element review. Interagency Ecological Program for the San Francisco Bay/Delta Estuary Technical Report 78**:** 67 pages plus appendices.

Hung, T. 2019. Longfin Smelt Culture and Marking Method Development Year 2019 Annual Report. Contract #4600012770, Fish Conservation and Culture Lab (FCCL), Byron, University of California, Davis.

Hung, T., Mulvaney, W., Stevenson, T., and Afentoulis, V. 2020. 2019-2020 Efforts and Progress on the Culture of Longfin Smelt *Spirinchus thaleichthys*. Fish Conservation & Culture Lab and Bay-Delta Office – SWP Fish Facilities, 2020 Interagency Ecological Program poster.

Janowitz-Koch, I., Rabe, C., Kinzer, R., Nelson, D., Hess, M.A. and Narum, S.R., 2019. Long-term evaluation of fitness and demographic effects of a Chinook Salmon supplementation program. *Evolutionary applications*, *12*(3), pp.456-469.

Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel JR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecol Appl 5:272–289. https://doi.org/10.2307/1942069 J

Jeffries, Ken M., Richard E. Connon, Brittany E. Davis, Lisa M. Komoroske, Monica T. Britton, Ted Sommer, Anne E. Todgham, and Nann A. Fangue. "Effects of high temperatures on threatened estuarine fishes during periods of extreme drought." Journal of Experimental Biology 219, no. 11 (2016): 1705-1716.

Jonsson, B., Jonsson, N. and Hansen, L.P., 1991. Differences in life history and migratory behaviour between wild and hatchery-reared Atlantic salmon in nature. *Aquaculture*, *98*(1-3), pp.69-78.

Kimmerer, W. J. 2002. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25:1275–1290.

Kimmerer, W. J., J. R. Burau, and W. A. Bennett (1998). "Tidally oriented vertical migration and position maintenance of zooplankton in a temperate estuary." *Limnology and Oceanography* 43.7: 1697-1709.

Kimmerer, W. J., Ignoffo, T. R., Kayfetz, K. R., & Slaughter, A. M. (2018). Effects of freshwater flow and phytoplankton biomass on growth, reproduction, and spatial subsidies of the estuarine copepod *Pseudodiaptomus forbesi*. Hydrobiologia, 807(1), 113-130.

Kimmerer, W.J. and Rose, K.A. (2018), Individual-Based Modeling of Delta Smelt Population Dynamics in the Upper San Francisco Estuary III. Effects of Entrainment Mortality and Changes in Prey. Trans Am Fish Soc, 147: 223-243. doi:10.1002/tafs.10015

Knudsen, C.M., Schroder, S.L., Busack, C.A., Johnston, M.V., Pearsons, T.N., Bosch, W.J. and Fast, D.E., 2006. Comparison of life history traits between first-generation hatchery and wild upper Yakima River spring Chinook salmon. *Transactions of the American Fisheries Society*, *135*(4), pp.1130-1144.

Latour, R. J. (2016). Explaining patterns of pelagic fish abundance in the Sacramento-San Joaquin Delta. Estuaries and Coasts, 39(1), 233-247.

Lewis, L., A. Barros, M. Willmes, C. Denney, C. Parker, M. Bisson, J. Hobbs, A. Finger, G, Auringer, A. Benjamin. Distribution of Adult, Larval and Juvenile Longfin Smelt in Tributaries and Marshes of the San Francisco Estuary. 2018-19 Annual Report for DWR contract 4600011196.

Lewis, L.S., Willmes, M., Barros, A., Crain, P.K. and Hobbs, J.A., 2020. Newly discovered spawning and recruitment of threatened Longfin Smelt in restored and underexplored tidal wetlands. *Ecology*, *101*(1), p.e02868.

Loboschefsky, E.  (2013). Bioenergetics Modeling of San Francisco Estuary Striped Bass and the Development of Individual Based Models for Striped Bass and Longfin Smelt in the San Francisco Estuary (Doctoral dissertation, University of California, Davis. Davis, California, USA).

Mac Nally, R., Thomson, J.R., Kimmerer, W.J., Feyrer, F., Newman, K.B., Sih, A., Bennett, W.A., Brown, L., Fleishman, E., Culberson, S.D. and Castillo, G., 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). Ecological Applications, 20(5), pp.1417-1430.

Mahardja, B., Young, M.J., Schreier, B. and Sommer, T., (2017). Understanding imperfect detection in a San Francisco Estuary long‐term larval and juvenile fish monitoring programme. *Fisheries Management and Ecology*, 24(6), pp.488-503.

Mahardja, Brian, Vanessa Tobias, Shruti Khanna, Lara Mitchell, Peggy Lehman, Ted Sommer, Larry Brown, Steve Culberson, and J. Louise Conrad. "Fish Community Resistance and Resilience to Drought in the San Francisco Estuary: A Retrospective of Five Decades of Drought Cycles." (2020).

Martin, K.L. and Swiderski, D.L., 2001. Beach spawning in fishes: phylogenetic tests of hypotheses. *American Zoologist*, *41*(3), pp.526-537.

