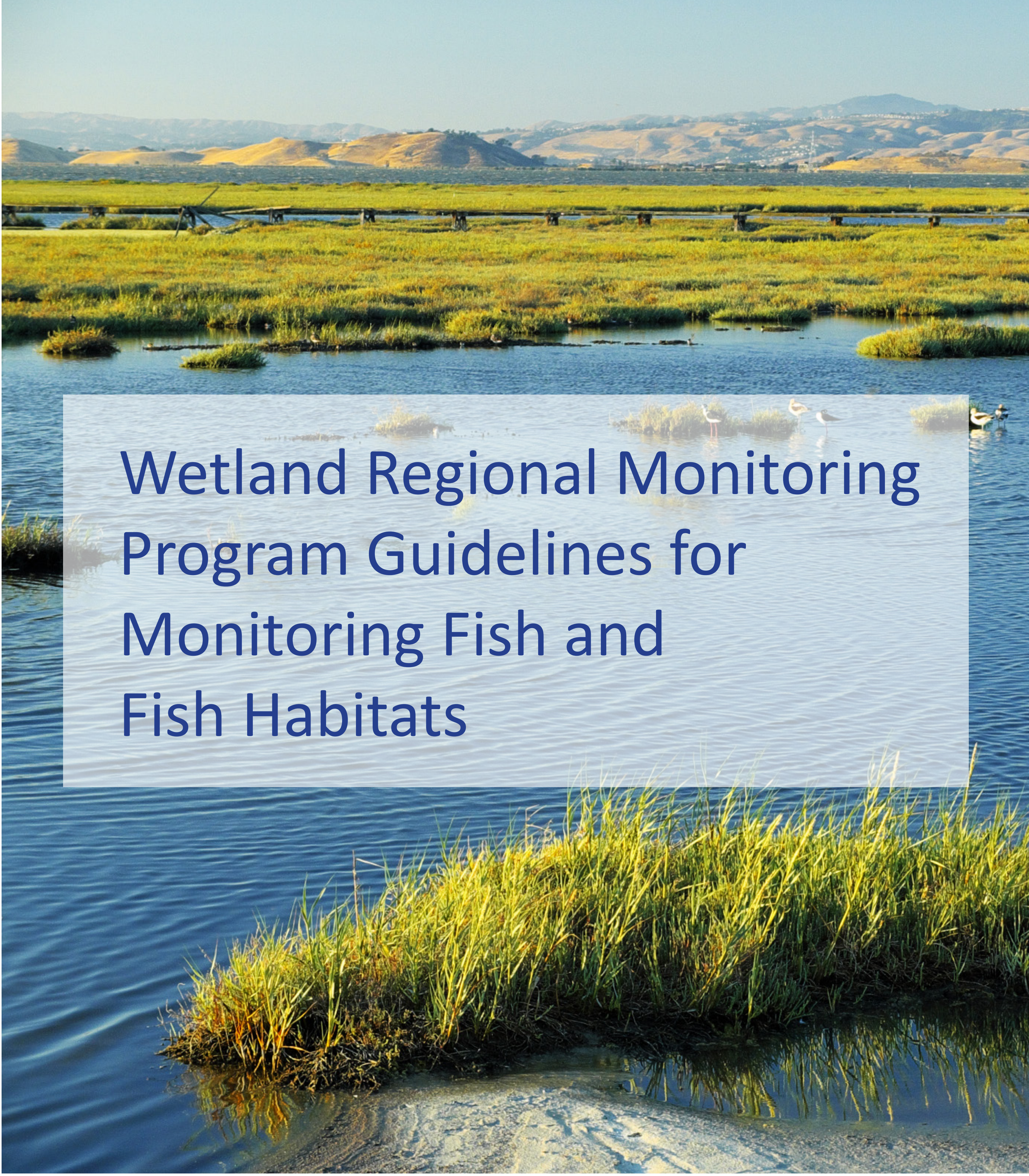
Wetland Regional Monitoring Program Guidelines for Monitoring Fish and Fish Habitats



NOAA FISHERIES

U.S. FISH & WILDLIFE SERVICE

US Army Corps of Engineers®
San Francisco District

SF ESTUARY Wetlands Regional Monitoring Program

UC DAVIS
DEPARTMENT OF WILDLIFE, FISH AND CONSERVATION BIOLOGY

SF ESTUARY
Wetlands Regional Monitoring Program

WRMP Guidelines for Monitoring Fish and Fish Habitats ("FFH SOP")

Cover Letter – March 2024

WRMP science framework context (Guiding and Management Questions):
At the request of the Technical Advisory Committee of the Wetland Regional Monitoring Program (WRMP), the Fish and Fish Habitat (FFH) Working Group was formed to develop standard operating procedures (SOPs) for monitoring aquatic communities, including fishes, macroinvertebrates, and dynamic habitat features (e.g, water quality), across the San Francisco Estuary (SFE). Data collected in alignment with this "FFH SOP" are intended to address the WRMP's Guiding Question Number 4 (GQ4) and its associated Management Questions (MQs) as they pertain to aquatic species, particularly fishes and macroinvertebrates, and their associated habitats.

- *GQ4: How do projects to protect and restore tidal marshes affect the distribution, abundance, and health of plants and animals?*
    - MQ4a: "*How are habitats for assemblages of resident species of fish and wildlife in tidal marsh ecosystems changing over time?"*
        - Indicators of change in aquatic habitats include dissolved oxygen, temperature, salinity, and turbidity.
    - MQ4b "*How are the distribution and abundance of key native species of fish and wildlife of tidal marsh ecosystems changing over time?"*
        - Indicators of change in aquatic communities include abundance, biomass, species diversity, and species composition.

SOP development process context:
The Fish and Fish Habitat workgroup is comprised of a diverse group of representatives from Federal and State agencies, non-profit organizations, restoration practitioners, and academia. Over nearly 2 years, the Fish and Fish Habitat workgroup systematically reviewed different techniques for monitoring fish and fish habitats, developed a structured framework for evaluating different monitoring options, and built consensus around decision-making to develop a shared monitoring protocol that can help answer the WRMP management questions.

Scientific context:
The FFH SOP was developed to be...

- A scientifically robust suite of technical considerations and recommendations for monitoring fishes and macroinvertebrates in wetland habitats of the SFE.
- Inclusive of the mosaic of habitats and species that occur within the SFE's tidal wetlands.
- Consistent with other long-term and short-term wetland monitoring efforts throughout the SFE.
- A resource for developing and implementing monitoring plans for the WRMP.
- A resource to help guide individual projects in developing monitoring plans that are consistent with the WRMP.

Value of the SOP:
The FFH SOP provides guidelines for collecting data that can be used to assess baselines and changes to the ecological integrity of the estuary's aquatic wetland ecosystems. Such data are key for evaluating ecological responses to restoration, climate change, and other anthropogenic factors. Variation in aquatic communities and environmental conditions can serve as indicators of the integrated ecological responses of wetlands to multiple interacting drivers of change.
The FFH SOP is intended to facilitate:

- Collection of new data regarding how fishes and macroinvertebrates use tidal wetland habitats across the SFE.
- Broad integration of prior and existing data with new data from across the SFE.
- An improved understanding of how aquatic communities respond to wetland restoration.
- New information regarding the biological integrity of wetlands across the SFE.
- Generation of data for informing the conservation and management of wetland-associated species.
- Generation of robust baselines for assessing ecological impairment and change.
- Improved efficiency of take and incidental harassment authorizations.

Regulatory context:
The data collected at WRMP monitoring sites following the FFH SOP are intended to provide long-term, regional context to support greater efficiencies and enhance the value of permit-driven monitoring of wetland restoration projects in several ways.

- Baseline data from the WRMP site network could support projects that are required to conduct before, after, control, impact (BACI) studies to evaluate the effectiveness of restoration actions.
- SOPs provide a widely-accepted template for monitoring that can readily be adjusted to specific projects, thus reducing costs and complexity in developing project-specific monitoring plans.
- Data collected can be analyzed and synthesized at the regional scale to enhance the inferences gained from both long-term and project-specific monitoring efforts.
- Data collected will provide managers critical information on the use of wetland habitats by ESA/CESA listed species as well as other managed species.

WRMP Monitoring Plan Implementation context:
The FFH SOP provides a set of methods for the WRMP's long-term vision for monitoring fish and fish habitats. The resulting data will inform management questions identified in the WRMP Program Plan. This document can be used to help guide the development and implementation of the initial WRMP Monitoring Plan; however, the SOP itself was not intended to serve as a monitoring plan.

- As noted above, recommendations in the SOP are not intended to be written directly into permits. Rather, they are intended to provide guidance regarding suitable sampling methods that will maximize the integration and value of permit-associated monitoring data.

U.C. Davis Fish Monitoring Team in Pond A17, Alviso Marsh, Lower South Bay. Credit: Levi Lewis.

Cover: High tide in San Francisco Bay marshland. Credit: Shutterstock.

OVERVIEW

I. Fish and Fish Habitat (FFH) Workgroup

Levi S. Lewis† (UC Davis), Alison Weber-Stover† (NOAA Fisheries), Jeff McLain† (USFWS), Beth Campbell† (USACE), Lu Wang (NOAA Fisheries), Isa Woo (USGS), Donna Ball (SFEI, SBSPRP), Chris Jasper (Vollmer Consulting), Alex Thomsen (SFEP), Cassie Pinnell (Vollmer Consulting), Dylan Stompe (CDFW), Josh Collins (SFEI), Karen Thorne (USGS), Kevin Buffington (USGS), Stephen Randall (SFBRWQCB), Zachary Duckworth (NOAA Fisheries, Ocean Associates), Susan de la Cruz (USGS), Christina Toms (SFBWQCB)††

†Members of FFH development subcommittee

††Chair of the WRMP Technical Advisory Committee

II. Purpose of the FFH Standard Operating Procedures (SOP)

This document recommends standard operating procedures (SOPs) for the monitoring of juvenile and adult fishes and macroinvertebrates in brackish and saline tidal wetlands of the San Francisco Estuary (SFE) to the Steering Committee (SC) of the Wetland Regional Monitoring Program (WRMP). The monitoring recommendations herein were developed by the Fish and Fish Habitat (FFH) Workgroup of the WRMP's Technical Advisory Committee (TAC) to inform Management Question 4A: *"How are habitats for assemblages of resident species of fish and wildlife in tidal marsh ecosystems changing over time?"* and Management Question 4B: *"How are the distribution and abundance of key native species of fish and wildlife of tidal marsh ecosystems changing over time?"*; each identified in the WRMP Plan (WRMP SC 2020). To inform the above management questions within the scope of the WRMP (**Section 1**), the FFH Workgroup identified three FFH-specific monitoring goals (**Section 2.4**), conducted a literature review (**Appendix 2**), evaluated and ranked numerous sampling options (**Section 3, Appendix 1**), and then drafted the recommendations and justifications herein (**Section 4**). This SOP is a methods document, and although it is intended to provide recommended standard operating procedures to inform future monitoring plans and data analysis approaches that can be utilized by the WRMP, it does not, by itself, constitute a monitoring plan or analytical approach. The WRMP Monitoring Plan (slated for completion in 2023) proposes and describes an implementation strategy for near-term program monitoring; it references this SOP as well as accompanying SOPs for monitoring non-FFH indicators (e.g. hydrogeomorphology, vegetation, etc.). Recommendations in the SOP are not intended to be written directly into permits, but are intended to provide guidance regarding suitable sampling methods that can maximize the integration and value of permit-associated monitoring data (see Section 1.3.2 for a discussion about the relationship between the WRMP, FFH monitoring, and regulatory requirements). This SOP is a living document, and the recommendations herein may be periodically reviewed and revised by the WRMP TAC, with an updated version of this document submitted to the SC for ratification.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

LIST OF ACRONYMS

AMMBS	UCD Alviso Marsh Mercury Beach Seine Study
ARIS	Adaptive Resolution Imaging Sonar Camera
BCDC	San Francisco Bay Conservation and Development Commission
CDFW	California Department of Fish and Wildlife
CESA	California Endangered Species Act
CPUE	Catch per unit effort
CTME	Complete tidal marsh ecosystem
DIDSON	Dual-Frequency Identification Sonar
DJFMP	USFWS Delta Juvenile Fish Monitoring Program Beach Seine Study
DPS	Distinct Population Segment
eDNA	Environmental deoxyribonucleic acid
EFH	Essential Fish Habitat
ESA	Endangered Species Act
ESU	Evolutionary Significant Unit
FE	Federally Endangered under the ESA
FFH	Fish and Fish Habitat
FGC	California Fish and Game Code
FT	Federally Threatened under the ESA
IEP	Interagency Ecological Program
ITP	Incidental Take Permit
MHHW	mean higher high water
MLLW	mean lower low water
MMPA	Marine Mammal Protection Act
MOU	Memorandum of Understanding
MSA	Magnuson-Stevens Fishery Conservation
MQ	WRMP management question
NBOTS	UCD North Bay Otter Trawl Study
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
OLU	Operational landscape unit
PIT/RFID	Passive Integrated Transponders/Radio Frequency Identification
qPCR	quantitative Polymerase Chain Reaction
SBSPRP	South Bay Salt Ponds Restoration Project
SBOTS	UCD South Bay Otter Trawl Study
SE	State Endangered under the CESA
SFBRWQCB	San Francisco Bay Regional Water Quality Control Board
SFE	San Francisco Estuary
SFEP	San Francisco Estuary Partnership
SFEI	San Francisco Estuary Institute
SMFMD	Suisun Marsh Fish Monitoring Program
ST	State Threatened under the CESA
TAC	Technical Advisory Committee
UCD	University of California at Davis
USGS	United States Geological Survey
USACE	United States Army Corps of Engineers
USFWS	United States Fish and Wildlife Service
WRMP	Wetland Regional Monitoring Program

A NOTE ON TERMINOLOGY

The San Francisco Estuary Wetland Regional Monitoring Program (WRMP) represents the most recent of multiple attempts by the San Francisco Estuary science community to develop a coordinated monitoring enterprise for the region's tidal wetland habitats. The WRMP leverages a long history of monitoring and research within the estuary by scientists from a broad variety of fields, including hydrology and geomorphology, community and landscape ecology, marine ecology, ichthyology, ornithology, mammalogy, and related fields. In some cases, different fields have tended to use different terminology for components of the region's estuarine habitats. However, estuarine science and management are inherently interdisciplinary fields, and as such, the WRMP recognizes that it can be helpful for program participants and stakeholders to share common definitions for habitats and landscape features. Therefore, as of 2023, the WRMP is developing those definitions within the SOP for Indicators 1 (map of baylands habitat types and their key landform features and 3 (map of estuarine-terrestrial transition zones and migration space). This shared terminology is expected to enhance the analysis, synthesis, and communication of program science.

The terminology used to describe habitats in this Fish and Fish Habitat SOP are fish-centric, and are based on the terminology used in much of the SFE's fish-related literature. This terminology is not intended to be generalizable across all WRMP SOPs; however, in many cases it does overlap considerably with the definitions in the SOP for Indicators 1 and 3. As the WRMP matures as a program, the language in this Fish and Fish Habitat SOP may be revised to reflect language in other program documents. The definitions of habitat and landscape features in this SOP are summarized as follows:

- **Intertidal:** Habitats between mean lower low water (MLLW) and mean higher high water (MHHW).
- **Subtidal:** Habitats below MLLW.
- **Tidal marsh/marsh plain:** Complex, mostly intertidal habitats consisting of vegetated marsh plain that is flooded and drained by intersecting networks of large and small tidal channels.
- **Tidal shoal/mudflat:** Flat expanses of unvegetated sedimentary habitats that can be subtidal or intertidal. When subtidal, they tend to be called "shoals"; when intertidal, they tend to be called "mudflats".
- **Tidal channel:** A channel with distinct bed and banks within or adjacent to a tidal marsh or shoal. Intertidal channels drain at low tide. Subtidal channels do not drain at low tide.
- **Sloughs:** Larger subtidal channels that meander between intertidal marsh and mudflat habitats, which connect tidal marshes to deeper bay habitats (beyond 4 m depth).
- **Rivulets** (from Rozas et al. 1988): Small, lower-order intertidal channels, distinct in form and function from larger intertidal channels, which serve as important corridors for fishes that make tidal movements between tidal marsh plain and higher-order channel habitats.

These habitats are described in greater detail in Section 3.4. Figure 2 in Section 1 illustrates how different fish species may use these different habitats at different tide stages.

U.C. Davis Fish Monitoring Team Deploying a Beach Seine in Artesian Slough, Alviso Marsh, Lower South Bay. Credit: Levi Lewis.

1. INTRODUCTION TO THE WRMP AND FFH WORKGROUP

California Central Coast Steelhead Trout (Oncorhynchus mykiss). Credit: James Hobbs.

1.1 The Wetland Regional Monitoring Program (WRMP)

The San Francisco Estuary Wetland Regional Monitoring Program (WRMP) is a multi-agency effort to coordinate the monitoring of estuarine wetland habitats within the San Francisco Estuary (SFE). The SFE is the largest enclosed estuary in the western United States, extending from the upper estuary (Suisun Marsh, Suisun Bay, and the Sacramento-San Joaquin Delta) which receives significant freshwater inputs from the Sacramento River and San Joaquin River to the lower estuary which receives less freshwater input and functions more like a Mediterranean-type lagoonal estuary. The overarching goals of the WRMP are to (1) understand how landscape-scale drivers such as climate change are affecting these ecosystems across space and time, (2) support decision-making informed by the best available science, and (3) facilitate improved coordination of the monitoring required by environmental regulatory (permitting and habitat/species recovery) processes.

The geographic scope of the WRMP includes brackish and saline wetland habitats throughout the SFE, including those within Suisun Bay, San Pablo Bay, and Central, South, and Lower South San Francisco Bay (**Figure 1**). The scope of the recommendations herein includes all fishes that use aquatic habitats within the "complete tidal marsh ecosystem" (CTME) (Goals Project 2015), including intertidal marsh, channel, and mudflat habitats, (up to approximately mean higher high water, MHHW), and tidally-influenced subtidal slough and open-water habitats (< 4 m below mean lower low water, MLLW) (**Figure 2**). Intertidal habitats are intermittently occupied each day by certain wetland-associated fishes during relatively higher tides, whereas adjacent subtidal habitats are occupied by these and other wetland-associated fishes during all tidal stages throughout each day (**Figure 2**). Additional background information about the WRMP can be found in the WRMP Project Plan (WRMP SC 2020).

Figure 2.1. The study area includes the watersheds and bayland habitats located within San Francisco Bay, from the Golden Gate to Broad Slough. Subembayments are based on Operational Landscape Unit (OLU) boundaries and USGS sediment flux monitoring locations.

Figure 1. *Geographic scope of the WRMP. Brackish and saline wetlands are found in Suisun Bay in the "Upper Estuary" and all major subregions of the "Lower Estuary" including San Pablo Bay, Central Bay, South Bay, and Lower South Bay. Operational landscape units (see SFEI and SPUR 2019) are nested within SFE's five subregions.*

1.2 Fish and Fish Habitat (FFH)

Tidal wetlands occur at the interface of terrestrial and aquatic habitats, where strong tidal amplitudes and variation in precipitation alter the inundation and biophysical characteristics on hourly, daily, seasonal and interannual scales (Colombano et al. 2020, Fichman et al. 2021). To understand the ecology of aquatic wetland ecosystems, one must examine the features and dynamics across the entire system, including intertidal and subtidal habitats (**Figure 2**). For example, to understand patterns in aquatic communities in these systems, studies must examine patterns across both (a) static habitat features (e.g., marsh plains, intertidal channels, subtidal sloughs, and adjacent open-water habitats) and (b) across dynamic physiochemical gradients (e.g., temperature, salinity, dissolved oxygen, and turbidity). Research must also explore key linkages (e.g., trophic and demographic) between intertidal and subtidal habitats, how these influence aquatic communities, and the effects of numerous stressors including sea level rise, increasing temperatures, contaminants, nutrients, invasive species, and habitat loss.

Long-term monitoring and directed applied research in the SFE's tidal wetland habitats is needed to understand tidal wetland ecology and to quantify the effects of multi-benefit restoration and enhancement actions for informing management actions (IEP TWM PWT 2017a). Identifying persistent gaps in our understanding, and prioritizing monitoring that informs critical management questions will enable managers to better optimize resource allocation and strengthen our estuary-wide research and monitoring efforts. Conceptually, restoration success in the lower SFE would be characterized by improved physical and biological habitat conditions that support native fish populations; however, key aspects of this conceptual model for the SFE still require validation.

Several gaps in our understanding of aquatic wetland ecosystems in the lower SFE remain. For example, baseline information regarding spatial and temporal patterns in the occurrence, abundance, diversity, and structure of aquatic organisms (e.g., fishes and macroinvertebrates) and associated water quality metrics in tidal wetland habitats all remain critical data gaps for developing and evaluating effective wetland management practices in the SFE. Similarly, mechanistic relationships between wetland restoration and subsequent effects on aquatic species (e.g., feeding, growth, survival, reproduction) and ecosystem functions (e.g., productivity) remain poorly described. Likewise, the importance of trophic transfer (e.g., consumption of fishes by terrestrial avian piscivores during high tide, or the export of primary, and secondary production from the marsh to adjacent sloughs during ebbing tides) remain to be characterized. Since most restoration projects in the lower SFE have been engineered to enhance shoreline protection, flood protection, public access, recreational opportunities, and habitats for avian and mammalian species, little is known regarding how these highly altered landscapes are likely to impact aquatic wetland ecosystems, including their fish and macroinvertebrate inhabitants.

The need for integrated, standardized monitoring is widely recognized. However, developing robust monitoring recommendations is a complex, challenging process. The FFH Workgroup recognized and acknowledged this complexity, noting that various monitoring approaches are likely to be largely determined by the specific objectives and logistical constraints of a given program (Reynolds et al. 2016, IEP TWM PWT 2017a). The recommended standard operating procedures (SOP) for monitoring Fish and Fish Habitat (FFH) provided herein were developed with this complexity in mind, and are intended to assist with the development of an integrated monitoring program for SFE wetlands.

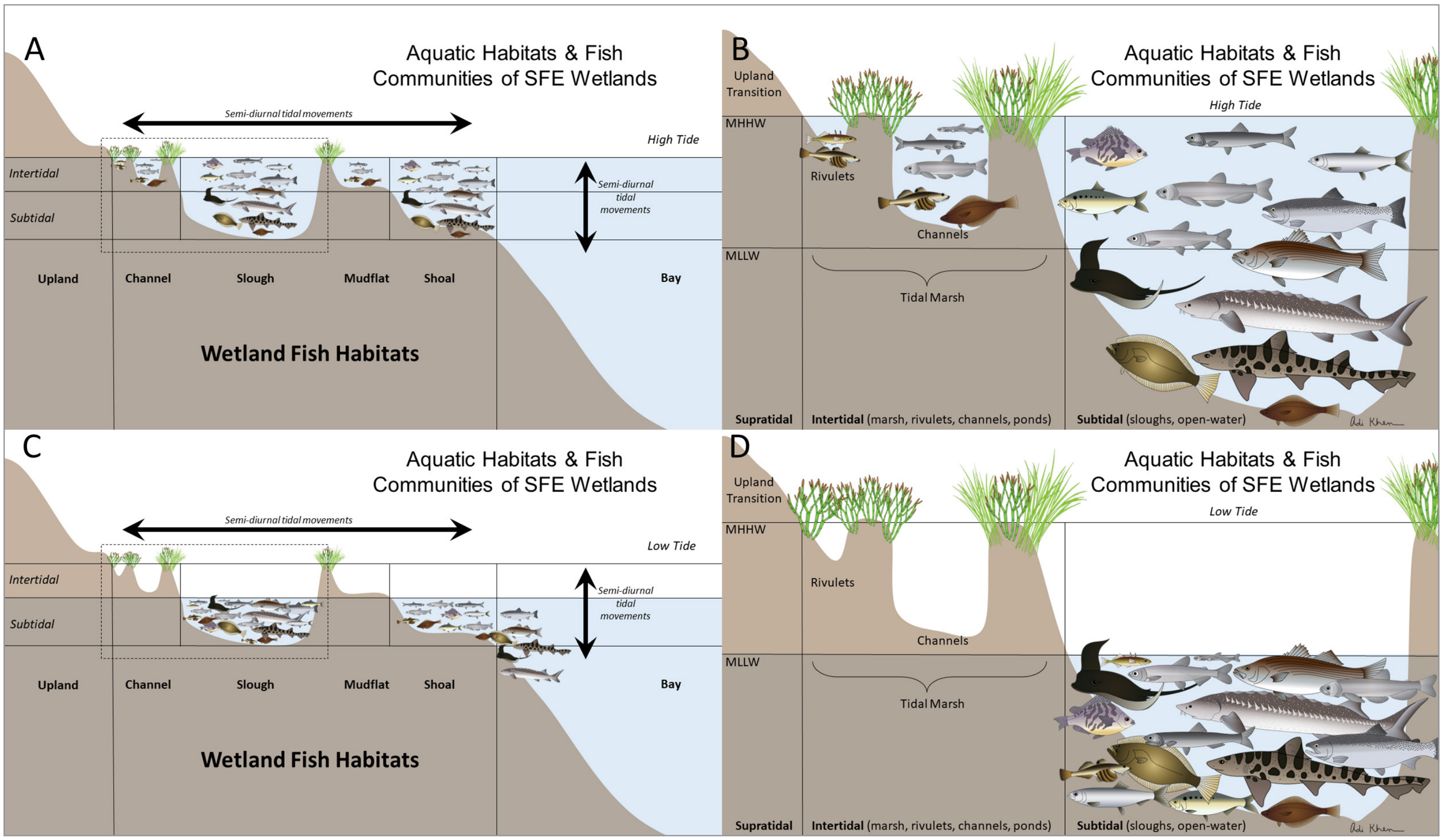


Figure 2. *Conceptual diagram of the aquatic habitats and associated fishes that are commonly found in SFE wetlands (B & D are zoomed areas within the dashed boxes in A & D). Every day, many fishes move back and forth (arrows) between intertidal and subtidal habitats during semi-diurnal tidal cycles to forage and avoid predators. The top (A, B) and bottom (C, D) rows illustrate the use of different habitats by fishes at high and low tides, respectively. Habitats are defined in part by their elevation in relation to tidal stages (MHHW - mean higher high water; MLLW - mean lower low water). This schematic is a generalized conceptual model and may not apply to or perfectly represent every wetland habitat within the SFE. Illustration by Levi Lewis and Adi Khen.*

1.3 Regulatory Considerations

Monitoring of fish and fish habitat within SF Estuary is implemented in support of numerous regulatory purposes related to aquatic resource protection and recovery. Monitoring approaches were evaluated to support natural resource managers tasked with managing fish populations and habitat as well as supporting restoration project proponents that may have monitoring requirements associated with their projects. Monitoring associated with these distinct purposes is described below and was used to inform the development of the monitoring goals (Section 2.3).

1.3.1 Monitoring Associated with Restoration Project Permitting

Restored wetlands often are intended to benefit fish and wildlife, particularly Endangered Species Act (ESA)- and California Endangered Species Act (CESA)-listed species, and other managed species (e.g. covered by the Magnuson-Stevens Fisheries Conservation and Management Act [MSA]) through increased productivity, improved habitat structure (e.g., offering juvenile fish protection from predators), and improved water quality through increased filtration and sequestration of contaminants. Projects that affect fish and fish habitat, including but not limited to tidal wetland restoration projects, can be subject to short- and long-term monitoring requirements to evaluate project implementation and performance. Monitoring requirements may be incorporated into multiple agency permitting and consultation processes such as the following:

- Clean Water Act Section 404, dredge/fill in Waters of the US individual and nationwide permits: US Army Corps of Engineers (USACE),
- Clean Water Act Section 401, water quality certifications, certifications for small habitat projects, and Porter-Cologne Water Quality Control Act waste discharge requirements: SF Bay Regional Water Quality Control Board (SFBRWQCB),
- ESA section 7 consultations: U.S. Fish and Wildlife Service (USFWS) and National Marine Fisheries Service (NMFS),
- ESA Sections 4(d) and 10(a) for research permits: USFWS, NMFS,
- CESA ITPs and consistency determinations for species listed under ESA and CESA: California Department of Fish and Wildlife (CDFW),
- CDFW Lake and Streambed Alteration Permit
- CDFW Scientific Collection Permit,
- EFH consultations under the MSA: NMFS,
- Marine Mammal Protection Act (MMPA) Incidental Harassment Authorization (IHA): NMFS, and
- Coastal Zone Management Act consistency determinations and individual permits: SF Bay Conservation and Development Commission (BCDC).

As described in the WRMP Program Plan (WRMP SC 2020), data collected by the WRMP is intended to support greater efficiencies and enhance the value of monitoring efforts associated with permitting assessment of wetland restoration projects. In its initial stages, WRMP monitoring of FFH indicators is unlikely to eliminate or substitute for compliance monitoring by individual restoration projects, especially those projects affecting imperiled species. However, as the program grows in scope and scale, and demonstrates the value of collecting and synthesizing FFH data within a regional context, regulatory agencies may determine that WRMP monitoring may in some cases serve as a suitable surrogate for compliance monitoring. The WRMP Monitoring Plan will describe a strategy for aligning monitoring activities with the information needs of its regulatory partners. One of the primary intents of the WRMP is to provide a mechanism to collect regional scientific information to evaluate project performance, improve regional assessment, and reduce data redundancy and monitoring pressure on individual restoration projects. The WRMP will use and standardize methods of data collection, management, and analysis to test broadly accepted conceptual models and assure that project data can be compared over time, relative to ambient conditions. This can provide restoration projects with a standardized monitoring framework and allow managers to synthesize monitoring data across multiple temporal and spatial scales, which is necessary to determine the relative influences of project design, management, interactions among projects, and regional factors (such as sea level rise and sediment supply) on the health of tidal marsh ecosystems. The development of the WRMP will support tidal marsh restoration projects by providing long-term data that, with agency approval, could be used to compare individual project performance with regional reference conditions. If data produced by the WRMP could be compared with (or substitute for) data from individual restoration projects, the time and costs for each project to comply with monitoring requirements could potentially be reduced. By reducing costs, time, effort, and redundancy involved in project monitoring throughout the San Francisco Estuary, robust monitoring results from the WRMP can improve regional efficiency in complying with regulatory requirements.

1.3.2 Monitoring to Inform Fish Conservation and Management

Several state and federal agencies have regulatory authority over the management of fish populations and their habitats in the SFE. SFE wetlands provide important habitats for several fish species listed under the ESA (e.g., ESA-listed salmonids and green sturgeon), and managed under the MSA through fisheries managements plans for Pacific Coast Groundfish, Pacific Coast Salmonids, and Coastal Pelagic Species by the National Marine Fisheries Service (NMFS). Degradation of aquatic tidal wetland habitats influences the quantity and quality of essential fish habitat (EFH) designated under the MSA that supports managed fish populations. Tidal wetland habitat also provides important functions for aquatic species listed and managed by the US Fish and Wildlife Service (USFWS) (e.g. Longfin smelt proposed for ESA listing) and California Department of Fish and Wildlife (CDFW) (e.g., inland fishes, including Delta Smelt and Longfin Smelt). Data collected by the WRMP will contribute to an improved understanding of the status, trends, and restoration of fishes and their habitats; including water quality, species assemblages, habitat use, trophic ecology, and migratory behaviors that will improve managers' abilities to provide effective and scientifically robust recommendations to better conserve wetland-associated species and their habitats.

For example, the SFE provides habitat for five genetically distinct salmonid populations, termed Evolutionary Significant Units [ESU] or Distinct Population Segments [DPS]. There are two ESA-listed Chinook Salmon ESUs (*Oncorhynchus tshawytscha*; Central Valley spring-run Chinook Salmon, Sacramento River Winter-run Chinook Salmon), and one stock (Central Valley Fall-run Chinook) for which there remains an active fishery managed under CDFW commercial and recreational fishing permits. Two ESA-listed DPS of steelhead, *Oncorhynchus mykiss*, also migrate through SFE wetlands (California Central Valley Steelhead, Central California Coast Steelhead), and there remains an active recreational fishery managed by CDFW for hatchery steelhead in select anadromous waters (NMFS 2014, 2016). The estuarine rearing life stage is important for many west coast salmonids and may also be important for SFE salmonids. Research from estuaries along the Pacific coast indicates increased ocean-survival rates and growth when juveniles make extensive use of estuaries (Rich 1920, 1939, Levy & Northcote 1982, Bond et al. 2008). In the SFE, most of the applied research has focused on Central Valley Fall-run Chinook Salmon and results indicate this species does not spend significant time rearing in the estuary (Kjelson et al. 1982, MacFarlane & Norton 2002, Sandstrom et al. 2013). Because of this research, the SFE is often discussed primarily as a migration corridor for salmonids. However, lack of residence time detected by these studies may be partially attributable to the hatchery-origin Fall-run Chinook Salmon used in past studies by researchers, given that rearing behavior and life history strategies expressed by salmonids of the SFE is notably diverse. Additionally, poor habitat conditions associated with major habitat and freshwater flow alterations in the SFE could also be a contributing factor. Monitoring and research in the lower SFE are needed to better understand the temporal presence and habitats used by juvenile anadromous salmonids, as restored and enhanced tidal marsh habitats may be an important part of enhancing the portfolio of life-history strategies to support resiliency for salmonid populations in the future (Bottom et al. 2001, Howe & Simenstad 2007, Munsch et al. 2017).

Similarly, the Southern DPS of North American Green Sturgeon (*Acipenser medirostris*) is federally listed as "threatened" and is known to forage and rear in the lower SFE throughout the year (NMFS 2018, Miller et al. 2020). Green Sturgeon have most often been observed at depths greater than 5 meters in San Pablo and Suisun Bays, where they forage on bay shrimp, crabs, amphipods, isopods, clams, and fish (Ganssle 1966). Although Green Sturgeon have been observed in wetlands throughout the SFE, little is known about the relative importance of brackish and saline wetland habitats for this species. For example, three Green Sturgeon have been collected in the Suisun Marsh otter trawl survey in the 1990s (O'Rear & Moyle 2017), at least one Green Sturgeon was collected in Alviso Marsh, Lower South Bay, in the 1980s by the South Bay Discharge Authority otter trawl survey (SBDA, **Appendix 2**), and one was observed in Lower South Bay by telemetry (Ducks Unlimited, Inc & ECORP Consulting, Inc 2013). However no Green Sturgeon have been observed in Alviso Marsh in the last decade, despite multiple years of monthly sampling with otter trawls and beach seines in the region (Hobbs et al. 2012, Hobbs 2017, Lewis et al. 2019b). Limited detections of Green Sturgeon in brackish and saline wetlands, however, may be due in part to their rarity, the use of ineffective sampling methods, and limited dedicated sampling for Green Sturgeon in wetland habitats (Miller et al. 2020). It is possible, therefore, that Green Sturgeon utilize brackish and saline wetlands of the SFE, including tidal mudflats and subtidal channels to forage, particularly at night, as they are known to do in other estuaries throughout their range (Dumbauld et al. 2008, Moser et al. 2017). As for salmonids, the impacts of highly-altered and degraded wetland habitats on the SFE Green Sturgeon population, and associated benefits of wetland restoration, have yet to be quantified and remain poorly understood.

Two species of native osmerid smelts, the Delta Smelt (*Hypomesus transpacificus*) and Longfin Smelt (*Spirinchus thaleichthys*), are commonly observed in wetland habitats of the SFE. Both species are listed under the CESA (Delta Smelt - endangered, Longfin Smelt - threatened), with Delta Smelt also listed as threatened under the ESA, and Longfin Smelt recommended for endangered listing under the ESA in October 2022 (USFWS 2022). Both species are managed by the CDFW, with Delta Smelt co-managed by the USFWs. Delta Smelt are only common within WRMP habitats of the upper estuary (primarily Suisun Marsh) (Nobriga et al. 2008, Hammock et al. 2019), but can be found further downstream, particularly in wet years with high freshwater outflow. Unlike Delta Smelt, Longfin Smelt are commonly observed in wetland habitats throughout the San Francisco Estuary, from the freshwater Delta to the salt marshes of Lower South San Francisco Bay (Merz et al. 2013, Lewis et al. 2019a). Both species are pelagic invertivores, feeding largely on copepods and mysid shrimp (Jungbluth et al. 2021, Barros et al. 2022, Lojkovic Burris et al. 2022). Spawning habitats remain unknown, but all life stages can be found in shallow wetlands as adults during the winter-spring spawning season (Merz et al. 2013, Grimaldo et al. 2017, Lewis et al. 2019a, 2020). This reliance on wetland habitats has spurred wetland restoration projects as one conservation strategy to help restore native smelt populations in the SFE.

1.3.3 Biological Integrity and Ecological Impairment

The monitoring of fish populations can provide important information on ecosystem health that can be used to guide the regulation and management of wetland habitats (SWRCB 2004). The diversity and structure of biological communities reflect the overall ecological integrity (i.e., chemical, physical, and biological integrity) of an ecosystem; thus in addition to regulatory needs for managing individual fish species, the monitoring of fish and aquatic communities can be important for inferring the status and trends in the ecological health of wetland habitats as a whole (Cooper et al. 2018). This is because the cumulative effects of multiple factors such as eutrophication, pollutants, temperature, and sediment loading are integrated by biological communities over time, with changes in aquatic communities reflecting how well a habitat can support aquatic life. Such time-integrated cumulative impacts are rarely evident with short-term or discrete observations of physical environmental conditions.

Bioassessments such as the Index of Biological Integrity, River Invertebrate Prediction and Classification System, and benthic macroinvertebrates are commonly used and accepted as valuable tools for evaluating ecosystem health and providing crucial information regarding water quality (SWRCB 2004). Such indicators have been applied to fishes in a variety of wetland habitats (Cooper et al. 2018), provide important data for assessing and managing the impacts of anthropogenic stressors (MacVean et al. 2018), and can be used to document the responses of aquatic communities to habitat restoration and environmental change (SWRCB 2004). For example, ongoing collaborative efforts between UC Davis and SFEI have utilized fish survey data from wetland habitats in Lower South Bay (Lewis et al. 2019b) to assess biotic integrity and the ecological impacts of nutrient loading and associated hypoxia (MacVean et al. 2018). Results of this work are being used to inform the San Francisco Bay Nutrient Management Strategy (NMS) and responses to recent fish kills due a severe harmful algal bloom (HAB) event. The California State Water Resources Control Board (SWRCB) Final Functional Equivalent Document for the Water Quality Control Policy for Developing California's Clean Water Act Section 303(d) List (SWRCB 2004) recommends the following in the development of fish-community-based indices of biological integrity:

> *Bioassessments using a fish assemblage requires that all fish species (and size classes), not just game fish, be collected. Fish are good indicators of long-term effects and broad habitat conditions because they are relatively long-lived, mobile and integrate various features of environmental quality, such as food and habitat availability (Simon and Lyons, 1995). The objective of a fish assemblage is to collect a representative sample of all species (except rare species) in the assemblage and provide a measure of the relative abundance of species in the assemblage. All fish should be identified to species level.*

1.3.4 Take and Incidental Harassment Authorization Efficiencies

All monitoring that results in "take" (including collection or harassment) of any ESA and CESA listed species in waters of the State of California for scientific purposes requires an approved Scientific Collection Permit from the CDFW under sections 1002 and 1002.5 of the California Fish and Game Code (FGC). Furthermore, sampling activities occurring as part of the WRMP are likely to capture species that are listed as threatened or endangered under the federal ESA or CESA, including specific ESUs or DPSs that have been listed. Listed taxa include Sacramento River Winter-run and Central Valley Spring-run Chinook Salmon, Central California Coast and Central Valley Steelhead), southern DPS of North American Green Sturgeon, Delta Smelt, and state-listed SFE Longfin Smelt. ESA section 4(d) or 10(a)1(A) permits or take exemption through section 7 consultation will need to be obtained from the National Marine Fisheries Service (NMFS) to authorize take of anadromous species (listed salmonids and sturgeon) and from the U.S. Fish and Wildlife Service (USFWS) to authorize take of delta smelt and possibly Longfin Smelt (proposed federal listing under the ESA). A CESA 2081a Memorandum of Understandings (MOU) for the take of Delta Smelt and Longfin Smelt will need to be obtained from CDFW and coordinated with the Interagency Ecological Program (for ESA-related take agreements). Certain types of sampling activities may also result in harassment of species protected under the MMPA (e.g., wetland-associated harbor seals [*Phoca vitulina*]) and ESA- and CESA- listed marsh-associated terrestrial taxa (e.g., Ridgway's rail [*Rallus obsoletus*]and salt marsh harvest mouse [*Reithrodontomys raviventris*]). A Letter of Authorization or Incidental Harassment Authorization may be needed from NMFS Protected Resources Division (marine mammals) or USFWS (harvest mouse and Ridgway's rail).

The application and approval process to obtain all of the permits, authorizations, and exemptions listed above is a critical barrier to restoration projects and the collection of standardized, long-term data in wetland habitats throughout the estuary. Permits are typically issued to "an appropriate public, private, or nonprofit entity, or a person, as determined by the department, in the name of a principal scientific investigator or the permitted entity or person" (FGC section 1002.5(a)). The process can take up to 1 year, and a single permitting challenge could readily derail an otherwise fully funded and permitted project or study. WRMP-level programmatic permits and authorizations (e.g., from NMFS, USFWS, and CDFW), however, could create significant efficiencies for agencies issuing permits as well as for projects, principal investigators, and research teams that need coverage to conduct research and restoration under WRMP work plans. For example, the take of federal- and state-listed species and of non-listed species could be estimated for the WRMP as a whole and applied to all WRMP-associated studies and projects. Similarly, approved training protocols and requirements could be institutionalized to minimize impacts (e.g., to rails and mice), and clearly documented as a requirement for conclusion in the WRMP work plan. Such a permitting approach has been used extensively under the Interagency Ecological Program Work Plan to facilitate permitting for research and management actions that might encounter Delta Smelt. Restoration projects that seek take exemption through section 7 consultation may also benefit from guidance provided in the SOP if using standardized methods fulfill or supplement the required project monitoring, or facilitate the ESA consultation review and permitting process.

2. PROGRAM DEVELOPMENT PROCESS

Pacific Herring (Clupea pallasii). Credit: James Ervin.

2.1 WRMP Science Framework

The process through which the WRMP is developing its science content is meant to be broadly consistent with the Wetland and Riparian Area Monitoring Plan (WRAMP) framework developed by the California Wetland Monitoring Workgroup of the California Water Quality Monitoring Council. The WRAMP framework uses key guiding questions and information needs for decision-makers to guide the selection of monitoring questions, indicators, metrics, and SOPs. The overall WRAMP framework is described in detail on the WRAMP webpage; an overview is provided below (**Figure 3**).