Martz, M., J. Dillon and P. Chigbu (1996). 1996 Longfin Smelt (*Spirinchus thaleichthys*) spawning survey in the Cedar River and four Lake Washington Tributaries. U.S. Army Corps of Engineers, Seattle District, Seattle, Washington: 22 pages.

Maunder, M. N., and R. B. Deriso. 2011. A state-space multistage life cycle model to evaluate population impacts in the presence of density dependence: illustrated with application to Delta Smelt (Hypomesus transpacificus). Canadian Journal of Fisheries and Aquatic Sciences 68:1285–1306.

Maunder MN, Deriso RB, Hanson CH. 2015. Use of state-space population dynamics models in hypothesis testing: advantages over simple log-linear regressions for modeling survival, illustrated with application to Longfin Smelt (Spirinchus thaleichthys.,Fisheries Research 164:102-111.

Merz, J.E., Bergman, P.S., Melgo, J.F. and Hamilton, S., 2013. Longfin Smelt: spatial dynamics and ontogeny in the San Francisco Estuary, California. *California Fish and Game*, *99*(3), pp.122-148.

Mitchell, L., K. Newman and R. Baxter (2017). A covered cod-end and tow-path evaluation of the midwater trawl gear efficiency for catching Delta Smelt (*Hypomesus transpacificus*). San Francisco Estuary and Watershed Science 15(4 Article 3): 19 pages.

Moulton, L. L. (1974). Abundance, growth, and spawning of the Longfin Smelt in Lake Washington. Transactions of the American Fisheries Society, 103(1), 46-52.

Moyle, P.B. 2002. *Inland fishes of California: revised and expanded*. Univ of California Press.

Moyle, P.B., Brown, L.R., Durand, J.R. and Hobbs, J.A., 2016. Delta smelt: life history and decline of a once-abundant species in the San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 14(2).

Newman, K. B. (2008). "Sample design-based methodology for estimating delta smelt abundance." San Francisco Estuary and Watershed Science **6**(3): article 3.

Nobriga M, Rosenfield JA. 2016. Population Dynamics of an Estuarine Forage Fish: Disaggregating Forces Driving Long-Term Decline of Longfin Smelt in California's San Francisco Estuary, Transactions of the American Fisheries Society, 145:1, 44-58, DOI: 10.1080/00028487.2015.1100136

Pascual, M.A. and Quinn, T.P., 1994. Geographical patterns of straying of fall chinook salmon, Oncorhynchus tshawytscha (Walbaum), from Columbia River (USA) hatcheries. *Aquaculture Research*, *25*(S2), pp.17-30.

Peterson, James T., and Miguel F. Barajas. "An Evaluation of Three Fish Surveys in the San Francisco Estuary, 1995–2015." *San Francisco Estuary and Watershed Science* 16.4 (2018).

Polansky, L., Mitchell, L. and Newman, K.B. (2019), Using Multistage Design-Based Methods to Construct Abundance Indices and Uncertainty Measures for Delta Smelt. Trans Am Fish Soc, 148: 710-724. doi:10.1002/tafs.10166

Polansky L, Newman KB, Mitchell L. Improving inference for nonlinear state-space models of animal population dynamics given biased sequential life stage data [published online ahead of print, 2020 Apr 3]. Biometrics. 2020;10.1111/biom.13267. doi:10.1111/biom.13267

Pollard, H.A. and Flagg, T.A., 2004. Guidelines for use of captive broodstocks in recovery efforts for Pacific salmon. In *American Fisheries Society Symposium* (Vol. 44, pp. 333-345).

Quinn, T. P., C. Sergeant, A. Beaudreau and D. Beauchamp (2012). Spatial and temporal patterns of vertical distribution for three planktivorous fishes in Lake Washington. Ecology of Freshwater Fish 21: 337-348.

Reyes, R.C. (2020 *in prep*) Standard Operating Procedures for Fish Handling Related to the Collection, Sampling, Transport, and Release of Salvaged Fish at the Tracy Fish Collection Facility. *Draft*

Rose, K. A., W. J. Kimmerer, K. P. Edwards, and W. A. Bennett. 2013a. Individual-based modeling of Delta Smelt population dynamics in the upper San Francisco Estuary I. Model description and baseline results. Transactions of the American Fisheries Society 142:1238–1259. , DOI: [10.1080/00028487.2013.799518](https://doi.org/10.1080/00028487.2013.799518)

Rose, K. A., Kimmerer, W. J., Edwards, K. P. and Bennett, W. A. 2013b. Individual-based modeling of Delta Smelt population dynamics in the upper San Francisco Estuary: II. Alternative baselines and good versus bad years. *Transactions of the American Fisheries Society*, 142: 1260–1272.

Rosenfield, J.A. and Baxter, R.D., 2007. Population dynamics and distribution patterns of Longfin Smelt in the San Francisco Estuary. *Transactions of the American Fisheries Society*, 136(6), pp.1577-1592.