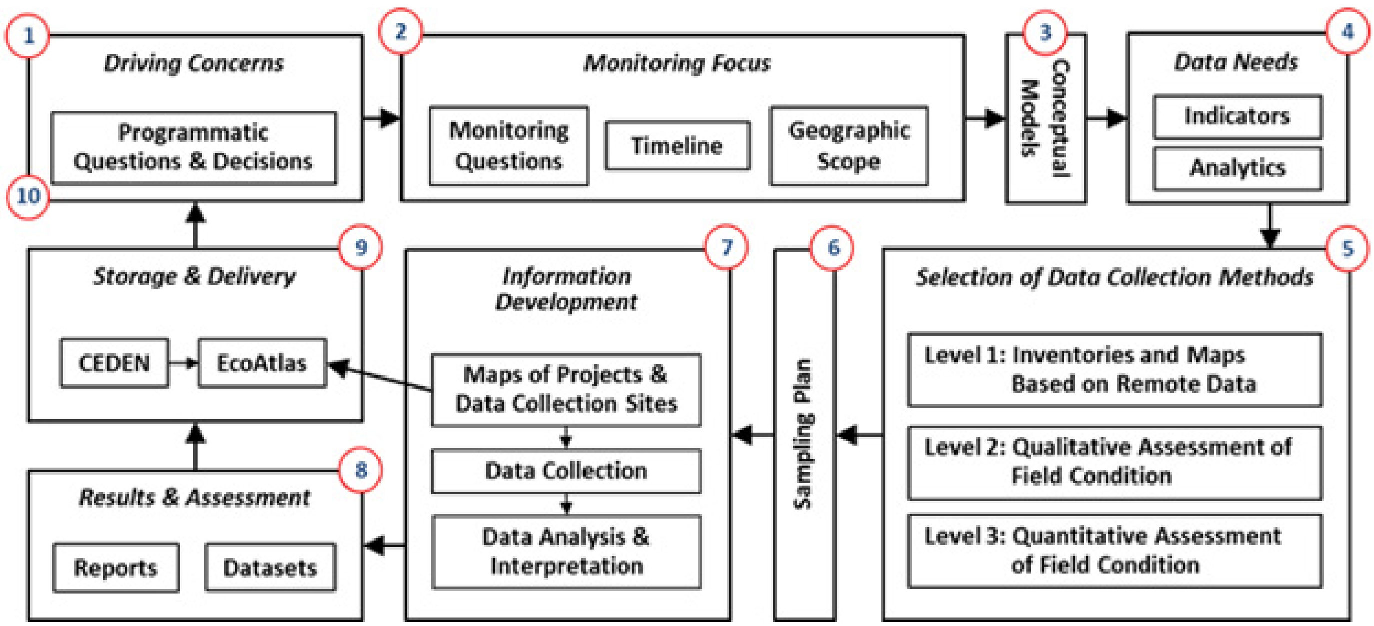


Figure 3. *The 10 sequential elements of the WRAMP.*

2.2 WRMP Science Process

2.2.1 Guiding and Management Questions

During the first phase of program development in 2018-2020, the WRMP developed its initial science content in consultation with a Science Advisory Team (SAT, composed of technical experts) and Steering Committee (composed of regulatory, funding, and related decision-makers). The SAT and Steering Committee helped identify the guiding questions (GQs) and associated management questions (MQs) for the WRMP:

GQ1: Where are the region's tidal marsh ecosystems, including tidal marsh restoration projects, and what net changes in ecosystem area and condition are occurring?

- MQ1a: What is the distribution, abundance, diversity, and condition of tidal marsh ecosystem, and how are they changing over time?
- MQ1b: Are changes in tidal marsh ecosystems impacting water quality?

GQ2: How are external drivers, such as accelerated sea level rise, development pressure, and changes in runoff and sediment supply, impacting tidal marsh ecosystems?

- MQ2a: How are tidal marshes and tidal flats, including restoration projects, changing in elevation and extent relative to local tidal datums?
- MQ2b: What are the regional differences in the sources and amounts of sediment available to support accretion in tidal marsh ecosystems?

GQ3: What new information do we need to better understand regional lessons from tidal marsh restoration projects, advance tidal marsh science, and ensure the continued success of restoration projects?

- MQ3a: Where and when can interventions, such as placement of dredged sediment, reconnection of restoration projects to watersheds, and construction of living shorelines, help to sustain or increase the quantity and quality of tidal marsh ecosystems?

GQ4*: How do projects to protect and restore tidal marshes affect the distribution, abundance, and health of plants and animals [e.g. fish and wildlife]?

- MQ4a: How are habitats for assemblages of resident species of fish and wildlife in tidal marsh ecosystems changing over time?
- MQ4b: How are the distribution and abundance of key resident species of fish and wildlife of tidal marsh ecosystems changing over time?

GQ5: How do projects to protect and restore tidal marshes affect public health, safety and recreation?

- MQ5a: What mosquito and vector control strategies need to be considered in restoration design and management to understand the effects that restoration can have on mosquito and vector populations?
- MQ5b: What monitoring data are needed to optimize the relationship between tidal marsh restoration, fish and wildlife support, and mosquito and vector control?

**GQ and MQs related to FFH*

The SAT helped the WRMP develop a variety of related science content, including a compendium of conceptual models of physical and ecological processes in San Francisco Estuary (SFE) estuarine wetlands (Appendix F in the Phase 1 WRMP Plan), and a "master matrix" of monitoring questions, indicators, and metrics to address the guiding and management questions. To support development of this content, the WRMP held four technical workshops with the SAT and broader regional science community (Appendix C in the Phase 1 WRMP Plan) (WRMP SC 2020). These workshops focused on physical processes, vegetation, mosquito and vector control, and fish and wildlife.

2.2.2 Initial FFH Recommendations (Phase 1: Fish and Wildlife Workshop)

In March 2019, the WRMP fish and wildlife workshop was attended by numerous representatives from the region's long-term fish monitoring efforts, such as the Interagency Ecological Program, San Francisco Bay Study, and Suisun Marsh Fish Study, as well as representatives from resource/regulatory agencies, research institutions, and other fish & fish habitat stakeholders. Workshop participants emphasized numerous key points regarding the challenges and opportunities of regional monitoring focused on fish and fish habitats, such as:

- Due to its life history, which is uniquely dependent on tidal marshes, Longjaw Mudsuckers could be a useful indicator of tidal wetland health, including but not limited to the impacts of methylmercury on tidal wetland biota. However, their distribution is limited largely to habitats downstream of the Carquinez Strait, constraining their utility as a regional indicator.
- Rare and listed fish species can be challenging indicators to monitor due to issues associated with take during sampling.
- Monitoring benthic, littoral, and pelagic fish species can help assess how habitats across the land/sea interface (e.g. from watersheds to tidal wetlands to open water) support aquatic ecosystems.
- Individual metrics of interest include growth rates, gut fullness, and fish condition; community metrics of interest include biomass, abundance, diversity, and age class distribution.
- WRMP monitoring of fish and fish habitats needs to carefully consider how to leverage ongoing fish monitoring efforts throughout the estuary, which largely sample deeper channel/shoal habitats. Monitoring of shallower nearshore and/or marsh habitats is limited and is typically done through shorter-term (<10 year) contracts.
- Aquatic invertebrates to consider monitoring include mysid shrimp and Dungeness Crab.

During the fish and wildlife workshop, participants noted the broad range of monitoring questions, indicators, and metrics that could potentially address Guiding Question 4, and Management Question 4A and 4B, and suggested further work to refine the WRMP's goals and needs with regards to the monitoring and assessment of fish and fish habitat (FFH). When the Phase 1 WRMP Plan was published (WRMP SC 2020), the science framework for FFH concerns remained relatively simple, and only included the "distribution and abundance of indicator species."

2.2.3 Updated FFH Recommendation (Phase 2: FFH Workgroup of the TAC)

During the second phase of program development, the WRMP convened a new Technical Advisory Committee (TAC) to further develop and refine the program's science content and prepare for possible program funding and implementation in 2022. To expand upon Guiding Question 4 and the associated Management Questions (MQ 4a, b), the TAC convened a special workgroup ("FFH Workgroup", **Table 1**) to help refine the FFH-related monitoring questions, indicators, and metrics. This workgroup was also tasked with developing a monitoring SOP for FFH that could build upon the efforts of the 2019 workshop, bridge the information needs of the regulatory compliance (permitting) and resource recovery sides of the region's regulatory agencies, and leverage historic and ongoing monitoring of the region's fisheries resources.

2.2.4 SOP Adoption, Validation, Revision, and Special Studies

Adoption of this SOP by the TAC and SC acknowledges that the monitoring recommendations herein likely represent the most effective and efficient approach to standardized regional long-term monitoring of aquatic wetland communities, and will address the WRMP's many information needs related to fish and fish habitat. As previously noted, adoption of the SOP does not constitute a formal plan to initiate fish and fish habitat monitoring at any sites within or outside the proposed WRMP monitoring site networks. In 2023, the TAC will develop a monitoring plan that will identify the indicators and sites that should be prioritized for initial monitoring implementation. With respect to implementation of FFH monitoring, it is expected that the recommendations within this SOP will be incorporated and refined to reflect the priorities identified in the monitoring plan.

As for all WRMP SOPs, it is recommended that the FFH SOP be periodically reviewed and revised by the FFH Workgroup to address monitoring realities and the program's evolving science needs. Therefore, following initial implementation of FFH monitoring, it is recommended that results be analyzed to (a) reassess the feasibility and effectiveness of recommended sampling procedures across habitat types; (b) refine details regarding gear-specific considerations such as gear features (net size, mesh size, etc.), deployment methods (e.g., boat, shore, depth, velocity, duration/effort, etc.), and best practices for minimizing environmental impacts, incidental take, and other wildlife interactions; and (c) assess any barriers to effective implementation, including site access and permit-based restrictions. In some cases, special studies may be recommended to address specific data needs that require methods beyond those recommended for standardized estuary-wide long-term monitoring (Section 4). For example, gear types such as gill nets, fyke nets, minnow traps, pop-up nets, and plankton nets may be optimal for special studies examining questions about specific taxa or habitat types. Significant revisions of the SOP and introduction of special studies will be reviewed/adopted by the TAC and submitted to the SC for approval following initial implementation.

2.3 The FFH Workgroup

The FFH Workgroup identified a subcommittee to lead the development of the monitoring considerations and alternatives for the WRMP's FFH SOP. The FFH subcommittee consisted of four fisheries biologists (**Table 1**) from different agencies including UC Davis, NMFS, USACE, and USFWS, each of whom actively work on fisheries related issues in the SFE. The subcommittee developed a stepwise process to draft initial monitoring recommendations that included (a) drafting FFH-specific monitoring goals for the WRMP (Section 2.3 below), (b) developing a comprehensive list of monitoring considerations and options (Section 3), (c) scoring the value of each monitoring option with respect to the FFH goals, and (d) developing and evaluating a suite of proposed FFH monitoring alternatives that would achieve the monitoring goals. The proposed FFH monitoring alternatives were then evaluated by the full FFH Workgroup of the TAC, with the final recommendations outlined and justified in an SOP document (present document) to be presented to the WRMP Steering Committee for final approval and inclusion as the WRMP FFH SOP (**Figure 4**). A detailed accounting of the alternatives development and ranking process is provided in **Appendix 1**. To inform and support the recommendations provided herein, the FFH Subcommittee also conducted a review study that outlined previous monitoring of FFH in brackish and saline habitats throughout the SFE (**Appendix 2**).

NAME	AFFILIATION
Levi S. Lewis*,#,†	UC Davis
Alison Weber-Stover*,#,†	NMFS
Elizabeth Campbell*,†	USACE
Jeff McLain*,†	USFWS
Christina Toms*	SFBRWQCB
Lu Wang*,#	NMFS
Zach Duckworth#	NMFS
Stephen Randall#	SFBRWQCB
Donna Ball	SFEI
Alex Thomsen	SFEP
Cassie Pinnell	Vollmar Consulting
Chris Jasper	Vollmar Consulting
Dylan Stompe	UC Davis
Isa Woo	USGS
Josh Collins	SFEI
Karen Thorne	USGS
Kevin Buffington	USGS
Susan de la Cruz	USGS

* Lead author of the FFH SOP Document
† Lead author of the Alternatives Ranking Report (Appendix 1)
\# Lead author/analyst to the FFH Monitoring Inventory Report (Appendix 2)

Table 1. *The FFH Workgroup of the WRMP TAC. Members of the FFH subcommittee who contributed to the drafting of the SOP document, the development and ranking of sampling alternatives, and the development and drafting of the Fish Monitoring Assessment/Inventory are noted below. All members of the FFH Workgroup (listed below) volunteered to review and comment on the SOP document and associated appendices, with comments and recommendations incorporated by the SOP authors.*

1	2	3	4	5	6
Identify Monitoring Goals Associated with the Guiding Question (FFH)	**Develop a Suite of Considerations for Proposed Monitoring, Informed by Inventory Data, and Drafted Appropriate Alternatives (Subgroup)**	**Rank Alternatives and Ability to Meet Monitoring Goals (Subgroup)**	**Coordinate with Agency Partners and Subsequently the FFH**	**Finalize SOP and Present to WRMP TAC for Approval**	**Present to the Steering Committee for Approval**

Figure 4. *The FFH Subcommittee collaborative process for developing monitoring alternatives.*

2.4 FFH Workgroup Monitoring Goals

The FFH workgroup identified three fish-specific monitoring goals that will provide data that are critical for addressing Management Questions 4A & 4B of the WRMP. The FFH monitoring alternatives and recommendations provided herein were developed to address these three FFH-specific monitoring goals.

2.4.1 Establish long-term fish monitoring in wetlands bay-wide

"Large-scale" in the ranking exercise (**Appendix 1**) to represent regional monitoring and the assessment of geographically large projects[1]: Provide standardized data, consistent or comparable with other concurrent and long-term research programs, that can be used to describe long-term trends in aquatic wetland communities throughout the SFE, including presence/absence, local abundance/biomass (index/CPUE), and community structure of juvenile and adult stages of select focal species and functional groups at established benchmark, reference, and project sites.

2.4.2 Monitor the use of wetland habitats by ESA/CESA listed fish species

"ESA/CESA listed species" in the ranking exercise (**Appendix 1**): Provide data regarding state and federally listed fish species use of the CTME of the SFE. Listed species include the southern distinct population segment (DPS) of North American Green Sturgeon (*Acipenser medirostris*), Central California Coast and California Central Valley Steelhead DPS (*Oncorhynchus mykiss*), Sacramento River Winter-Run Chinook Salmon (*O. tshawytscha)*, Central Valley Spring-Run Chinook Salmon (*O. tshawytscha*), Longfin Smelt (*Spirinchus thaleichthys*), and Delta Smelt (*Hypomesus transpacificus*).

2.4.3 Provide context and guidance regarding fish responses to individual projects

"Small Scale" in the ranking exercise (**Appendix 1**) to represent marsh-specific monitoring for the assessment of individual projects with smaller geographic footprints): Provide temporal and regional ecological context with metrics to facilitate the assessment of restoration effectiveness and support adaptive management of SFE wetlands. Data are intended to help guide and evaluate future special studies, permitted projects, and restoration actions. Long-term data collected throughout the estuary using standard reproducible methods can be contrasted with data from project sites, restorations, or rapid assessments, to evaluate whether local patterns in aquatic communities and water quality are in alignment with, or deviate from, expectations based on regional patterns. Such results will greatly improve the interpretation and utility of project-specific monitoring efforts that utilize the WRMP sampling framework for fish and fish habitat.

[1] The subgroup considered projects like the South Bay Salt Pond Restoration Project (Valoppi 2018) with large footprint, multiple habitat types, and/or projects that extend to different geographic WRMP subregions of the SFE as "Large-scale".

3. CONSIDERATIONS FOR MONITORING FISH & FISH HABITATS

California Halibut (Paralichthys californicus). Credit: Levi Lewis (with Micah Bisson).

This document provides recommended standard operating procedures for the monitoring of wetland fishes and macroinvertebrates to the Steering Committee of the Wetland Regional Monitoring Program (WRMP). The monitoring recommendations herein were developed by the Fish and Fish Habitat (FFH) Workgroup of the WRMP's Technical Advisory Committee (TAC) to address the three FFH-related monitoring goals identified by the FFH Workgroup (Section 2.3) that are ultimately intended to inform Management Questions 4A and 4B of the WRMP (Section 2.2). This document outlines options and recommendations regarding the "**what**" (*species, life stages, and associated data*), "**how**" (*gears & methods*), "**when**" (*time of year and frequency*), and "**where**" (*general and specific locations and habitats*) regarding FFH sampling, as well as "**why**" (*justifications*) for each of the recommendations as they pertain to the monitoring goals and management questions.

The scope of the WRMP includes all brackish and saline wetland habitats (salinity > 0.5 ppt) of the San Francisco Estuary (SFE). The geographic scope of these recommendations, therefore, is limited to Suisun Bay (in the "upper estuary") and San Pablo Bay, and Central-, South-, and Lower South San Francisco Bay (in the "lower estuary"); and all fish-associated habitats within the CTME (Goals Project 2015). The CTME includes all intertidal marsh, channel, and mudflat habitats (up to MHHW) and extends downward to include all tidally-influenced subtidal slough and open-water habitats that are < 4 m below MLLW (Section 1.1, Figure 2).

Key considerations for the monitoring of fish & fish habitat were developed to identify a broad suite of fish and fish habitat assessment metrics that could be important to the WRMP, with a specific focus on the quantification of juvenile and adult life stages of nektonic and benthic taxa, along with associated macroinvertebrates and dynamic habitat features (e.g., water quality and other environmental metrics) aimed at informing the monitoring goals (Section 2.3). Although sampling of benthic and planktonic elements of wetland food webs (e.g., chlorophyll, particulate organic matter, submerged aquatic vegetation, zooplankton, phytoplankton, benthic diatoms, meiofauna, infauna, ichthyoplankton, etc.) can be key to understanding habitat suitability and underlying mechanisms that influence the distribution of fishes in wetland habitats (IEP TWM PWT 2017a); these topics were deemed to be beyond the scope of this FFH SOP. Additional SOPs for characterizing planktonic and benthic food webs would likely prove valuable for the WRMP.

3.1 Focal Species and Functional Groups

Many species of fishes use wetland habitats throughout the SFE. Here, we identify 3 focal groups that are likely important to consider for understanding marsh-specific and estuary-wide trends: large-bodied fishes (top predators and fisheries targets), small-bodied fishes (forage fishes and juvenile life stages), and marsh-plain fishes (species that heavily occupy or utilize tidal marsh and associated habitats). We also identify a fourth category of ESA/CESA-listed species that span the three other focal groups. Together, these groups were identified as important components for quantifying key patterns in tidal marsh and wetland fish communities across varying spatial and temporal scales.

3.1.1 Large-bodied fishes (top predators and fishery targets)

Large-bodied fish species (e.g., Green and White Sturgeon, Striped Bass, Leopard Sharks, Bat Rays, California Halibut, Salmon, Steelhead Rainbow Trout) are important as major predators or consumers in the region, and support important recreational fishing industries. Although most commonly found in tidal sloughs adjacent to marsh habitats, many of these species are known to periodically use and benefit from intertidal channels and marsh/mudflat habitats for foraging. As charismatic species that support key fisheries and ecological functions, these taxa have high socio-ecological value; however, are not directly associated with tidal marsh habitats throughout most of their life cycles.

Large-bodied species are commonly monitored using set nets (gill nets or trammel nets), angling (e.g., long lines), and telemetry. Sampling these species may require a lot of effort due to their lower relative abundance and difficulty in capture, in comparison to smaller-bodies species. Several large-bodied species belong to CESA/ESA lists, including Green Sturgeon and several runs of Chinook Salmon.

3.1.2 Small-bodied fishes (forage fishes, recruits, and macro-invertebrates)

Smaller-bodied species and juveniles of larger bodied species can also provide valuable information regarding the status of wetland ecosystems. For example, sampling of juveniles provides key inferences about recruitment, survival, and adult population dynamics of larger species. Smaller-bodied species (e.g., anchovies, herring, smelts, gobies, and sculpins) serve as important components of aquatic food webs, providing an important prey base for larger fishes, birds, and marine mammals. In tidal marshes, smaller bodied species are frequently preyed upon by terrestrial and marsh predators, thus serving as an important trophic link between terrestrial and aquatic food webs. Other nektonic and epibenthic macroinvertebrates (e.g., Crangonid and Palaemonid shrimps) are often collected with smaller-bodies species, providing additional information regarding food web dynamics.

Such species are commonly sampled using otter trawls, midwater trawls, minnow traps, beach seines, boat-based seines, and fyke/block nets. The sampling of this group may be the most feasible across all habitat types given the numerous gear types available, and numerous on-going surveys that provide data for informing survey development. The monitoring of this group is particularly relevant for understanding food web dynamics, recruitment dynamics, and for the protection of smaller-bodied CESA/ESA-listed species such as Delta Smelt and Longfin Smelt. Several species are known to spend significant parts of their lifecycle in tidal marsh habitats, and many others likely benefit from such habitats periodically.

3.1.3 Tidal marsh associated fishes (and macroinvertebrates)

A selection of fishes and invertebrates (e.g., Longjaw Mudsucker, Threespine Stickleback, Topsmelt, Staghorn Sculpin, Yellow Shore Crab) commonly utilize tidal marshes and associated habitats (e.g. rivulets and intertidal channels/mudflats). Although these belong to the small-bodied category, given the WRMP's focus on monitoring changes in restored tidal marsh habitats, we found it valuable to specifically identify and include tidal marsh-associated species as a separate, more specialized focal group.

Such species are commonly sampled using minnow traps, block/fyke type nets, drop nets, and beach seines. The sampling of fishes in this group may be challenging due to access to marsh habitats, permitting limitations due to the presence of other listed species (e.g., salt marsh harvest mouse & Ridgway's rail). To address access issues, sampling of fishes in marsh habitats may need to be closely linked to other permitted research activities within marsh habitats. The monitoring of this group is particularly relevant for assessing responses of fishes to tidal marsh restoration. No fishes within this group are listed under the CESA or ESA.

3.1.4 ESA/CESA listed species

As noted in 3.1.1-4 above, several CESA/ESA-listed fishes are known to occupy tidal wetland habitats. These include both large-bodied and small-bodied taxa that commonly occur in open-water and tidal slough habitats, and occasionally in tidal marsh habitats. Species may be federally threatened (FT), federally endangered (FE) under the ESA or state threatened (ST) and state endangered (SE) under the CESA. Species may also be considered as candidates for federal (FC). Species may also be considered "special concern," but few regulations are associated with such classifications, thus these taxa are not included below.

- Winter-Run Chinook Salmon (*Oncorhynchus tshawytscha*) (FE, SE)
- Spring-Run Chinook Salmon (*O. tshawytscha*) (FT, ST)
- Central California Coast Steelhead (*O. mykiss irideus*) (FT)
- Central Valley Steelhead (*O. mykiss irideus*) (FT)
- Green Sturgeon (*Acipenser medirostris*) (FT)
- Longfin Smelt (*Spirinchus thaleichthys*) (FC, ST)
- Delta Smelt (*Hypomesus transpacificus*) (FT, SE)

Each species should be given careful consideration in the development of sampling programs in order to address (1) minimization of impacts to listed species, (2) federal [USFWS/NOAA] and state (CDFW) permitting requirements, and (3) quantification of presence/absence in wetland habitats.

3.2 Monitoring Data/Metrics

Several types of data are required to make the best use of long-term monitoring data on fish and fish habitats. These include data on the organisms sampled as well as associated data on water quality and the sampling details and conditions. By carefully standardizing the data captured, and combining biological and physical parameters, a more robust and standardized assessment of ecological condition can be achieved. The parameters listed below include those that are commonly included in FFH monitoring. While additional water quality parameters (e.g., pollutants, nutrients, chl a, etc.) could be included, protocols for the assessment of water quality and the impairment of water bodies, per se, are being developed by a separate WRMP workgroup.

3.2.1 Fish/nekton data

- presence/absence: rare taxa
- abundance/density/biomass/CPUE: common taxa
- diversity/community structure: common taxa
- trophic structure/age structure/size structure: common taxa

3.2.2 Water quality data

- dissolved oxygen (concentration [mg/L] and saturation [%])

- temperature (ºC)
- electrical conductance/sp. conductance (µS/cm^{-1}, µS/cm^{-1}@ 25 ºC)
- salinity (practical salinity, psu/ppt)
- Secchi depth (m)
- turbidity (ntu, nfu)
- note: sample top & bottom, start & end (when feasible)

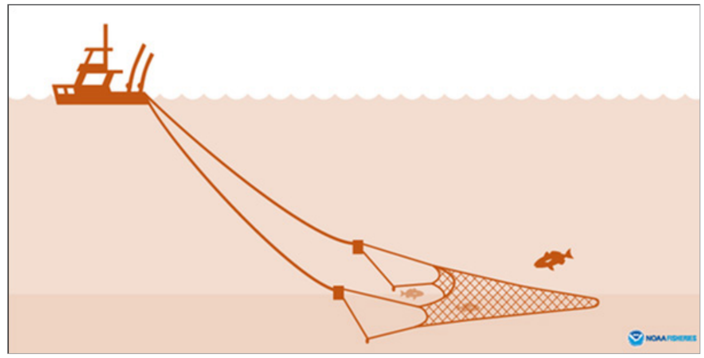
3.2.3 Sampling data

- date/time (yyyy:mm:dd:hh:mm:ss)
- lat/long (decimal degrees)
- depth (m)
- method (gear, approach)
- effort
  - sampling duration: time actively sampling in hrs
  - distance sampled: GPS or meter
  - area sampled: GPS (distance x area)
  - volume sampled: cubic m (using flow meter)
- tides/moon
  - lunar cycle: moon phase
  - tide height: m relative to MLLW
  - tide stage: high/low/ebb/flood

3.3 Sampling Gears

The following sampling gears were evaluated separately and in combination with respect to how they would support the FFH goals of the WRMP. This section provides an overview of each sampling gear type, while Section 4.3 will provide discussion on specific gear type recommendations. The gears included in this list are those identified by the FFH workgroup as both effective and previously utilized in wetlands of the SFE (**Appendix 2**), thus maximizing consistency and integration between past and future studies. While this list is fairly comprehensive given methods commonly utilized within the SFE, it does not include all possible sampling gears or approaches that could be utilized. For example, we did not include baited hooks (e.g., longlines), surface nets (e.g., Kodiak Trawl), or chemical agents (e.g., rotenone) for sampling fishes in SFE wetlands as they were deemed uncommon, less effective for key taxa, or too disruptive to aquatic ecosystems.

3.3.1 Benthic otter trawl

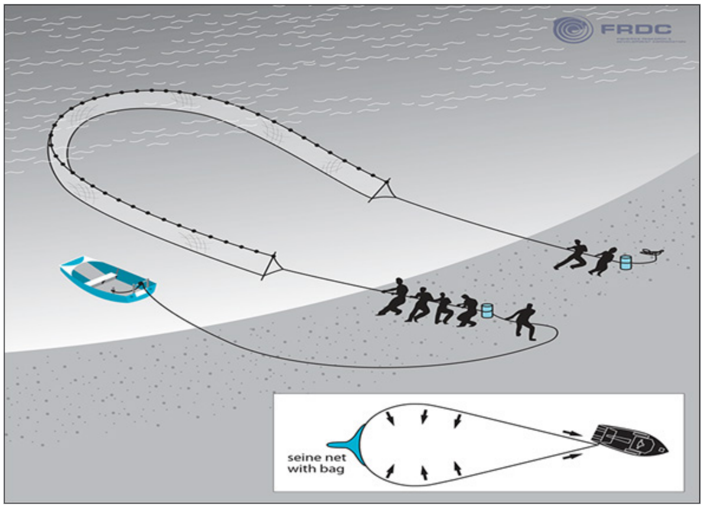


Benthic Otter Trawl. Credit: NOAA Fisheries. "Fishing Gear: Bottom Trawls." 18 May 2022. https://ww.fisheries.noaa.gov/national/bycatch/fishing-gear-bottom-trawls.

Trawling is an active sampling method where a net is towed through the water column (midwater trawl) or along the ocean floor (bottom/benthic trawling) (Mearns & Allen 1978). The otter trawl derives its name from the wooden or steel otter boards at the mouth of the net, which keeps the net open during the trawl. Conducting an otter trawl will require a vessel, tow vehicle, launch ramp, netting, and a team of 2-3, including a trained captain. Technicians are needed to identify, count, and process captured fish and macroinvertebrates. Trawling data can provide information on relative abundance, diversity, and health of fish and macroinvertebrate communities. Trawling intervals and replicates should be standardized and reported across surveys for statistical comparison. Benthic otter trawls can access multiple habitat types (sloughs, shoals, open water), and can collect a broad range of taxa and sizes (2.5 - 500+ cm) based on mesh size. Midwater trawling typically collects pelagic species while benthic trawling collects epibenthic organisms, including macroinvertebrates. Otter trawling in the SFE, particularly in shallow habitats, will capture both pelagic and epibenthic species. Trawling is limited by weather and tide conditions, as well as the expense of ship time and personnel. Additional disadvantages of benthic trawling are potential by-catch of marine mammals and sea turtles, as well as disturbances to benthic biota and sediment (Hiddink et al. 2017).

Recommended: see Section 4.3.1.

3.3.2 Shore-based Seine (Beach Seine)

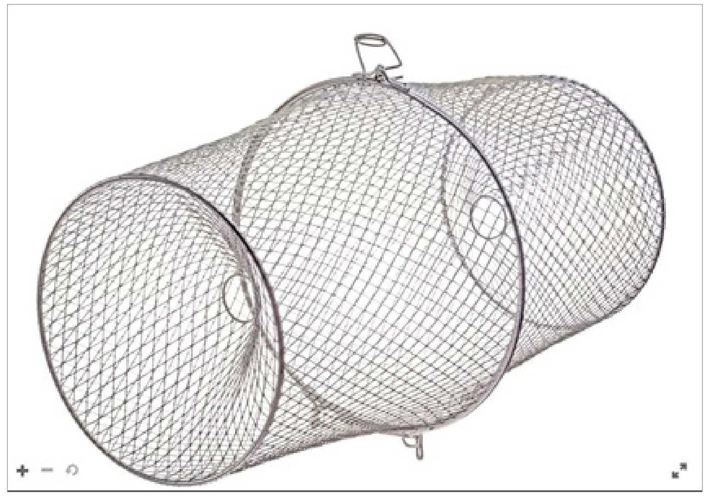


Shore-based Seine (Beach Seine). Credit: FRDC. "Nets: Beach-seine net. "Fisheries Research and Development Corporation. 18 May 2022. [https://www.fish.gov.au/fishing-methods/nets.](https://www.fish.gov.au/fishing-methods/nets)

Shore-based seining methods, such as beach seining, is an active sampling method that involves deploying a net from shore to surround and trap a school of littoral (along-shore) species of fish (Hahn et al. 2007, O'Rear & Moyle 2017, Mahardja et al. 2017). The net can also be deployed further from or along shore using a boat. The net is equipped with weight along the bottom (lead line), and buoys along the top (float or cork line), to sustain a vertical shape in the water. Beach seining requires a truck, seine net, and a team of 2-3 people. Once the seine is deployed, retrieval speed will be important to minimize opportunities for fish to escape. Seining can provide information regarding relative abundance, diversity, and/or absolute abundance (mark and recapture) of fish communities. This method will mainly target small-medium littoral fishes, including salmonids (Sims & Johnsen 1974), in shallow sloughs and intertidal channels, though mesh size, net length, and deployment methods will determine effectiveness for different target species. Additional advantages to beach seining is the low cost of supplies and equipment, and the low likelihood of stress or injury to surveyed fish. However, beach seining is limited to shorelines and shallow coastal regions, and will be affected by tide stages. Site selection is crucial, as the seine may snag in areas with rock, wood, vegetation, or other debris. Thus, it will be difficult to survey fish that use habitats with complex benthos Additionally, individual samples are limited in area or volume covered, thus rare taxa may not be well represented and many replicate samples are often needed to sample entire fish communities.

Recommended: see Section 4.3.3

3.3.3 Minnow trap



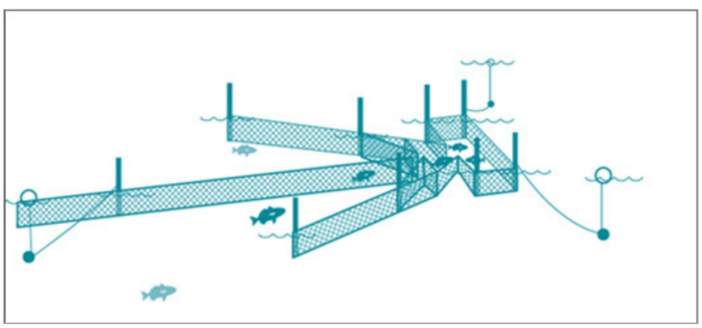
Minnow Trap. Credit: Cabelas.com. "Galvanized Minnow Trap." 18, May 2022. https://www.cabelas.com/shop/en/bass-pro-shops-galvanized-minnow-trap.

Minnow trapping is a passive, baited sampling method for collecting small fishes. Minnow traps are lightweight mesh structures constructed of metal or plastic (Portt et al. 2006, McGourty et al. 2009). These traps are available in a variety of dimensions, sizes, and mesh sizes, which can be configured based on the target species. Placing minnow traps requires a team of 1-2 people, a truck, and traps and bait - making this method relatively economical compared other fish survey techniques. These traps can be deployed in shallow water areas such as low velocity streams, the littoral zone, and areas with aquatic vegetation or woody debris where other survey methods perform poorly. For example, minnow traps can be used to target small fishes in intertidal rivulets, creeks, and vegetated tidal marsh habitats. In intertidal wetland habitats, traps are placed in the sampling area and are attached to a buoy or an immobile structure at low tide, and are subsequently collected during the next low tide (sampling while inundated by the high tide).

Minnow traps can be highly size and species selective, resulting in the capture of relatively few taxa (low diversity) and an inability for the data to answer broader ecological questions. Catch rates and species selectivity are strongly affected by trap design and variation in fish behaviors due to choice of baits, presence and abundance of avian predators, and even nearby foot traffic. Sampling time varies significantly with trap elevation, tidal amplitude, and inundation time. Inundation timing (e.g., day vs night) also varies seasonally with tidal patterns and can significantly affect catch rates.

As a passive (unsupervised) sampling approach, fishes within minnow traps may escape, consume each other, become stressed or die due to exposure at low tide, or be damaged and consumed by other creatures in the trap (e.g., crabs). Trap placement and recovery occurs at low tide and thus requires access to the marsh plain, resulting in trampling of vegetated habitats and disruption to wetland birds and mammals (e.g., salt marsh harvest mouse and Ridgway's rail) where sampling is repeatedly conducted. Furthermore, since traps are passive and emergent, concerns over potential trapping of endangered small birds and mammals (e.g., salt marsh harvest mouse and Ridgway's rail) can limit access and sampling in sensitive habitats due to federal or state regulations.

3.3.4 Block-style Nets (Fyke Nets, Block Nets, Pound Nets)



Pound Net. Credit: NOAA Fisheries. "Pound Nets." 18 May 2022. https://www.fisheries.noaa.gov/national/bycatch/fishing-gear-pound-nets.

Block-style nets (e.g., including fyke nets and pound nets) are passive, unbaited sampling methods for collecting mobile species that are swimming through a habitat (Portt et al. 2006, Visintainer et al. 2006). Block nets can be of any design and are placed across channels at high tide to block fish from moving out of a habitat, for example during an ebbing tide. Fish can then be collected by scooping with additional hand nets, beach seines, or by enclosing the block net. Fyke nets (also pound nets) are more complex, consisting of a series of long mesh wings held up by frames and posts driven into the seafloor, or stabilized with anchors in deeper waters. The mesh wings create channels of netting that taper towards the posterior region of the net, where migrating fish become trapped. Net structures can differ based on size, shape, mesh material and size, and other factors configured based on targeted species. Setting fyke or block nets requires a team of a minimum of 2 people to set and lift the net, as well as access to a truck and vessel to transport gear and access sites.

These nets are set and submerged in shallow water areas with even bottoms, such as sheltered bays and estuarine, intertidal, and coastal zones, including intertidal channels within tidal marshes. They are not recommended for areas with aquatic vegetation, benthic structure, or debris that can entangle and block the mesh. Nets can be set parallel or perpendicular to primary currents, depending on the taxa being sampled. Although less selective than minnow traps, the gear is biased towards mobile species traveling greater distances, such as during migration or those moving in and out of tidal habitats. Catch rates and species selectivity are strongly affected by trap design, orientation, seasons, tides, presence and abundance of avian predators, and even nearby foot traffic. In intertidal habitats, sampling time varies significantly with trap elevation, tidal amplitude, and inundation time. Inundation timing (e.g., day vs night) also varies seasonally with tidal patterns and can significantly affect catch rates.

As a passive (unsupervised) sampling approach, fishes within fyke nets may escape, consume each other, become stressed or die due to exposure at low tide, or be damaged and consumed by other creatures in the trap (e.g., crabs). These effects may be reduced in block-nets that are more closely tended. Trap placement and recovery typically occurs at low tide and thus requires access to the marsh plain, resulting in trampling of vegetated habitats and disruption to sensitive species (e.g., salt marsh harvest mouse and Ridgway's rail) where sampling is repeatedly conducted. Furthermore, since traps are passive and emergent, concerns over potential trapping of endangered wetland birds and mammals (e.g., salt marsh harvest mouse, Ridgway's rail, harbor seal, and other waterfowl) can limit access and sampling in sensitive habitats due to federal or state regulations.

3.3.5 Telemetry (Acoustic or PIT/RFID)

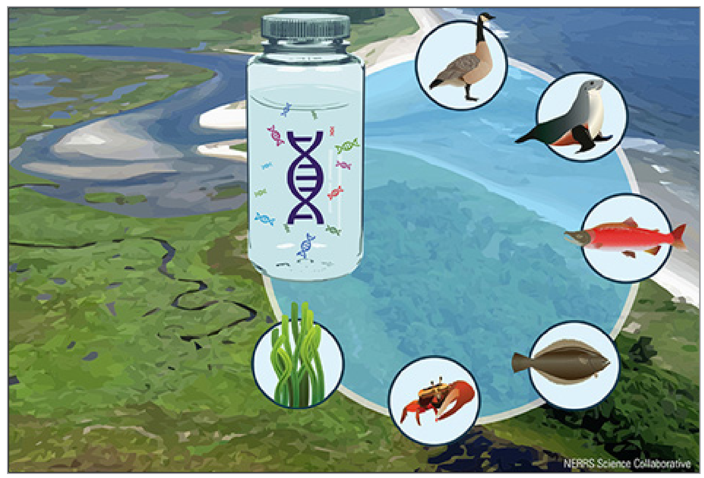
Acoustic Tag Used in Telemetry Studies. Credit: Great Lakes Acoustic Telemetry Observation System (GLATOS). "What is acoustic telemetry?" 18 May 2022. https://glatos.glos.us/acoustic.

Passive telemetry employs the transmission of sound (acoustic) or radio signals (PIT/RFID) from transmitting tags that are attached to individual fish, with signals being detected and recorded by receivers that have been placed in designated locations of interest in the fish's environment (Brownscombe et al. 2019). PIT tags are good for in-stream use, but have a relatively limited range & application in estuaries. Nevertheless, PIT tags have been used for specific estuarine applications, typically at relatively smaller scales than acoustic receivers (Adams et al. 2006). In deep freshwater systems and marine environments, however, acoustic transmitters perform better than radio transmitters, providing much larger detection ranges and broader networks of receivers that can be placed in open-water habitats (Cooke et al. 2004, Hussey et al. 2015).

Setup for an acoustic tracking system requires a team of 2-3 people, a truck, research vessel, and an array of receivers and individual tags. Staff need to be trained for tag injection and fish handling, including surgery; as well as in the spatial analysis of time-series data. Receiver placement will need to consider habitat structure, water depth, currents, and physical obstructions; all of which can affect data quality. Receivers are best placed within pinch points of subtidal habitats to maximize detection. The high cost of expendable equipment (tags) and potential effects of tags on fish behavior are important considerations. While acoustic telemetry can provide valuable continuous data regarding the presence/absence and duration of habitat use for tagged individuals, telemetry alone cannot provide information on population-level patterns or individual fish health. Fish capture methods and locations for tagging can introduce bias, thus tag-retention and fish conditions studies should be conducted, and tagged fish should be selected to be as representative of the population as feasible.

Recommended: see Section 4.3.4.

3.3.6 eDNA



eDNA in Water Samples can Detect Organism in the Ecosystem. Credit: National Estuarine Research Reserve System (NERRS). "Developing eDNA Methods." 18 May 2022. https://nerrssciencecollaborative.org/project/Watts17.

Environmental DNA (eDNA) analysis allows for the detection and characterization of aquatic communities in a given location by sampling organic particles in the water. For fisheries science, this involves collecting a water sample in an area of interest, which will contain organic traces (e.g., sloughed cells, feces, mucus, gametes, etc.) left behind by all organisms in the environment including fishes, plants, wildlife, humans, bacteria, viruses, etc. It is assumed that the organic material in the water sample is representative of the local aquatic community. The water sample is then filtered to concentrate the organic particles onto a filter, and the filter is preserved in a solution to prevent the breakdown of DNA and RNA during transport and storage. In the lab, the organic material on the filter is broken down and the genetic material is extracted through a series of standardized processing steps.

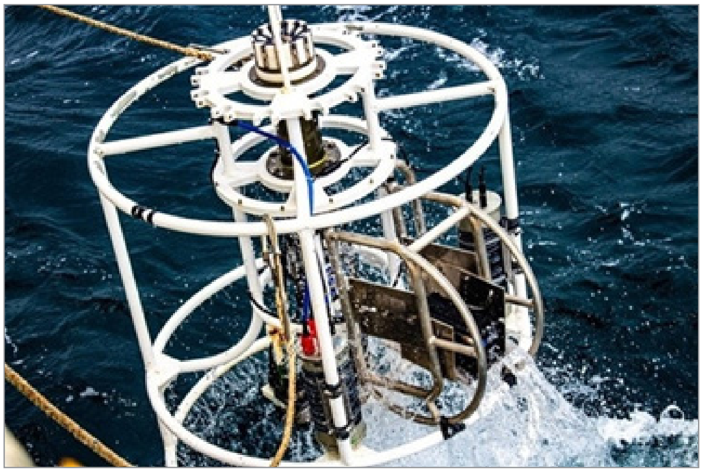
Several types of analysis can be applied to eDNA. Quantitative Polymerase Chain Reaction (qPCR) (Bergman et al. 2016) can be used to identify the presence and relative abundance of individual species. In qPCR, taxon-specific genetic tags (primers) are used to detect the DNA of individual species, and the abundance can be estimated using a reference curve. Similar to qPCR, Digital PCR can also be used to assess abundance, but without the use of a reference standard curve. In contrast to qPCR, metabarcoding methods can also be applied to characterize the composition of entire fish assemblages that consist of many different species (Miya 2022). In metabarcoding, primers are used to sequence all genetic material belonging to the taxonomic group of interest, with sequencing results then compared to reference DNA databases to identify the presence of each species in the sample. Thus eDNA analysis can be used to identify community members to the species or subspecies level, provide measures of biodiversity, and provide presence information regarding rare species that may be unobserved with other surveying methods.

Gathering of water samples requires a team of 1-2 people, a car, and a vessel if collecting samples in open water. For sample collection in the field, the team will require gloves, ethanol, sample preservation solution, sterile bottles for water collection, a way to filter water (i.e. vacuum pump), and training on aseptic technique. The team will also need access to a lab with equipment needed for DNA/RNA extraction, sample sequencing preparation, and equipment for quantitative Polymerase Chain Reaction (qPCR), Polymerase Chain Reaction, and sequencing. Many private companies offer genomic extraction and sequencing services. The collection of water samples is non-invasive, with limited risk of by-catch or injury to fishes, and limited permitting requirements. Furthermore, many eDNA samples can be processed and analyzed simultaneously, and sample preparation and sequencing costs are rapidly decreasing.

However, there are several limitations in using eDNA as a monitoring tool. Small variations in the sampling design and sample collection methods can have strong effects on the results and their interpretation. The analysis of sequencing data can also be subjective, and while analyses can be contracted out, the results should be compared among labs or groups to ensure accuracy and precision in interpretation. In particular, genomic analysis requires that each species' genetic information be already available in a database for comparison. Although eDNA approaches can estimate presence/absence and relative abundance for numerous organisms, interpretation can be limited by biases introduced during sample collection, DNA extraction, sequencing, and analysis. Last, our basic ecological understanding of eDNA is continuing to evolve, including the factors affecting abundance (e.g., taxon-specific biology and behavior), persistence and degradation (e.g., UV exposure, microbial metabolism, temperature, salinity, etc.), and the distribution and dispersal of organic particles (e.g., tides, currents, predators, migrations). For example, detections could indicate a species using the habitat, passing through, or being deposited as waste by a highly mobile predator. Thus, in its current form, eDNA appears to be an emerging and promising tool that likely needs to be paired with other monitoring methods for ground truthing and development (Shelton et al. 2022).

Recommended: see Section 4.3.4.

3.3.7 Acoustic Imaging (e.g. DIDSON/ARIS Cameras)



ARIS Camera. Credit: NOAA Fisheries. "Instruments - ARIS Sonar Imaging and CTD." 18 May 2022. https://www.fisheries.noaa.gov/science-blog/instruments-aris-sonar-imaging-and-ctd.

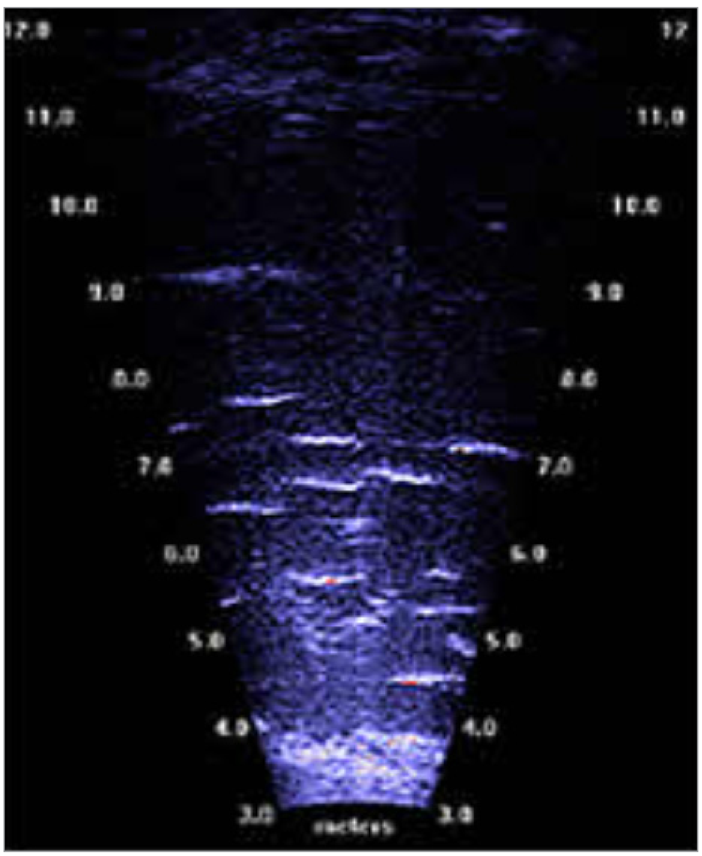
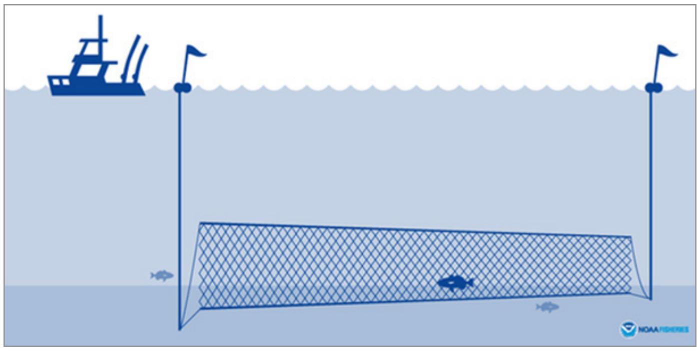


Image produced from ARIS Camera. Credit: Alaska Department of Fish and Game. "Sonar tools." https://www.adfg.alaska.gov/index.cfm?adfg=sonar.didson.

Acoustic imaging devices are cameras that send out high frequency sonar pulses (sound) into the environment, and collect the sound waves bouncing back to the camera, creating a high-resolution image. Sound waves return at different rates based on how well a substrate absorbs and reflects sound, allowing differentiation between a fish and background water column or rock. Examples of acoustic imaging devices include the Adaptive Resolution Imaging Sonar Camera (ARIS 1800) (Vojnovich 2021) and the Dual-Frequency Identification Sonar (DIDSON) (McCann et al. 2018). Cameras can be mounted to a stationary point, attached to the side of a vessel, or deployed into the water column via a CTD Rosette. Cameras will take images parallel to the water surface, and can typically detect organisms from up to 15 meters away. Underwater cameras are useful for ecological observations of predation, behavior, size, and abundance of fish communities. Though the images are difficult to identify down to the species level, particularly for smaller sized fish, they are useful for monitoring areas with known species use, such as monitoring and counting salmonids along known migration routes (Atkinson et al. 2016).

Depending on the point of installation, surveyors will need a truck, vessel, a team of 2-3 people, and a deployment or installation mechanism. Acoustic imaging is a non-intrusive surveying method and is particularly useful for low-light and high turbidity waters. Proper site selection and good study design are needed to answer management questions, and cameras need to be placed away from obstructions that can potentially block sound waves, such as air bubbles. Additionally, obtaining good data quality from boat deployment is oftentimes difficult. Data analysis will require a computer, analysis software, and expertise in visual identification of fish species. Large amounts of video data arising from acoustic cameras can require extensive time for processing. Lastly, cameras are relatively expensive compared to other surveying methods.

3.3.8 Set Nets (Trammel Net or Gill Net)



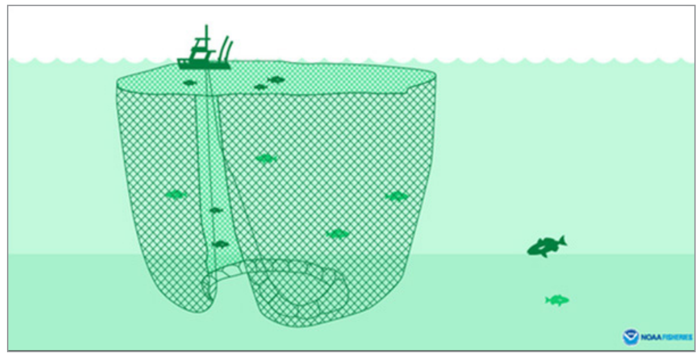
Gill Net. Credit: NOAA Fisheries. "Fishing Gear: Gillnets." 18 May 2022. https://www.fisheries.noaa.gov/national/bycatch/fishing-gear-gillnets.

Set nets such as trammel nets and gill nets are wide swaths of netting that hang vertically in the water column, with fish that swim into the net becoming gilled, tangled, or wedged in the mesh. Unlike a gill net alone, a trammel net is a gillnet with extra panels that are designed to entangle fish with a lower risk of fatally damaging the gills. Nets can be set in place via attachment to poles anchored to substrate or other secure location, or attached to buoys and allowed to drift (Portt et al. 2006, Saiki & Mejia 2009, Danos et al. 2019, Wulff et al. 2022). Nets can vary based on length, size of mesh openings, and material; thus, can capture fishes of varying sizes; and multiple panels of varying mesh sizes can be deployed simultaneously to target a variety of different species (Saiki & Mejia 2009, Wulff et al. 2022). Nets retain their shape via a float line at the top and a lead line at the bottom, and the buoyancy can be adjusted to determine the depth of the net. Nets can be deployed by a team of 2-3 with a small boat, including a trained captain, in a variety of habitats including rivers, estuaries, and offshore environments. These nets are particularly effective at capturing large, mobile species, including listed species and important fisheries targets: sharks, rays, striped bass, salmonids, and sturgeon (Danos et al. 2019).

However, this method is fairly expensive as it requires trained personnel, access to a vessel, and expensive netting. Nets anchored close to the shoreline are sensitive to the tide cycle and can be exposed during low tide. Care is needed to ensure the nets do not tangle due to debris, vegetation, or opposing currents. Additionally, this method is biased towards capturing highly mobile species of fish that travel great distances on diurnal or tidal cycles. Stress, injury, and mortality are high in gill nets; however, this risk is reduced in part with trammel netting. Nevertheless, temporal and spatial restrictions in sampling may be required to avoid or limit interactions with marine mammals and endangered salmonids (e.g., Winter-run Chinook Salmon).

Recommended: see Section 4.3.2.

3.3.9 Boat-based Seine (Purse Seine, Lampara Net)



Purse Seines. Credit: NOAA Fisheries. "Fishing Gear: Purse Seines." 18 May 2022. https://www.fisheries.noaa.gov/national/bycatch/fishing-gear-purse-seines.

Purse seines (e.g., Lampara net) are large nets deployed from a vessel to capture groups of fish. Nets hold their shape in the water column through a float line at the top and a lead line at the bottom. Purse seines, commonly used for deeper water surveys, have rings attached to the lead line that can be pulled shut like a purse string to prevent fish from escaping (Phillips 1930). Lampara seines target epipelagic fish in open water. Lampara seine lead lines are shorter than the float line, resulting in an enveloping shape when deployed into the surface water. This design prevents fish from diving down and escaping. There are no rings to close with lampara seines. Instead, fish capture efficiency is dependent upon the speed with which seines are deployed and retrieved. Both seines do well in open water and subtidal sloughs, and perform best with preliminary knowledge of fish locations. Nets can be deployed using a vessel, tow vehicle, launch ramp, and a team of 2-3, including a trained captain. In wetland habitats, Lampara nets have also been used to sample fishes from shore, being deployed similarly to a large beach seine (IEP TWM PWT 2017b). Lampara nets provide access to shallower habitats and creeklets than purse seines, while avoiding benthic snags, vegetation, and minimizing disturbance of soft bottom habitats. These nets primarily target pelagic species of fish including forage fishes (smelts, herring, shad) and salmonids (Chinook, Coho, Sockeye, and Steelhead Trout), but can also catch benthic species in shallow tidal channels. The large mesh and wings of Lampara nets makes them less effective than beach seines for sampling small wetland fishes, as fish readily swim through the larger mesh, especially when the large net becomes snagged. Such issues are less common with beach seines, depending on the habitat sampled. In the SFE, boat-based seines have been used to target Delta Smelt for the collection of live broodstock in the upper estuary (Ellison et al. 2022), and one survey, the Fish Restoration Monitoring Program, has used Lamparas to sample tidal channels in wetlands (IEP TWM PWT 2017b).

3.4 Habitats

The scope of the WRMP includes all fish-associated habitats of the CTME, including intertidal habitats (i.e., marshes, mudflats, and tidal channels) and subtidal habitats (sloughs, shoals, and open water) to a maximum depth of 4 m below MLLW (**Figure 1**, **Figure 2**). Given that environmental conditions in wetlands are highly dynamic on tidal, daily, seasonal, and interannual scales, many species have evolved to move throughout their habitats in response to rapidly changing environmental conditions. Similarly, many species make predictable diel movements between intertidal and subtidal habitats. For example, most species utilize subtidal habitats at lower tides, but can only access intertidal habitats during tides of sufficient height. Thus most aquatic species can be found across a variety of habitat types, depths, and environmental conditions throughout wetland ecosystems. Here, we identified three general categories that encompass the majority of habitat types that fishes experience in tidal wetlands of the SFE: (a) intertidal marshes, mudflats, and channel networks, (b) subtidal sloughs, and (c) subtidal open-water 'bay' and shoal habitats (**Figure 2**, **Figure 5**).

3.4.1 Intertidal Marshes/Mudflats/Channels

Habitats at intertidal elevations (**Figure 2**, **Figure 5)** include fully intertidal marshes, mudflats, and their embedded networks of intertidal channels (Horton 1945, Rozas et al. 1988). The highest elevation intertidal habitats (e.g., marsh plain & rivulets) are mostly utilized by transient fish species that are present only during high tides, with few obligate marsh residents remaining within perennially inundated depressions such as pannes and burrows. Many fishes remain in larger, deeper, higher-order channels during mid-tides and move to subtidal habitats during lower tides. In North American coastal wetlands, the smallest intertidal channels, also called 'rivulets' (Rozas et al. 1988), are thought to be preferred habitats for a select few 'resident' species, with diversity increasing with increasing creek order (Desmond et al. 2000, Visintainer et al. 2006, McGourty et al. 2009).

3.4.2 Subtidal Sloughs

Subtidal sloughs (**Figure 2**, **Figure 5**) are typically embedded within larger networks of intertidal habitats, serving as higher-order, deeper-water channels that capture waters draining from intertidal habitats as the tide ebbs, while receiving bay waters from downstream as the tides flood. These habitats exhibit high shoreline:area ratios and serve as a corridor between intertidal and bay habitats, thus all wetland fishes, at given times, can be observed in slough habitats contingent on environmental conditions and tidal stage. In particular, larger-bodied species are more common in subtidal sloughs than intertidal habitats, while fishes that utilize intertidal habitats may become concentrated in sloughs as flooded habitats become unavailable at lower tidal stages. Sloughs can also bisect expansive intertidal mudflats that are inundated only during high tide.

3.4.3 Subtidal Open Water and Shoals

Open-water 'bay' habitats (**Figure 2**, **Figure 5**) are characterized as large expanses of subtidal aquatic habitat with limited shoreline:area ratios. These habitats include open bay and shallower shoal habitats, with shoals at depths shallower than 4 m below MLLW falling within the CTME and scope of the WRMP. Many wetland-associated species occur in these habitats, moving back and forth between open water/shoal, slough, and intertidal habitats to feed as the tides flood and ebb. Similarly, wetland-associated species that typically occur only in slough or intertidal habitats can occur in open water habitats, especially at low tide or following precipitation that stimulates significant freshwater runoff and outflow into open water habitats. In the SFE, open water habitats commonly occur adjacent to extensive intertidal mudflats that are exposed during mid to low tides.

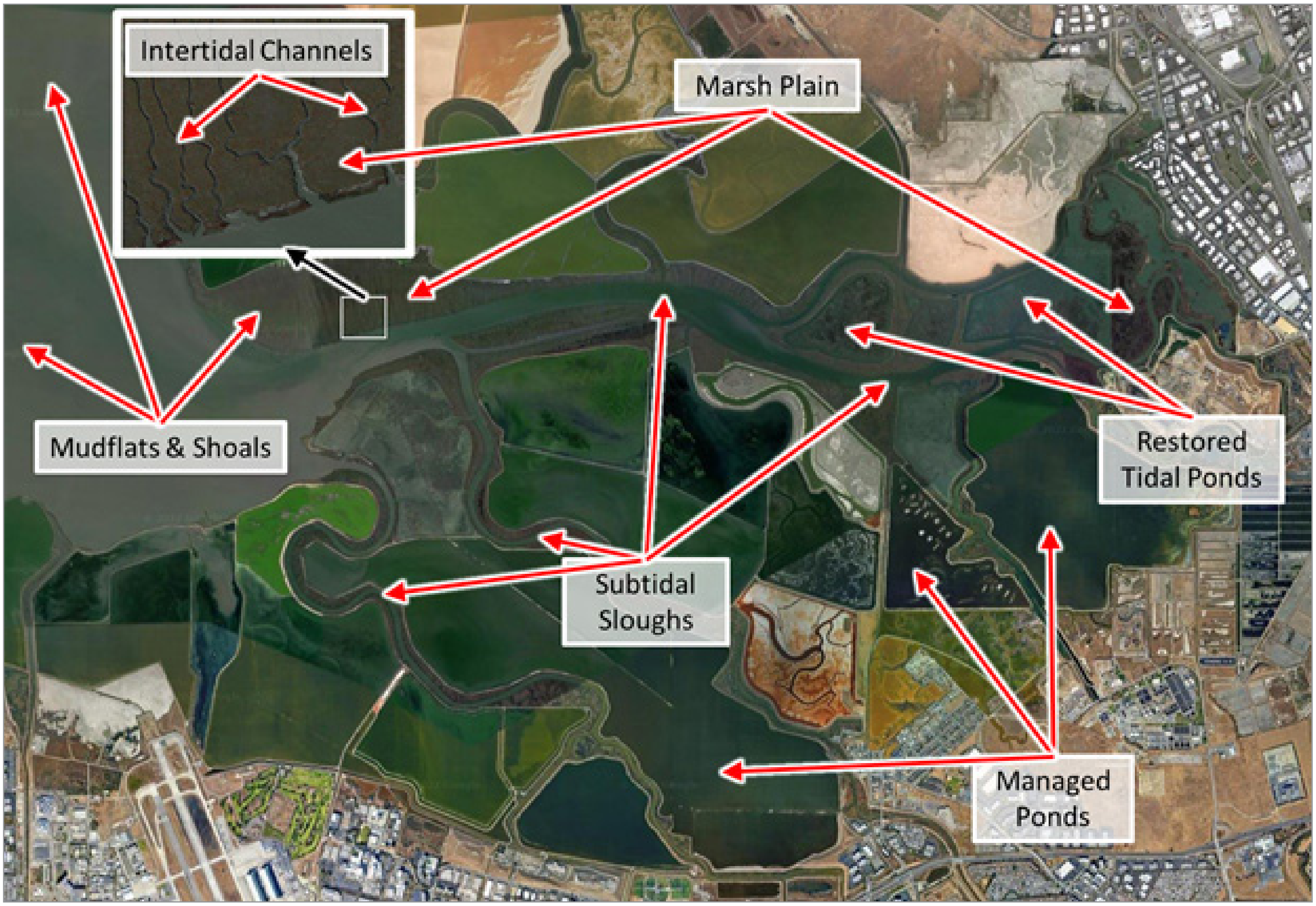


Figure 5. *Habitat types in the Alviso Marsh Complex. Intertidal habitats include mudflats, marshes, and tidal channel networks. Subtidal habitats include deeper sloughs and shallow open water and shoal habitats. Aquatic species commonly move between intertidal and subtidal habitats as the tide floods and ebbs. Diked baylands that are separated from the tides or experience muted tides (labeled here as "managed ponds") are currently outside the scope of the WRMP. However, once restored to tidal action, these areas typically support shallow open water/shoals, mudflats, and tidal marsh habitats that would be within the WRMP scope (e.g. the habitats within Ponds A19, A16, and A21, labeled here as "restored tidal ponds").*

3.5 Frequency of Sampling

The frequency of sampling determines the temporal resolution at which ecological patterns can be observed. While surveys that sample at lower sampling frequencies are more feasible due to reduced costs and effort, the data that are generated may not be sufficient to address the ecological questions of interest, thus the savings in costs are not justified given the loss in value of the data. In contrast, higher sampling frequencies provide higher-resolution information that may be of higher quality, however, if such high temporal resolution is not needed to address the questions of interest, then the additional cost of higher frequency sampling is unjustified and suboptimal.

Here we outline five potential sampling regimes that were each evaluated with respect to the goals of the WRMP (from highest-frequency/cost to lowest): monthly, quarterly, semi-annual, annual, bi-annual. Monthly sampling is commonly used by several existing long-term surveys including the San Francisco Bay Study Otter Trawl Survey, Suisun Marsh Otter Trawl Survey, North Bay Otter Trawl Survey, South Bay Otter Trawl Survey, and the Delta Juvenile Fish Monitoring Program (**Appendix 2**). As a precedent, this frequency allows for the capture of multiple data points within each season, or for the modeling of intra-annual patterns as continuous functions at 12 monthly time steps. While quarterly sampling allows for the assessment of interannual with limited intra-annual replication, the lack of seasonal replication results in a loss of inference associated with seasonal patterns. Similarly, semi-annual sampling provides even more limited seasonal data without replication and limited intra-annual replication, while annual sampling and bi-annual sampling are likely only sufficient for describing very large changes or patterns over longer time periods (e.g., decades).

3.6 Sampling Teams

The size of sampling teams needed to conduct various surveys is a key element for consideration when selecting gears and sampling frequencies. Some gears (e.g., minnow traps) can be deployed by a single technician, whereas other gears (e.g., Kodiak trawl) require multiple vessels, each including captain and crew (see Section 3.3). As the frequency of sampling, the number of locations, and the number of sites per location increase, so does the size of field teams necessary for effectively completing the study. For example, larger teams are needed to subdivide regions or habitats and sample them simultaneously over shorter intervals. Here we identify small teams as those with 1-2 technicians, medium teams as those with 3-4 technicians, and large teams as those with 5 or greater technicians. These team sizes are based on the number of field crew required to complete a variety of prior and on-going surveys. A given sampling effort may require multiple teams depending on the spatial and temporal scope of sampling.

3.7 Data Collection, Storage, and Analysis

Data management plans should be a prerequisite for any project associated with the WRMP. Within the data management plan, established best practices of metadata documentation, data storage, backup, quality assurance and control, long-term storage and integration with existing repositories, and statistical frameworks or experimental designs should be described.

3.8 Geographic Distribution of Sampling

The geographic scope of FFH sampling includes all wetland habitats (defined as > 4 m below MLLW up to MHHW) from Suisun Marsh (upper estuary) downstream to Lower South Bay (lower estuary). Sampling effort for different fish focal groups, different gear types, habitat types, and monitoring objectives may vary among regions of the estuary.

3.9 Consistency with Other Programs

A key goal of the WRMP is to generate data that can readily be integrated across space and time, thus maximizing the value of all generated data with respect to informing both local and regional trends and processes. Thus, a key goal and consideration of the FFH workgroup is to develop an SOP that maximizes consistency with complementary long-term FFH monitoring programs in brackish wetlands of the SFE. Examples include the UC

Davis Suisun Marsh Fish Survey (otter trawl, 42 years), San Francisco Bay Study (otter trawl & midwater trawl, 42 years), UC Davis South Bay Otter Trawl Survey (otter trawl, 11 years), and the Delta Juvenile Fish Monitoring Program (beach seine, 46 yrs.) (**Appendix 2**). The approaches adopted by the WRMP as best practices should aim to maximize standardization and integration of new data with existing sampling programs and databases.

3.10 Updates and Revisions to the SOP

The assessment and revision of the fish habitat sampling recommendations provided herein could occur at a variety of frequencies (e.g., 5 years, 10 years, other) with a review process that is established herein or that follows policies previously established by the WRMP.

Alviso Marsh Wetlands, South San Francisco Bay. Credit: Shutterstock.

4. RECOMMENDATIONS FOR FFH MONITORING

Alviso Boat Launch in Lower South Bay & U.C. Davis Field Team. Credit: James Hobbs.

4.1 Focal Species & Functional Groups

4.1.1 Recommendation

Here, we identify 3 key focal groups that are important for understanding marsh-specific and estuary-wide processes: **large-bodied species** (e.g., Green and White Sturgeon, Striped Bass, Leopard Sharks, Bat Rays, Halibut, etc.), **small-bodied species** (e.g., herring, anchovies, smelts, gobies, sculpins, and juveniles of larger bodied species), and **marsh-plain species** (subgroup of small-bodied species) that are facultative or obligate tidal marsh residents (e.g., Longjaw Mudsucker, Threespine Stickleback). Within these groups, we also identify 7 evolutionary significant units (ESU) and distinct population segments (DPS) of fishes that are listed under the ESA or CESA as threatened or endangered, emphasizing the need for distribution data as well as federal and state permits and MOUs for sampling programs: Delta Smelt, Longfin Smelt, North American Green Sturgeon (southern DPS), Sacramento River Winter-Run Chinook Salmon ESU, Central Valley Spring-Run Chinook Salmon ESU, Central California Coast Steelhead DPS, and California Central Valley Steelhead DPS. We recommend that sampling programs of the WRMP aim to quantify the abundance of the 3 focal groups listed above, with a specific focus on the presence/absence and abundance of listed species, as is allowed by state and federal regulations.

4.1.2 Justification

Large-bodied species such as Green and White Sturgeon, Striped Bass, Leopard Sharks, Bat Rays, Halibut, etc. are important as major predators or consumers in the region, and support important recreational fishing industries. These species are known to use subtidal wetland habitats for significant portions of their lives, and even intertidal habitats during high tides. Furthermore, many large-bodied species belong to CESA/ESA lists, including Green Sturgeon and several runs of Chinook Salmon. Similarly, smaller-bodied species and juveniles of larger bodied species can also provide valuable information regarding the status of wetland ecosystems and species populations. For example, sampling of juveniles provides key inferences about recruitment, survival, and adult population dynamics of larger species. Furthermore, smaller-bodied species (e.g., anchovies, herring, smelts, gobies, and sculpins) serve as important components of aquatic food webs, providing an important prey base for larger fishes, birds, and marine mammals. Similarly, other nektonic and epibenthic macroinvertebrates are often collected with smaller-bodies species, and can provide additional information regarding food web dynamics. Some smaller-bodied species, such as Delta Smelt and Longfin Smelt, are also listed under the CESA or ESA, further emphasizing the need to monitor this group. Therefore, we emphasize the value in sampling both large-bodied and small-bodied fishes, with an emphasis on listed species within each group. Last, some fishes (e.g., Longjaw Mudsuckers, Threespine Sticklebacks) directly utilize intertidal and marsh-plain habitats. Given the importance of monitoring changes in restored tidal marsh habitats, we found it valuable to also specify a subgroup of small-bodied species that utilize the marsh-plain and may require specific sampling approaches within intertidal habitats.

4.2 Monitoring Data/Metrics

4.2.1 Recommendation

Here we identify several key data types that should be provided as a result of any form of monitoring of aquatic wetland communities. All measurements should be disaggregated to the individual recorded values (not averaged).

Biological metrics from surveys (3.2.1) should include total counts and individual lengths (e.g., standard length) for each species observed during a sampling event. A maximum number of each species (e.g., 30-50 per event) should be established for which lengths of all individuals are measured, with additional individuals recorded as counts only ('plus counts'). If subsampled, measured individuals should be randomly sampled (e.g., do not first measure all large individuals). Additional calculated metrics should also be reported or readily calculated from the data, such as presence/absence (0,1), catch-per-unit effort (CPUE, based on the recorded event- and gear-specific value of effort), total fish biomass (calculated and extrapolated from length-frequency data), and diversity (e.g., species richness).

Environmental data associated with fish monitoring (3.2.2) should be collected including dissolved oxygen (concentration, mg/L), dissolved oxygen (saturation, %), temperature (degrees Celsius, °C), conductance (siemens, S), specific conductance (µS/cm at 25 °C), salinity (practical salinity units, psu), Secchi depth (m), turbidity (nephelometric turbidity unit, ntu). For environmental data, we recommend the collection of multiple replicates at the beginning and end of a sampling event. For sampling in deeper habitats (e.g., > 1 m), we also recommend sampling at both the surface and adjacent to the bottom. For otter trawling, for example, sonde-based water quality measurements should be collected at the beginning (surface and bottom) and the end (surface and bottom) of each tow.

Sampling data (3.2.3) should also be measured with each sampling event, dependent upon the type of sampling being conducted. Event-specific sampling metrics include date/time (yyyy:mm:dd:hh:mm:ss), latitude and longitude (decimal degrees), sampling depth (m), gear type (with dimensions and method of deployment), effort [sampling duration (min.): time gear was actively sampling, distance sampled (m): based on GPS track, area swept (m2): based on distance sampled x area of gear, volume sampled (m3, based on flow meter), tidal height (m relative to MLLW), tidal stage (high, low, ebb, flood).

4.2.2 Justification

Several key metrics can be derived from surveys of aquatic communities, with each providing unique and useful information regarding the aquatic health of the system. Presence and absence (disaggregated to individual sampling events) are the easiest to quantify and analyze, especially for rare species or species that are sparsely distributed in wetland habitats. In contrast, estimates of relative local abundance (e.g., catch per unit effort, or catch-density per volume) provide higher-level information on not only where and when species occur, but also where the center(s) of their distribution lie, which can be informative for prioritizing habitats for conservation and understanding population dynamics of species. Similarly, biomass (often converted from field-collected length-frequency data using established taxon-specific length-weight functions) can be even more informative with respect to ecological processes in wetland ecosystems, thus requiring the collection of accurate length-frequency data that can be applied to weight conversion functions. Last, variation in diversity (both richness and evenness, as exemplified in the Shannon Diversity Index or 'effective number of species') can be highly informative regarding variation in the biocomplexity of aquatic communities across space and time. All of these metrics can be readily calculated from a variety of sampling protocols if careful attention is given to the collection of proper field data, particularly taxonomic identifications and length measurements. Thus each of these metrics should be considered a specific objective or requirement of any sampling protocol that is utilized for monitoring aquatic communities.

The proper interpretation of biological and community data in aquatic habitats requires an understanding of static and dynamic environmental features, as well as numerous data summarizing critical aspects of the sampling approach and conditions. In the absence of sufficient associated data, the utility and value of any data collected on biological communities becomes greatly diminished. The environmental and sampling metrics listed above are commonly collected by other long-term studies of wetland fishes (**Appendix 2**) and are critical for the broadest use, integration, and accurate interpretation of any data collected on aquatic wetland communities.

4.3 Sampling Gears

Here we identify several fish sampling gear types and associated methodologies that are likely to provide the most comprehensive and integratable long-term datasets on the distribution of fishes in aquatic wetland habitats throughout the San Francisco Estuary (SFE). The preferred (top-ranked) combination of gears included benthic otter trawls, trammel nets, shore-based seines, and limited acoustic monitoring (**Appendix 1)**. These gear types and associated sampling methodologies were selected, in combination, to provide a broad, comprehensive assessment of fishes (spanning a wide variety of taxa, body sizes, and habitat types) in order to best inform the WRMP guiding, management, and FFH-specific questions and objectives. The selected gears are some of the most commonly used to sample wetland fishes throughout the SFE (**Appendix 2**); therefore, facilitating the integration of WRMP data with existing long-term datasets, and maximizing its value. Detailed recommendations and justifications for each gear type are provided within each subsection below.

4.3.1 Benthic Otter Trawls [see section 3.3.1]

Recommendation: Benthic otter trawls (of similar design as those used in the UCD Suisun Marsh Fish Monitoring Program (SMFMD), UCD South Bay Otter Trawl Study (SBOTS), UCD North Bay Otter Trawl Study (NBOTS), and CDFW San Francisco Bay Study (SFBS), **Appendix 2**) are recommended for sampling smaller-bodied fishes (e.g., forage fishes and recruits of larger-bodied fishes) within sloughs, major creek channels, and shallow open water habitats of SFE wetlands. In particular, long-term monitoring using otter trawls is recommended in wetland habitats that are immediately downstream of major watersheds. These include Suisun Marsh and wetlands associated with the Petaluma River, Sonoma Creek, Napa River, Coyote Creek, and Guadalupe River watersheds. For example, otter trawls used by the SMFMD had a headrope length of 4.3m, a body consisting of 3.5-cm stretched mesh, and a cod end with 6-mm stretch mesh. Otter trawls are typically conducted at depts > 1.5 m for 5-10 min against prevailing currents at approximately 3 km/h.

Justification: The benthic otter trawl is one of the most extensively utilized methods for sampling wetland fishes throughout the SFE (**Appendix 2**). For example, otter trawls have been used for more than 40 years by the San Francisco Bay Study and Suisun Marsh Survey to sample wetland fishes. Overall, 45% (13/29) of all projects studying wetland fishes within the scope of the WRMP used otter trawls, second only to beach seines (48% of projects), and more than double the next two most common gear types, gill nets and minnow traps (20% of projects, each). The spatial extent of otter sampling was even greater, with > 150 stations sampled by otter trawls within wetland habitats of the SFE, compared to < 90 for beach seines and gill nets. Otter trawls have been used to sample every region and every habitat type within SFE wetlands, except for higher-elevation vegetated marsh, mudflat, and rivulet habitats. Otter trawls are effective at collecting most groups of nektonic organisms, including pelagic forage fishes (e.g., anchovies and herring), benthic species (e.g., gobies and flatfishes), and macroinvertebrates (e.g., Crangon shrimp). Otter trawls collected several listed species (e.g., Delta Smelt, Longfin Smelt, Green Sturgeon, salmonids); however, are most effective at sampling smaller bodied taxa or juveniles of larger-bodied taxa. Thus the otter trawl gear type provides the most comprehensive tool to sample a broad array of aquatic wetland species across regions and habitat types, and with some of the best opportunities for direct integration with other long-term sampling programs throughout the SFE. As a result, otter trawls were ranked as one of the top gears for inclusion in the WRMP (**Table 1 of Appendix 1**) and were included in all of the top-ranked multiple gear sampling alternatives (**Table 2 of Appendix 1**).

4.3.2 Trammel Nets [see section 3.3.8]

Recommendation: Trammel nets (of similar design as those used by the (Danos et al. 2019)) are recommended for sampling larger-bodied, highly mobile fishes (e.g., sturgeon, striped bass, sharks, rays) within sloughs and shallow, open-water wetland habitats of the SFE. In particular, long-term monitoring using trammel nets is recommended in wetland habitats that are immediately downstream of major watersheds. These include Suisun Marsh and wetlands associated with the Petaluma River, Sonoma Creek, Napa River, Coyote Creek, and Guadalupe River watersheds. As an example, the CDFW trammel net is constructed of four contiguous 150 ft (45.7 m) long by 12 ft (3.7 m) deep sections. Each section consists of a gillnet panel sandwiched between two panels of trammel net. The gillnet panel is an Alaska salmon-style webbing made up of multi-strand monofilament twist. The trammel net panels are made up of three multi-strand twisted nylon braids. Each section is constructed using a different mesh-size gill net, with the stretched diagonal dimensions being 8” (20.3 cm), 7” (17.8 cm), 6” (15.2 cm), and 8” (20.3 cm) for sections 1-4, respectively (Danos et al. 2019).

Justification: Set nets (e.g., gill nets and trammel nets) are highly effective at sampling mobile species that move

Adult steelhead (Oncorhynchus mykiss). Credit: NOAA Southwest Fisheries Science Center.

significant distances on diurnal or tidal cycles. Gill nets have been utilized to examine fish communities in slough habitats in South Bay wetlands (Mejia et al. 2008, Saiki & Mejia 2009), and more recently in North Bay habitats (Wulff et al. 2022) (**Appendix 2**). While gill nets are designed to entangle fish's gills, often causing harm or death, trammel nets are designed to entangle fish with a much lower risk of significant harm. This is why trammel nets are utilized by the CDFW monitoring and tagging program for White and Green Sturgeon, and why trammel nets are recommended here over gill nets. Trammel nets have been utilized by CDFW to study Green Sturgeon and White Sturgeon in Suisun Bay and San Pablo bay since 1954. Of all the gear types evaluated, trammel nets were scored as the best gear for sampling a broad diversity of larger, mobile fauna (**Table 1 of Appendix 1**), including endangered green sturgeon and fisheries targets such as flounder, striped bass, sharks, and rays; all of which are highly mobile and utilize wetland habitats adjacent to tidal marshes. The trammel net plus otter trawl option (**Alternative 7 in Table 2 of Appendix 1**) was the highest-ranked 2-gear alternative in the ranking exercise, and was scored nearly as high as most 3- and 4-gear alternatives, indicating that this alternative was likely the most efficient option for sampling a broad diversity of species and habitats.

Methods for detecting Green Sturgeon and White Sturgeon, in particular, are needed because current and long-term efforts for monitoring have been restricted to the upper estuary. Thus the SFE sturgeon research and management community lacks data on the use of wetland habitats throughout the lower SFE. The Interagency Ecological Program's Green Sturgeon Coordination Team strongly encouraged the importance of including sturgeon monitoring in the WRMP's FFH monitoring program in order to fill this critical information gap, which was identified in the recent 5-year status review of the Green Sturgeon Recovery Plan (NMFS 2018). Similarly, little is known about the presence and abundance of other important large-bodied fisheries targets that are important for the management of these fisheries and for understanding the effects of human activities of opportunities for recreation, such as fishing, in SFE wetland habitats.

Dungeness crab (Metacarcinus magister). Credit: Levi Lewis.

4.3.3 Beach Seine [see section 3.3.2]

Recommendation: Shore-based seines (of similar design as beach seines used by the DJFMP, AMMBS, and SMFMD), are recommended for sampling littoral fishes within sloughs and tidal marsh habitats, including intertidal creek channels and higher-order rivulets. In particular, shore-based seines are recommended for quantifying the abundance of littoral fishes within natural and restored tidal marshes, and in tidally-muted open water/shoal habitats throughout the SFE. In specific applications, sampling of marsh habitats using fyke or block nets [3.3.4] (as in Visintainer et al. (2006)) or minnow traps [3.3.3] (as in McGourty et al. (2009)) may also be suitable, in lieu of or in addition to shore-based seining. Similarly in channels that are too deep or have significant benthic vegetation or structure, a Lampara net (e.g., as designed and used by the CDFW FRP) could be used as an alternative gear for sampling intertidal channels.

Justification: The sampling of intertidal wetland habitats (**Figure 2, Figure 5**), including fully tidal, vegetated marshes and their bisecting lower-order intertidal creeks/rivulets (Horton 1945, Rozas et al. 1988) require specialized approaches that are effective in shallow waters and can be deployed and retrieved during the highest stages of flooding and ebbing tides. These higher-elevation wetland habitats are utilized largely by transitory fish species that are present only during high tides (Levy & Northcote 1982, McIvor & Odum 1988, Rozas et al. 1988, Haltiner et al. 1996, Desmond et al. 2000), with few obligate marsh residents remaining within perennially inundated intertidal pools, channels, and burrows (McGourty et al. 2009). Thus the smallest intertidal creeks are preferred habitats only for a select few resident species, with diversity increasing with increasing creek order and size due to the presence of transient species (Rozas et al. 1988, Desmond et al. 2000, Visintainer et al. 2006).

Although otter trawls were the highest ranked gear for sampling fishes in intertidal marsh and associated habitats (**Appendix 1**), this gear type is relegated to only to the largest and deepest (to allow for boat access) intertidal creek channels in marsh habitats. In order to sample smaller intertidal channels, other gears must be utilized such as beach seines, fyke/block nets, telemetry, or minnow traps. Fyke/block style nets were ranked as the next most effective gear for sampling these intertidal habitats (**Appendix 1**); however, these habitats typically only contain a small fraction of wetland fish diversity. fyke/block nets are passive gears that are installed during flooding or ebbing high tides and capture a variety of fishes and invertebrates as they move through tidal channels (Visintainer et al. 2006). However, the installment of fyke/block nets can be both time and labor intensive, can limit the geographic distribution and replication of sampling, and nets can entrap endangered mammals and birds, or cause mortality to captured fishes, as tides recede. Furthermore, fyke/block have limited prior use throughout SFE wetlands, thus limiting the integration of results of monitoring with past and on-going monitoring efforts (**Appendix 2**). While telemetry was also ranked relatively high for sampling intertidal habitats, several limitations including the need to establish battery-powered receivers in intertidal habitats, the limited ability to only detect individual fish that have been implanted with tags, and limited use throughout SFE wetlands (**Appendix 2**) made this gear type less valuable for monitoring intertidal fish communities in brackish wetlands.

Although minnow traps are excellent at sampling intertidal channels and rivulets, they are highly selective, can only sample while inundated (with ambiguous effort), are dependent on fish behavior due to their reliance on bait, and limited prior and ongoing sampling exists for comparison and integration (**Appendix 2**). For example, specific focal species (e.g., Longjaw Mudsucker) that are obligate residents of vegetated tidal marsh are likely best sampled with minnow traps; however, minnow traps are less effective at sampling many other species of fishes and macroinvertebrates (McGourty et al. 2009). As for fyke/block nets, minnow traps are passive gears that may inadvertently trap wildlife species of concern, thus complicating permitting for their use. For this reason, minnow traps were ranked relatively low relative to other gear types (**Appendix 1**). Lampara nets have been used by the CDFW FRP to sample wetland fishes, primarily in freshwater habitats where vegetation or geomorphology precludes the use of other gear types. However, Lampara nets primarily target pelagic species of fish and are less effective for sampling many benthic species that occur in brackish wetlands. For example, the large mesh and wings of Lampara nets make them less effective than beach seines for sampling small wetland fishes, as fish readily swim through the larger mesh, especially when the large net becomes snagged on structure. Such issues are less common with beach seines, depending on the design and habitat sampled. One monitoring program in the SFE, the Fish Restoration Monitoring Program, has used Lamparas to sample tidal channels in wetlands, with most of these sites occurring in fresher habitats upstream (IEP TWM PWT 2017b).