Saglam, I., Hobbs, J., Baxter, R., Benjamin, A., and Finger, A. *Submitted manuscript*. Adaptive variation and ongoing outward migration support high conservation priority for Longfin Smelt in the San Francisco Estuary.

Sibley, T. & R. Brocksmith. 1996. Lower Cedar River Section'205 Longfin Smelt study, Final Report. Report to the U.S. Army Corps of Engineers, Seattle District.

Sirois, P. and Dodson, J.J., 2000. Influence of turbidity, food density and parasites on the ingestion and growth of larval rainbow smelt Osmerus mordax in an estuarine turbidity maximum. *Marine Ecology Progress Series*, 193, pp.167-179.

Sommer, T., Armor, C., Baxter, R., Breuer, R., Brown, L., Chotkowski, M., Culberson, S., Feyrer, F., Gingras, M., Herbold, B., Kimmerer, W., Mueller-Solger, A., Nobriga, M. and Souza, K. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries, 32: 270–277.

Sommer, T., F. Mejia, M. Nobriga, F. Feyrer and L. Grimaldo (2011). The spawning migration of Delta smelt in the upper San Francisco Estuary. San Francisco Estuary and Watershed(9(2))**:** 1-16.

Stevens, D. E., & Miller, L. W. (1983). Effects of river flow on abundance of young Chinook salmon, American shad, Longfin Smelt, and delta smelt in the Sacramento-San Joaquin River system. North American Journal of Fisheries Management, 3(4), 425-437.

Stompe, D. K., Moyle, P. B., Kruger, A., & Durand, J. R. (2020). Comparing and Integrating Fish Surveys in the San Francisco Estuary: Why Diverse Long-Term Monitoring Programs are Important. San Francisco Estuary and Watershed Science, 18(2).

Swanson, C., Reid, T., Young, P. S., & Cech Jr, J. J. (2000). Comparative environmental tolerances of threatened delta smelt (*Hypomesus transpacificus*) and introduced wakasagi (*H. nipponensis*) in an altered California estuary. Oecologia, 123(3), 384-390.

Szoboszlai, A. I., Thayer, J. A., Wood, S. A., Sydeman, W. J., & Koehn, L. E. (2015). Forage species in predator diets: synthesis of data from the California Current. Ecological Informatics, 29, 45-56.

Tamburello, N., Connors, B. M., Fullerton, D., & Phillis, C. C. (2019). Durability of environment–recruitment relationships in aquatic ecosystems: insights from long-term monitoring in a highly modified estuary and implications for management. Limnology and Oceanography, 64(S1), S223-S239.

Tempel T. and L. Damon (2018) 2017 20-mm Survey. *Interagency Ecological Program Newsletter* 31(1): 9-11.

Thompson, Steven K. "Sampling" 3rd Edition, Wiley Series in Probability and Statistics. (2012).

Thomson, James R., Wim J. Kimmerer, Larry R. Brown, Ken B. Newman, Ralph Mac Nally, William A. Bennett, Frederick Feyrer, and Erica Fleishman. "Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary." Ecological Applications 20, no. 5 (2010): 1431-1448.

Thorstensen, M., Bates, P., Lepla, K. and Schreier, A., 2019. To breed or not to breed? Maintaining genetic diversity in white sturgeon supplementation programs. *Conservation Genetics*, *20*(5), pp.997-1007.

Tigan, G., Fetherolf, S., and Hung, T. 2018. Longfin Smelt Culture and Marking Study Final Report. Contract #4600011161, Fish Conservation and Culture Lab (FCCL), Byron, University of California, Davis.

USFWS. 2012. Endangered and Threatened Wildlife and Plants; 12-month Finding on a Petition to List the San Francisco Bay-Delta Population of the Longfin Smelt as Endangered or Threatened. 50 CFR Part 17 [Docket No. FWS-R8-ES-2008-0045].

USFWS and NOAA. 2019. Biological Opinions for the Reinitiation of Consultation on the Long Term Coordinated Operations of the Central Valley Project and State Water Project.

Wang, J. C. S. 1986. Fishes of the Sacramento-San Joaquin Estuary and adjacent waters, California: A guide to the early life histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary., Sacramento, California

Wang, J. C. S. 2007. Spawning, early life stages and early life histories of the Osmerids found in the Sacramento-San Joaquin Delta of California. U.S. Department of the Interior, Bureau of Reclamation, Mid-Pacific Region, Byron, California. Volume 38. 72 pages plus appendices.

Waples, R.S., 1991. Genetic interactions between hatchery and wild salmonids: lessons from the Pacific Northwest. *Canadian Journal of Fisheries and Aquatic Sciences*, 48(S1), pp.124-133.

Yanagitsuru, Y., Mauduit, F., Segarra, A., Hobbs, J., Lewis, L., Hung, T., Connon, R., and Fangue, N. 2020. Current progress on Longfin Smelt aquaculture and ecophysiology research. Presentation to the U.S. Fish and Wildlife Service on June 11, 2020, preliminary data and progress report.