Beach seines, therefore, were the preferred gear for sampling intertidal wetland habitats. In contrast to other gear types mentioned above, beach seines are effective in sampling a broad diversity of small-bodied fishes, including ESA/CESA listed taxa (**Figure 8 in Appendix 2**). As an active gear type, they limit interactions with protected wildlife, and allow for site-level replication of sampling. In addition to the general effectiveness of beach seines, they also exhibited the broadest use across numerous projects, habitats. More projects (14/29, 48%) used beach seines than any other gear type (**Figure 5 in Appendix 2**), and beach seines exhibited the second broadest distribution of stations (150 total stations), second only to otter trawls (whose numbers were inflated by randomization) (**Figure 6 in Appendix 2**). Beach seines have been utilized across all subregions of the SFE, and across most habitat types including tidal marshes, intertidal creeks, sloughs, and restoring diked baylands (open water/shoals/ mudflats) (Mejia et al. 2008, Hobbs et al. 2012, Hobbs 2017) (**Figures 10 and 11 in Appendix 2**). Furthermore, beach seines have a long and diverse history of use in several SFE monitoring programs, including 46 years by the USFWS DJFMP (**Figure 3 in Appendix 2**). Given these considerations, Alternative #13 (otter trawl + trammel net + beach seine) was the highest-ranking 3-gear alternative that was considered in the alternatives ranking exercise (**Table 2 in Appendix 1**).

4.3.4 Acoustic Telemetry [see section 3.3.5]

Recommendation: Acoustic telemetry, of similar design and methodology as used by previous studies of migratory fishes (Kelly et al. 2007, Miller et al. 2020, Colborne et al. 2022), is recommended for continuous monitoring the presence/absence and patterns of habitat utilization by large-bodied, highly migratory species including sturgeons, salmonids, striped bass, elasmobranchs, and other taxa that are often tagged with acoustic tracking devices and frequent wetland habitats of the SFE. In particular, acoustic monitoring is recommended in wetland habitats that are immediately downstream of major watersheds. These include Suisun Marsh and wetlands associated with the Petaluma River, Sonoma Creek, Napa River, Coyote Creek, and Guadalupe River watersheds. At minimum, we recommend an array of receivers (e.g., 1-2) to be maintained in the mainstem sloughs of at least 3 major watersheds: Petaluma River, Coyote Creek, and Napa River. Ideally, a broader array including additional watersheds (e.g., Gallinas Creek, Alameda Creek, Sonoma Creek, etc.) and marsh networks (e.g., Eden Landing, Ravenswood, Alviso Marsh, Napa Marsh) could also be valuable.

Justification: Of all the gear types evaluated, telemetry was scored as one of the best gears (score of 4.8, second only to trammel nets with score of 5.0) for monitoring the use of wetland habitats by ESA/CESA-listed species including endangered green sturgeon (**Table 1 of Appendix 1**). Although telemetry includes acoustic and radio-based approaches (PIT/RFID), the much larger detection ranges of acoustic approaches, their effectiveness across a broad range of salinities, and the presence of existing arrays of acoustic receivers across the SFE makes acoustic telemetry preferable in this application (Cooke et al. 2004; Hussey et al. 2015). Although alternatives with telemetry were not ranked higher than those that already included trammel nets (**Table 2 of Appendix 1**), it was noted by participants that the added benefit of adding telemetry-based monitoring (particularly for rare ESA/CESA listed species) was not fully captured by the ranking exercise. For example, whereas trammel netting provides valuable, but limited discrete data on the presence of large-bodied fishes, acoustic monitoring instead provides continuous data, which is critical for determining presence/absence of rare taxa (e.g., listed species) as well as quantifying the relative frequency and duration of occupancy by mobile species in wetland habitats across the SFE. The establishment of trammel netting will provide ample opportunity and funding to facilitate the capture and implantation of tags in focal species and individuals that utilize wetland habitats, and the addition of a small number of WRMP-maintained receivers in currently unmonitored wetlands throughout the SFE will both leverage and expand upon the existing broader SFE-wide acoustic telemetry array (Chapman et al. 2019, Miller et al. 2020, Colborne et al. 2022) (see also UCD Fish Tracking Consortium), with direct integration of WRMP-supported data.

U.C. Davis Fish Monitoring Team Deploying a Beach Seine in Pond A4, Alviso Marsh, Lower South Bay. Credit: Levi Lewis.

Expansion of acoustic monitoring into wetlands associated with major watersheds of the lower SFE will provide critical data for the management of threatened and endangered species, fisheries, and ecosystems. For example, few data exist regarding the use of wetland habitats by Green Sturgeon and White Sturgeon throughout the lower SFE, with prior and ongoing efforts being restricted to the upper estuary. The Interagency Ecological Program's Sturgeon Project Work Team strongly encouraged the importance of including acoustic-based sturgeon monitoring in major watersheds of the WRMP's FFH monitoring program in order to fill this critical information gap, which was identified in the recent 5-year status review of the Green Sturgeon Recovery Plan (NMFS 2018).

Similarly, little is known about the presence and abundance of other important migratory fishes in brackish and saline habits of the lower SFE. For example, juvenile salmonids are known to spawn in watersheds throughout the lower SFE including Alameda Creek, Guadalupe River, Coyote Creek, Napa River, Petaluma River, and others (Leidy et al. 2005, NMFS 2016), and are known to benefit from estuarine rearing in other estuaries . However, few studies have examined the use of brackish and saline wetlands by salmonids in the lower SFE, despite their presence in these habitats being confirmed by limited trawl and PIT tag studies (Hobbs et al. 2014, Lewis et al. 2019b). More attention should be directed toward considering how the WRMP can monitor the utilization of wetlands by salmonids in order to better inform life cycle models and better understand how these habitats can contribute to recovery of threatened and endangered species. The same is likely true for other species that are known to occur in wetland habitats including other endangered species and fisheries targets that are important for the management of populations, ecosystems, and fisheries; and for understanding the effects of restoration on opportunities for recreation, such as fishing. Thus it is recommended that the WRMP contribute to expanding the existing acoustic monitoring network of the SFE into wetland habitats of the lower SFE.

Juvenile green sturgeon (Acipenser medirostris). Credit: Thomas Dunklin.

4.4 Habitats

4.4.1 Recommendation

It is recommended that all aquatic wetland habitats within the CTME that are commonly utilized by fishes be included in FFH monitoring, specifically intertidal marsh, mudflat, and channel habitats, and subtidal slough and shoal habitats. Habitat-specific sampling approaches (see above) are recommended, with an emphasis on maximizing the interpretation of data with long-term datasets and maximizing the diversity of wetland fishes sampled. Additional details regarding the distribution and types of sampling are described in gear-specific recommendations (**Section 4.3**) and recommendations regarding the geographic distribution of sampling (**Section 4.8**).

4.4.2 Justification

The aquatic footprint of the WRMP, that is commonly occupied by fishes, ranges from the upper-most tidally inundated habitats (typically marshes and mudflats) to a maximum depth of 12 feet (4 m) below mean lower low water (MLLW) levels. Given that environmental conditions in wetlands are highly dynamic on tidal, daily, seasonal, and interannual scales, many species have evolved to move rapidly and frequently in relation to rapidly changing environmental conditions at each of these spatiotemporal scales. All wetland-associated fishes are known to utilize at least one of the wetland habitat types listed above, with many species existing across habitat types. Most species make regular movements between intertidal and subtidal habitats, with intertidal habitats only utilized during higher tides by certain species, and subtidal habitats providing suitable habitat for nearly all species across all tidal stages. Most fishes that are found in intertidal habitats have migrated from subtidal sloughs and shoals at low tide into marsh, channel, and mudflat habitats during high tides to feed (Levy & Northcote 1982, McIvor & Odum 1988, Rozas et al. 1988, Haltiner et al. 1996, Desmond et al. 2000). The continuous flux of aquatic organisms into and out of intertidal and subtidal wetland habitats is key to facilitating multi-directional trophic transfer between intertidal and subtidal habitats, thus supporting terrestrial predators such as piscivorous shore birds and aquatic predators such as sharks and Striped Bass. For example, several studies have shown that estuarine fishes within subtidal habitats benefit from nearby wetlands, and conversely, are likely harmed by the degradation or loss of adjacent wetland habitats (Hammock et al. 2019 20, Colombano et al. 2020).

The greatest abundance, diversity, and stability of fish communities occurs in habitats that remain wetted for significant fractions of the day. Thus, in order to capture the patterns and dynamics listed above, it is recommended that both subtidal and intertidal habitats be sampled, with a specific focus on intertidal marsh channels that serve as corridors for fishes that utilize smaller creek and marsh habitats during higher tides, as well as adjacent subtidal sloughs and shoals that provide habitats across the full tidal range for these species and numerous other wetland-associated taxa.

4.5 Frequency of Sampling

4.5.1 Recommendation

Monthly sampling is recommended as the preferred frequency of sampling for benchmark, reference, and project sites. If monthly sampling throughout the year is not feasible, then monthly sampling within a focal season (e.g., summer or winter) is suggested. Higher-frequency sampling is also favored; however, not at the expense of being able to account for seasonal patterns.

4.5.2 Justification

Monthly sampling is likely the most cost-effective sampling frequency for documenting spatial and interannual variation in the distribution of fishes and habitat features, while also accounting for seasonal patterns. For this reason, monthly sampling is the standard practice of several other long-term wetland monitoring programs in the SF Estuary including the SFBS, SMFMD, DJFMP, and SBOTS. Monthly sampling provides the necessary temporal resolution needed to assess spatial, seasonal, and long-term trends in fish community abundance, diversity, and community structure.

4.6 Sampling Teams

4.6.1 Recommendation

Large teams (>4 people, unless small project specific marsh sampling is being conducted) are recommended to achieve monthly sampling using the recommended gears and frequencies provided above within each of the five WRMP subregions. Multiple smaller teams may be appropriate for specific efforts (e.g., fyke netting, beach seining).

4.6.2 Justification

Experts from the FFH subcommittee ranked large crews as the preferred choice (Appendix 1). Large crews are needed to support a regional sampling program in accordance with the sampling recommendations provided herein.

4.7 Data Collection, Storage, and Analysis

4.7.1 Recommendation

It is recommended that an approved data management plan (DMP) be a prerequisite for any fish monitoring project to be associated with or incorporated into the WRMP. The DMP should be consistent with the requirements of the WRMP Data Submission Portal and Geospatial Data Catalog (in draft), and should detail how the monitoring project is to follow general established best practices for data storage, backup, quality assurance and control, and long-term storage and integration. To facilitate this, it would be valuable to have clear instructions and WRMP-approved templates of data management plans (see the IEP DMPs) and data tables with standardized headings, field-specific limitations, etc.

Temporary Storage & backup. We recommend that, upon completion of discrete field excursions, that all datasheets be immediately imaged, with images labeled and uploaded to an online server. Digital spreadsheets (e.g., Excel) or a relational database (e.g., MS Access), where data are entered and stored locally, should also be immediately saved onto an online server, with regular backups occurring as data are added to existing spreadsheets and databases.

Quality Assurance and Quality Control (QAQC) Procedures. We recommend 2-person quality assurance checks for all data that are hand-entered from datasheets into digital spreadsheets or tables (e.g., Excel, Access, or other). We recommend data validation limits (e.g., in digital spreadsheets or databases) to minimize entry errors and out-of-bound values. We also recommend the plotting of all raw data to identify and correct outliers (with data validation limits in place) and examination of known relationships (e.g., conductivity and salinity; dissolved oxygen concentration and % saturation; etc.) to control for data integrity and accuracy. For instruments that automatically record data (e.g., flow meters, sondes), a record of instrument calibrations and tests using established protocols, including standard reference solutions, known conditions, and paired instruments, should be used to confirm the accuracy of instrument-collected values. All QAQC procedures, outcomes, and adjustments should be documented in a metadata file and respective tables associated with the project.

Long-term storage: Final, clean data sets, including metadata and QAQC history, should be uploaded to the WRMP Data Submission Portal annually for long-term monitoring or at the completion of a short-term project window, or as is otherwise specified by WRMP guidelines.

Analysis: Data on fish and fish habitat should be collected and maintained in a manner that will facilitate the broadest use of the data in a variety of statistical, modeling, and management applications. Examples include spatially and temporally explicit models of fish, macroinvertebrate, and dynamic habitat features (e.g., water quality) that can be used to assess variation in the distribution and abundances of individual species, patterns in biodiversity, and variation in environmental conditions. Modeling approaches may include generalized additive models, spatially explicit autoregressive models, and machine learning approaches (e.g., boosted regression trees), each of which can account for seasonal and interannual patterns, and can incorporate environmental covariates when describing patterns in FFH data. Data should also facilitate the construction of indices of biotic integrity and habitat suitability using joint community-environmental data, as well as provide temporal trends in species and community data that can be used as bioindicators, such as those included in the State of the Estuary Report (SFEP & DSC 2019). At a minimum, WRMP-associated data on FFH should be integrated and summarized periodically to examine temporal and spatial variation (among wetland habitats and across years) in total fish abundance, the abundances of focal species or groups, presence of listed (CESA or ESA) species, biodiversity, community structure, and environmental conditions, including water quality. Therefore, to maximize their utility and value, all data should be provided in an atomic, disaggregated form without calculation or summarization (e.g., means, totals, etc.). Any calculated values (e.g., CPUE) that are provided should only be included in addition to, not in lieu of, raw data values (e.g., catch and effort) from which calculated values were derived.

4.7.2 Justification

A key goal of the WRMP is to provide a standardized platform for the collection and integration of data on wetland habitats throughout the SFE. Standardized data management practices will maximize the quality, utility, and accessibility of all data generated as part of the WRMP to maximize its short-term and long-term value. In aggregate, the recommendations provided herein were developed to facilitate the broadest use of the data to address the aforementioned goals of the WRMP utilizing a variety modeling frameworks. The data management recommendations and examples of analytical approaches provided above have each previously been used to examine spatiotemporal patterns in fish and fish habitat in the SFE and provide a strong foundation for how data should be structured and maintained to maximize their value; however, we emphasize that these represent only a subset of the full range of analyses for which the data are intended to be suitable.

4.8 Geographic Distribution of Sampling

4.8.1 Recommendation

Long-term, large-scale FFH monitoring efforts (e.g., using otter trawls, trammel nets, and acoustic methods) are recommended in accessible subtidal slough, shoal, and

Longjaw Mudsuckers (Gillichthys mirabilis). Credit: James Ervin.

open-water habitats that occur within and adjacent to WRMP sites (including benchmark, reference, and project sites) and are associated with regional tributaries of the SFE (e.g., Petaluma River, Napa River, and Coyote Creek watersheds), including Suisun Marsh. FFH monitoring within intertidal wetland habitats (e.g., vegetated marsh, channels, and rivulets) that are associated with WRMP benchmark, reference, and project sites is also recommended using shore-based seines (e.g., beach seines), or alternatively with block/fyke-style nets that sample intertidal channels. Minnow traps are recommended for sampling only where the abundance of resident marsh-obligate fishes (e.g., Longjaw Mudsucker) is needed and minnow traps can be permitted (e.g., due to interactions with endangered mammals and shorebirds). Habitat-specific approaches for monitoring listed (ESA/CESA) species is recommended for all proposed sites associated with the WRMP.

4.8.2 Justification

The WRMP designated benchmark sites in 2021 (see [Technical Memo: WRMP Benchmark Site recommendations]), and in 2023, proposed a series of priority monitoring site networks throughout the estuary built around particular benchmark sites (see [Technical Memo: WRMP Priority Monitoring Site Networks]). These priority networks are composed of benchmark, reference, and project sites. Benchmark sites in particular are intended to provide a long-term baseline of the status and trends for SFE wetland ecosystems. By the end of 2023, the WRMP TAC is scheduled to develop an Initial Monitoring Plan that will describe which indicators should be prioritized for monitoring at which WRMP sites (including, if necessary, sites that have yet to be designated by the WRMP) over roughly the next 3-5 years. The FFH Workgroup is expected to help the TAC integrate FFH monitoring into this Plan.

As part of this work, the FFH Workgroup will evaluate the proposed sites in the Monitoring Site Network memo with respect to the three FFH monitoring goals identified above, and reclassify sites with respect to their association with major watersheds and tributaries of the lower SFE, including the Sacramento-San Joaquin Delta, Petaluma River Watershed, Sonoma Creek Watershed, Napa River Watershed, Alameda Creek Watershed, and Coyote Creek Watershed. Sites that are associated with major watersheds can act as micro-estuaries within the greater SFE, each exhibiting their own salinity gradients and transitions among habitats from upland to tidal marsh, and fresh to brackish or saline habitats. Migratory fishes are known to use these estuaries as corridors to spawning habitats within associated watersheds, and resident estuarine fishes are known to remain within these distinct habitats throughout much of the year. Thus understanding how aquatic communities, including those in adjacent subtidal slough and open-water habitats, within each estuarine ecosystem vary in relation to other estuarine habitats over long temporal scales will be important for understanding differences in the functioning of estuarine habitats throughout the SFE. Previous and ongoing monitoring in these watersheds (e.g., SBOTS, NBOTS, SMFMS, and SFSBS; **Appendix 2**) can be used to inform the establishment of monitoring efforts, and continued funding for these programs may contribute matching funds and effort to the WRMP.

In contrast, "fringing" marshes around the margins of the lower SFE with much smaller or more ephemeral associated watersheds are generally influenced more strongly by larger regional processes and conditions, lack major persistent estuarine gradients to support distinct aquatic estuarine communities year-round, and lack significant upland aquatic habitats to support spawning populations of migratory fishes. Thus a monitoring focus on fishes that utilize intertidal marsh-associated habitats is of the highest priority at these sites, with a specific focus on monitoring spatiotemporal patterns among marshes with different environmental conditions and restoration status. In particular, the sampling of intertidal creeks and rivulets is recommended at these sites. Again, detailed recommendations about proposed FFH monitoring indicators, locations, and frequency will be described in the WRMP's Initial Monitoring Plan.

4.9 Consistency with Other Wetland Monitoring Programs

4.9.1 Recommendation

It is recommended that the approaches adopted by the WRMP as best practices for monitoring fishes and fish habitats should aim to maximize the standardization and integration of new data with the methods and data standards of existing sampling programs and databases. This consideration should remain a priority in the selection of standard operating procedures for the collection and integration of biological, environmental, and sampling data associated with any prescribed monitoring activities.

4.9.2 Justification

A key goal of the WRMP is to generate data that can readily be integrated across space and time, thus maximizing the value of all generated data with respect to informing both local and regional trends and processes. Thus, the recommendations provided herein are intended to maximize consistency and complementarity with previous and continuing long-term FFH monitoring programs in brackish and saline wetlands of the SFE. To facilitate this, a review was conducted to provide information on methods and gears that have been used to monitor fishes in wetland habitats that lie within the scope of the WRMP (Appendix 2). In this review, we explored spatiotemporal variation in sampling activity, the diversity of methods utilized, types of data that were collected, and the presence of certain focal species, including those listed under state and federal Endangered Species Acts. Specifically, we summarized (a) where fish monitoring has occurred in brackish and saline wetland habitats of the SFE, (b) when monitoring occurred and for how long, (c) what sampling methods have been utilized, (d) which environmental data have been collected, and (e) what managed species have been observed. Furthermore, we aimed to identify common practices, information gaps, and provide recommendations to inform future coordinated monitoring of fishes in brackish and saline wetland habitats throughout the lower SFE. Several long-term (> 20 yrs) surveys were included in the review: UC Davis Suisun Marsh Fish Survey (otter trawl, 42 years), San Francisco Bay Study (otter trawl & midwater trawl, 42 years), and the Delta Juvenile Fish Monitoring Program (beach seine, 46 yrs) (Appendix 2). Additional shorter-term projects were also summarized to inform this SOP with respect to the most common and effective approaches for sampling fish and fish habitats in the SFE.

5. ACKNOWLEDGEMENTS

Sunrise over Pond A17, Alviso Marsh, Lower South Bay. Credit: Levi Lewis.

Numerous community members participated in workshops, committees, and subgroups to discuss, refine, and draft these recommendations. Participants included stakeholders, scientists, and managers from numerous institutions and agencies, including the University of California, Davis, National Marine Fisheries Service, US Geological Survey, CA Department of Fish and Wildlife, US Fish and Wildlife Service, CA State Water Resources Control Board, Vollmar Consulting, San Francisco Estuary Institute, and the San Francisco Estuary Partnership. Members of the WRMP Technical Advisory Committee and Fish and Fish Habitat Workgroup provided final guidance regarding the recommendations and justifications herein.

6. LITERATURE CITED

Adams AJ, Wolfe RK, Pine WE, Thornton BL (2006) Efficacy of PIT tags and an autonomous antenna system to study the juvenile life stage of an estuarine-dependent fish. Estuaries Coasts 29:311–317.

Barros A, Hobbs JA, Willmes M, Parker CM, Bisson M, Fangue NA, Rypel AL, Lewis LS (2022) Spatial Heterogeneity in Prey Availability, Feeding Success, and Dietary Selectivity for the Threatened Longfin Smelt. Estuaries Coasts.

Bergman PS, Schumer G, Blankenship S, Campbell E (2016) Detection of Adult Green Sturgeon Using Environmental DNA Analysis. PLOS ONE 11:e0153500.

Bond MH, Hayes SA, Hanson CV, MacFarlane BR (2008) Marine Survival of Steelhead (Oncorhynchus mykiss) enhanced by a seasonally closed estuary. Can J Fish Aquat Sci 65:2242–2252.

Bottom DL, Jones KK, Cornwell T, Simenstad CA (2001) Rearing of Juvenile Salmon in Recovering Wetlands of the Salmon River Estuary: Functional Development with Marsh Age.

Brownscombe JW, Lédée EJI, Raby GD, Struthers DP, Gutowsky LFG, Nguyen VM, Young N, Stokesbury MJW, Holbrook CM, Brenden TO, Vandergoot CS, Murchie KJ, Whoriskey K, Mills Flemming J, Kessel ST, Krueger CC, Cooke SJ (2019) Conducting and interpreting fish telemetry studies: considerations for researchers and resource managers. Rev Fish Biol Fish 29:369–400.

Chapman ED, Miller EA, Singer GP, Hearn AR, Thomas MJ, Brostoff WN, LaCivita PE, Klimley AP (2019) Spatiotemporal occurrence of green sturgeon at dredging and placement sites in the San Francisco estuary. Environ Biol Fishes 102:27–40.

Colborne SF, Sheppard LW, O'Donnell DR, Reuman DC, Walter JA, Singer GP, Kelly JT, Thomas MJ, Rypel AL (2022) Intraspecific variation in migration timing of green sturgeon in the Sacramento River system. Ecosphere 13:e4139.

Colombano DD, Manfree AD, O'Rear TA, Durand JR, Moyle PB (2020) Estuarine-terrestrial habitat gradients enhance nursery function for resident and transient fishes in the San Francisco Estuary. Mar Ecol Prog Ser 637:141–157.

Cooke SJ, Hinch SG, Wikelski M, Andrews RD, Kuchel LJ, Wolcott TG, Butler PJ (2004) Biotelemetry: a mechanistic approach to ecology. Trends Ecol Evol 19:334–343.

Cooper MJ, Lamberti GA, Moerke AH, Ruetz CR, Wilcox DA, Brady VJ, Brown TN, Ciborowski JJH, Gathman JP, Grabas GP, Johnson LB, Uzarski DG (2018) An expanded fish-based index of biotic integrity for Great Lakes coastal wetlands. Environ Monit Assess 190:580.

Danos A, Kelly J, Chalfin J, DuBois J (2019) 2019 Field Season Summary for the Sturgeon Population Study.

Desmond JS, Zedler JB, Williams G (2000) Fish use of tidal creek habitats in two southern California salt marshes. Ecol Eng 14:233–252.

Ducks Unlimited, Inc, ECORP Consulting, Inc (2013) NOAA ARRA Tidal Marsh Restoration Project, San Francisco Bay Estuary: South Bay Fish Acoustic Tagging and Monitoring Study, DU Project Number US-CA-446-5.

Dumbauld BR, Holden DL, Langness OP (2008) Do sturgeon limit burrowing shrimp populations in Pacific Northwest Estuaries? Environ Biol Fishes 83:283–296.

Ellison L, Rahman M, Finger A, Sandford M, Hsueh C-H, Schultz AA, Hung T-C (2022) (Accepted Manuscript) Size, fecundity and condition factor changes of endangered delta smelt Hypomesus transpacificus over 10 generations in captivity. Aquac Fish Fish.

Fichman RA, Khen A, Willmes M, Kuntz J, Scott AR, Hobbs JA, Lewis LS (2021) The Clever Strategies That Fishes Use to Survive in San Francisco's Dynamic Estuary. Front Young Minds 9:608881.

Ganssle D (1966) Fishes and decapods of the San Pablo and Suisun Bays. California Department of Fish and Game.

Goals Project (2015) The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015. https://www.sfei.org/documents/baylandsgoalsreport

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 Coasts 40:1771–1784.

Hahn PKJ, Bailey RE, Ritchie A (2007) Beach Seining. In: Salmonid Field Protocols Handbook: Techniques for Assessing Status and Trends in Salmon and Trout Populations.

Haltiner J, Zedler J, Boyer K, Williams G, Callaway J (1996) Influence of physical processes on the design, functioning and evolution of restored tidal wetlands in California (USA). Wetl Ecol Manage 4:73–91.

Hammock BG, Hartman R, Slater SB, Hennessy A, Teh SJ (2019) Tidal Wetlands Associated with Foraging Success of Delta Smelt. Estuaries Coasts 42:857–867.

Hiddink JG, Jennings S, Sciberras M, Szostek CL, Hughes KM, Ellis N, Rijnsdorp AD, McConnaughey RA, Mazor T, Hilborn R, Collie JS, Pitcher CR, Amoroso RO, Parma AM, Suuronen P, Kaiser MJ (2017) Global analysis of depletion and recovery of seabed biota after bottom trawling disturbance. Proc Natl Acad Sci 114:8301–8306.

Hobbs J, Cook J, La Luz F (2014) Steelhead Smolt Outmigration and Survival Study: Pond A8, A7 & A5 Entrainment and Escapement. Final Report.

Hobbs J, Moyle P, Buckmaster N (2012) Monitoring the Response of Fish Communities to Salt Pond Restoration: Final Report.

Hobbs JA (2017) Comparison of nekton assemblages among restoring salt ponds in the Alviso Marsh, San Francisco Estuary: final report. Prepared for: Santa Clara Valley Water District & South Bay Salt Pond Restoration Project, Don Edwards San Francisco Bay National Wildlife Refuge. University of California, Davis, Department of Wildlife, Fish and Conservation Biology.

Horton RE (1945) Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology. GSA Bull 56:275–370.

Howe E, Simenstad C (2007) Restoration trajectories and food web linkages in San Francisco Bay's estuarine marshes: A manipulative translocation experiment. Mar Ecol-Prog Ser 351:65–76.

Hussey NE, Kessel ST, Aarestrup K, Cooke SJ, Cowley PD, Fisk AT, Harcourt RG, Holland KN, Iverson SJ, Kocik JF, Mills Flemming JE, Whoriskey FG (2015) Aquatic animal telemetry: A panoramic window into the underwater world. Science 348:1255642.

IEP TWM PWT (2017a) Interagency Ecological Program Tidal Wetland Monitoring Project Work Team: Tidal Wetland Monitoring Framework for the Upper San Francisco Estuary, Version 1.0.

IEP TWM PWT (2017b) Interagency Ecological Program Tidal Wetland Monitoring Project Work Team: Tidal Wetland Monitoring Framework for the Upper San Francisco Estuary Volume II: Standard Operating Procedures.

Jungbluth MJ, Burns J, Grimaldo L, Slaughter A, Katla A, Kimmerer W (2021) Feeding habits and novel prey of larval fishes in the northern San Francisco Estuary. Environ DNA 3:1059–1080.

Kelly JT, Klimley AP, Crocker CE (2007) Movements of green sturgeon, Acipenser medirostris, in the San Francisco Bay estuary, California. Environ Biol Fishes 79:281–295.

Kjelson MA, Raquel PF, Fisher FW (1982) Life History of Fall-run Juvenile Chinook Salmon, Oncorhynchus tshawytscha, in the Sacramento- San Joaquin Estuary, California. In: Estuarine Comparisons. Kennedy VS (ed) Academic Press Inc., New York, NY, p 393–411

Leidy RA, Becker GS, Harvey BN (2005) Historical distribution and current status of steelhead/rainbow trout (Oncorhynchus mykiss) in streams of the San Francisco Estuary, California. Center for Ecosystem Management and Restoration, Oakland, CA.

Levy DA, Northcote TG (1982) Juvenile Salmon Residency in a Marsh Area of the Fraser River Estuary. Can J Fish Aquat Sci 39:270–276.

Lewis LS, Barros A, Willmes M, Bisson M, Hobbs J, Finger A, Auringer G, Benjamin A (2019a) Interdisciplinary Studies on Longfin Smelt in the San Francisco Estuary.

Lewis LS, Hobbs JA, Willmes M, Crain PK, Barros A, Denney C (2019b) Community Structure of Fishes and Macroinvertebrates in the Alviso Marsh Complex 2011-2018. Department of Wildlife, Fish and Conservation Biology, University of California, Davis.

Lewis LS, Willmes M, Barros A, Crain PK, Hobbs JA (2020) Newly discovered spawning and recruitment of threatened Longfin Smelt in restored and underexplored tidal wetlands. ECOLOGY 101.

Lojkovic Burris ZP, Baxter RD, Burdi CE (2022) Larval and juvenile Longfin Smelt diets as a function of fish size and prey density in the San Francisco Estuary. Calif Fish Wildl J 108.

MacFarlane BR, Norton EC (2002) Physiological ecology of juvenile Chinook salmon (Oncorhynchus tshawytscha) at the southern end of their distribution, the San Francisco Estuary and Gulf of the Farallones, California. Fish Bull 100:244–257.

MacVean L, Trowbridge P, Lewis L, Hobbs J, Sylvester Z, Winchell T, Senn D (2018) Dissolved Oxygen in South San Francisco Bay: Variability, Important Processes, and Implications for Understanding Fish Habitat. San Francisco Estuary Institute, Richmond, Ca.

Mahardja B, Farruggia MJ, Schreier B, Sommer T (2017) Evidence of a Shift in the Littoral Fish Community of the Sacramento-San Joaquin Delta. PLOS ONE 12.

McCann E, Li L, Pangle K, Johnson N, Eickholt J (2018) An underwater observation dataset for fish classification and fishery assessment. Sci Data 5:180190.

McGourty CR, Hobbs JA, Bennett WA, Green PG, Hwang H-M, Ikemiyagi N, Lewis L, Cope JM (2009) Likely Population-Level Effects of Contaminants on a Resident Estuarine Fish Species: Comparing Gillichthys mirabilis Population Static Measurements and Vital Rates in San Francisco and Tomales Bays. ESTUARIES COASTS 32:1111–1120.

McIvor C, Odum WE (1988) Food, Predation Risk, and Microhabitat Selection in a Marsh Fish Assemblage. Ecology 69.

Mearns A, Allen M (1978) Use of Small Otter Trawls in Coastal Biological Surveys.

Mejia F, Saiki MK, Takekawa JY (2008) Relation Between Species Assemblages Of Fishes and Water Quality In Salt Ponds and Sloughs In South San Francisco Bay. Southwest Nat 53:335–345.

Merz JE, Bergman PS, Melgo JF, Hamilton S (2013) Longfin smelt: spatial dynamics and ontogeny in the San Francisco Estuary, California. Calif FISH GAME 99:122–148.

Miller EA, Singer GP, Peterson ML, Chapman ED, Johnston ME, Thomas MJ, Battleson RD, Gingras M, Klimley AP (2020) Spatio-temporal distribution of Green Sturgeon (Acipenser medirostris) and White Sturgeon (A. transmontanus) in the San Francisco Estuary and Sacramento River, California. Environ Biol Fishes 103:577–603.

Miya M (2022) Environmental DNA Metabarcoding: A Novel Method for Biodiversity Monitoring of Marine Fish Communities. Annu Rev Mar Sci 14:161–185.

Moser ML, Patten K, Corbett SC, Feist BE, Lindley ST (2017) Abundance and distribution of sturgeon feeding pits in a Washington estuary. Environ Biol Fishes 100:597–609.

Munsch SH, Cordell JR, Toft JD (2017) Effects of shoreline armouring and overwater structures on coastal and estuarine fish: opportunities for habitat improvement. J Appl Ecol 54:1373–1384.

NMFS (2016) Final Coastal Multispecies Recovery Plan for California Coastal Chinook Salmon, Northern California Steelhead and Central California Coast Steelhead | NOAA Fisheries. https://www.fisheries.noaa.gov/resource/document/final-coastal-multispecies-recovery-plan-california-coastal-chinook-salmon (accessed October 13, 2022)

NMFS (2014) Recovery Plan for The Evolutionarily Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the DPS of California Central Valley Steelhead | NOAA Fisheries. https://www.fisheries.noaa.gov/resource/document/recovery-plan-evolutionarily-significant-units-sacramento-river-winter-run (accessed October 13, 2022)

NMFS (2018) Recovery Plan for the Southern Distinct Population Segment of North American Green Sturgeon.

Nobriga ML, Sommer TR, Feyrer F, Fleming K (2008) Long-Term Trends in Summertime Habitat Suitability for Delta Smelt, Hypomesus transpacificus. San Franc Estuary Watershed Sci 6.

O'Rear TA, Moyle PB (2017) Trends in fish and invertebrate populations of suisun marsh January 2012- December 2012. University of California, Davis.

Phillips JB (1930) Fish Bulletin No. 23. Success of the Purse Seine Boat in the Sardine Fishery at Monterey, California (1929–1930 Fishing Season). State of California Division of Fish and Game.

Portt CB, Coker GA, Ming DL, Randall RG (2006) A review of fish sampling methods commonly used in Canadian freshwater habitats. Canadian Technical Report of Fisheries and Aquatic Sciences.

Reynolds JH, Knutson MG, Newman KB, Silverman ED, Thompson WL (2016) A road map for designing and implementing a biological monitoring program. Environ Monit Assess 188:399.

Rich WH (1920) Early History and Seaward Migration of Chinook Salmon in the Columbia and Sacramento Rivers. Bull U S Bur Fish 37:1–74.

Rich WH (1939) Local populations and migration in relation to the conservation of Pacific salmon in the western states and Alaska. - Google Search. (accessed October 13, 2022)

Rozas L, Mcivor C, Odum W (1988) Intertidal rivulets and creekbanks: Corridors between tidal creeks and marshes. Mar Ecol Prog Ser 47:303–307.

Saiki MK, Mejia FH (2009) Utilization by fishes of the Alviso island ponds and adjacent waters in south San Francisco bay following restoration to tidal influence. Calif Fish Game 95:38–52.

Sandstrom PT, Keegan T, Singer G (2013) Survival and movement patterns of central California coast native steelhead trout (Oncorhynchus mykiss) in the Napa River. Environ Biol Fishes 96:287–302.

SFEP, DSC (2019) The State of the San Francisco Estuary, 2019 Update, Trends and Indicators of Ecosystem Health. San Francisco, CA.

Shelton AO, Ramón-Laca A, Wells A, Clemons J, Chu D, Feist BE, Kelly RP, Parker-Stetter SL, Thomas R, Nichols KM, Park L (2022) Environmental DNA provides quantitative estimates of Pacific hake abundance and distribution in the open ocean. Proc R Soc B Biol Sci 289:20212613.

Sims CW, Johnsen RDH (1974) Variable-Mesh Beach Seine for Sampling Juvenile Salmon in Columbia River Estuary. 4.

SWRCB (2004) Functional Equivalent Document: Water Quality Control Policy for Developing California's Clean Water Act Section 303(D) List. 331.

USFWS (2022) Endangered and Threatened Wildlife and Plants; Endangered Species Status for the San Francisco Bay-Delta Distinct Population Segment of the Longfin Smelt. A Proposed Rule by the Fish and Wildlife Service on 10/07/2022.

Valoppi L (2018) Phase 1 studies summary of major findings of the South Bay Salt Pond Restoration Project, South San Francisco Bay, California. Reston, VA.

Visintainer TA, Bollens SM, Simenstad C (2006) Community composition and diet of fishes as a function of tidal channel geomorphology. Mar Ecol Prog Ser 321:227–243.

Vojnovich S (2021) Instruments - ARIS Sonar Imaging and CTD | NOAA Fisheries. https://www.fisheries.noaa.gov/science-blog/instruments-aris-sonar-imaging-and-ctd (accessed October 14, 2022)

WRMP SC (2020) Wetland Regional Monitoring Program Steering Committee: San Francisco Estuary Wetland Regional Monitoring Program Plan. San Francisco, CA.

WRMP TAC (2021) Wetland Regional Monitoring Program Technical Advisory Committee: Priority Monitoring Site Networks Technical Memorandum.

Wulff M, Feyrer F, US Geological Survey, Young M, US Geological Survey (2022) Gill Net Selectivity for Fifteen Fish Species of the Upper San Francisco Estuary. San Franc Estuary Watershed Sci 20.

7. APPENDICES

Appendix 1. Ranking of monitoring alternatives

Appendix 2. [DRAFT] Inventory of fish studies in the lower SFE

Appendix 3. Comment history of the FFH SOP

Appendix 1.

Developing Alternatives for the Fish and Fish Habitat Workgroup of the Wetland Regional Monitoring Program

APPENDIX 1

DEVELOPING ALTERNATIVES FOR THE FISH AND FISH HABITAT WORKGROUP OF THE WETLANDS REGIONAL MONITORING PROGRAM

Fish and Fish Habitat Sub-Group

Levi Lewis, University of California at Davis
Alison Weber-Stover, National Marine Fisheries Service
Elizabeth Campbell, U. S. Army Corps of Engineers
Jeff McLain, U. S. Fish and Wildlife Service

April 2022

Developing Alternatives for the Fish and Fish Habitat Workgroup of the Wetlands Regional Monitoring Program

The Fish and Fish Habitat (FFH) Workgroup of the Wetlands Regional Monitoring Program (WRMP) was established to develop monitoring recommendations and standard operating procedures (FFH SOP[1]) that would inform Guiding Question 3 and the associated management questions specifically related to fish and fish habitat of the WRMP[2].

> ***WRMP GUIDING QUESTION 4*** *How do policies, programs, and projects to protect and restore tidal marshes affect the distribution, abundance, and health of plants and animals?*
>
> > ***MANAGEMENT QUESTION 4A.*** *How are habitats for assemblages of resident species of fish and wildlife in tidal marsh ecosystems changing over time?*
> >
> > ***MANAGEMENT QUESTION 4B.*** *How are the distribution and abundance of key nativeresident species of fish and wildlife of tidal marsh ecosystems changing over time?*

A subgroup of the FFH volunteered to develop a stepwise process to draft initial monitoring recommendations that included (a) establishing FFH-specific monitoring goals related to the WRMP management questions, (b) identifying and evaluating a wide range of monitoring considerations, (c) developing a suite of monitoring alternatives, and (d) ranking the ability of monitoring alternatives to achieve the FFH monitoring goals (Figure 1). The subgroup consisted of four members from multiple agencies (NOAA, USFWS, USACE, UC Davis), each identified as fisheries biologists with expertise in sampling habitats of the San Francisco Estuary. This document describes the first three steps of that process and will be presented to the FFH for discussion.

---

[1] WRMP FFH SOP. *In preparation*. Fish and Fish Habitat Monitoring Recommendations and Standard Operating Procedures for the Wetland Regional Monitoring Program. Prepared by the Fish and Fish Habitat Workgroup. San Francisco Estuary Partnership, San Francisco, CA.

[2] WRMP. 2020. San Francisco Estuary Wetland Regional Monitoring Program Plan prepared by the WRMP Steering Committee. San Francisco Estuary Partnership, San Francisco, CA. Available online at: https://www.wrmp.org/wp-content/uploads/2021/04/SFE_WRMP-Program-Plan_040121_Web_ADA.pdf.

Figure 1. Process for developing monitoring alternatives.

FFH Monitoring Goals

The FFH subgroup developed three monitoring goals associated with the WRMP management questions that were used to guide development of FFH monitoring alternatives. The FFH recognized that there are number of important monitoring goals related to fish and fish habitat that could have been developed to inform the WRMP management questions[3]. For instance, monitoring the effectiveness of restoration projects and including lower trophic level monitoring that fish depend on for growth and survival is notably important and a focus of the Fish Restoration Program Tidal Wetland Monitoring. However, due to the limitations of funding this initial effort, the FFH subgroup set a modest goal to focus on establishing three achievable monitoring goals:

1. Establish Long-term Wetland Monitoring Bay-wide ["Large-scale" in the ranking exercise to represent regional monitoring and the assessment of geographically large projects[4]]: Provide standardized data, ***consistent or comparable with other concurrent and long-term research programs***, that can be used to describe long-term ecological trends in wetlands throughout the San Francisco Estuary (SFE), including presence/absence, local abundance/biomass (index/CPUE), and community structure of select focal species and functional groups at established benchmark, reference, and project sites.

2. Monitor the use of Wetland Habitats by ESA/CESA Listed Species ["ESA/CESA

[3] An excellent report details types of monitoring and hypothesis testing related to tidal marsh restoration: Interagency Ecological Program Tidal Wetlands Monitoring Project Work Team (IEP TWM PWT). 2017. Tidal Wetland Monitoring Framework for the Upper San Francisco Estuary, Version 1.0. Retrieved from: http://www.water.ca.gov/iep/about/tidal_wetland_monitoring.cfm. NOAA also has a number of guidance principles and suggestions for monitoring restoration projects https://www.fisheries.noaa.gov/national/habitat-conservation/monitoring-and-evaluation-restoration-projects.
[4] The subgroup considered projects like the South Bay Salt Pond Restoration Project with large footprint, multiple habitat types, and/or projects that extend to different geographic WRMP subregions of the SFE as "Large-scale".

listed species" in the ranking exercise]: Provide data regarding state and federally listed fish species use of the complete tidal marsh ecosystem of the SFE[5]. Listed species include the southern distinct population segment (DPS) of North American green sturgeon (*Acipenser medirostris*), Central California Coast and California Central Valley steelhead DPS (*Oncorhynchus mykiss*), Sacramento River winter-run Chinook salmon (*O. tshawytscha*), Central Valley spring-run Chinook salmon (*O. tshawytscha*), Longfin Smelt (*Spirinchus thaleichthys*), and Delta Smelt (*Hypomesus transpacificus*).

3. Provide Context and Guidance to Smaller Individual Projects ["Small Scale" in the ranking exercise to represent marsh-specific monitoring for the assessment of individual projects with smaller geographic footprints)]: Provide temporal and regional ecological context with metrics to support adaptive management of SFE wetlands and to guide and evaluate future special studies, permitted projects, and restoration actions. Long-term data collected throughout the estuary using standard reproducible methods can be contrasted with data from project sites, restorations, or rapid assessments, to evaluate whether local patterns in aquatic communities and water quality are in alignment with, or deviate from, expectations based on regional patterns. Such results will greatly improve the interpretation and utility of project-specific monitoring efforts that utilize the WRMP sampling framework for fish and fish habitat.

Evaluating Monitoring Considerations

To support the development of FFH monitoring alternatives, the FFH subgroup first identified 29 monitoring options associated with 7 monitoring considerations (Table 1). Each option was then scored by each member of the FFH subgroup based on its value/importance with respect to achieving each of the three FFH monitoring goals. Scores ranged from one to five, with one representing the least importance and five being essential. Mean scores of each option were then calculated for each FFH goal and across all goals. Mean scores were used to rank the various options within each of the 7 monitoring considerations (Table 1, Figures 2 and 3). Results were then used to inform the development of a suite of candidate FFH monitoring options/alternatives for further evaluation.

During the evaluation process, the FFH subgroup identified several caveats that are important to consider:

[5] The complete tidal marsh ecosystem is described in Goals Project. 2015. The Baylands and Climate Change: What We Can Do. Baylands Habitat Goals Science Update 2015. California State Coastal Conservancy. Oakland, CA: prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project.

- Permitting feasibility challenges are not addressed in this document but are anticipated to need future discussion. Challenges may be related to working and/or collecting data in marshes where sensitive species like Ridgeways Rails, salt marsh harvest mice, or marine mammals may be present (e.g. minnow traps may need special avoidance and minimization measures associated with deployment).
- Scores and ranking provided by the FFH subgroup remain open to discussion and modification by members of the FFH Workgroup.
- The scores herein focused only on value with respect to meeting FFH goals and did not account for differences in costs associated with various monitoring options. It was determined that cost considerations would be addressed at a later stage of the WRMP development process.
- All gear types commonly used in the SFE were considered, but some were determined to be inappropriate or ineffective for addressing FFH goals as outlined by the WRMP, and thus not all possible gears or methods were explicitly ranked. For example, the Kodiak trawl requires two vessels, two separate field teams, and only samples organisms in the upper water column (missing benthic species); thus it was determined that this method would not be appropriate for the FFH goals of the WRMP.
- The final SOP (developed out of this process) will be designed to provide recommendations to support agency and project proponent needs for large-scale, long-term monitoring throughout the SFE and for smaller-scale individual projects, with the understanding that each individual project may also require specific monitoring protocols that are tailored to the habitats, actions, and goals at the site.

Table 1. Monitoring considerations & mean averaged scores of ranked scoring exercise for each evaluated option

Consideration	Option	Small-Scale, Marsh-specific	ESA/CESA Listed Species	Large-Scale, Regional	Compo-site
3.1. Functional Groups	3.1.1. Large-bodied fishes/fishery targets	2.5	4.5	3.5	**3.5**
	3.1.2. Slough/open-water forage fishes, recruits, and macro-invertebrates	3.5	5.0	4.8	**4.4**
	3.1.3. Marsh plain/pond forage fishes and macroinvertebrates	4.3	2.8	3.8	**3.6**
	3.1.4. ESA/CESA listed species	5.0	5.0	5.0	**5.0**
3.2. Monitoring Metrics	3.2.1. Fish/nekton data	5.0	5.0	5.0	**5.0**
	3.2.2. Water quality data	5.0	5.0	5.0	**5.0**
	3.2.3. Sampling data	5.0	5.0	5.0	**5.0**
3.3. Sampling Gears	3.3.1. Benthic otter trawl	3.8	4.5	4.8	**4.4**
	3.3.2. Shore-Based (Beach/Lampara) seine	3.5	3.0	3.5	**3.3**
	3.3.3. Minnow trap	3.8	0.5	2.0	**2.1**
	3.3.4. Fyke or Block net	3.8	2.8	3.8	**3.5**
	3.3.5. Acoustic Tracking (Telemetry/PIT)	1.8	4.8	2.8	**3.1**
	3.3.6. eDNA	1.0	3.5	3.0	**2.5**
	3.3.7. Acoustic imaging (DIDSON/ARIS)	2.8	2.3	1.0	**2.0**
	3.3.8. Set net (Trammel/Gill)	1.8	5.0	4.0	**3.6**
	3.3.9. Boat-based Seine (Lampara net)	1.3	3.3	2.8	**2.5**
3.4. Habitats	3.4.1 marsh/pond/creeklet	4.3	3.0	4.5	**3.9**
	3.4.2 slough	4.3	4.8	5.0	**4.7**
	3.4.3 open-water	2.3	4.8	4.0	**3.7**
3.5. Sampling Frequency	3.5.1 monthly	5.0	5.0	5.0	**5.0**
	3.5.2 quarterly	4.0	4.0	4.0	**4.0**
	3.5.3 semi-annual	1.5	1.5	1.5	**1.5**
	3.5.4 annual	1.0	1.0	1.0	**1.0**
	3.5.5 bi-annual+	1.0	1.0	1.0	**1.0**
3.6. Sampling Teams	3.6.1 small (1-2 crew)	3.8	1.3	1.3	**2.1**
	3.6.2 med (3-4 crew)	4.3	3.5	3.5	**3.8**
	3.6.2 large (> 4 crew)	3.8	4.8	4.8	**4.5**
3.7-8 Data	3.7. Centralized Storage	4.0	5.0	5.0	**4.7**
	3.8. Consistency with Other Programs	4.5	4.5	5.0	**4.7**

Essential Monitoring Options

Several monitoring considerations and options were identified as essential (score ≅ 5) for all three FFH monitoring goals (Table 1), and were therefore incorporated into all evaluated monitoring alternatives (Figure 2). These essential considerations are described in more detail in Section 3 of the draft FFH SOP[6] and include:

- **Focal Species:** Monitoring of the ESA/CESA listed fish species focal group corresponds directly with FFH Monitoring Goal 2, and was scored as essential across all three FFH Monitoring Goals (Score = 5, draft FFH SOP Section 3.1.4).
- **Data and Metrics:** Details regarding the types of data to be collected during monitoring, including fish/nekton, water quality, and sampling metrics, were identified as essential (Score = 5, draft FFH SOP Section 3.2).
- **Habitats:** Monitoring of slough habitats was rated as essential because these habitats serve as part of the transition zone between open water and intertidal habitats, thus supporting a broad diversity of species (e.g., small and large-bodied, marsh resident and transient) (Score = 4.7, SOP Section 3.4). However, to monitor the complete tidal marsh ecosystem would include additional habitats such as creeklets and ponds.
- **Data:** Centralized data storage and consistency with other regional programs were rated highly for most monitoring goals (Score = 4.7, draft FFH SOP Section 3.7).
- **Sampling Team Size:** Ranking for size of the sampling team varied slightly with the monitoring goal. For smaller project specific monitoring, a small to medium size team may be ideal, but for long-term monitoring, medium to larger size sampling teams (3-4 people or larger) ranked highest.
- **Frequency of Sampling:** Monthly sampling consistently ranked the highest for the three monitoring goals, because this frequency is consistent with other long-term monitoring programs in the SF Estuary and provides the necessary temporal resolution needed to assess long-term trends in fish community abundance, diversity, and spatial distribution (Score = 5, draft FFH SOP Section 3.5).

[6] Draft available here: https://docs.google.com/document/d/14uJR7HH45FlKb7a-PxoAl-5OPefhEBNRJbG__RwN8Pw/edit?usp=sharing.

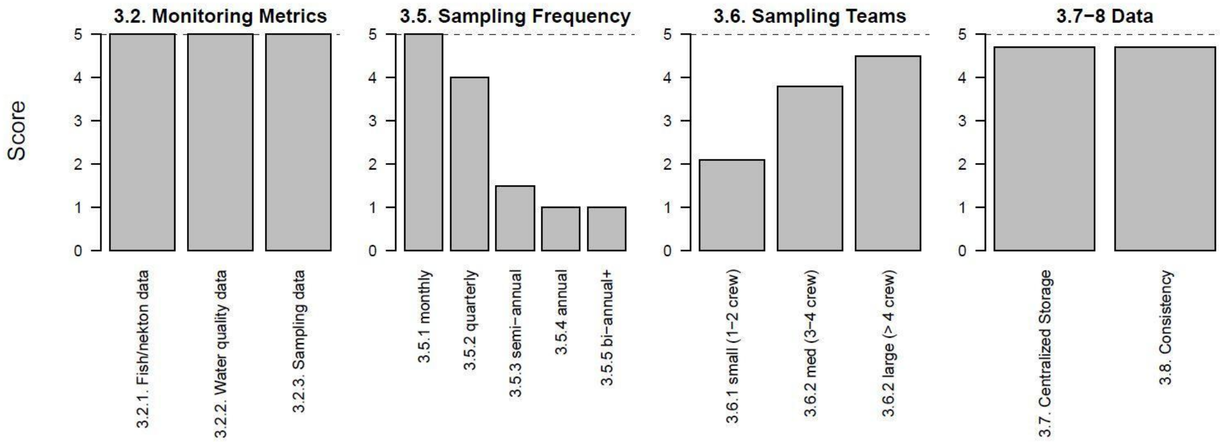


Figure 2. Monitoring considerations that were scored as essential for all three FFH monitoring goals. Mean scores are provided for each monitoring option.

Goal-Specific Monitoring Options

Scores for each option in the remaining monitoring considerations (e.g., focal groups, gears, and habitats) varied considerably among FFH goals (Figure 3). While scores for focal groups and habitats varied somewhat, the greatest variation was observed for gear types which, in part, were linked to the focal groups and habitats. Therefore, details regarding the mostly highly ranked options for focal groups, habitats, and gear types were evaluated separately for each FFH Monitoring Goal.

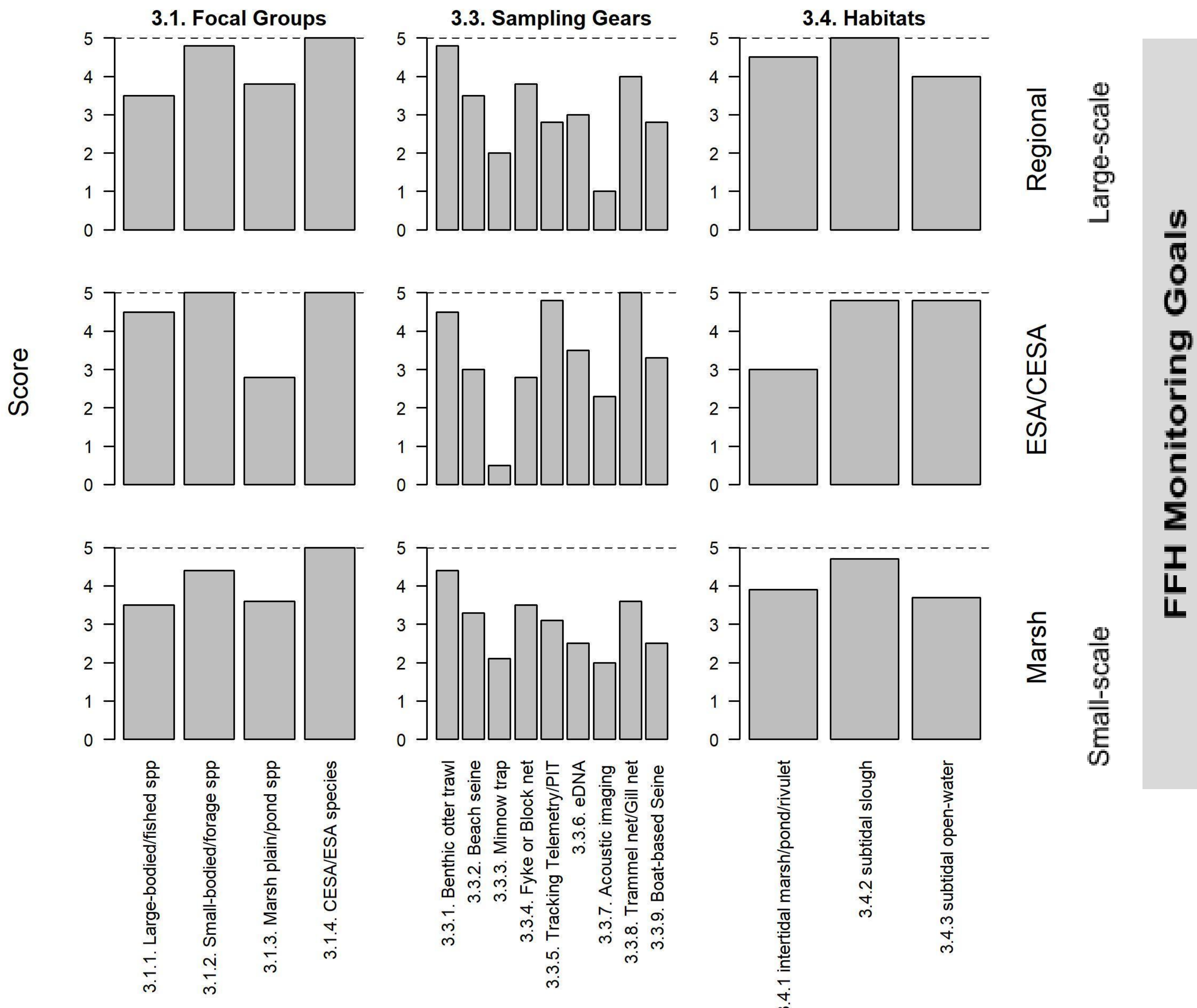


Figure 3. Monitoring considerations with goal-specific scores.

FFH Monitoring Goal 1. Long-term Wetland Monitoring Bay-wide ("Large-scale", Table 1, Figure 2)

For FFH Monitoring Goal 1, establishment of long-term wetland monitoring Bay-wide (Large-scale), monitoring of the "forage fishes, recruits, and macroinvertebrates" focal group ranked highest because this focal group is the most abundant and diverse group of nekton in the tidal sloughs, intertidal channels, ponds, marshes, and rivulets in SFE wetlands. The other focal groups, including "top predators, large bodied fish" and "marsh plain and pond fishes" also ranked highly. Closeness in ranking of focal groups was based on the importance of developing a monitoring program to accurately assess the health of fish communities associated within the complete tidal marsh ecosystem[7].

The highest ranked gears for Large-scale monitoring were benthic otter trawl, trammel net/gill net, fyke or block net, and beach seining. These methods are consistently used in several long-term monitoring programs in the estuary and are appropriate for sampling the identified range of focal fish species and functional groups.

Due to the scale of sampling across the region, in multiple habitat types, a large crew ranked highest for this monitoring goal.

FFH Monitoring Goal 2. Monitoring the use of Wetland Habitats by ESA/CESA Listed Species (Table 1, Figure 3)

For FFH Monitoring Goal 2, monitoring the use of wetland habitats by ESA/CESA listed species in wetlands Bay-wide, monitoring the focal groups of forage fishes, recruits, macroinvertebrates and top predator/large-bodied fishes in sloughs and open water habitat were ranked highest. The highest ranked gears for long-term monitoring had some overlap with Monitoring Goal 1, where benthic otter trawl and trammel net/gill net were ranked highly. However, other methods that are designed to detect individuals in site specific locations were also highly ranked (e.g. acoustic telemetry, PIT tags and receivers to detect tagged fishes such as green sturgeon or salmonids). eDNA also ranked fairly high as an emerging tool with the potential to provide important information on the presence and absence of listed species in the SFE. With the exception of eDNA, all highly-ranked sampling gears are consistently used in several long-term monitoring programs in the estuary and are appropriate for sampling the identified focal fish species

---

[7] The complete tidal marsh ecosystem is described in Goals Project. 2015. The Baylands and Climate Change: What We Can Do. Baylands Habitat Goals Science Update 2015. California State Coastal Conservancy. Oakland, CA: prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project.

and functional groups.

As for Monitoring Goal 1, due to the scale of sampling across the region, in multiple habitat types, a large crew ranked highest for this monitoring goal.

FFH Monitoring Goal 3. Monitoring of Individual Marshes to Provide Context and Guidance to Individual Projects ("Small-scale")

For Monitoring Goal 3, providing context and guidance to individual projects (Small-scale) monitoring the use of wetland habitats by ESA/CESA listed species, monitoring forage fishes, recruits, macroinvertebrates in sloughs and marsh ponds and rivulets was ranked highest. The highest ranked gears for small-scale monitoring had some overlap with Monitoring Goals 1 and 2, where benthic otter trawl, beach seining, and fyke or block net gear was ranked highly. Minnow trapping ranked highly for this Monitoring Goal because minnow traps work well for sampling marsh/pond/rivulet habitats (although there are limitations associated with behavior due to the baiting of traps). With the exception of minnow trapping, these gears are all also consistently used in several long-term monitoring programs in the estuary and are appropriate for sampling the identified focal fish species and functional groups.

Similarly to Monitoring Goals 1 and 2, sampling monthly ranked highest, but a medium size crew may be more appropriate for a small-scale project effort, particularly if the effort involved more walking through a marsh to deploy gear (e.g. minnow traps). However, as noted previously, this goal would be project site specific if sensitive species like Ridgeways Rails or salt marsh harvest mice are present in the area.

Alternative Development

A suite of fish monitoring alternatives were developed from the highest ranked considerations identified in the ranking exercise. Essential elements identified during the considerations rankings were included in all alternatives (Figure 2). Specific options for sampling frequency and team size were discussed an included as follows:

> **Sampling Frequency:** Only monthly sampling (highest ranked frequency for all FFH goals) was included in all final alternatives that were evaluated. Quarterly sampling was discussed at length, and may be appropriate for assessment of long-term trends of life stage-specific abundance and habitat use; however, quarterly sampling was deemed insufficient to fully achieve the monitoring goals in a timely manner due to the variability associated with fish populations from daily, seasonal, and annual drivers. Furthermore, several existing monitoring programs sample monthly for this reason. The subgroup agreed this topic is nuanced, and a monthly sampling program could require considerably more resources than a quarterly sampling program. Participants also discussed several additional sampling frequencies, such as specific sampling for longfin smelt or salmonids that might include intensive sampling during spawning or migration season, or high frequency diel sampling. These additional frequencies were removed from alternatives because they were deemed too specific to accomplish the Long-term monitoring goals of the WRMP and would be better discussed as targeted monitoring efforts or special studies.
>
> **Sampling Team Size:** "Large" team size was the only option included in all proposed alternatives. As for monthly sampling, this was the highest ranked option across all monitoring goals. The rationale was that a large-scale regional program would likely require a large-crew to accomplish the goals; however, the subgroup acknowledged that smaller team size may be appropriate for smaller-scale efforts.

Therefore, the alternatives proposed for evaluation below varied primarily with respect to the gears included, along with the associated focal groups and habitat types for which the gears were deemed most appropriate.

Evaluating Fish Monitoring Alternatives

Fifteen FFH monitoring alternatives were ranked by each member of the FFH subgroup with respect to their ability to satisfy the three FFH monitoring goals (Table 2, Figure 4). Rankings were from zero to three, where zero did not address the monitoring goal, 1 partially addressed the monitoring goal, 2 addressed the monitoring goal and 3 optimally addressed the monitoring goal.

Table 2. Evaluating FFH Monitoring Alternatives[8]

Alternatives	Description	3.3.1. Benthic Otter Trawl	3.3.2. Beach Seine	3.3.3. Minnow Trap	3.3.4. Fyke or Block Net	3.3.5. Acoustic Tracking	3.3.6. eDNA	3.3.7. Acoustic Imaging	3.3.8. Trammel/Gill Net	3.3.9. Boat-based Seine	No. of Gears	1. Large-scale	2. ESA/CESA	3. Small-scale	Composite Score
1	Forage Fishes: Otter Trawls	X									1	2.3	1.4	1	1.6
2	Large-bodied /Fishery Targets: Trammel Nets								X		1	1	1	0.9	1
3	Large-bodied/Fishery Targets: Acoustic					X					1	0.6	1	0.4	0.7
4	Marsh Plain/Pond Species: Minnow Trap			X							1	0.5	0.1	1.4	0.7
5	Marsh Plain/Pond Species: Fyke/Block				X						1	1.3	1	1.9	1.4
6	Marsh Plain/Pond Species: Beach Seine		X								1	1.3	1.3	1.9	1.5
7	Forage fishes+Listed Fishes: OT+ Trammel net	X							X		2	2.3	2.6	1.3	2.1
8	Large-bodied/Fishery Targets: Acoustic + Trammel Nets					X			X		2	1.3	1.5	0.5	1.1
9	Forage Fishes + Marsh Plain Fishes: Beach Seine + Minnow Trap		X	X							2	1	0.8	1.9	1.2
10	Forage Fishes + Marsh Plain Fishes: Beach Seine + Fyke		X		X						2	1	0.9	1.8	1.2
11	Forage Fishes + Listed spp + large-bodied: OT + Acoustic + Trammel Nets	X				X			X		3	2.3	2.8	1	2
12	Forage Fishes + Marsh Fishes + Large-bodied: OT + Trammel + Fyke	X			X				X		3	2.1	2.3	2.4	2.3
13	Forage Fishes + Marsh Fishes + Large-bodied: OT + Trammel + Beach Seine	X	X						X		3	2.4	2.5	2.5	2.5
14	Forage Fishes + Listed spp + Large-bodied + Marsh Fishes: OT + Acoustic + Trammel Nets + Minnow Trap	X		X		X			X		4	2.1	2.3	2.1	2.2
15	Forage Fishes + Listed spp + Large-bodied + Marsh Fishes: OT + Acoustic + Trammel Nets + Beach Seine	X	X			X			X		4	2.4	2.8	2.3	2.5

Score	Description
0	fails to address goal
1	partially addresses goal
2	addresses goal
3	optimally addresses goal

[8] As noted in the text, gear types were limited to those that ranked the highest in the initial evaluation of options. Gear types less commonly used in the SFE, such 3.3.6 eDNA, 3.3.7 Acoustic Imaging (DIDSON/ARIS cameras) and 3.3.9. Boat-based Seine were deemed too specialized to address the FFH goals.

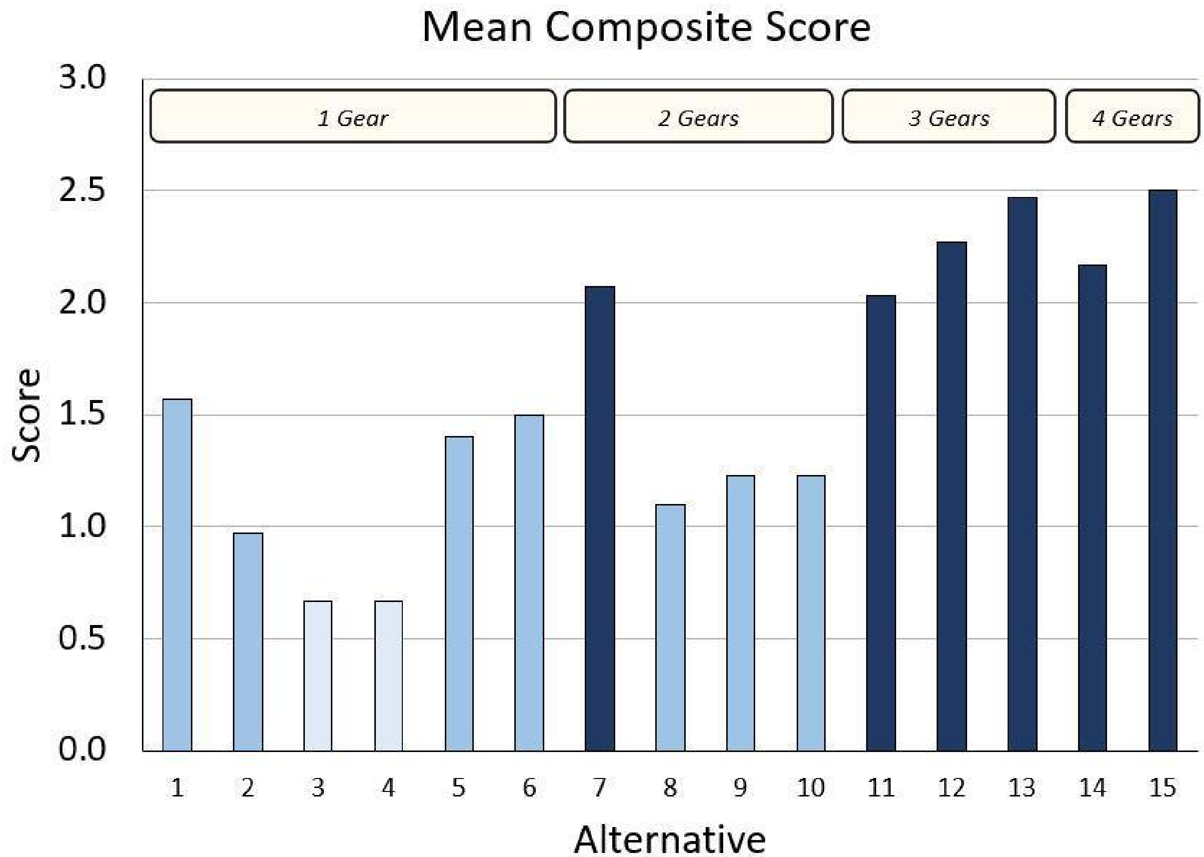


Figure 4. Mean overall composite score for each monitoring alternative. Scores ≥ 2 were determined to satisfy most of the FFH goals.

Single-gear Alternatives: One Gear Type Ranked as Failing to Address Goals.

Alternatives 1 to 6 were limited to one gear type and often targeted a single focal group. These single-gear alternatives were scored as insufficient to satisfactorily address the FFH monitoring goals. However, otter trawls scored highly with respect to their utility in addressing Large-scale Monitoring Goal 1 (Table 2). This is because otter trawls sample a large variety of small-bodied species and in sufficient numbers to be useful in characterizing spatial and temporal trends in abundance. Trammel nets, acoustic tagging, or minnow traps, alone, were each scored as too limited in the scope of questions they could address due to limitations in the habitats/species/sizes they target. However, the unique strengths of each gear type made them complementary monitoring methods that, when combined, could fully satisfy the FFH monitoring goals. For example, trammel nets may be *the* best method for monitoring sturgeon.

Two-gear Alternatives: Otter Trawl and Trammel Nets Address Most Goals.

Alternatives with two gears (Alternatives 7 through 10) were also generally scored as only partially addressing the FFH monitoring goals (Table 2, Figure 4). However, the combination of otter trawls and trammel nets (Alternative 7), was ranked highly (>2) for their joint ability to address Monitoring Goals 1 and 2; however, these only partially addressed the Small-Scale Monitoring Goal 3. The addition of trammel nets to the otter trawl only alternative allows the monitoring to include a broader assortment of fishes and access habitats that may not be accessible with only boats. However, some habitats such as marsh rivulets and smaller ponds may not be best sampled with otter trawls and trammel nets.

Three- and Four-gear Alternatives: Needed to Most Fully Address All Goals.

Alternatives 11 to 15 all included otter trawls and trammel nets, along with one additional gear type that could effectively sample intertidal marsh or pond habitats (e.g., fyke/block nets, beach seines, or minnow traps). Each of these were scored as fully satisfying the FFH monitoring goals. In other cases, however, alternatives with more gear types exhibited lower scores than otter trawl plus trammel net alone because the additional gear did not add value for the monitoring goal. For instance, adding a fyke net increased the ranking for Small-scale Monitoring Goal 3, but lowered the score for Monitoring Goals 1 and 2 because fyke nets are not used in any existing long-term or large-scale monitoring program in the lower SFE, nor were fyke nets ranked as the best gear for capturing ESA/CESA species in these habitats. It is valuable to note, however, that large fyke nets are used in the upper watershed as part of a long-term monitoring program, and they do effectively sample large-bodied species (e.g., Striped Bass) and listed species (e.g., Green Sturgeon, Chinook Salmon). In wetlands of the lower estuary, however, the fyke nets previously used are much smaller and would likely be designed to sample intertidal channels and rivulets in marsh habitats.

Alternative 13 (otter trawl + trammel net + beach seine) was the highest-ranking three-gear alternative considered. All three of these gears are currently used in existing long-term monitoring programs and are complementary, maximizing the program's ability to capture the widest array of species in the broadest suite of habitat types.

Additional Gears and Considerations

Acoustic tracking methods for detecting green sturgeon and salmonids increased the rankings for Monitoring Goal 2 ESA/CESA listed species. The addition of acoustic gear greatly increased the score for Monitoring Goal 2 because current long-term efforts for sturgeon lack receivers below the Bay Bridge and information is lacking on potential use of wetland habitats and adjacent subtidal mudflat in the SF Bay by this threatened species, which may benefit from tidal habitat restoration. The Interagency Ecological Program's Green Sturgeon Coordination Team strongly encouraged the importance of including this gear type for the long term management of this species in benchmark locations to fill a critical information gap identified in the 5-year status review for the most recent Green Sturgeon Recovery Plan Review[9].

Additionally, PIT tag data for steelhead, especially in the lower SFE and Bays, are limited and not readily available nor synthesized. Although juvenile salmonids are known to benefit from estuarine rearing in other north coast populations, there are few studies that have studied this life stage and habitat in the lower SFE, although prior otter trawl and acoustic studies have identified their presence in these habitats. More attention should likely be directed to considering how the WRMP can monitor salmonids in the complete tidal marsh ecosystem to inform life cycle models and better understand how these habitats can contribute to recovery of threatened and endangered salmonids. Alternatively, the WRMP may be able to at a minimum provide a place to store and manage the data that are available and incorporate new data as it becomes available.

Finally, eDNA has been used in estuarine environments to assess species presence and biodiversity in sediment and plankton communities (e.g. Ruppert et al. 2019[10]) as well as estimate abundance and distribution (e.g. Shelton et al. 2022[11]). Several projects are exploring the use of eDNA to detect rare species in the upper estuary. As with any emerging technology, using eDNA to assess diversity in tidal marsh habitats has limitations, but should be considered for use as an additional non-invasive tool to supplement traditional fisheries sampling methods to increase understanding of presence of rare species in restored habitats, better understand the effectiveness of this tool, and potentially be integrated in to the WRMP at the program level in the future.

---

[9] NMFS. 2021. Southern Distinct Population Segment of North American Green Sturgeon (Acipenser medirostris) 5-Year Review: Summary and Evaluation. Available online: https://www.fisheries.noaa.gov/resource/document/green-sturgeon-5-year-review

[10] Ruppert, K. M., R. J. Kline, and M. S. Rahman. 2019. Past, present, and future perspectives of environmental DNA (eDNA) metabarcoding: A systematic review in methods, monitoring, and applications of global eDNA. Global Ecology and Conservation 17: e00547.

[11] Shelton, A., A. Ramón-Laca, A. Wells, J. Clemons, D. Chu, B. Feist, R. Kelly, S. Parker-Stetter, R. Thomas, K. Nichols, and L. Park. 2022. Environmental DNA provides quantitative estimates of Pacific hake abundance and distribution in the open ocean.Proceedings of the Royal Society B: Biological sciences. 289. 20212613. 10.1098/rspb.2021.2613.

Benchmark Locations for Fish Sampling

The WRMP TAC identified several wetland habitats throughout the SFE that can serve as benchmark sites[12]. These sites are intended to provide a long-term baseline of the status and trends for SFE wetland ecosystems (Table 3). The FFH subgroup evaluated the current list of benchmark locations with respect to the three FFH monitoring goals identified above. Sites were re-classified with respect to their association with major watersheds and tributaries of the lower SFE, including the Sacramento-San Joaquin Delta, Petaluma River Watershed, Sonoma Creek Watershed, Napa River Watershed, Alameda Creek Watershed, and Coyote Creek Watershed. Other sites were considered "fringing" around the margins of the lower SFE. Large-scale monitoring goals were proposed as most valuable at sites adjacent to major tributaries, that are important to recovery objectives for imperiled species, as well as to capture regional patterns in estuarine dynamics. ESA/CESA and marsh-specific monitoring goals were considered valuable across all proposed benchmark sites.

Additionally, some of the locations below already have on-going fish monitoring at the proposed benchmark location. The FFH subgroup anticipates that some coordination with those efforts may be possible to leverage existing data and lessen the sampling burden of the WRMP.

[12] WRMP Technical Memorandum on Benchmark Sites, available on-line:
https://www.wrmp.org/wp-content/uploads/2021/12/WRMP-TAC-Benchmark-site-recommendations_20210315_ADA.pdf

Table 3. Proposed WRMP benchmark sites and proposed sampling to satisfy the FFH goals of the WRMP (MJ = Major Tributary, FR = Fringing Marsh)

	Suisun/West Delta*		**North Bay**			**Central Bay**		**South Bay**		**Lower South Bay**		
	Brown's Island	**Rush Ranch**	Older Coon Island/Fagan Marsh	Petaluma Marsh	**China Camp**	**Wildcat Creek**	Heerdt Marsh	Whale's Tail	**Greco Island**	**Laumeister Marsh**	Dumbarton Point	Older Warm Springs Marsh
	MT:Sac-SJ R.	MT Sac-SJ R.	MT: Napa R.	MTb: Petaluma R.	FR	FR	FR	MT: Alameda Cr.	FR	FR	FF	MTb: Coyote Cr.
Current Proposed locations for fish	x	x	x	x			x		x			x
1. Large-scale/ Regional Monitoring	x	x	x	x				x				x
2. Listed species Monitoring	x	x	x	x	x	x	x	x	x	x	x	x
3. Marsh-specific Monitoring	x	x	x	x	x	x	x	x	x	x	x	x

* Sites in Suisun Marsh and the West Delta are proposed for the WRMP benchmark monitoring, however long term monitoring for fish and fish habitat is extensive and ongoing in these areas. No new fish and fish habitat monitoring is proposed for these areas, but the WRMP would leverage available data from those efforts.

Reference Locations for Fish Sampling

The WRMP is currently evaluating additional reference locations for fish sampling that may be evaluated by the FFH at a later date.

Appendix 2.

[DRAFT] Inventory of Fish Studies in the Lower San Francisco Estuary

Ichthyofaunal Sampling in Brackish and Saline Wetlands of the San Francisco Estuary: *A review with implications for developing an integrated wetland monitoring program*

L. Lewis[1], A. Weber-Stover[2], Z. Duckworth[2], S. Randall[3, 4], L. Wang[2], E. Farley[3], M. Williams[3], C. Toms[3]

[1] University of California, Davis
[2] NOAA Fisheries, West Coast region
[3] San Francisco Bay Regional Water Quality Control Board
[4] San Francisco State University

Abstract

Long-term, standardized datasets are integral to understanding the status and dynamics of complex ecosystems. In wetlands, the monitoring of aquatic communities can provide valuable information regarding variation in water quality and ecosystem health, both of which are critical for guiding management and restoration. For example, patterns in the abundance, diversity, and structure of fish communities can be used to assess the responses of wetland ecosystems to human impacts, restoration, and climate change. Such information is critical to the San Francisco Estuary (SFE), where 95% of wetlands have been severely degraded. However, most long-term monitoring of aquatic wetland communities in the SFE has focused on freshwater and low-salinity habitats of the "Upper Estuary" (e.g., the Delta and Suisun Bay). Much less is known about the extensive brackish and saline wetlands throughout the "Lower Estuary", including San Pablo Bay and San Francisco Bay. Nevertheless, the collation and review of numerous short-term studies can provide valuable information to help guide future monitoring, management, and restoration in these ecosystems. Here we conducted a literature review to identify, catalog, and summarize prior and ongoing studies of fishes in brackish and saline tidal wetlands throughout the SFE. Specifically, we explored spatiotemporal patterns in prior monitoring efforts, including the regions and habitats sampled, gears utilized, environmental data collected, and observations of managed species. The results highlight best practices and critical information gaps–key information that will be used to guide future restoration and the establishment of long-term monitoring in wetlands of the lower SFE.

Table of Contents

List of Tables

List of Figures

Introduction

The Value of Long-Term Ecological Monitoring

Long-term standardized datasets are key to understanding ecological dynamics and the relative effects of natural versus anthropogenic drivers of ecosystem change (Magurran et al. 2010, Cloern & Jassby 2012, Stompe et al. 2020, Cusser et al. 2021, Tempel et al. 2021). For example, the relative influence of different mechanisms driving ecological variation may themselves vary in space and time, with mechanistic relationships strengthening and weakening over broad spatiotemporal scales (Tamburello et al. 2019). Thus, long-term monitoring is needed to increase the scope and scale of understanding with respect to ecological dynamics, and by doing so, can reduce uncertainty in resource management decision making (Walters 1986, Lund et al. 2016). Furthermore, as the ecological literature and computational tools evolve, new inferences based on updated analyses of carefully-planned long-term monitoring datasets can contribute greatly to an improved understanding of myriad ecosystem processes (Reynolds et al. 2016).

Aquatic communities reflect the health of estuaries

In estuaries, the monitoring of aquatic communities can provide important information on water quality and ecosystem health, each of which are important for guiding the management and restoration of wetland ecosystems (SWRCB 2004). The diversity and structure of fish communities, for example, reflect the overall ecological integrity (i.e., chemical, physical, and biological integrity) of an ecosystem. Thus, in addition to providing information to help manage individually regulated fish populations, the monitoring of fish and aquatic communities can also be important for understanding broader integrated patterns of biotic integrity (Whitfield & Elliott 2002, Cooper et al. 2018). This is because the cumulative effects of multiple factors such as eutrophication, pollutants, temperature, and sediment loading are integrated by biological communities over time, with changes in aquatic communities reflecting how well a habitat can support aquatic life.

The application of biological assessments in aquatic habitats

Biological assessments such as the index of biological integrity (IBI), River Invertebrate Prediction and Classification System (RIVPACS), and benthic macroinvertebrate index (BMI) are valuable community-based metrics that are commonly used to evaluate the biotic integrity of ecosystems (Barbour et al. 1999, SWRCB 2004), and such indicators have been applied to fishes in a variety of wetland habitats, providing important data for the assessment and management of anthropogenic stressors, and for evaluating the responses of aquatic communities to habitat restoration and environmental change (SWRCB 2004, MacVean et al. 2018, Cooper et al. 2018). Such time-integrated cumulative impacts are rarely evident with short-term or discrete observations of physical environmental conditions, thus emphasizing the need for long-term ecological monitoring of aquatic communities.

Long-term monitoring of fishes in the San Francisco Estuary

Long-term monitoring in the San Francisco Estuary (SFE) has been conducted by numerous federal and state agencies, with efforts historically coordinated by interagency collaborations such as the CALFED Bay-Delta Program and the Interagency Ecological Program (IEP) (Healey et al. 2008, 2016, Stompe et al. 2020, Tempel et al. 2021, Bashevkin et al. 2022a). These coordinated long-term (some > 50 years) monitoring efforts have identified many ecologically significant patterns and changes in the SFE, thus informing numerous important decisions and policies pertaining to resource management and conservation in the SFE (Sommer et al. 2007, Nobriga et al. 2008, Nobriga & Rosenfield 2016, Cloern et al. 2016, O'Rear & Moyle 2017, Mahardja et al. 2017, 2019).

However, most of these long-term monitoring programs have focused on freshwater and low-salinity habitats of the Sacramento-San Joaquin River Delta and Suisun Bay ("Upper Estuary"), where monitoring is required by state and federal resource agencies to evaluate and mitigate the impacts of water management practices (Reis et al. 2019). Only one IEP long-term monitoring program, the San Francisco Bay Study (SFBS), operated by the California Department of Fish and Wildlife (CDFW), has conducted sampling of fishes and invertebrates in deeper, open-water habitats across all regions of the SFE. However, this survey fails to sample the shallower tributaries, sloughs, and tidal wetlands that occur throughout the margins of the "Lower Estuary," including San Pablo Bay, and Central, South, and Lower-South San Francisco Bay.

Monitoring brackish-saline wetlands of the lower SFE

In stark contrast with the Upper Estuary, long-term monitoring in brackish-saline wetlands of the lower SFE is largely lacking. This lack of knowledge is of great concern, considering that 95% of wetland habitats within San Francisco Bay have been lost or degraded, along with many of the critical ecological services that these habitats provide (Nichols et al. 1986, Lotze et al. 2006, Goals Project 2015). Furthermore, ongoing efforts to restore vast areas of degraded wetlands throughout the SFE (Valoppi 2018), require a robust science enterprise to inform key management decisions and evaluate drivers of ecological change (Cloern & Jassby 2012). However, nearly all prior ecological studies in brackish-saline wetland habitats of the Lower Estuary have been short-term, isolated projects that lack an integrated regional approach to planning and design. Furthermore, although much effort has been placed on the review and synthesis of prior studies in the Upper Estuary (Nelitz et al. 2020), no such analyses have been conducted for monitoring studies in the Lower Estuary. As a result, relatively little is known about the comparative ecology, health, and status of aquatic communities in wetlands throughout much of the SFE, thus limiting inferences that can be made regarding spatiotemporal patterns and processes that are key to effective wetland management and restoration.

The Wetland Regional Monitoring Program (WRMP) of the SFE

Over the past several decades, interagency resource management groups such as CALFED and the IEP have identified the need for project work teams to develop robust monitoring programs for shallow-water wetland habitats throughout the SFE (Herrgesell 2012, IEP TWM PWT 2017). The Wetland Regional Monitoring Program (WRMP) is a recent multi-agency collaborative effort to address this need by establishing long-term monitoring in wetlands throughout the lower SFE (WRMP SC 2020). The ultimate goal is to develop a monitoring program that will produce data at relevant spatial and temporal scales to inform and improve the management and restoration of wetland habitats throughout the SFE. To accomplish this, the WRMP is establishing a network of monitoring sites in brackish and saline wetlands across the SFE, along with standard monitoring protocols, and an open data sharing platform. Conceptually, healthy wetlands would be characterized, in part, by improved physical and biological conditions that support thriving aquatic communities. Thus a key element of the WRMP is the collection and analysis of long-term data on the status and trends of aquatic wetland communities, especially native fishes.

Study objectives

Although wetlands of the Lower SFE lack long-term monitoring, the collection and review of numerous independent studies can help inform on-going restoration and the development of a regional monitoring program. Here we conducted a literature review to identify, catalog, and summarize prior and ongoing studies of fishes in brackish and saline tidal wetlands of the lower SFE. Specifically, we aimed to explore spatiotemporal variation in sampling activity, the diversity of methods utilized, types of data that were collected, and the presence of certain focal species, including those listed under state and federal Endangered Species Acts. Specifically, we summarized (a) where fish monitoring occurred in brackish and saline wetland habitats of the SFE, (b) when monitoring occurred and for how long, (c) what sampling methods were utilized, (d) which environmental data were collected, and (e) what managed species were observed. Furthermore, we aimed to identify common practices, information gaps, and provide recommendations to inform future coordinated monitoring of fishes in brackish and saline wetland habitats throughout the lower SFE.

Methods

Study site

The SFE is the largest estuary in California, characterized by an Upper Estuary which receives the majority of freshwater inputs from the Sacramento River and San Joaquin River watersheds that each flow into the North and South Delta, respectively, converging in Suisun Bay and eventually flowing into San Francisco Bay (Fig. 1). The Mediterranean climate of the SFE results in dynamic conditions, with freshwater flows, salinity gradients, and temperature gradients varying seasonally, with cool-wet winters and warm-dry summers (Cloern & Jassby 2012). Native estuarine fishes have evolved to survive within these stressful ecosystems (Fichman et al. 2021); however, human alterations to the habitats, hydrograph, and climate are compressing the quality and quantity of habitats available to native species (Brown et al. 2016, Cloern et al. 2016).

The SFE is a highly altered ecosystem, with 7.5 million neighboring residents, valuable commercial shipping and agriculture industries, thousands of dams and diversions that modify the hydrograph, a variety of important commercial and recreational fisheries, numerous introduced non-native species, and >50 wastewater treatment facilities that each discharge nutrients directly into the waterways (Nichols et al. 1986, Cloern & Jassby 2012, Cloern et al. 2016, Liu et al. 2018). Due to human activities, more than 95% of tidal marsh habitats have been degraded within the SFE, thus impacting the numerous species and important ecological processes that depend on them. Furthermore, thermal stress due to climate change is increasingly impacting SFE wetlands, and reduced freshwater outflows due to the combined effects of diversions and climate change are likely to push salinity gradients further inland, thus exacerbating warming trends (Nobriga et al. 2008, Feyrer et al. 2011, Brown et al. 2016, Cloern et al. 2016).

Geographic and ecological scope

This study aimed to identify, collate, and summarize independent long-term and short-term studies that have sampled wetland fish communities in brackish-saline wetlands of the San Francisco Estuary. The geographic scope includes wetland habitats that occur within several subregions of the SFE, including Suisun Bay, San Pablo Bay, and San Francisco Bay (including Central Bay, South Bay, and Lower South Bay) (Figure 1). The scope spans several aquatic habitat types considered part of the “complete tidal marsh ecosystem” (CTME), including wetted baylands (intertidal mud flats, vegetated marshes, and associated creeks and rivulets), tidally restored ponds or polders, and shallow subtidal habitats (including sloughs and open-water shoals) to a depth of 3.7 m below local Mean Lower Low Water (Goals Project 2015). Here, we characterize the distribution and intensity of fish sampling that has previously occurred in the lower SFE with respect to various subregions, watersheds, habitats, sampling gears, water quality parameters, and managed species. Specifically, this review focused on direct methods for quantifying the abundance and distribution of juvenile and adult life stages of common wetland-associated fishes, and did not include methods for sampling ichthyoplankton, birds, zooplankton, contaminants, benthic infauna, and other parameters deemed beyond the scope of the study.

Project selection

A literature review was conducted using Web of Science, Google Scholar, and by contacting a broad network of fisheries researchers and managers in the SFE. A total of 80 documents, including monitoring reports, targeted research, synthesis studies, conceptual models, literature reviews, and monitoring frameworks, were compiled for review and assessment. Documents were evaluated to identify projects that (a) incorporated data from fish surveys, (b) occurred within the geographic scope of this study, and (c) provided sufficient metadata for inclusion in this review. Here, a "project" was defined as a contiguous study conducted by the same entity using generally consistent methodology. Thus a project could represent different types of activities such as a long-term monitoring program, short-term compliance monitoring effort, or scientific study; and multiple reports or documents could be associated with a single project. Projects that were designed to target specific pelagic fishes (e.g., Delta Smelt and juvenile Striped Bass) in open water, while omitting many benthic species (e.g., gobies, sculpins, flatfishes, sharks, rays, etc.) that are common to wetland habitats, were not included. Similarly, studies targeting planktonic organisms, including ichthyoplankton, were not included.

Database Development

Information regarding the duration of monitoring, gear types, habitat types, environmental data, select listed and managed species, and geospatial information were recorded at the project-level and station-level, where applicable. Project-specific data (Table 1) included those assigned to projects, but not to individual stations. These included factors such as project duration, environmental parameters, and listed/managed species. Station-specific data (Table 2) were those that were assigned to each station. Station-specific data included factors such as sampling duration, habitat type, latitude, and longitude. Project-specific and station-specific data could be linked using a unique project-specific identifier, "Project ID"; thus tables functioned as a relational database that could be integrated, visualized, and analyzed using common geographic information systems (GIS) and statistical software. Although some metrics were assigned at both the project- and station-level, others were only assigned to one or the other. For example, "subregion" was assigned to both projects and stations, with large-scale projects spanning multiple subregions. In contrast, habitat type was only assigned to stations, and environmental parameters were only assigned to projects.

Project-specific data

Project duration was calculated as the total number of calendar years in which a project actively conducted sampling. For example, Project Duration = 1 for a project starting and ending within the same calendar year, Project Duration = 5 for a project sampling in all years from 2014-2018, and Project Duration = 3 for a project sampling intermittently during 2014-2015 and 2019. Project Duration was used as a coarse approximation to contrast variation among individual projects and project-specific metrics, with respect to their total relative effort, measured here as the total number of years in which sampling occurred. Project Duration, however, does not capture the true intensity of sampling by a project, which is also a function of the number of stations, sampling frequency, and sampling-event-specific sampling effort. Station-specific data were also collected and evaluated for factors with available station-level data (see “Station-specific Data”).

Data on species (and genetically-distinct populations) of fishes for which specific government protections exist was also compiled for each project. To accomplish this, a select group of “listed/managed species” was identified, with observations of each taxon recorded for each project. Select taxa are either protected or intensively managed under the United States Endangered Species Act (ESA), California Endangered Species Act (CESA), or other special fisheries regulations (e.g., Magnuson-Stevens Act). Species included Longfin Smelt (*Spirinchus thaleichthys*, CESA-threatened, ESA-candidate), Delta Smelt (*Hypomesus transpacificus*, ESA-threatened, CESA-endangered), Green Sturgeon (*Acipenser medirostris, Southern DPS*, ESA-threatened), Winter-run Chinook Salmon (*Oncorhynchus tshawytscha*, CESA and ESA-endangered), Spring-run Chinook Salmon (*O. tshawytscha*, CESA and ESA-endangered), , Central Valley and California Central Coast varieties of Steelhead (*O. mykiss*, ESA-threatened), Fall-run Chinook Salmon (*O. tshawytscha*, managed under the Pacific Coast Salmon Fishery Management Plan), and varieties of Chinook Salmon and non-specified Salmonids (steelhead or salmon) for which specific runs or population segments were not identified. Few projects provided station-specific species occurrences; thus all taxonomic comparisons were conducted at the project-level.

Environmental data that was collected in association of fish monitoring was often recorded for each project. Common metrics included temperature, salinity, and dissolved oxygen, as well as other sampling information related to tidal conditions or sampling depth (see Appendix 3). Environmental data was reported at the project-level, but could not be discerned at the station level.

Station-specific data

Sampling duration was calculated as the total number of calendar years in which a given station was sampled at least once. As for project duration, sampling duration was used as a coarse approximation for assessing the relative amount of effort that occurred at a given station, and for station-specific metrics, thus facilitating contrasts of spatial patterns in relative sampling activity across subregions, habitat types, and watershed-level operational landscape units (OLUs) (SFEI and SPUR 2019). Although sampling duration was useful for assessing broad patterns in activity, it did not fully capture intensity of sampling at a given station, which is also a function of the station-specific sampling frequency and event-specific sampling effort; data which were not readily available for many of the monitoring projects included in this review.

Most projects repeatedly sampled fixed stations, however the use of random or stratified-random sampling designs could complicate comparisons of sampling duration. For example, the UC Davis (UCD) North Bay Otter Trawl & Plankton Study (NBOTS) was unique in that stations were randomly selected each month over the six-year monitoring period. Although the duration for this project could be listed as six years, individual stations varied each month and were not repeatedly visited across years. To reduce the number of stations and improve comparability with other surveys, NBOTS stations were aggregated into sampling polygons as defined by the study, with each polygon representing from one to twenty original stations. Polygon centroids were then treated as "stations" and assigned a sampling duration of 1 year (the minimum value) instead of 6, thus reducing their relative influence. Nevertheless, the large number of polygons sampled by NBOTS may have influenced some analyses, thus these differences in survey design should be considered when interpreting the results.

Habitat types

Each station was assigned a "habitat type" based on its geographic location and intersection with habitat layers in the Bay Area Aquatic Resources Inventory (BAARI) (SFEI 2017), accessed through the California Aquatic Resources Inventory (CARI, v. 0.3). For the present study, BAARI habitat layers were aggregated into higher-level groupings: "pond/polder" ("depressional" and "estuarine pond" in BAARI), "marsh/mudflat" ("estuarine intertidal" and "estuarine intertidal vegetated" in BAARI), and "slough and open water" ("estuarine subtidal" in BAARI). BAARI habitat layers were most recently updated in 2017; therefore, they reflect conditions prior to recent changes due to ongoing restoration activities (Valoppi 2018). To assure the quality and accuracy of GPS data and habitat designations, all stations were mapped in ArcGIS Pro (2.9.1, ESRI) and their habitat designation confirmed or adjusted in relation to underlying BAARI shapefiles, Google Earth satellite imagery, and expert knowledge within each region.

Data synthesis and visualization

Variation in sampling activity among projects, regions, OLUs, subregions, and habitat types was evaluated using summary statistics, plotting, and mapping. Projects were contrasted with respect to their duration, gear types utilized, listed/managed species observed, and measured environmental parameters. The number of stations, as an estimate of monitoring activity, was then contrasted among OLUs, habitat types, gear types, sampling duration, and habitat types. Maps were constructed to visualize the spatial distribution of sampling activity across subregions, habitats, and gear types. All analyses, plotting, and mapping were conducted using R version 4.2.2 (R Core Team 2019).

Results

Summary of monitoring projects

A total of 25 individual wetland fish monitoring projects consisting of 565 stations were identified for inclusion in this review (Table 1). Projects ranged from 1 to > 40 years in duration and sampled diverse habitats (e.g., tidal marshes, mudflats, managed ponds/polders, sloughs and open-water habitats) across 22 OLUs within all 5 SFE subregions that contain brackish-saline wetlands. Projects utilized a total of 17 different fish-sampling gear types (e.g., otter trawls, beach seines, gill nets, and fyke nets) and measured 16 distinct environmental parameters (e.g., temperature, salinity, and water clarity). Projects observed several listed and managed fish species (and populations) including Chinook Salmon, Steelhead, Sturgeon, and Smelt.

Three long-term (duration > 20 years) IEP monitoring projects were included in the study, including the UC Davis Suisun Marsh Otter Trawl & Beach Seine Survey (SMFMD), the California Department of Fish and Wildlife (CDFW) San Francisco Bay Study Otter Trawl Survey (SFBS), and the CDFW Delta Juvenile Fish Monitoring Program Beach Seine Survey (DJFMP). However, several other long-term IEP surveys were deemed to be beyond the scope of the present study. For example, the CDFW Spring Kodiak Trawl, CDFW Fall Midwater Trawl, and US Fish and Wildlife Service Enhanced Delta Smelt Monitoring Survey were not included because each program was designed to target specific pelagic fishes (e.g., Delta Smelt and juvenile Striped Bass) while omitting key benthic species (e.g., gobies, sculpins, flatfishes, sharks, rays, etc.) that are characteristic to brackish-saline wetlands of the SFE. Similarly, studies targeting planktonic organisms, including ichthyoplankton (e.g., CDFW Smelt Larval Survey and 20mm Survey) were not included in analyses.

Project duration

Of the 25 projects included in this study, 21 (84%) were classified as “short-term” projects (duration < 6 years), with the most lasting only 1 to 3 years (Fig. 2). Three projects (12%, including the DJFMP, SFBS, and SMFMD) were considered “long-term” projects (duration > 20 years) (Fig. 3). Each of these long-term programs receive continuous funding from the U.S. Bureau of Reclamation (USBR) and/or the California Department of Water Resources (DWR). In contrast, only one project, the UC Davis South Bay Otter Trawl Survey (SBOTS) was identified as a “medium-term” project (duration 7-20 years), having sampled for 13 years. In contrast to long-term projects, SBOTS has thus far been sustained by a less-reliable patchwork of small short-term grants from the City of San Jose, SBSPRP, and NOAA Fisheries; as well as by dedicated volunteers who assist with monthly field sampling.

Geographic Distribution

The geographic distribution of sampling activity varied widely among projects. Two long-term projects (SFBS and DJFMP) sampled broadly and diffusely across multiple subregions of the SFE, including South Bay, Central Bay, San Pablo Bay, and Suisun Bay (Fig. 2). These projects also included numerous stations beyond the scope of this study, in freshwater habitats of the Sacramento-San Joaquin River Delta. One long-term (SMFMD) and one medium-term (SBOTS) project, each focusing on a specific marsh ecosystem, sampled more densely throughout a single subregion (Suisun Bay and Lower South Bay, respectively). In contrast, short-term projects were sampled more intensively within even smaller geographic areas, typically within individual subregions and often within just one or two individual OLUs (Figs. 3,4).

Sampling activity also varied spatially among subregions and OLUs of the SFE (Fig. 4). For example, San Pablo Bay exhibited the highest number of sampling stations (n = 250); though, this number was influenced in part by the randomized design of SBOTS. Lower South Bay contained the next highest number of stations (n = 175), followed by South Bay (n = 75), Suisun Bay (n = 40), and Central Bay (n = 10) (Fig. 4a). Two OLUs in particular exhibited exceptionally high numbers of stations, with the highest number occurring within the Santa Clara Valley OLU in Lower South Bay (n = 160), and the second highest number occurring in the Napa-Sonoma OLU in San Pablo Bay (n = 145) (Fig. 4b). Each of these two OLUs contained > 400% more stations than any other OLU in the study. Most of these patterns are driven by stations belonging to short-term projects. In contrast, relatively little long-term sampling has occurred in brackish-saline wetlands of the SFE, particularly within tidal marshes, mudflats and sloughs of San Pablo Bay, South Bay, and Lower South Bay; where extensive restoration has occurred or is planned for the future (Valoppi 2018).

Habitat Types

Sampling activity also varied among habitat types. Overall, 46.5% (n = 263) of stations occurred within “slough/open-water” habitats, 39.8% (n = 225) within “tidal marsh/mudflat” habitats and 13.6% (n = 77) within muted tidal pond/polder habitats (Fig. 4c). The Napa-Sonoma and Santa Clara Valley OLUs exhibited similarly high numbers of stations; however, these were distributed differently among the three habitat types. For example, 75.2% (n = 106) of stations in the Napa-Sonoma OLU occurred within slough/open-water habitats, whereas 77.0% (n = 124) of stations in the Santa Clara OLU occurred within either tidal marsh/mudflat (48.4%, n = 78) or tidal pond/polder habitats (28.6%, n = 46) (Fig. 4d).

Gear types

A total of 17 different gear types were used to sample fishes in SFE wetlands, with the number of gear types utilized by a project varying from 1 to 7 (median = 2) (Fig. 3b). Beach seines, otter trawls, gill nets, and minnow traps were the most commonly used gears (Fig. 3b, Fig. 5a-b). Of the 25 projects in this study, 52% (n=13) used beach seines, 44% (n=11) otter trawls, 24% (n=6) gill nets, and 24% (n=6) minnow traps (Fig. 5a). Similarly, of the 565 stations included in this study, 55% (n=310) used otter trawls, 28% (n=160) beach seines, 16% (n=90) gill nets, and 13% (n=72) minnow traps (Fig. 5b). We note that the randomized survey design of NBOTS may have influenced the number of otter trawl stations.

The utilization of each gear type also varied among habitats (Figs. 5b, 6). In "tidal marsh/ mudflat" habitats, 42% (n = 95) of stations used beach seines, 32% (n = 73) otter trawls, and 21% (n = 47) gill nets. In "managed ponds/polders," 65% (n = 50) of stations used beach seines, 26% (n = 20) gill nets, and 30% (n = 23) minnow traps. In slough/open-water habitats, 89% (n = 223) of stations used otter trawls and 9% (n = 23) gill net, and 9% (n = 23) midwater trawl.

The majority of otter trawl stations (74%, n = 233) occurred within slough/open-water habitats (Figs. 5b, 6). In contrast, the majority of beach seines 91% (n = 145) were conducted in either "marsh/mudflat" 59% (n = 95) or "pond/polder" 31% (n = 50) habitats. Gill nets and minnow traps were deployed more evenly (25%-50%) within each of the three habitat types, whereas fyke/block nets were used almost exclusively (92%, n = 25) within marsh/mudflat habitats. Patterns in the application of different fish sampling gear types varied across SFE subregions (Fig. 7). Otter trawls and beach seines were the most widely distributed gears, having been used across all five SFE subregions. Gill nets and minnow traps have also been utilized in marshes across several subregions; however, most were concentrated in South Bay and Lower South Bay (Fig. 7).

Listed/managed species

Of the 25 projects in this inventory, 12 (48%) observed zero and (52%, n = 13) observed at least one listed/managed species (defined above) (Fig. 3c). The total number of listed species observed (including all distinct salmonid populations) ranged from 0 to 6, with a median of 2 spp. Salmonids were observed by 44% (n=11) of projects, Longfin Smelt by 36% (n=9) of projects, Delta Smelt by 16% (n=4) of projects, and Green Sturgeon by 16% (n=4) of projects.

A total of 9 (36%) of projects observed multiple (2 or more) listed/managed species (Fig. 3c). The greatest diversity of listed/managed species was observed by the three long-term projects: DJFMP (6 spp), SFBS (5 spp), and SMFMD (5 spp), including all distinct salmonid populations. Inclusive of the long-term projects, most listed/managed species were observed by projects using otter trawl and beach seine gear types. CCC Steelhead were observed by the NBOTS and SBOTS projects (using otter trawls), as well as by telemetry in the SOGRW project. Green Sturgeon were observed by the SFBS, SMFMD, and SBDA (all using otter trawls), and by the SFBLS (using telemetry). Winter-run and Spring-run Chinook Salmon and CV Steelhead were observed only in the DJFMP Beach Seine Study.

As previously noted, data on listed/managed species were only evaluated at the project level, as data often could not be linked to individual stations. Therefore, for projects that have stations both inside and outside of brackish-saline wetlands (e.g., DJFMP and SFBS), reported observations of listed/managed species may have occurred beyond the geographic scope of this study. Similarly, two gear types (otter trawl and midwater trawl) were utilized by the SFBS, thus catches of some listed species may have not been specific to the otter trawl gear type.

Discussion

Summary

Here, we reviewed a total of 25 projects conducted over the past 40 years that sampled fish communities in brackish-saline wetlands of the San Francisco Estuary. During this period, sampling was conducted at 565 stations spread across 17 watersheds within all 5 major subregions of the SFE that lie within the scope of the study. Results of these analyses provide answers to key questions regarding spatiotemporal patterns and features of previous monitoring efforts with respect to the timing and duration; the subregions, watersheds (OLUs), and habitats sampled; and the gear types, environmental parameters, and observed listed/managed species. Our analyses highlight that long-term monitoring is lacking in wetlands of the lower estuary, where 95% of habitats are degraded and significant restoration activity is planned and ongoing. Furthermore, we highlight that these habitats are central to the recovery planning for several listed fish species, including Longfin Smelt and Central California Coast Steelhead. Results of these analyses are vital for informing key decisions regarding the restoration and monitoring of the SFE’s wetland ecosystems, and in forecasting how they will respond to local stressors, restoration, and climate change.

Inferences regarding sampling methods for aquatic wetland communities

Otter trawls and beach seines were the most commonly utilized gears for sampling wetland habitats throughout the SFE. Similarly, the most common environmental data collected in association with fish sampling included salinity, temperature, water clarity, and dissolved oxygen. Thus, inclusion of these gear types and environmental data in future wetland monitoring efforts is likely key to maximizing the value of new. For example, standardized methods allow for the leveraging of other long-term and broad-scale monitoring programs in order to contextualize the spatial and temporal relevance of new data that are collected. However, inclusion of other gear types and environmental data may also be valuable. Although otter trawls may be optimal for sampling communities of small-bodied fishes in open-water, sloughs, and creek channels; they are are less suitable for sampling species that primarily utilize smaller channel margins or vegetated tidal marshes and rivulets; or for sampling large-bodied fishes that migrate between marsh, channel, and open-water habitats. Thus, in addition to otter trawls and beach seines, additional gear types are likely needed for special studies or applications when certain functional groups of fishes or habitats are the core focus of monitoring efforts.

Listed/managed species

A key goal of monitoring programs, as they relate to fisheries management and conservation, is to provide data regarding the presence/absence of listed/managed species and genetically distinct populations. Although several projects observed a variety of listed and managed species, including salmonids, smelts, and sturgeons, many of these include sites and stations that were upstream of the study area, outside of brackish-saline habitats. Given that observations could not be reduced to individual stations or sampling time points, further analysis is needed to describe spatial variation among OLUs, subregions, and among gear types with respect to observations of listed and managed species in the lower SFE. Nevertheless, projects that utilized otter trawls and beach seines appeared to observe the most species within this group, thus further solidifying the importance of these gears for achieving the broadest suite of monitoring objectives.

However, certain focal species likely require specific gears and methods for effective monitoring of their use of wetland habitats. For example, specific methods for tracking or surveying rare salmonids (e.g., PIT tags, e-fishing upper watersheds) may be key for acquiring useful data on listed salmonid species. Similarly, trammel netting and acoustic monitoring may be necessary for monitoring Green Sturgeon in wetland habitats. This is particularly valuable to consider, given that the 5-year status review for North American Green Sturgeon stresses the importance of adding acoustic tracking to the Lower South Bay to inform management of this southernmost distinct population of the species (NMFS 2018) (NMFS 2021). This review did not include the CDFW trammel net surveys or Green Sturgeon telemetry data because these fell beyond the geographic scope of WRMP; however, expansion of such approaches into wetlands of the lower SFE could be valuable, given that they have been observed in otter trawls and adjacent receivers in Lower South Bay.

Emerging technologies

Emerging technologies such as environmental DNA (eDNA) and acoustic imaging (e.g., with ARIS or DIDSON systems) hold great promise for addressing specific monitoring questions in wetland ecosystems. These novel tools are often under-represented in literature reviews because they have not had sufficient time to be widely incorporated into accepted monitoring programs and reflected in the literature. Nevertheless, their prior utilization and relative effectiveness should be evaluated when designing any long-term monitoring effort. In particular, these tools could prove valuable as non-invasive methods for collecting data on aquatic communities in wetlands. For example, eDNA holds promise for detecting the presence/absence of species within wetland systems (e.g., eDNA) by simply collecting water samples (CITE). Here, water samples are collected from the environment and filtered, particulate organic matter (POM) containing DNA is gathered on the filter, the DNA is extracted from the filter, amplified, and sequenced; and the sequences are matched with existing genomic libraries to identify the species present in the system (defined by the presence of detectable DNA in the water sample.

Similarly, acoustic imaging is a non-invasive tool that utilizes stationary or towed acoustic "cameras" that use reflected sound to generate images and video that can then be used to assess the abundance of fishes in dark or murky water.

Although these novel tools hold great promise, they also have key limitations that may limit their utility for addressing the ecological questions and goals of a given monitoring program. For example, key limitations in the application of eDNA include uncertainties regarding variation (taxon-specific, life-stage-specific, and environmental) in the generation, transport, degradation, and detectability of genetic material; the lack of data on the features (e.g., life-stage, size-class, sex, and condition) of detected organisms, and the availability of sufficient genomic libraries to identify all potential species (including outside invaders) that occur or might occur in the system. Similarly, while acoustic imaging techniques can provide information on the abundance and size classes of fish, it can be difficult to identify fish to species and no data on the features (e.g., life-stage, size-class, sex, and condition) of detected organisms is captured. Evaluating the relative strengths and weaknesses of all methodological considerations, in relation to previously established research questions and monitoring goals, is a key step in designing any effective long-term monitoring program.

The South Bay Otter Trawl Survey (SBOTS)

Monitoring programs of the WRMP benefit greatly from being integratable with other long-term programs such as the CDFW San Francisco Bay Study and UC Davis Suisun Marsh Fish Study. A review like the present study provides the strongest foundation for identifying such opportunities by providing context regarding the best and most widely used sampling approaches. As a case example, we highlight the only continuous, standardized fish sampling project in wetlands of the lower estuary: the South Bay Otter Trawl Survey (SBOTS) (Hobbs 2017, Lewis et al. 2019b). The survey is operated by the UC Davis Otolith Geochemistry and Fish Ecology Laboratory (OGFL) and currently provides the only long-term fish monitoring data in wetlands of Lower South Bay, where significant restoration activity is planned and ongoing. SBOTS uses the methodology of the 40-year-old IEP Suisun Marsh Otter Trawl Survey, thus allowing for direct integration and comparisons with larger-scale and longer-term IEP datasets (e.g., NBOTS, Suisun Marsh Survey, San Francisco Bay Study Survey). The survey uses an otter trawl to sample 20 fixed stations monthly, including restored tidal marsh/mudflat and slough/open-water habitats, quantifying all fish and macroinvertebrate species. It also collects four replicate measurements of several water quality parameters (temperature, salinity, dissolved oxygen, and turbidity) with each tow, thus providing a robust dataset for evaluating water quality and relationships between fish communities and dynamic water quality gradients (MacVean et al. 2018). The SBOTS database is stored online as a Microsoft Access relational database, with explicit records of quality assurance and control procedures, including 2-person error checking, plotting, and outlier detection routines, and records of instrument tests and calibrations.

The SBOTS project has served as a foundation for informing numerous management efforts throughout SFE: (a) the CDFW incidental take permit for operation of the State Water

Project (Lewis et al. 2019a), (b) status assessment of Longfin Smelt by the USFWS (Lewis et al. 2019a, 2020), (c) the Nutrient Management Strategy, led by SFEI, for understanding the effects of nutrient-induced hypoxia on fishes in South Bay wetlands (MacVean et al. 2018), and (d) informing the South Bay Salt Pond Restoration Project with respect to the utilization of restored habitats by aquatic species (Hobbs 2017, Valoppi 2018). Furthermore, the survey has been awarded a UC Davis Center for Watershed Sciences "Science Incubator" award (January 2023) to integrate SBOTS data with the Suisun Marsh Fish Monitoring Database (SMFMD) in order to provide the first ever assessment of aquatic communities in brackish-saline wetlands throughout the SFE. However, unlike the fully-funded long-term IEP surveys of the Upper Estuary, SBOTS is operated using volunteers, is funded by smaller, short-term contracts from the City of San Jose, and continues to lack a stable funding future. Nevertheless, at just over 12-years-old, SBOTS serves as a model of how an aquatic wetland monitoring program can maximize value of collected data while minimizing the costs of collection. The establishment of similar programs throughout the SFE would greatly broaden our ecological knowledge of SFE wetlands and would help guide restoration actions estuary-wide.

Maximizing the value of short-term projects

Considerable variability in gears, sampling methods, habitats sampled, target species, and quality among short-term projects (1 to 6 years) was observed. Short-term projects reviewed for the inventory did not always include information that would be needed to leverage those monitoring efforts into greater understanding of the project actions and beyond the project. Additionally, short-term projects often cannot account for natural variation in fish populations and habitat conditions. Understandably, short-term studies were developed for specific purposes and may not have considered the benefits of contributing to broader regional analyses. However, with improved standardization of methods and integration of higher-quality data and metadata, broader impacts and conclusions could arise from the time, funding, and effort taken for smaller projects.

Data limitations and recommendations

Analyses herein could have provided additional details and insights if prior studies had been conducted following an open-science framework, with disaggregated data readily available and citable to facilitate meaningful comparisons. As provided, however, key questions of interest often could not be fully explored or addressed. For example, several projects noted the presence of special-status species, but failed to note the location, date, time of day, type of gear, or environmental conditions associated with these observations. Similarly, the intensity of sampling was often difficult to assess across stations and metrics due to a lack of station-specific frequency and effort data, which often varied significantly through time. With minimal cost, the development of standard procedures for the collection, management, storage and sharing of data would greatly enhance the value of wetland monitoring programs (of all spatiotemporal scales) within the SFE. Standardized data management plans (DMPs) could provide such a framework, for example, if required for permit approvals and funding awards. Following a reasonable embargo period (e.g., 2 years) to support publication by principal investigators, projects would could be required to provide disaggregated data, with sufficient metadata for independent analysis, to be archived in reputable online data repositories (e.g., Environmental Data Initiative-EDI or Open Science Framework-OSF). This open-science approach greatly increases the value of all data that are generated, and is becoming a standard component of many integrated monitoring programs (Stompe et al. 2020, Tempel et al. 2021, Bashevkin et al. 2022a b).

Conclusion

Here, we review and summarize 25 projects that sampled aquatic wetland communities at 565 stations within brackish and saline habitats throughout the San Francisco Estuary. Our results highlight that significant prior information is available to inform the development of a standardized and integrated aquatic monitoring program in wetlands of the lower SFE. In this respect, the otter trawl and beach seine have been most extensively utilized gear types across regions and habitat types (including marsh, slough and open-water habitats), especially for longer-term monitoring efforts (e.g., > 30 years). Other gear types such as fyke nets, minnow traps, and gill nets have also been utilized for shorter-term projects with smaller geographic footprints, particularly in intertidal marsh habitats. Multiple water quality parameters have been measured, with temperature, salinity (or conductivity), Secchi depth, and dissolved oxygen being the most commonly recorded data. Listed and federally managed species have been observed in a variety of gear types, particularly smelts (otter trawl, beach seine), salmonids (otter trawl, gill net), and sturgeon (otter trawl, trammel net). Although certain wetland habitats within the SFE have experienced significant long-term sampling (e.g., Suisun Marsh, Alviso Marsh), aquatic wetland communities within most SFE watersheds remain largely unexplored. Results of project reviews, such as ours, are key to highlighting information gaps and identifying best practices; each of which is critical for designing effective long-term monitoring programs in wetland ecosystems.

Tables

Table 1. Project-specific data fields and definitions.

Field	Description
Initials	Initials of individuals who entered the record.
Project Name	Unique name assigned to each project.
Project ID	Unique code assigned to each project.
WRMP	Indicating whether stations associated with a project are inside (Yes), outside (No), or both (Yes and No). Projects labeled as “No” were deemed beyond the scope of this study and are not included in analyses.
Description	Short description of the project.
Report Version	Year or version of the project, if applicable.
Record Type	Choices included: literature review, conceptual model, manuscript, monitoring framework, raw data source, technical report, thesis, and supporting document.
GPS Method	Source of GPS coordinates: (a) provided by study or (b) estimated from map.
Project Lead	Agency, institution, or organization leading the project.
Contact	Name of person that can be contacted regarding the project, if available.
Email	Email addresses for project contact, if available.
Subregions	Subregions sampled: Suisun Marsh, San Pablo Bay, Central Bay, South Bay, Lower South Bay, Multiple.
Year Start	Year when the project started.
Year End	Year when the project ended or "NA" if ongoing.
Project Duration	Number of calendar years in which a project actively sampled. Project Duration = Year End or current year (if ongoing) - Year Start - Number of Inactive Years.
Gear Types	List of all fish sampling gears used by a project (see Appendix 2).
Listed & Select Managed Species	List of ESA/CESA and select managed species observed by a project. Individual columns for each focal species were used as dummy variables (1-present, 0-not present). Choices include: Longfin Smelt, Delta Smelt, Winter-run Salmon, Spring-Run Salmon, Fall-run Salmon, Salmonids, CV Steelhead, CCC Steelhead, Green Sturgeon.
Frequency	Text description of how often sampling occurred in each year.
Environmental Data	List of environmental data that were collected with fish monitoring or “NA” if not applicable (listed in Appendix 34).
Project Link	Web link to project website, report, or manuscript DOI; or "NA" if not available.
Data Link	Web link to raw data; or "NA" if not available.
Metadata	Whether the metadata is available to describe details about the project. Limited to Yes and No.
Notes	Additional considerations for the record.

Table 2. Station-specific data fields and definitions.

Field	Description
Project ID	Unique code assigned to each project (as in Table 1).
Station Code	Unique identifier for an individual station (if assigned by the project).
Station Name	Common name of the station (if assigned by the project).
Sampling Duration	The number of calendar years in which an individual station was sampled by gear type. May differ from project duration.
Latitude	Latitude of each station in decimal degrees.
Longitude	Longitude of each station in decimal degrees.
Subregion	Individual columns for each subregion were used as dummy variables (1-present, 0-not present). Subregions included: Suisun Bay, San Pablo Bay, Central Bay, South Bay, Lower South Bay. See Fig. 1.
OLU	Individual columns for each OLU were used as dummy variables (1-present, 0-not present). See Table S1 for a list of all OLUs. Stations not present within an OLU were considered beyond the scope of this study.
Gear Types	Individual columns for each gear type were used as dummy variables (1-present, 0-not present). See Table 4 for a list and description of all gear types considered.
Habitat	Individual columns for each habitat type were used as dummy variables (1-present, 0-not present). Habitats included: “marsh/mudflat”, “pond/polder”, and “slough/open-water”.

Table 3. Identification codes and descriptive names for each project included in this review. UCD-UC Davis, SFSU-San Francisco State University, SJSU-San Jose State University, USGS-US Geological Survey, CDFW-CA Dept. of Fish and Wildlife, USFWS-US Fish and Wildlife Service, WSU-Washington State University, NOAA-National Oceanic and Atmospheric Administration. Asterisk (*) indicates projects that included multiple stations located beyond the scope of the present study (stations that were excluded from analyses).

Project ID	Project Name
PGMTS	USGS Pond Gillnet & Minnow Trap Study
NBOTS	UCD North Bay Otter Trawl & Plankton Study
SBOTS	UCD South Bay Otter Trawl & Plankton Study
AMMBS	UCD Alviso Marsh Mercury Beach Seine Study
CCFNS	SFSU China Camp Fyke Net Study
CCSSM	SFSU China Camp Source or Sink of Mysids
SFEFA	WSU SF Estuary Fish Assemblage Study
SPRFM	HELIX and FISHBIO Sears Point Restoration Fish Monitoring
JSCWC	CCCPWD and Jones & Stokes Chinook in Walnut Creek
HAMRP	Hamilton Wetlands Restoration Project
SFBLS	SCC SF Bay Living Shorelines: Near-shore Linkages Project
SPVFI	SJSU Salt Pond variation and impacts on fish and inverts
SPWQF	USGS Salt Pond water quality impacts on fish assemblages
SBWF	NOAA South Bay wetlands fisheries
FCSPR	UCD Fish Communities response to salt pond restoration
SOGRW	UCD Steelhead Out Migration in Guadalupe River Watershed
LSSPR	UCD Leopard Shark benefits from salt pond restoration
NACS	UCD Nekton assemblage comparison
SMFMD	UCD Suisun Marsh Fish Monitoring Database
NASP	URS/NOAA Napa Salt Ponds
MALA	WRA Marin Lagoon
SBDA	South Bay Discharge Authority Otter Trawl Study
PEEIR*	UCD Pacific Estuarine Ecosystem Indicator Research Minnow Trap Study*
SFBS*	CDFW San Francisco Bay Study Otter Trawl & Midwater Trawl Study
DJFMP*	USFWS Delta Juvenile Fish Monitoring Program Beach Seine Study*
FRMP*	CDFW Fish Restoration Monitoring Program*

Table 4. Descriptions of the gear type that were utilized by projects in the current review. Passive–set and left alone; active–actively moved or tended.

Gear Type	Description
Minnow Trap	Passive. A baited trap that is used to collect benthic and littoral fishes.
Otter Trawl	Active. Benthic trawl-style net used to collect benthic fishes and macroinvertebrates.
Midwater Trawl	Active. Open-water trawl-style net used to collect pelagic fishes and macroinvertebrates.
Kodiak Trawl	Included in analysis
Beach Seine	Active. A net that is deployed and pulled(typically by hand) along shore to collect littoral fishes.
Fyke Net	Passive. Array of linked netting material that is set in channels and designed to entrap fishes as they move upstream or downstream along a river, creek, or slough.
Gill Net	Passive. Set net designed to entangle fish by the gills when they swim through. Can be single mesh size or multi-mesh size ("experimental").
Trammel Net	Passive. Gill net modified with additional mesh to entangle fish without damaging gills
Hook & Line	Passive. Angling method for catching fish using baited hooks.
RFID	Passive. Radio frequency identification system: typically, an antennae array used to detect and record movements of nearby fish containing passive integrated transponder (PIT) tags.
Visual Tag	Active/Passive. External or subcutaneous tags (e.g., elastomer, alphanumeric, or spaghetti) that are used to identify recaptured fish in mark-recapture studies.
ARIS Imaging	Passive. Adaptive resolution imaging sonar: high-frequency sonar used to acoustically image fishes in situ and estimate abundance.
Lampara Net	Active. A purse-style seine used to encircle and collect pelagic fishes.
Beam Trawl	Active. A trawl-style net used to collect benthic fishes.
eDNA	Active. Environmental DNA: used to detect the presence/absence of species from genetic analysis of water samples.
Block net	Passive/Active. A net designed to block movements of fishes in creeks and channels from which they can be collected.
Acoustic Telemetry	Passive. Tags that are attached or embedded into fish that are used to track movements across arrays of passive acoustic receivers.

Table 5. Description of environmental parameters that were measured by projects in the current review.

Parameter	Description
Temperature	Water temperature (in °C), typically measured with a sonde, probe, or sonar
Dissolved Oxygen	Concentration (mg/L) or saturation (%) of O_2 in water
Salinity	Concentration of dissolved sodium ions in water; combined with conductivity (Sal_Cond) for analysis
Conductivity	Ability of water to conduct electricity (raw or specific conductance); used to estimate salinity. Combined with salinity (Sal_Cond) for analysis.
Turbidity	Nephelometric measure of water clarity; combined with Secchi depth for analysis (Water Clarity)
Secchi Depth	Vision-based measure of water clarity using a Secchi disk; combined with Turbidity (Water Clarity)
Chlorophyll	Concentration of Chl-a as an indicator of phytoplankton biomass
POM	Concentration of particulate organic matter in water
Nitrogen	Concentrations of any or all nitrogen species (NO_3, NO_2, NH_3, NH_4^+) in water
Phosphorus	Concentration of phosphorus (PO_4) in water
Methylmercury	Abundance of methyl mercury (CH_3Hg) in sediments, water, or organisms
Water Flow Rate	Velocity of moving water; measured in various units (e.g., cm/s)
Depth	Water depth where sampling occurred
Tide	Tide stage or height when sampling occurred
Light Attenuation	Percentage Of photosynthetically active radiation (PAR) at depth
pH	Scale used to specify the acidity or basicity of an aqueous solution

Figures

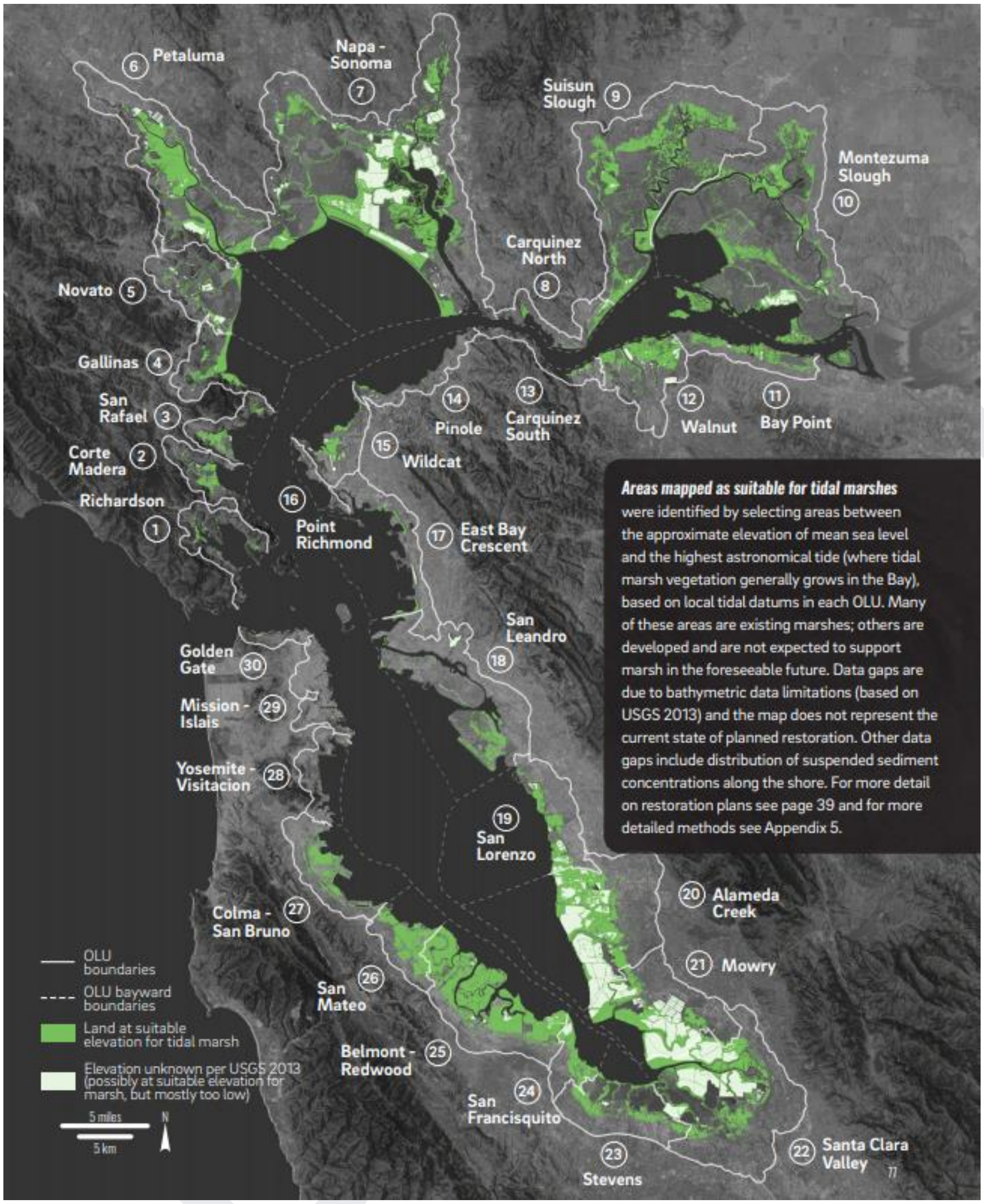


Figure 1. Geographic scope of the Wetland Regional Monitoring Program (WRMP) and present study. Brackish and saline wetlands are found in Suisun Bay in the Upper Estuary and all major subregions of the "Lower Estuary" including San Pablo Bay, Central Bay, South Bay, and Lower South Bay (See Fig 4 for OLU subregional grouping). Watershed-level operational landscape units (OLUs, gray boundaries) are provided, indicating the approximate extent of "wetland" habitats within the complete total marsh ecosystem (CTME) (Goals Project 2015). https://www.sfei.org/data/adaptation-atlas-data#sthash.DVbx9fjm.qL89sI8V.dpbs

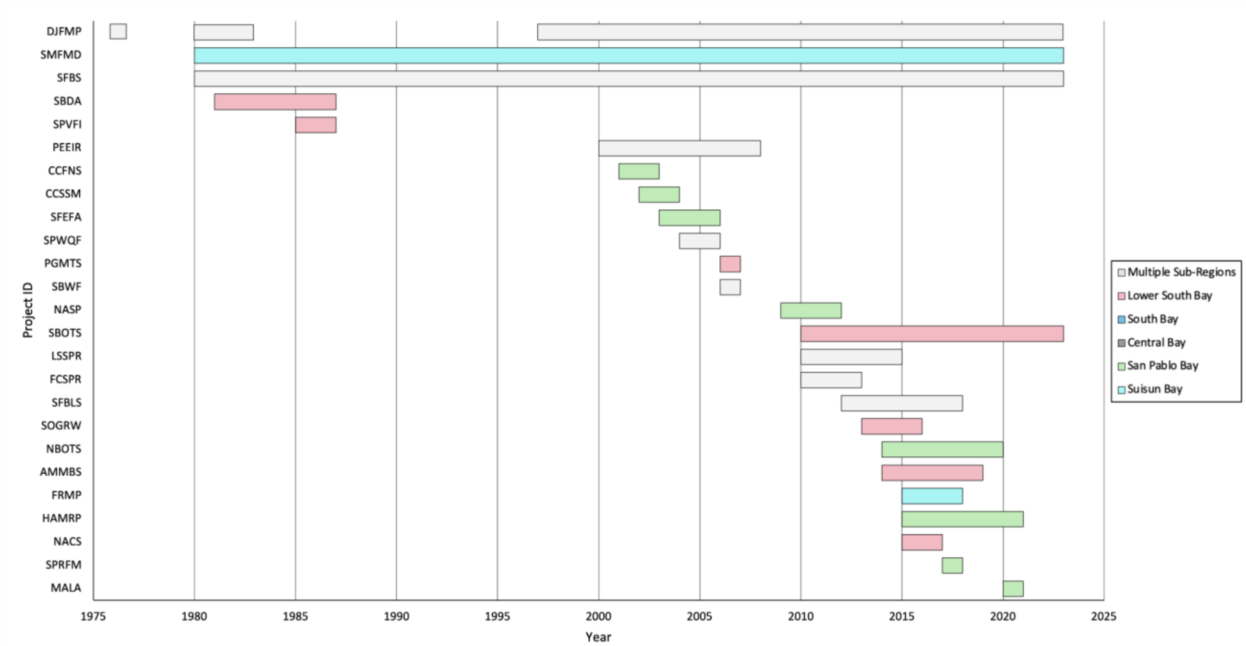


Figure 2. Gantt chart showing the sampling chronology and regional focus for each of the 25 wetland fish monitoring programs included in this review. “Multiple Subregions” indicates projects with stations in more than one WRMP subregion. Project IDs are defined in Appendix 1. Note that DJFMP sampling occurred during three discontinuous periods.

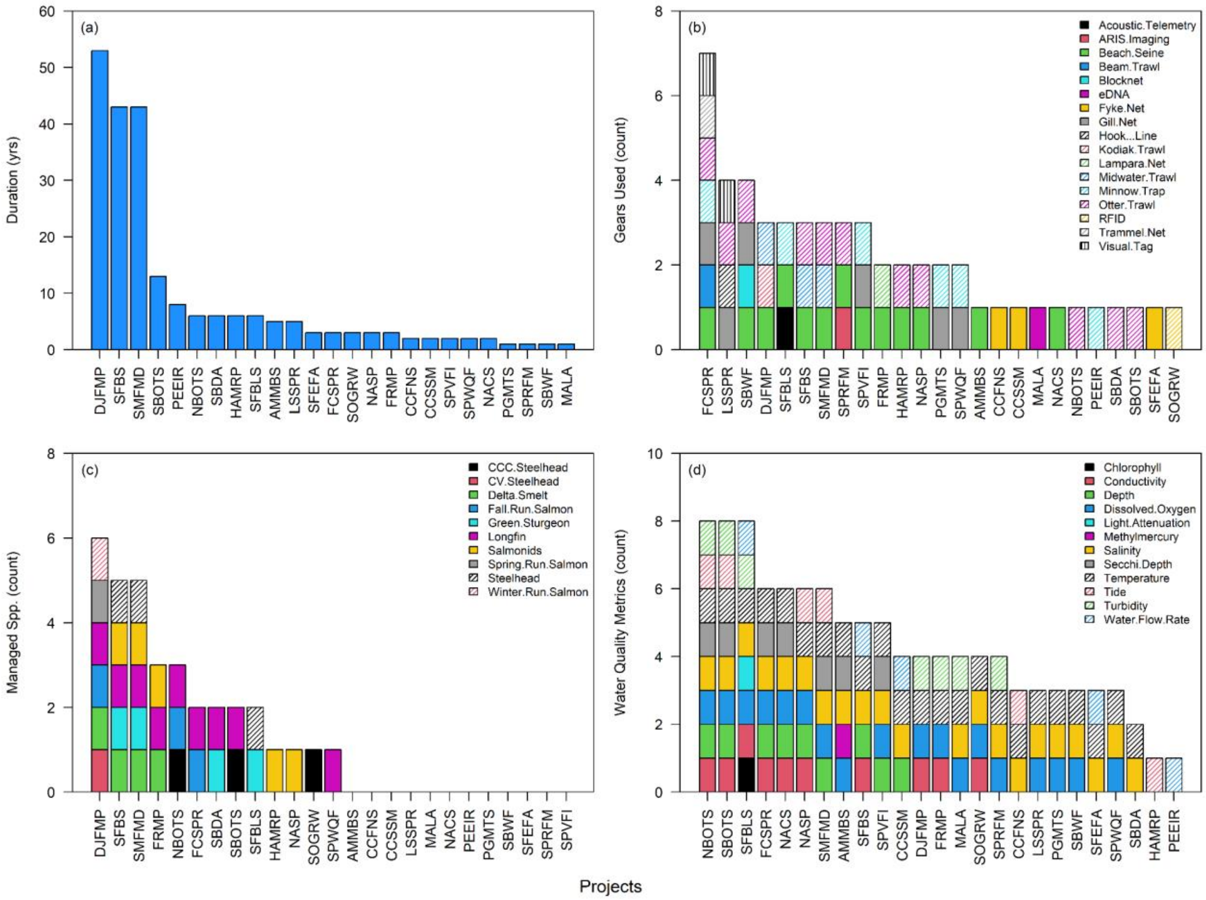


Figure 3. Project-level summaries of the (a) duration, (b) sampling gears, (c) species, and (d) water quality metrics recorded by each of the 25 wetland fish monitoring studies included in this review.

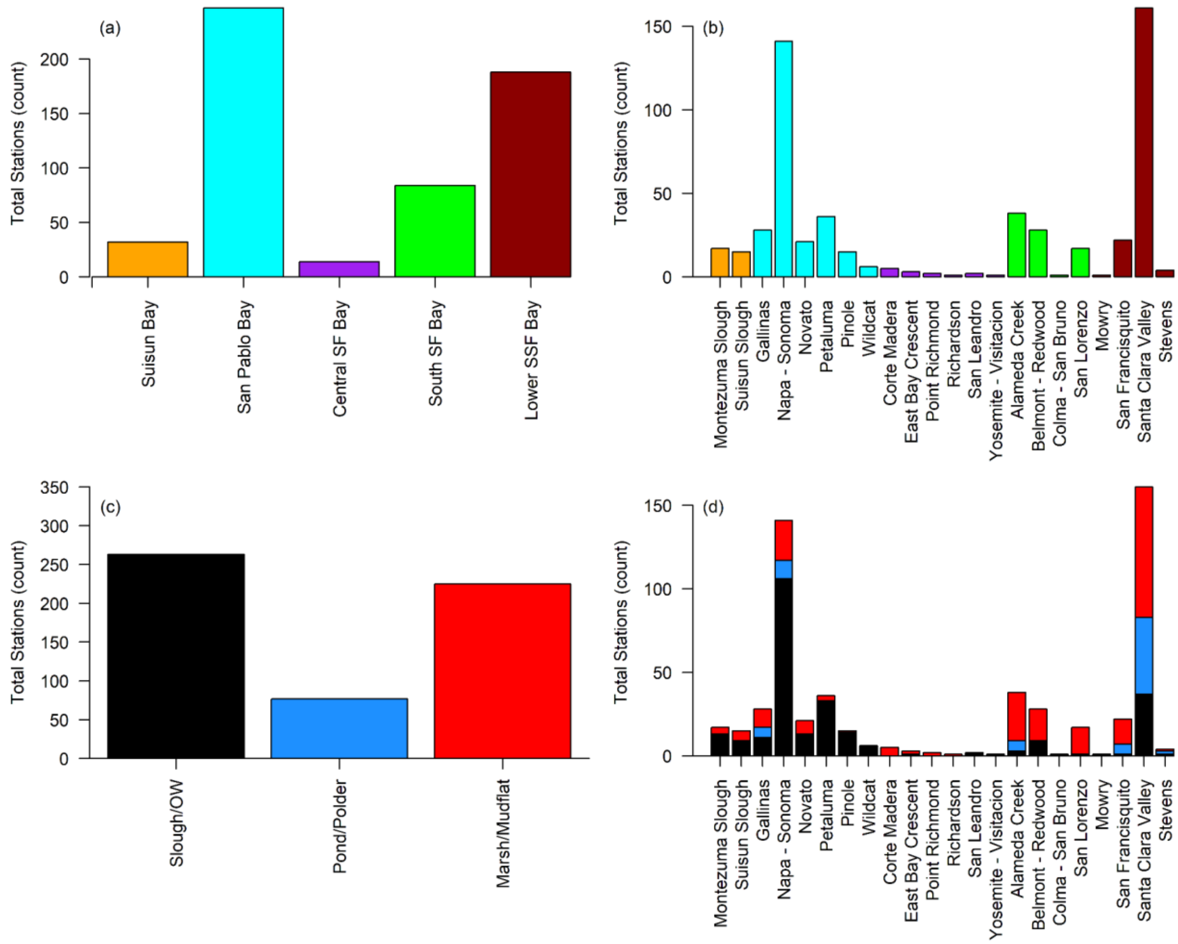


Figure 4. The distribution of sampling effort across regions, watersheds (OLUs), and habitat types as measured by the total number of stations sampled.*Note that the number of stations in Napa-Sonoma is influenced in part by the randomized design of the NBOTS.

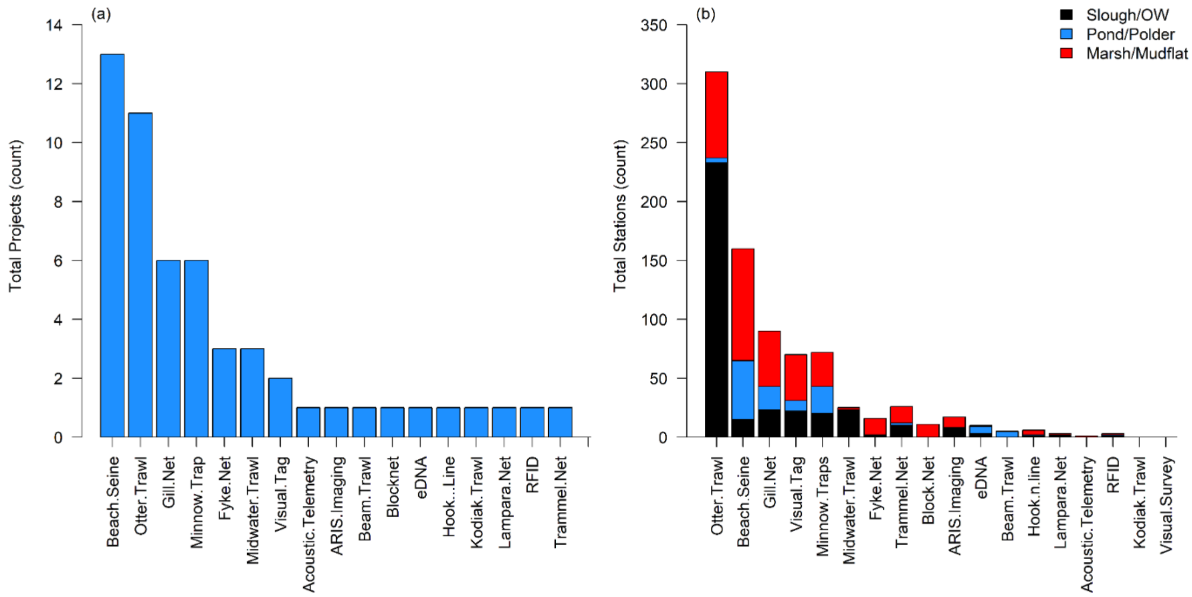


Figure 5. Distribution of sampling effort by gear type reflected as (a) number of projects and (b) number of stations by habitat type. *Note that the number of otter trawl stations (in b) is influenced in part by the randomized design of NBOTS.

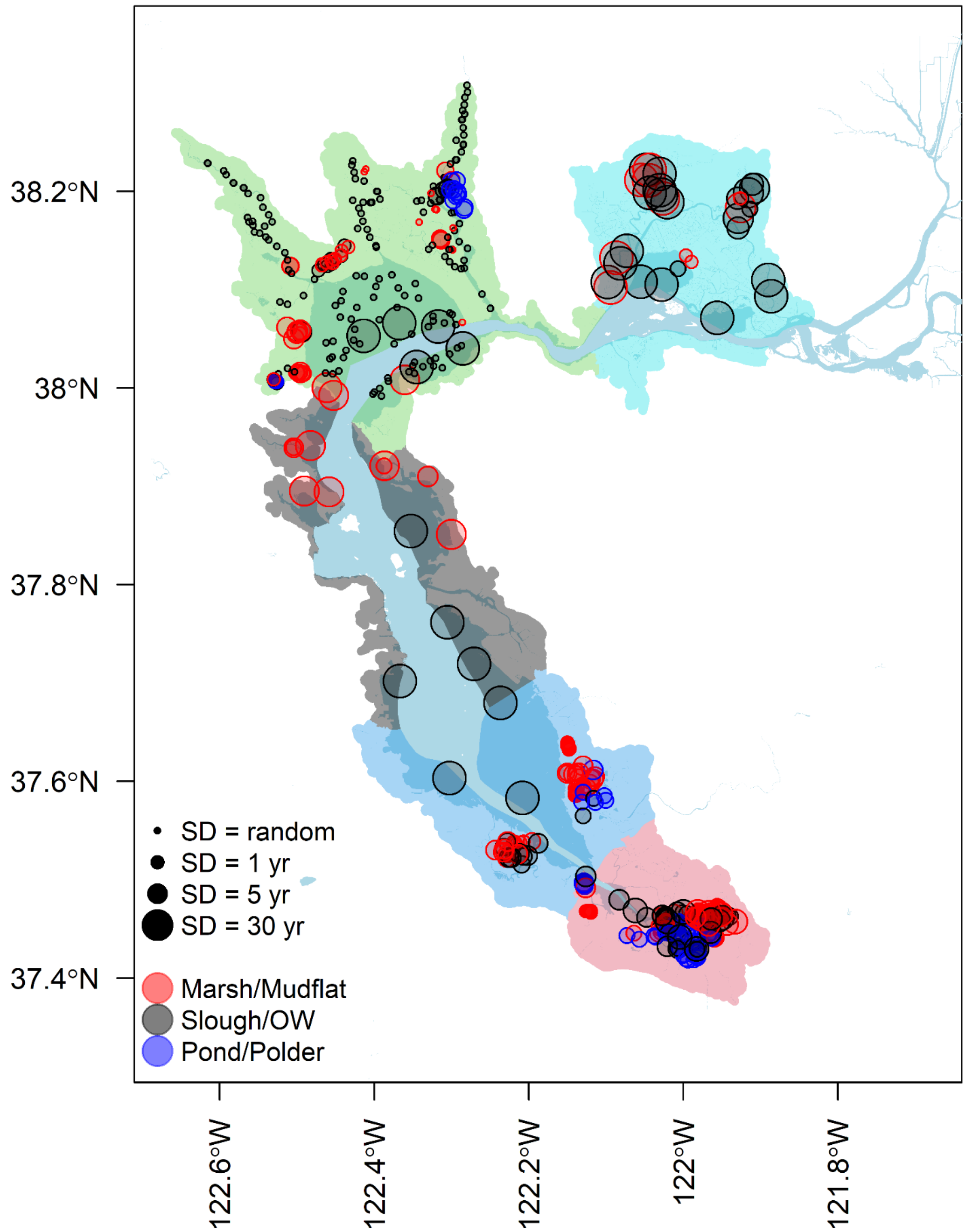


Figure 6. The geographic distribution of sampling across regions and habitat types. Each point reflects a sampling station with the size of the point reflecting the sampling duration (in years). Stations with a "random" sampling duration (SD) belonged to NBOTS, which utilized a randomized sampling design.

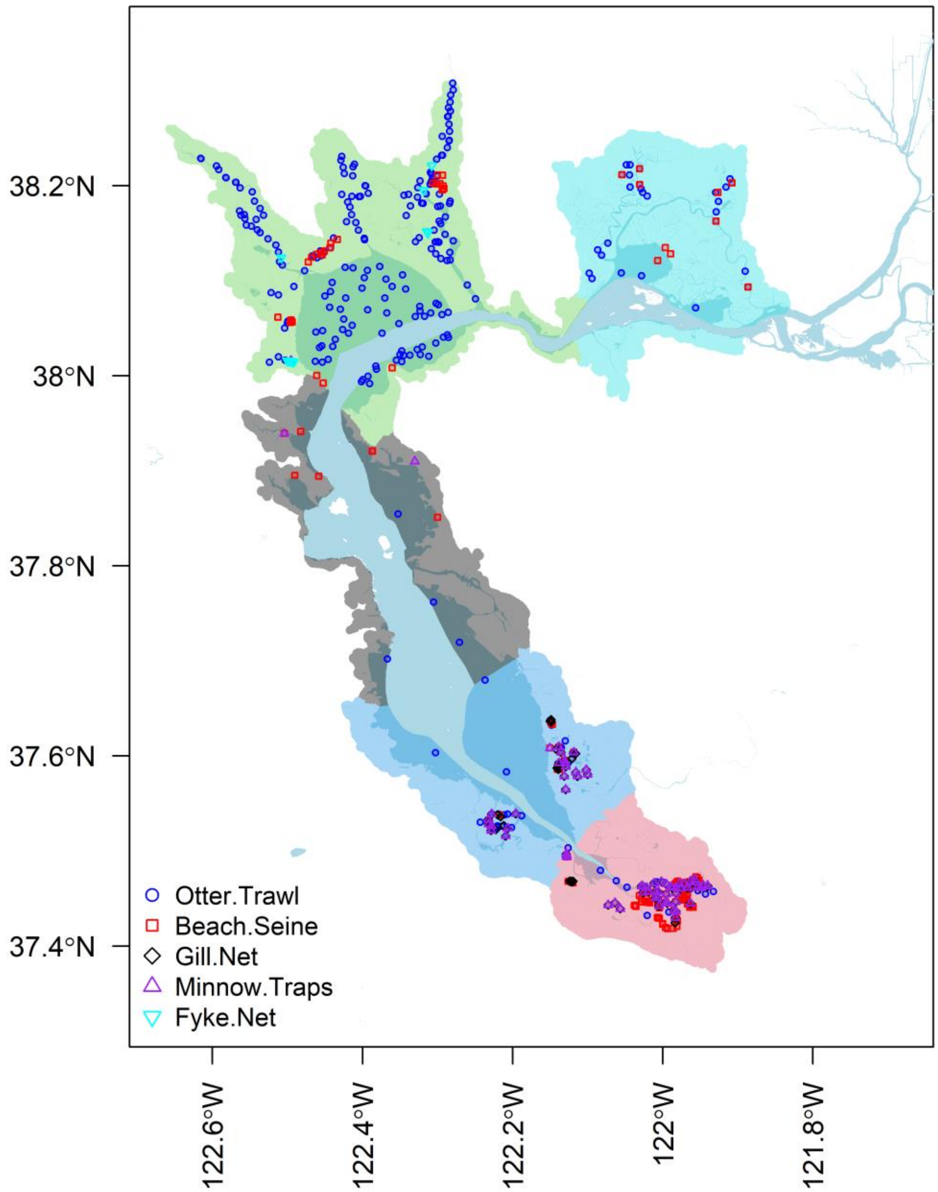


Figure 7. The geographic distribution of sampling across regions by gear type. Each point represents a sampling station, with gear types indicated by shape and color. Note that some stations were sampled with multiple gear types.

Acknowledgements

We thank the many members of the Wetland Regional Monitoring Program (WRMP) Technical Advisory Committee (TAC) and Fish and Fish Habitat (FFH) Work Group who provided comments and insights regarding wetland monitoring throughout the San Francisco Estuary. Brian Meux assisted with the initial development of the wetland project inventory. Daniel Jessurun assisted with generating station-specific habitat classifications from the BARI dataset. Funding for this study was provided by the San Francisco Estuary Partnership, San Francisco Estuary Institute, AmeriCorps, and the National Marine Fisheries Service.

Literature Cited

Barbour MT, Gerritsen J, Snyder BD, Stribling JB (1999) Rapid bioassessment protocols for use in streams and wadeable rivers: periphyton, benthic macroinvertebrates and fish. Second edition. US Environmental Protection Agency, Office of Water, Washington DC.

Bashevkin SM, Hartman R, Thomas M, Barros A, Burdi CE, Hennessy A, Tempel T, Kayfetz K (2022a) Five decades (1972–2020) of zooplankton monitoring in the upper San Francisco Estuary. PLOS ONE 17:e0265402.

Bashevkin SM, Mahardja B, Brown LR (2022b) Warming in the upper San Francisco Estuary: Patterns of water temperature change from five decades of data. Limnol Oceanogr 67:1065–1080.

Brown LR, Komoroske LM, Wagner RW, Morgan-King T, May JT, Connon RE, Fangue NA (2016) Coupled Downscaled Climate Models and Ecophysiological Metrics Forecast Habitat Compression for an Endangered Estuarine Fish. PLOS ONE 11:e0146724.

Cloern JE, Abreu PC, Carstensen J, Chauvaud L, Elmgren R, Grall J, Greening H, Johansson JOR, Kahru M, Sherwood ET, Xu J, Yin K (2016) Human activities and climate variability drive fast-paced change across the world’s estuarine-coastal ecosystems. Glob CHANGE Biol 22:513–529.

Cloern JE, Jassby AD (2012) Drivers of change in estuarine-coastal ecosystems: discoveries from four decades of study in San Francisco Bay. Rev Geophys 50.

Cooper MJ, Lamberti GA, Moerke AH, Ruetz CR, Wilcox DA, Brady VJ, Brown TN, Ciborowski JJH, Gathman JP, Grabas GP, Johnson LB, Uzarski DG (2018) An expanded fish-based index of biotic integrity for Great Lakes coastal wetlands. Environ Monit Assess 190:580.

Cusser S, Helms IV J, Bahlai CA, Haddad NM (2021) How long do population level field experiments need to be? Utilising data from the 40-year-old LTER network. Ecol Lett 24:1103–1111.

Feyrer F, Newman K, Nobriga M, Sommer T (2011) Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. Estuaries Coasts 34:120–128.

Fichman RA, Khen A, Willmes M, Kuntz J, Scott AR, Hobbs JA, Lewis LS (2021) The Clever Strategies That Fishes Use to Survive in San Francisco’s Dynamic Estuary. Front Young Minds 9:608881.

Goals Project (2015) The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015. https://www.sfei.org/documents/baylandsgoalsreport

Healey M, Dettinger M, Norgaard R, eds. (2008) The State of Bay-Delta Science, 2008. Sacramento, California.

Healey M, Goodwin P, Dettinger M, Norgaard R (2016) The State of Bay–Delta Science 2016: An Introduction. San Franc Estuary Watershed Sci 14.

Herrgesell PL (2012) A Historical Perspective of the Interagency Ecological Program: Bridging Multi-Agency Studies into Ecological Understanding of the Sacramento-San Joaquin Delta and Estuary for 40 Years. Interagency Ecological Program.

Hobbs JA (2017) Comparison of nekton assemblages among restoring salt ponds in the Alviso Marsh, San Francisco Estuary: final report. Prepared for: Santa Clara Valley Water District & South Bay Salt Pond Restoration Project, Don Edwards San Francisco Bay National Wildlife Refuge. University of California, Davis, Department of Wildlife, Fish and Conservation Biology.

IEP TWM PWT (2017) Interagency Ecological Program Tidal Wetland Monitoring Project Work Team: Tidal Wetland Monitoring Framework for the Upper San Francisco Estuary, Version 1.0.

Lewis LS, Barros A, Willmes M, Bisson M, Hobbs J, Finger A, Auringer G, Benjamin A (2019a) Interdisciplinary Studies on Longfin Smelt in the San Francisco Estuary.

Lewis LS, Hobbs JA, Willmes M, Crain PK, Barros A, Denney C (2019b) Community Structure of Fishes and Macroinvertebrates in the Alviso Marsh Complex 2011-2018. Department of Wildlife, Fish and Conservation Biology, University of California, Davis.

Lewis LS, Willmes M, Barros A, Crain PK, Hobbs JA (2020) Newly discovered spawning and recruitment of threatened Longfin Smelt in restored and underexplored tidal wetlands. ECOLOGY 101.

Liu Q, Chai F, Dugdale R, Chao Y, Xue H, Rao S, Wilkerson F, Farrara J, Zhang H, Wang Z, Zhang Y (2018) San Francisco Bay nutrients and plankton dynamics as simulated by a coupled hydrodynamic-ecosystem model. Cont Shelf Res 161:29–48.

Lotze HK, Lenihan H, Bourque BJ, Bradbury RH, Cooke RG, Kay MC, Kidwell SM, Kirby MX, Peterson CH, Jackson JBC (2006) Depletion, degradation, and recovery potential of estuaries and coastal seas. Science 312:1806–1809.

Lund J, Brandt S, Collier T, Atwater B, Canuel E, Shermal Fernando HJ, Norgaard R, Resh, Wiens J, Zedler J (2016) Improving Adaptive Management in the Sacramento-San Joaquin Delta. A Review by the Delta Independent Science Board.

MacVean L, Trowbridge P, Lewis L, Hobbs J, Sylvester Z, Winchell T, Senn D (2018) Dissolved Oxygen in South San Francisco Bay: Variability, Important Processes, and Implications for Understanding Fish Habitat. San Francisco Estuary Institute, Richmond, Ca.

Magurran AE, Baillie SR, Buckland ST, Dick JMcP, Elston DA, Scott EM, Smith RI, Somerfield PJ, Watt AD (2010) Long-term datasets in biodiversity research and monitoring: assessing change in ecological communities through time. Spec Issue Long-Term Ecol Res 25:574–582.

Mahardja B, Farruggia MJ, Schreier B, Sommer T (2017) Evidence of a Shift in the Littoral Fish Community of the Sacramento-San Joaquin Delta. PLOS ONE 12.

Mahardja B, Hobbs JA, Ikemiyagi N, Benjamin A, Finger AJ (2019) Role of freshwater floodplain-tidal slough complex in the persistence of the endangered delta smelt. PLOS ONE 14:e0208084.

Nelitz M, Morton C, Tamburello N, Shellenbarger G, Singh J, Semmens C, Koford EJ, Lagerquist T (2020) Monitoring Enterprise Review: Comprehensive Synthesis Report.

Nichols FH, Cloern JE, Luoma SN, Peterson DH (1986) The Modification of an Estuary. Science 231:567–573.

NMFS (2018) Recovery Plan for the Southern Distinct Population Segment of North American Green Sturgeon.

Nobriga ML, 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. Trans Am Fish Soc 145:44–58.

Nobriga ML, Sommer TR, Feyrer F, Fleming K (2008) Long-Term Trends in Summertime Habitat Suitability for Delta Smelt, Hypomesus transpacificus. San Franc Estuary Watershed Sci 6:1–13.

O'Rear TA, Moyle PB (2017) Trends in fish and invertebrate populations of suisun marsh

January 2012- December 2012. University of California, Davis.

R Core Team (2019) R: A language and environment for statistical computing.

Reis G, Howard J, Rosenfield J (2019) Clarifying Effects of Environmental Protections on Freshwater Flows to—and Water Exports from—the San Francisco Bay Estuary. San Franc Estuary Watershed Sci 17:1–22.

Reynolds JH, Knutson MG, Newman KB, Silverman ED, Thompson WL (2016) A road map for designing and implementing a biological monitoring program. Environ Monit Assess 188:399.

SFEI and SPUR (2019) San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise Using Operational Landscape Units. San Francisco Estuary Institute, Richmond, Ca.

SFEI SFEI and ASC (2017) Bay Area Aquatic Resource Inventory (BAARI) Version 2.1 GIS Data.

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, Souza K (2007) The collapse of pelagic fishes in the Upper San Francisco Estuary. Fisheries 32:270–277.

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

SWRCB SWRCB (2004) Functional Equivalent Document: Water Quality Control Policy for Developing California’s Clean Water Act Section 303(D) List. 331.

Tamburello N, Connors BM, Fullerton D, Phillis CC (2019) Durability of environment-recruitment relationships in aquatic ecosystems: insights from long-term monitoring in a highly modified estuary and implications for management. Limnol Oceanogr 64:S223–S239.

Tempel TL, Malinich TD, Burns J, Barros A, Burdi CE, Hobbs JA (2021) The value of long-term monitoring of the San Francisco Estuary for Delta Smelt and Longfin Smelt. Calif Fish Wildl J:148–171.

Valoppi L (2018) Phase 1 studies summary of major findings of the South Bay Salt Pond Restoration Project, South San Francisco Bay, California. Reston, VA.

Walters CJ (1986) Adaptive Management of Renewable Resources. Macmillan Publishers Ltd, Basingstoke.

Whitfield AK, Elliott M (2002) Fishes as indicators of environmental and ecological changes within estuaries: a review of progress and some suggestions for the future. J Fish Biol 61:229–250.

WRMP SC (2020) Wetland Regional Monitoring Program Steering Committee: San Francisco Estuary Wetland Regional Monitoring Program Plan. San Francisco, CA.

Appendices

Table S1. The 22 watershed-oriented operational landscape units (OLUs) within the scope of this study and their associated subregion designations. OLU boundaries are based on layers developed by SFEI and SPUR (2019).

OLU	Subregion
Santa Clara Valley	Lower South Bay
Napa - Sonoma	San Pablo Bay
Alameda Creek	South Bay
Petaluma	San Pablo Bay
Belmont - Redwood	South Bay
Gallinas	San Pablo Bay
Novato	San Pablo Bay
San Francisquito	Lower South Bay
Montezuma Slough	Suisun Bay
San Lorenzo	South Bay
Pinole	San Pablo Bay
Suisun Slough	Suisun Bay
Wildcat	Central Bay
Corte Madera	Central Bay
East Bay Crescent	Central Bay
Stevens	Lower South Bay
San Leandro	South Bay
Colma - San Bruno	South Bay
Mowry	Lower South Bay
Point Richmond	Central Bay
Richardson	Central Bay
Yosemite - Visitacion	South Bay

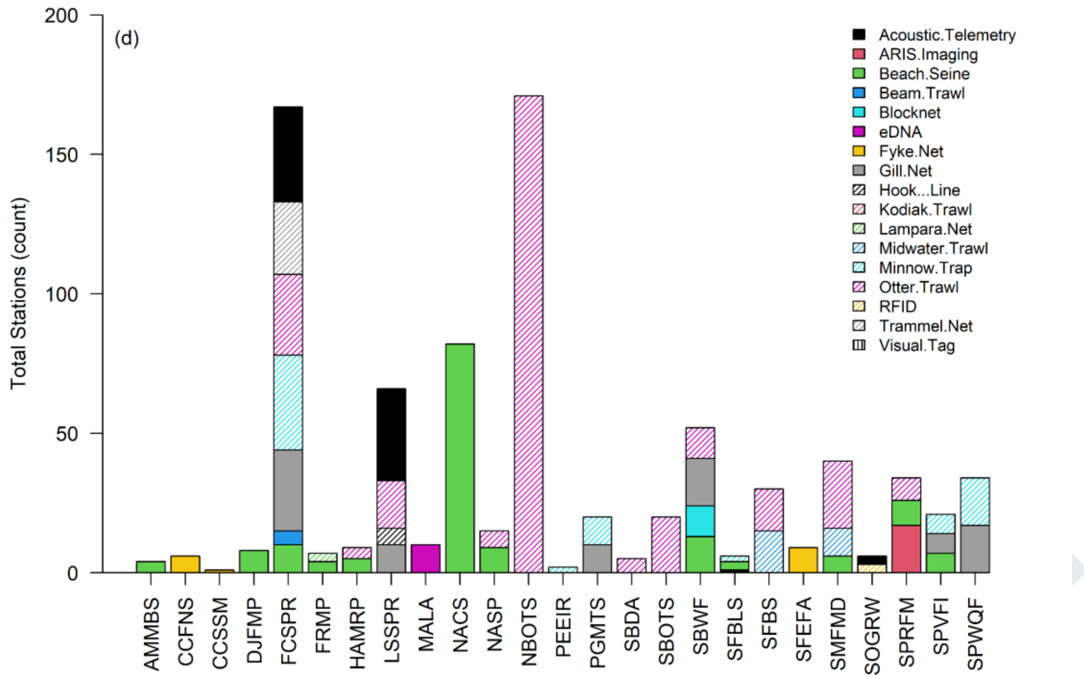


Figure S1. Distribution of sampling effort by project and gear type as reflected by the total number of stations sampled. *Note that the number of stations for NBOTS is influenced by the randomized design.

Appendix 3.

Comment history for the Wetlands Regional Monitoring Program Guidelines for Monitoring Fish and Fish Habitats

APPENDIX 3

Date	Place Where Comment Originated	Section of Document	Commenter	Comment	Response	Incorporated into SOP or otherwise addressed?
12/14	WRMP Steering Committee	n/a	Tony Hale	How often would you expect the SOP to be opened for revision? On 5 year intervals, 10 year intervals, or something more continuous? Is there any disadvantage to continuous evolution?	It seems it should be reviewed after sufficient data have been collected for a report to be produce (5 years?) The review would then take into account he findings of the report in order to confirm the existing SOP or recommend changes. Just thoughts; nothing has been decided. Perhaps the WRMP SC should determine a review process for all SOPs [LL]	Yes. Added to section
12/14	WRMP Steering Committee	n/a	Stacy Sherman	Check in with IEP Longfin monitoring development effort: https://water.ca.gov/-/media/DWR-Website/Web-Pages/Programs/State-Water-Project/Files/ITP/ITP-Longfin-Science-Plan_SWP_12232020_-FINAL.pdf	The recommendations provided herein are based on data used to inform the LFSSP [LL]	yes. Already incorporated
12/14	WRMP Steering Committee	n/a	Stacy Sherman	Look at MER, and talk with those involved in the IEP redesign	Aware of the MER and the IEP redesign. Fish monitoring synthesis report influenced from the MER. Reached out to some involved in the IEP redesign (J. Hobbs, J. McLain, S. Fong) and initiated coordination with IEP.	n/a
	FFH TAC meeting		Isa Woo	Change WRMP Management Question 4B from "resident" species to "native" species.	Changed in the SOP with C. Toms approval. May still need to change in WRMP documents.	Yes. Updated.
10/14	WRMP TAC	n/a	Tony Hale	Levi, thinking about regionality and geography (the big picture): Does your guide identify how to distribute site selection across the region to characterize species movement, distribution, and habitat use at the broadest scales?	[LL, in meeting] Good point. No. I think the TAC has already made those decisions in selecting benchmark and reference sites. So the FFH sampling is mostly the 'how' but not the where. For large-scale sampling of subtidal habitats, we recommend focusing on habitats downstream of major watersheds It would be wise to repeat that in the introduction...maybe we should even include a map with the locations identified.	yes. Updated in introduction. Map added.
10/14	WRMP TAC	n/a	Jen Siu	J. Siu - Relevance aspect very important and I would advocate a very clear treatment of that discussion. for instance, is relevance related to NEED for data end points?	Currently, relevance is related to the WRMP MQs and FFH goals, assuming that those accurately reflect the management and data needs of the WRMP, specifically for understanding patterns and change in space, time, effects of various actions (e.g., restoration) on aquatic communities, and the presence/impacts for listed species (e.g., for permitting). [AWS, LL]	n/a
10/14	WRMP TAC		Host	Really like the distinction between long term monitoring approach and project specific. Need to consider how project specific can nest into long term.	The nesting will be contingent on the standardization of methods, regions, and timelines. In particular, the long-term data will allow for BACI-type analysis by comparing trends across numerous marshes and contrasting trends at project sites to determine whether changes are due to region-scale or local-scale processes. [AWS, LL]	No (not yet). Similar to G. Stern's comment below, developing project-specific guidance could be a next step, but not within the scope at this time [AWS]. This could be added to the statistical analyses section and described in more detail there. [LL]. Draft monitoring plan is being developed, this could be addressed there as well [AWS].
10/14	WRMP TAC		Tony Hale	This is really fantastic work. Thank you for your great review of this critical effort. What do you see as the continuing value/applications of the "considerations" section once the "recommendations" section is finalized?	I think the considerations are valuable for anyone questioning the final recommendations. They clearly show the comprehensive list of options that were considered (e.g., we didn't just forget eDNA) and will be important references to support specific decisions that have been made. They may also be important for developing project-specific or applied efforts at a later time. [LL]	n/a

10/14	WRMP TAC		Jen Siu	in intro I would make clear that report not only covers fish and nekton, but also benthic or epiphytic invert metrics/monitoring	Most gears will not sample smal epiphytic organisms well; but benthic macroninvertebrates could be sampled, if of sufficient size. Although this SOP focusess on fish, we can more clearly note that the methods will sample both fish and and macroinvertebrates, including nektonic and benthic fauna. [AWS, LL]	Yes. SOP states that fish and macroinvetrates will be sampled and quantified. However, smaller organisms are beyond the scope. For example, the SOP states: "Sampling methods for basal or planktonic elements of wetland food webs (e.g., chlorophyll, POM, SAV, zooplankton, phytoplankton, benthic diatoms, meiofauna, infauna, ichthyoplankton, etc.) were determined to be beyond the scope of the FFH protocol." The FFH workgroup recognized the importance of sampling and understanding food webs, however, agreed that a separate SOP with methods specific for sampling smaller organisms as part of wetland food webs (e.g., mesoinvertrabtes, zooplankton, phyoplankton, benthic diatoms, etc.) should be developed by a food-web specific workgroup.
11/22/22	Comment in draft		A. Weber-Stover	Section 3.1. add something about EFH or change to T&A species. Maybe fold EFH into other categories and keep this more constrained?	n/a	n/a can be added in next revision if desired.
			A. Weber-Stover	might need to define creeklets	creeklet has been removed. 'rivulet' has been added, cited, and defined, but has been question by the TAC...under review [LL]	Yes. "Channel" is utilized more broadly now, but is a bit ambigous. "Intertidal channel" is used to separate 'intertidal reeks" from 'subtidal sloughs'. Smaller low-order intertidal creeks are clustered as 'rivulets' with clear defniitions and citations: smaller low-order intertidal channels that serve as corridors for fishes between larger intertidal channels and the marsh plain.
		3.1	A. Weber-Stover	does this section need an opening prior to launching into the focal groups?	n/a	n/a can be added in next revision if desired.
	overview		A. Weber-Stover	since this section is separated like an executive summary, should we also add the actual recommendations in brief?	maybe...not sure...could change to an executive summary...but perhaps revisit after all else is complete. [LL]	yes [LL]
12/6/2021			C. Toms	Hi @alison.weber-stover@noaa.gov - all of these questions are new management and monitoring questions that have been identified by the FFH workgroup. The Guiding Questions from the WRMP Program Plan are in Section 2.2 above. The Program Plan contains no specific management or monitoring questions relevant to fish, with the very nonspecific exception of the monitoring question "What is the response of resident tidal marsh fishes [to tidal wetland restoration, climate change, etc.]?" One of the goals of the FFH workgroup was to transform this nonspecific question into a more useful series of specific questions. I hope this makes sense - please let me know if it doesn't! Show less	L. Lewis: @Christina.Toms@waterboards.ca.gov many of the questions ("WRMP") are from the WRMP MASTER MATRIX ("indicators" ?) even though they were not explicitly in the WRMP Plan document. We tried to keep questions from the MM and FFH group separate, as an exercise. This section likely needs further review and discussion before it can be finalized.	Yes. These questions were related to our first brainstorming with FFH on what were appropriate questions that were omitted in the first WRMP program plan. I think it makes sense to remove them and leave just the monitoring goals where we landed.
		1.2	L. Lewis	curious if we should cite this...it seems like a great resource with lots of citations. https://stacks.stanford.edu/file/druid:sn468cy7652/fishandwetlands.pdf	no. found a better source [LL]	Yes. found a better source [LL]
		1.2	A. Weber-Stover	https://academic.oup.com/bioscience/article/67/3/271/3057250	n/a	n/a

11/17/2022	WRMP TAC - email	n/a	Letitia/Josh	Based on this conversation and the TAC meeting conversation just now, I am thinking it would be useful to set up some standard, agreed-upon terminology for the WRMP. Maybe it could be a very small glossary that we add to as we go. Those of us who work in different parts of the estuary have different lexicons and it can be confusing (LG). Good idea! I support forming a common lexicon. It's not unusual for multi-disciplinary ventures. Since this is about tidal wetlands I suggest emphasizing the tidal wetlands terminology (JC).	[LL] No curent classification scheme for tidal channels or subtidal habitats exists for the WRMP. I'd be happy to discuss some options, which would be helpful from the fish SOP perspective. I'd note that the comments in the habitat classification matrix indicate that rails have specific channel definitions. "Rivulet" (Rozas 1988) is an elegant way to aggregate and describe a variety of lower-order channels that that are used by fishes as corridors to the marsh plain; it is a nested type of 'channel.' These types of channels will often have different species and require different sampling approaches than larger channels. Happy to discuss and modify to improve clarity. [AWS] There is this document the WRMP created which may be helpful: https://docs.google.com/spreadsheets/d/1wiqoGT8b_QjnzZVRripc5HYj_gLgLA-6f7uoQPnyPHo/edit#gid=0	Yes. (partial). For the FFH SOP we are using the following scheme: unvegtated channel through which tidal waters flow into and out of marsh complexes = channel; subtidal channel = slough; intertidal channel = tidal creek, small low-order creek that connects large channels to the marsh plain = rivulet. Happy to discuss/modify. These are now defined more clearly in the SOP.
11/16/2022	Email	n/a	Josh	Given the number and complexity of gear types and their correct usage, which involves considerable technique, training and certification might be warranted. I suggest adopting standard geomorphic terminology for habitat elements. For example, "rivulets" is not a tidal marsh geomorphology term. All such features that convey the flow of tide water to and from the marsh plain are termed channels. They are further classified by their "order" following the Strahler scheme for dendritic or trellis channel networks. According to the usual parlance, "low-order channels" (usually orders 1 and 2 but sometimes including the upstream reaches of 3rd-order channels) tend to dewater during ebb phase, are as deep or deeper than they are wide, lack natural levees, and commonly develop on the marsh surface after it has formed. In contrast, "high-order channels" (from the downstream reaches of 3rd-order channels to the largest channels in marsh landscapes, including the tidal reaches of rivers and streams) do not dewater during ebb phase, tend to be wider than they are deep, have natural levees, and are antecedent to the marsh surface (having existed on the preceding tidal flats or formed as the flats became vegetated). I'm curious about the use of existing data. I suppose this is a topic for a later discussion. I'm thinking of older datasets like Peter Moyle's inventory of fishes in low-order channels of Corte Madera Marsh using minnow traps, as well as the field surveys done by Kathy Hieb. There might be more data than anyone has ever compiled and they might be a source of info on historical changes in marsh fish assemblages. Have they already been compiled? Is their a plan to compile them? Does the team think that would be useful?	[LL] Lots of excellent thoughts. (1) "rivulet" is a wetland fish ecology term from the literature that aggregates low-order channels with specific physical features and functions for fishes. They are currently defined in the SOP as you've described, though even Strahler's (or Scheidegger's) scheme seems to have some issues when it comes to ecological definitions of habitat types as it is often applied. I'm curious if there is a similar easy way to distinguish these channel types from larger order channels. (2) For the inventory, we've added as many datasets that we could find with sufficient reports/info to include in the study...but always happy to add more (3) Yes, great idea! The SBSPRP is considering funding work to expand upon the current inventory report (Appendix 2 of the SOP); this effort could potentially include comparisons with past studies, though methods are aften not standardized, making direct comparisons a bit challenging.	Yes (partial). See response above.
11/17/2022	email	2.4.3	G. Stern	The 3rd monitoring goal by the FFH is really important: Provide context and guidance regarding fish responses to individual projects and it makes reference in the last sentence to the "project-specific monitoring efforts that utilize the WRMP sampling framework for fish and fish habitat". Will there be a stand-alone document that provides guidance for individual restoration projects and describes how they can use the WRMP sampling framework? If yes, suggest the SOP expand the description of that future guidance document.	[AWS] Agreed, perhaps the FFH can discuss this as a next project if funds become available. This SOP provides general recommendations that can be useful for project proponents. [LL] As noted in previous comments/replies, specific details for how long-term data could contribute to BACI-style statistical designes to distinguish project effects from regional patterns.	Yes. In the statistical analyis recommendation (4.7), the SOP states: *Data should also facilitate the construction of indices of biotic integrity and habitat suitability using joint community-environmental data, . . .*

11/17/2022	email	1.3.1	G. Stern	The SOP could make the point that the WRMP is not going to eliminate/replace the need for monitoring by individual restoration projects. The place to do that may be associated with the statement at the top of page 12 in Section 1.3.1 (Data collected as part of the WRMP will support project proponent's tidal wetland compliance monitoring that may be required or recommended under federal and state regulations in a number of ways). I was thinking after the indented text from the WRMP SC 2020, should it say something like "As stated above, data collected by the WRMP will support assessment of wetland restoration projects, but it will not eliminate or substitute for compliance monitoring by individual restoration projects. Information is provided in Appendix 1 to support the development of small scale project-specific monitoring plans by restoration practitioners". However, I'm not sure that Appendix 1 provides that kind of information - or perhaps it is something that will be forthcoming by the FFH/WRMP.	We agree with this statement. I believe the WRMP is specifically developing these SOPs to guide compliance monitoring vs replace it. We can consider if/where that might be unclear. [LL]	Yes. Reversions to text in Section 1.3.
11/17/2022	email		G. Stern	For Section 1.3.4 (Incidental Take and ESA Section 10 Research Permits) - It may be worthwhile to discuss the ability for individual restoration projects to obtain a take exemption through an ESA Section 7 consultation during the Corps permitting process. Use of the guidance provided via the FFH Goal #3 would streamline the ESA consultation review and permitting process.	[AWS] Agreed.	Yes. Revisions to text in Section 1.3.4 [AWS]
11/17/2022	SOP - comment exchange	ES 2. Purpose	J. Collins	In brief, the SOP reflects the conventional Bay-centric perspective on tidal wetlands. It will improve our understanding about the use of wetlands by Bay fishes, which for a variety of reasons may change as sea level rises, but it is not focused on wetland fishes per se because it does not address fish distribution and abundance throughout the typical wetland channel network or across the marsh plain. This conceptual model provides a counter perspective of fish assemblages in SFE saline-brackish tidal wetlands. https://www.researchgate.net/figure/A-conceptual-model-for-fish-habitat-use-in-San-Francisco-Bay-tidal-wetlands-Species_fig4_26386797	[LL]Thanks, Josh for providing this perspective. Interesting; I'd suggest that the approaches recommended herein were centered on wetland fishes, moving us away from bay-centric long-term monitoring, and are in alignment the wetland fisheries literature. But, admitteldy, ones perspective is related to ones perch. Perhaps 'wetland fishes' is too ambiguous and needs to be further refined (obligate, facultative, resident, transient), as well as the conceptual model re: the value of wetland habitats to the aquatic organisms that utilize & benefit from wetland habitats; perhaps then perspectives can be better aligned. It'd be great to review and discuss the body of literature with you and the group, and how we define habitats & functional groups from various perches/perspectives.	Yes. (in part). Conceptual diagrams and descriptions have been updated to emphasize the wetland vs bay emphasis of the recommendations in the SOP. [LL]
	cont.			Agreed. I respect and appreciate that this SOP is a departure from conventional, bay-centric, long-term fish monitoring. Does it depart for enough? Does it look far enough into the marsh? A wonderful truth about wetlands is their position between aquatic and terrestrial systems. Maybe a useful exercise is to look at the marsh from an upland perch. How would we ascribe habitat to the fishes if we surveyed them from the land to the bay, rather than from the bay to the land? Or, from the air, like a piscivorous bird? I'm suggesting the three perspective are equally meaningful, and useful together. Perhaps that's the "tidal wetland perspective."	[LL] Interesting exercise. The Fish SOP is admittedly 'fish-centric.' By necessity, therefore, it focuses on watered habitats that ebb and flow, and drain and flood with the tides. If fish community dynamics are of interest, it seems to be the optimal perspective. Even from that perch, the SOP was balanced to provide valuable data on forage fishes in both intertidal and subtidal wetland habitats, many of which serve as prey for both diving (eg terns) and wading (herons) avian piscivores. This seems to fit the tidal wetland perspective noted above. Per the above suggested exercise, if we imagine the perspective flipped to upland habitats/birds as the primary focus of 'fish' monitoring, then the SOP/WRMP would likely become a much weaker tool for understanding wetland fish community dynamics at regional scales throughout the SFE, and for addressing other fish-related data and management needs, particularly in wetlands of the lower SFE.	Yes (in part). The current SOP includes recommended methods for sampling intertidal channel habitats to make sure that fishes that used intertidal wetland habitats are sampled. Modifications to the conceptual model have been added, emphasizing the the highest order channels and marsh vegetation only occasionally provide habitat for fish during the highest tides...whereas larger channels and sloughs provide habitat across the full tidal prism. [LL]

	cont.			I assume the wetland fish sop needs to be about wetland fish, for their own sake and as components of wetland food webs, which link the channels to the plain, the marsh to the bay, and the marsh to the uplands. In this context I'm still left with the basic question: does the sop cover enough of the wetland as fish habitat, if the low-order channels are excluded? Given that the program is focused on wetlands, then the wetlands perspective is probably justified, and the sop should include the whole wetlands channel network.	[LL] It's a valid question. I think we agree that a representative wetland approach to fish sampling is needed; this is precisely what the fish SOP is intended to provide in its current form. I think there is a conceptual/logistical disconnect that is difficult to address in comments here, so I'll send an email, and perhaps we could chat sometime. :) [AWS] I think we are in agreement about the importance of the low order channels, but the disagreement is about how to sample the representative fish community. I was surprised to see "ignoring low order channels", from my perspective we did consider low order channels. We just thought about the constraints of sampling intermittently-wet habitat as well as constraints with gear that may trap non-fish sensitive species like mice and rails (a concern CDFW and USFWS have made in the past). The smallest channels are only inundated at high tides, so sampling the secondary channels as water recedes from low-order channels was disucssed as a means of avoiding the challenges with intermittently wet habitat and still capturing the fish that use those habitats.	Yes (in part). The SOP language us updated to focus on 'fishes that utilize wetland habitats', to avoid confusion regarding the definition of a 'wetland fish' and to add clarity regarding why and how habitats are recommended to be sampled. For example, fishes that utilized 1st-order channels only do so during the higher tides, but are present in all channel types during mid tides and are in subtidal habitats during low tides. Therefore, most of these fishes that periodically use higher elevation habitats can be sampled most effectively across the full tidal range by focusing sampling on intertidal channels and subtidal habitats, as is recommended in the SOP. [LL]
	cont.			I regret using the term "ignore." The workgroup did not ignore the heads of the drainage networks it it's deliberations. I apologize for that implication. I should have simply said the current sop dots not include those lower order channels. I think my questioning has zeroed in on this: does the team feel as though it understands the value or importance of these small channels we'll enough as fish habitat and in terms of the relation of fish to the marsh foodweb? If so, then I'm thumbs up on the SOP. If not, then my thumb is sideways and I suggest a special study or maybe just a heavy lit search is warranted to understand the small channel functions better, before they're excluded or included in the SOP.	Agreed, the FFH workgroup carefully considered how best to sample these fishes that move between intertidal and subtidal habitats during diel tidal fluctuations. This careful consideration is included in the recommendations that we've provided. [LL]	Yes (in part). The FFH SOP identifies the importance of intertidal weltand habitats and recommends methods for sampling intertidal channels to quantify the abundance of wetland fishes that periodically utilize low-order intertidal creek habitats during higher tidal stages. [LL]
	cont.			And a sideways thumb for me is not a no vote. I'm just saying that we might not understand the habitat values of the small channels well enough to exclude them, and if we do exclude them, we may never know enough about the small channels to know whether they should've been excluded or not. Again, if the team feels as though it has enough information about these channels to make that decision then I defer to the team and I'm thumbs up on the SOP. I just want to make sure that we don't exclude the small channels and then later regret that decision.	Agreed. The SOP focuses on sampling fishes that use a variety of wetland habitats, including small channels. The recommendations provided in the SOP will allow for the quantificaiton of fishes that periodically utilizine low order channels during higher tides.	Yes (in part). The FFH SOP identifies the importance of intertidal weltand habitats and recommends methods for sampling intertidal channels to quantify the abundance of wetland fishes that periodically utilize low-order intertidal creek habitats during higher tidal stages. [LL]

11/17/2022	SOP - comment exchange	ES III Scope	J. Collins	In fact the CTME extends landward into the estuarine-terrestrial transition zone. This SOP need not go there at this time, but if it's going to eventually cover tidal wetlands fishes than it should extend throughout the tidal wetland channel network. Maybe we can acknowledge that the SOP will initially focus on the Bay-Wetlands fish linkages and expand or shift in focus to cover the wetland fish fauna more comprehensively in the future. I don't think that will satisfy all the marsh ecologists but I think it's defensible. It starts to build a bridge from the sure-footing of bay fish science to the less well known wetland fish science. That's a possible rationale. However, if it were up to me, .I'd focus more exclusively on the wetland fish fauna. Why? Because the WRMP is about tidal wetlands, and the Bay perspective on them should be balanced with a wetland-centric and even a terrestrial perspective. Here's a few more contextual thoughts that could be reflected in the scope. The tidal wetlands have food webs unto themselves that are much celebrated owing to their inclusion of multiple TE species. These food webs become most complex around the low-order channels in part because these channels comprise most of the interface between tide waters and the marsh surface, due to the fractal geometry of marsh channel networks (there are on average three 1st order channels for every 2nd-order, and three 2nd-order for every 3rd-order), as well as the rise and fall of the tides. The fish fauna is surprisingly species-rich in these channels when observed across tidal phase and season. And these fishes are food for other wildlife that mainly inhabit the marsh plain or T-zone, aerial predators included. There's a wealth of literature and I've been away from it for a few years. From me you're getting the remembrances of past syntheses and distillations - career takeaways. Links between the wetlands and	Thanks, Josh for these thoughts. To clarify, the draft SOP currently recommends several methods for sampling fishes in intertidal wetland habitats as a critical component of the WRMP. The trophic subsidies to terristrial life is really interesting & important. Similarly, the production in marshes is transported downstream and benefits the many wetland fishes in adjacent wetland habitats, with diversity and size of wetland fishes increasing with channel size and depth. Perhaps it would be valuable to review & highlight some of the papers addressing these different functions and flows. [LL]	Yes (in part). Trophic exchange between terrestrial, marsh, and subtidal wetland habitats is now noted in the SOP. The SOP recommends the sampling of intertidal channels to quantify the abundance of wetland fishes that utilized these habitats, as suggested. [LL] We cite several recent papers and reports that emphasize the value of the approaches that are recommended in the SOP for assessing wetland fishes, their habitats, and terrestrial-estuarine gradients. Some examples are provided below: Colombano DD, Manfree AD, O'Rear TA, Durand JR, Moyle PB (2020) Estuarine-terrestrial habitat gradients enhance nursery function for resident and transient fishes in the San Francisco Estuary. Mar Ecol Prog Ser 637:141–157. Hammock BG, Hartman R, Slater SB, Hennessy A, Teh SJ (2019) Tidal Wetlands Associated with Foraging Success of Delta Smelt. Estuaries Coasts 42:857–867. Barros A, Hobbs JA, Willmes M, Parker CM, Bisson M, Fangue NA, Rypel AL, Lewis LS (2022) Spatial Heterogeneity in Prey Availability, Feeding Success, and Dietary Selectivity for the Threatened Longfin Smelt. Estuaries Coasts.
11/17/2022	SOP - comment exchange	ES III Monitoirn g Goals	J. Collins	another criterion or objective would be to focus on fishes that play major roles on tidal wetland food webs as prey for birds and small mammals. This begins to prioritize rainwater killifish and Gambusia and gobi's.	[LL, in SOP] Thanks Josh. This is a good point that the SOP does not currently address. That said, the methods recommended in the current draft SOP for monitoring intertidal channels are effective for quantitying the abundance of both Gambusia and Lucania. In the justifications, we focused on quantifying the benefits of wetland habitats to native wetland fish communities, vs to non-native fishes that might support native birds and mammals. We could add the value of these NN fishes to birds in the justification for these gears (and to the conceptual model). **[AWS] The challenge with adding a new monitoring goal at this stage is that then we should go back to the ranking exercise and evaluate each consideration and the ability to meet the monitoring goal. Although I agree this is an important objective we could have developed, there were many goals we did not include. For instance, the group also opted out of other food web goals, such as monitoring benthic invertebrates and zooplankton. For NMFS, focusing on essential fish habitats and supporting sustainable fisheries would have been an important goal that could also have been included. During an FFH meeting, we noted these would be wonderful additions, but we had to constrain the goals. Food web we decided to leave for another sub-group. Although EFH is not specifically called out, this protocol will provide abundant information useful to NMFS related to EFH. Similarly, this protocol will provide data that can be easily used in the State of the Estuary Report. Also, I agree with Levi that the current proposal would provide information on available fish as food for others. Perhaps once the terrestrial vertebrate group is established, special diet studies of targeted birds may be identified and synergies could be established between the fish data being collected and those studies. Bird experts probably have much better ideas than me on	Yes (in part). Additional text has been added to address trophic transfer between marshes and upland habitats, and marshes and subtidal habitats. The recommendations provided in the FFH SOP focused on quantification of entire wetland fish community across intertidal and subtidal wetland habitats, and with a focus on both native and non-native fishes that serve important trophic functions. Many native and non-native species are preyed upon by piscivorous birds for example, and the recommended methods in the SOP will be highly effective for quantifying the abundances of the majority of these species across wetland habitats. Methods specifically for sampling invasive killifish and mosquitfish, at the expense of sampling the broader fish community, were ranked relatively low for this reason.

				Well, you know, in this very invaded estuary, we have N wildlife depending on or utilizing NN wildlife in many ways, including as food. "Bad least tern! Bad! Drop the Lucania! Drop the Lucania!	[LL] ...or rather, "good tern, eat them all." :)	n/a
11/17/2022	WRMP TAC	overall	Matt Ferner	Matt Ferner (and others) expressed concern that this protocol de-emphasizes the importance of transfer of fish and fish food on and off the marsh surface at high tides, or the importance of the marsh as nursery and rearing grounds for large pelagics. He thinks it reads as an Estuarine fish sampling protocol rather than a wetland fish sampling protocol. Argues that the cost for fish sampling in small channels is small compared with boat-based sampling. Denise Colombano (?) in Suisun has important work that should be recognized. We recognize that there are resident marsh fish and juvenile and young-of-the year pelagics using the small channels.	[LL, during meeting] Those concerns have been considered by the members of the FFH workgroup. Managers and fish ecologists in the FFH workgroup designed the SOP to focus on a broad diversity of species that utilize a variety of wetland habitats. The recommended approaches will allow the WRMP to sample all fishes that utilize the diverse habitats within the scope of the WRMP, and the recommendations are in agreement with historic wetland fish monitoring methods (including those reported in the wetland fish ecology literature, many of which outlined in detail the appendices). He acknowledges the tradeoffs in a "sentinel species approach", such as focusing on minnow traps to quanity longjawed mudsuckers in small rivulets that connect marsh plain to tidal channels; however, the FFH workgroup recommended an approach that aims to address a the diversity of data needs by monitoring a broader fraction of wetland fish biodiversity, as has been conducted by similar aquatic wetland monitoring programs (e.g., UC Davis Suisun Marsh Survey). [AWS during meeting] This may be an issue of presentation rather than content; we can revise the SOP to make the connections between landscapes and seascapes more clear [Letitia Grenier, during meeting] expanded this point that the amount of effort to collect the juvenile fish on the marsh plain or small rivulets wouldn't be warranted, but that the communication acknowledging these processes could be strengthened.	Yes. Revised some language in the SOP to reflect these comments and provide more clarity on the rationale. [AWS]
11/17/2022	WRMP TAC	overall	Julian Wood	What is the biggest cost component for sampling small channels?	The SOP does not assess financial costs directly. The considerations (Section 3) and justifications (Section 4) discuss logicstical, feasibility, data, and other trade offs associated with all sampling considerations. [AWS] The biggest 'cost' to sampling only the smallest, highest-elevation intertidal channels is the loss of data about the bulk of the wetland fish community. These habitats (on a relative scale) rarely have fish in them & can rarely be sampled (bc they rarely have water in them & fish need water), only a subset of the fish community uses them, and they can only be sampled with certain gears. For example, nearly all of the individuals in 1st order intertidal channels at the higest tides, are also found in larger intertidal channels during average tides, and are also found in subtidal sloughs at low tides (bc most fish need water). Thus focusing on high-elevation intertidal habitats when attempting to comprehensively sample and assess aquatic communities and fishes is highly inefficient and less effective for addressing the fish-related MQs and FFH goals; a more comprehensive approach to sampling is therefore recommended. The recommendations provided in the SOP reflect this approach and are in alignment with other long-term studies that have attempted to quantify similar large-scale patterns in wetland associated fish communities (e.g., Suisun Marsh Study, DJFMP, etc.). [LL]	Yes (in part). Revised language in the SOP to clarify the conceptual model for how fishes use wetland habitatas and the rationale and tradeoffs between sampling approaches.
11/17/2022	WRMP TAC	overall	Susan De La Cruz	Small channels can produce a lot of food for export out to larger channels where there are more fish. And for juvenile fish in small channels.	Agreed, but SOP is not designed to assess fish food web exports, but to answer the monitoring goal questions. If we want to add food web would need to revise the monitoirng goals. The SOP does recommend sampling juvenile fish that use small channels. [AWS]	Yes. Revised language in the SOP relating to defining channel size and sampling based on the conversation in the TAC. [AWS, LL]
11/17/2022	WRMP TAC	overall	unknown	Suggestions to edit the figure to show tidal movement and add a wider marsh plain to visually convey the idea of fish feeding in the marsh.	Agreed. [LL, AWS]	Yes. Revised conceptual Figure 2 in the SOP [AWS, LL]

11/17/2022	WRMP TAC	overall	J. Collins	An important early step in the development of the WRMP is to improve the understanding of the linkages between the tidal wetlands and the Bay. Looking at the marshes from the Bay perspective is traditional and yet the linkages between the Bay and marshes needs to be better understood. Moving bay fish sampling methods into the marsh channel networks is part of that. But there will also be a need to look at the wetlands from the terrestrial perspective. Fishes in the channels become linkages to terrestrial foodwebs. I hope the wet people keep pushing upstream and meet the wetlands people and then the land and creek people and that will happen around the heardward reaches of the wetland drainage systems - aka small-order channels. I think the Bay perspective has been so strong since passing the US CWA that the nature of wetlands as transitional between the land and the bay gets too little attention. The focus on sediment source (watersheds) and transport (streams) and fate (marshes) helps but is not ecological.	The SOP was drafted to address the managment questions and FFH goals identified by the work group. I agree that linkages are important and may require special studies. [LL]	Yes. Revised language and conceptual model in the SOP, clarifying channel sizes and sampling approaches, as well as value of trophic linkages. See related comments above. [AWS, LL]
11/17/2022	WRMP TAC	overall	C. Toms	Suggested that some text be added to the SOP to reflect the connections between the marsh and subtidal fish communities more explicitly and move to a vote on email.	Agreed. [LL, AWS]	Yes. Revised language and conceptual model in the SOP, clarifying channel sizes and sampling approaches, as well as value of trophic linkages. See related comments above. [AWS, LL]
12/13/2022	SOP	ES	S. Siegel	Recommend inserting the graphic from BEHGU illustrating what is meant by the CTME (Fig 11 in BEGHU)	Stuart, I'm happy to consider. Do you have a link to BEGHU (not familiar and quick google search came up blank).[LL]	Yes
12/12/2022	SOP	TOC	L. Grenier	add glossary right before or after this? using figure that shows marsh plain, intertidal channels, subtidal channels, shallow bay?	Agree that a glossary could be useful. Perhaps can be group-populated?	Yes. SOP now includes an introductory note on terminology that summarizes the definitions of habitats used in the FFH SOP and relates them to the WRMP habitat definitions in the SOP for Indicators 1 and 3.
12/12/2022	SOP		L. Grenier	yes. I think it's a responsibility of the WRMP and needs to be coordinated at that level (rather than the responsibility of just the FFH doc). However, that's just my individual view so not sure that the WRMP leaders agree. Caitlin Crane did approach me about setting something up. Don't want to hold up the FFH timeline due to glossary on another timeline also.	[LL] Appreciated. What is or is not "wetland" and "tidal marsh" seems to have varying definitions by various members. Here, sloughs are being described as wetland habitats. Lots of historic monitoring of "wetland fishes" has occurred in sloughs, and sloughs are expressly within the scope of the "wetland" regional monitoring program. But that is just my logic, which is far from infallible. We decided to not include sloughs as "tidal marsh", however, some members have suggested that even this was in error.	Yes. SOP now includes an introductory note on terminology that summarizes the definitions of habitats used in the FFH SOP and relates them to the WRMP habitat definitions in the SOP for Indicators 1 and 3.
12/12/2022	SOP	overall	L. Grenier	Suggest globally changing this to intertidal channels, marsh channels, low-order channels -- something like that, which can be defined at the start and used consistently throughout. I personally am not familiar with the word rivulets in this context so I wonder if it may not resonate with the more marsh-plain focused audience.	[LL] Thanks. This was already changed to "3.4.1 Marshes/Channels/Ponds (‘intertidal’):" based on previous comments, the TOC just hadn't been refreshed yet.	Yes.
12/12/2022	SOP	1.2	L. Grenier	(Fig. 2). This figure looks great! maybe use this figure to define language? How is rivulet different than channel? Are there particular channel orders involved?	[LL] Thanks Letitia...clarity was our intention. I've made some changes to address your and Stuart's comments. Let me know if these seem clear to you.	Yes. SOP now includes an introductory note on terminology that summarizes the definitions of habitats used in the FFH SOP and relates them to the WRMP habitat definitions in the SOP for Indicators 1 and 3.
12/13/2022	SOP	1.2	S. Siegel	(Fig. 2) Would to notate the graphic and state in the caption that the top row is "high tide" and the bottom row is "low tide"	[LL] Thanks, Stuart. I've added this distinction to the legend.	Yes

12/13/2022	SOP	1.2	S. Siegel	(Fig. 2) This description of tidal marshes is not consistently accurate in SFE. Specifically, tidal marshes can include subtidal-depth channels "inside" what we commonly perceive as the marshes, rather than these larger channels being limited to "bisecting" contiguous marsh. In more saline marshes, the larger marshes can have subtidal channels, and in brackish marshes (eg Suisun) many but the narrower channels are subtidal. Consequently, in this figure, the "tidal marsh" notated segment is not correct in all instances. This distinction is very relevant - take Rush Ranch, where First and Second Mallard sloughs are subtidal very far into the marsh; for this protocol, is the marsh on left and right banks of these two sloughs "contiguous marsh habitat" or the tidal marsh at Rush Ranch? Those two sloughs are pretty much "hanging valleys" where they meet Suisun and Cutoff sloughs, vs. adjacent open-water shoal habitat. Subtidal channels can also have tidal marsh on one side and a levee on the other side. What would this be classified as?	[LL] Thanks, Stuart. The distinction between intertidal and subtidal was a compromise based on previous feedback from TAC members who suggested that subtidal habitats should not be considered "marsh" or even "wetland" habitats. In the figure legend, I've added that marshes are "mostly" intertidal (and will try to add this throughout). In the legend, we also now note that this is a general conceptual model & may not apply perfectly to every location. If you have any other specific suggestions for how to improve it/clarify, we would be happy to apply them. [LL] Following up; I looked at first and second mallard; they are large/broad channels like most of the subtidal sloughs that we sample across the lower estuary. I'm curious why they would be classified otherwise; perhaps there is some nuance here that would add further clarity... "Contiguous" was a general descriptor; removed in case it caused confusion. I've also broadened definitions to avoid any language that appears exclusive.	Yes. SOP now includes an introductory note on terminology that summarizes the definitions of habitats used in the FFH SOP and relates them to the WRMP habitat definitions in the SOP for Indicators 1 and 3.
12/12/2022	SOP	overall	L. Grenier	(SMHM, RWR) check spelling and standardize capitalization throughout	[LL] Will aim to capitalize throughout. Thanks!	Yes, eliminated capitalization of SMHM and "rail" in RR
12/13/2022	SOP	3.1.2	L. Grenier	add that smaller bodied species may be more closely tied to terrestrial and wetland food webs, being eaten more frequently by terrestrial and marsh predators? The idea being to balance emphasis on aquatic food web with emphasis on terrestrial food web	[LL] Added: In wetlands, smaller bodied species are frequently preyed upon by terrestrial and marsh predators, thus serving as an important trophic link between terrestrial and aquatic food webs.	yes
12/13/2022	SOP	3.1.3	L. Grenier	Again suggest renaming this as low-order channel or similar.	[LL] A more accurate description might be "Tidal-Marsh and Tidal Pond Associated Fishes and Invertebrates." Happy to make this change. The name is a bit burdensome; curious if there is an acceptable short-hand name we might use. (e.g., 'marsh/pond-associated species)	Yes. Replace: “Marsh plain/pond” with “Tidal marsh and associated”
12/13/2022	SOP	3.3.2	S. Siegel	This term not used in WRMP and not consistent with habitat descriptions in this protocol	[LL] edited.	Yes. Replace: “creeklets” with “intertidal channels,”
12/13/2022	SOP	3.3.4	L. Lewis	Follow up to comment above	[LL] addressing same issue in other sections	Yes. Replace: “rivulets and creek” with “intertidal channels"
12/13/2022	SOP	3.3.4	L. Grenier	suggest standardizing approach to capitalizing mammal common names. Like birds, mammals now have a unique list of common names associated with their scientific name (and so can be capitalized correctly) but it's still not that common outside of mammal publications. Here both methods are used in the same sentence. Since this is fish focused, I suggest only capitalizing proper nouns for birds and fish (Ridgway's rail, salt marsh harvest mouse).	[LL] Thanks, Letitia. According to AFS, all fish names should be capitalized, regardless of proper nouns. "Delta Smelt". Is this true for mammals now? We can update this for all common names. [AWS] I went through the document and tried to capitalize all the species. Still need to do this in Appendix 1 and 2.	Yes. Addressed in SOP, Appendices may need review.
			L. Grenier	(follow up response) It's been true for birds for many decades (according to the AOU but not to regular copy editors). Yes, it's true now for mammals but also very uncommonly used outside the mammalian literature. I tend to get shot down when I capitalize bird or mammal names. I think it's OK not to given that this is a fish focused pub.	[Donna Ball] agree that it's okay not to capitalize mammal names	Yes
12/13/2022	SOP	3.4	S. Siegel	Mudflat not captured in any of the habitat groupings below. There are intertidal and subtidal mudflats, with the latter maybe being the "shallow shoal habitats" in open bay? A rather common and important habitat in SFE.	[L. Grenier] I think this may be an example of language mismatch. A small glossary or well annotated graphic might help.	Yes. SOP now includes an introductory note on terminology that summarizes the definitions of habitats used in the FFH SOP and relates them to the WRMP habitat definitions in the SOP for Indicators 1 and 3.
12/13/2022	SOP	3.4	L. Grenier	remove the seasonally? Since fish are moving by the hour in response to these changes. as written doesn't tie closely to the first half of the sentence	[AWS] removed	Yes
12/13/2022	SOP	3.4	S. Siegel	A fish can use a tidal marsh channel at low/lower tides if the channel is deep enough. Larger marshes and brackish marshes tend to have deeper and often subtidal-depth channels. Proposed revised text: [delete "higher" add "tides of sufficient height".	accepted revision	yes

12/13/2022	SOP	3.4	L. Grenier	(*regarding: some habitats within sloughs/bays (e.g., mudflats) may become dewatered at low tides.*) another good example is that large sloughs often have bars along the sides that dewater at lower tides.	interesting point. we now more clearly note that the conceptual model and descriptions are not intended to describe every possibly habitat type that can be found in wetlands.	yes
12/13/2022	SOP	3.4.1	S. Siegel/L. Grenier	(*regarding: as well as tidally restored diked baylands, and managed diked ponds or polders with muted or no tidal action*). [SS] This is confusing. There are differences between tidally restored diked baylands (whether were salt ponds, ag fields, etc.) and tidally managed marsh and ponds (and these can be separate or combined). And by "muted" tidal action does this mean must have twice-daily tidal variation at reduced magnitude or does it include areas that are managed with longer time scales of varied water levels (like Suisun duck clubs)? [LG] I'm also confused by these descriptions. Suggest describing the habitats as they present rather than per the history. For example, are "tidally restored diked baylands" functioning as mudflats currently? or as shallow bay?	[LL] Thanks for these comments. All good points. Let me know if the changes add clarity. Edits made to address this comment.	Yes. SOP now includes an introductory note on terminology that summarizes the definitions of habitats used in the FFH SOP and relates them to the WRMP habitat definitions in the SOP for Indicators 1 and 3. References to tidal "ponds" have been eliminated to reduce confusion, as the WRMP will map habitats in restoring salt ponds as tidal marsh/mudflat/channel/slough/embayment.
12/13/2022	SOP	3.4.1	S. Siegel/L. Grenier	(*regarding: present only during high tides*) [SS] As long as there is water in a channel, a fish can be there. Larger channels are wetted at lower tides, so "only during high tide" not correct. [LG] Also confused because fish may not be able to easily leave muted tidal or microtidal	[LL] good points. added clarification. let me know if that helps. Edits made to address this comment.	yes
12/13/2022	SOP	3.4.1	L. Grenier	Replace: "bisecting" with "embedded"	[LL] agreed. Edited as suggested.	Yes
12/13/2022	SOP	3.4.1	S. Siegel	what does this mean separate from active management? Need there be water control structures for active management?	[LL] was keeping it broad. feel free to suggest additional clarification if needed.	yes, in part
12/13/2022	SOP	3.4.1	L. Grenier	(*regarding: creeks*).again a place to standardize language. Creek can be confusing since it implied a freshwater source/connection.	[LL] changed per suggestion	Yes
12/13/2022	SOP	3.4.2	S. Siegel	(*regarding: Subtidal sloughs (Figure 2, Figure 5) bisect larger networks of intertidal habitats)* That is true in some settings, but also have setting of subtidal sloughs with a marsh - the norm in Suisun and the case for larger salt marshes.	[LL] Hm. I agree. some TAC members say sloughs are not marsh habitats. would be good to get group clarification. bissect was changed to embedded within or meander through.	yes, in part
12/13/2022	SOP	3.4.2	S. Siegel	(*regarding: while receiving fresh bay waters from downstream as the tides flood*) All channels receive flood tide waters, not clear why stated here	[LL] emphasis was on their direct connection to both bay and marsh habitats (unlike some lower order rivulets); open to other ways to word this. Minor edits applied.	yes, in part
12/13/2022	SOP	3.4.2	S. Siegel	(*regarding: fresh*) [SS] why is salinity mentioned here? [LG] is this meant to refer to salinity? confusing since bay water may be saline of course.	[LL] not salinity, also not needed. emphasis is on mixing with bay waters that have different properties than waters that drain from the marsh. fresh was an uninformative colloquialism. Removed "fresh"	Yes
12/13/2022	SOP	3.4.2	S. Siegel	(*regarding: thus all wetland fishes, at given times, can be observed in slough habitats contingent on environmental conditions and tidal stage*) So long as "slough" includes deeper channels within a marsh, then this statement is true. But if exclude those channels then this statement is not correct.	[LL] sloughs are now broadly described as subtidal channels that meander between marsh habitats. curious what species or specific habitats might violate this statement.	yes, in part
12/13/2022	SOP	3.4.2	S. Siegel	(*regarding: intertidal mudflats that are exposedinundated only during mid to lowhigh tides*) This is not correct. Most mudflats are relatively lower in the tidal frame and thus are inundated much more of the time. Once elevations get high enough, they become marsh (unless too energetic of an environment). See Nichols 1978 (or 1981? forget).	[LL] If you're aware of specific elevations, I'd be happy to add them for clarity...changed to clarify; primarily distinguishing that these are intertidal habitats whereas shoals are subtidal 'mudflats' if you will, as defined in the San Francisco Bay Study fish survey.	yes, in part
12/13/2022	SOP	3.4.3	L. Grenier	(Fig. 5) suggest renaming "restored tidal ponds". This is not common language (at least from my experience). One of these ponds is definitely restored marsh at this point, and the others may be mixed marsh and mudflat?	[LL] These are tidally restored ponds that have different stages of restored marsh vegetation. We could use tidally resored ponds. Would this suffice? We're happy to use other general terms...	Yes. SOP now includes an introductory note on terminology that summarizes the definitions of habitats used in the FFH SOP and relates them to the WRMP habitat definitions in the SOP for Indicators 1 and 3. References to tidal "ponds" have been eliminated to reduce confusion, as the WRMP will map habitats in restoring salt ponds as tidal marsh/mudflat/channel/slough/embayment.

12/13/2022	SOP	4.3	S. Siegel	Based on the descriptions in Sec 3.3 about all the different methods, the first three do not seem to be applicable to intertidal or subtidal channels in tidal marshes. Description of acoustic monitoring doesn't talk about habitat types it works in. This suggests that all sampling will be done in larger subtidal sloughs, open water, and maybe along marsh/open water edges or channel shoals (seines). Are the WRMP management questions and FFH goals being met by what is proposed here? I would suggest a matrix (yup) of the mgmt Qs and goals on one axis and the 9 recommendations in Sec 4 to make sure the plan is meeting its targets.	[LL] summarised response: I believe the matrices in Appendix 1 and results in Appendix largely address this comment. Appendix 1 (alternatives ranking exercise) shows the relative rankngs of each gear type in relation to its ability to meet the FFH Goals which are linked to the management & guiding questions. Appendix 2 (literature review) shows that the first 4 gear types have been used in intertidal and subtidal 'marsh' habitats fairly extensively. Please note that Section 4 outlines how the spatial distribution and intensity of recommend sampling varies by method, with beach seine having the broadest application across all marsh, channel, pond/polder habitats. The justifications for each of the recommended gear types should address which habitats the gear type is suited for based on literature review. We are happy to address any omissions or confusing items that you catch.	yes
12/13/2022	SOP	4.4.1	S. Siegel	Add: intertidal and subtidal marsh	[AWS] accepted.	Yes
12/13/2022	SOP	4.4.1	S. Siegel	(*regarding: pond habitats)* See comment above re what is meant by pond (muted daily tides? diked managed pond and/or marsh? ponds and/or pannes within marshes?)	[LL] I believe this was disambiguated above; here I believe pond is intended to include most varieties.	yes, in part
12/13/2022	SOP	4.4.2	S. Siegel	Odd here. Yes subtidal habitats are wetted "across the full tidal range." Permanency implies a lot. I'd suggest deleting with edit of moving the tide range qualifier.	[LL] Deleted.	Yes
12/13/2022	SOP	ES and overall	L. Lewis	[LL] In response to several comments on the conceptual model, text was revised added in the several ways through doc[AWS] Left revisions in the document because there were many and the were text dependent. A few minor edit also tracked below.	"Wetland" was added here, though would like to add a disambiguation that we are recommending that all 'aquatic wetland' habitats be sampled, including intermittently aquatic (e.g., intertidal habitats). Fish can only be sampled in aquatic habitats.	yes, in part
12/13/2022	SOP	3.1.3	L. Lewis	*in response to various recommended edits*	Replace: “Marsh plain/pond” with “Tidal marsh and associated”	yes
12/13/2022	SOP	3.3.2	L. Lewis	*in response to various recommended edits*	Replace: “creeklets” with “intertidal channels,”	yes
12/13/2022	SOP	3.3.5	L. Lewis	*in response to various recommended edits*	Replace: “waterways” with “subtidal habitats”	yes
12/13/2022	SOP	3.4.3	L. Lewis	*in response to various recommended edits*	Replace: “inundated” with “exposed”	yes
12/13/2022	SOP	3.4.3	L. Lewis	*in response to various recommended edits*	Replace: “high” with “mid to low”	yes
12/15/2022	separate doc	overall	C. Ambrose/A. Cranford	A compilation of existing monitoring programs in these areas would be beneficial. In addition, collaborating with other monitoring entities or building on previous datasets is recommended (for example UC Davis Suisun Marsh/Bay sampling and others).	[AWS] We are in agreement on this comment. Appendix II is working on this compilation of existing and past monitoring programs. We have also begun discussions with the WRMP data team and other IEP entities regarding this topic of collaborating and leveraging	yes
12/15/2022	separate doc	overall	C. Ambrose/A. Cranford	Recent monitoring reviews for Delta surveys and IEP provide invaluable insights into trap/gear efficiencies and recommendations for improvements. We recommend you consult these reviews for the specific protocols described in your report.	[AWS] Thank you for sharing these resources. We reviewed the majority of these documents during development of the SOP but the protocol for Sturgeon was new and will improve protocol development in the next phase.	yes, in part. Documents were reviewed but not referenced specifically in SOP. Can be added later in the implementation phase if needed.
12/15/2022	separate doc	ES	C. Ambrose/A. Cranford	Confirm the monitoring recommendations are informing the two management questions and the three monitoring goals as outlined in the purpose statement.	The FFH workgroup has confirmed this.	yes
12/15/2022	separate doc	ES	C. Ambrose/A. Cranford	There appears to be a disconnect regarding fish habitat monitoring. Specifically, parameters to assess habitat quality are unclear. Instead, the recommendations for habitat monitoring seem to focus on fish presence/absence and use of a particular area, which does not necessarily translate to effectiveness of a restoration project.	[LL] Habitat utilization is one metric of restoration success; however we acknoweldge there are many other metrics. Some of these are being assesed by other workgroups and can be used to address changes in suitability.	yes, in part

12/15/2022	separate doc	ES	C. Ambrose/A. Cranford	The goal to "Provide context and guidance regarding fish responses to individual projects" is extremely difficult to achieve. Fish responses including absence and distribution is influenced by multiple variables. We recommend a suitability index be developed to more accurately determine the quality of habitats.	[LL] This could potentially be added to the analysis portion if the TAC or SC desire; however, the specific suitability criteria first need to be assessed. The data collected, including water quality by the FFH sampling, and geomorphological by other workgroups, could be integrated to develop habitat suitability indices. The response functions for individual fish to enviromental covariates could be developed based on the fish monitoring data that would be produced using the recommended approaches herein.	n/a
12/15/2022	separate doc	1.1	C. Ambrose/A. Cranford	The summary of the WRMP FFH Monitoring Goals and Recommendations within the Executive Summary is helpful. However, within the main document, these goals may be confused with the WRMP Goals (in Section 1.1). Thus, we recommend revisions in Section 1.1. to include a stepped down description of 1) goals for the WRMP, 2) the objectives associated with the WRMP FFH recommendations to inform the two management questions, and 3) intended goals associated with the implementation of the WRMP FFH recommendations.	For clarity, the reference to the FFH Goals in the executive summary has been modified/moved. The WRMP Science Framework is described in Section 2.1, the Guiding and Management Questions in Section 2.2.1, the development of the FFH in section 2.3, and the specific FFH Goals in Section 2.4. [LL]	yes
12/15/2022	separate doc	1.3.2	C. Ambrose/A. Cranford	If "data collected by the WRMP will contribute to an improved understanding of the status, trends…" of salmonids. We recommend you review monitoring recommendations in the Central Valley and Coast Recovery Plans regarding monitoring protocols to inform these demographic parameters.	We have reviewed these Recovery Plans as requested. To clarify, we note that the recommneded guidelines will "contribute" to our understaning of their use of wetland habitats, but are not themselves intended to be sufficient for evaluating the status and trends of salmonds, or to replace otehr monitoring protocols that inform key demographic patterns.	yes
12/15/2022	separate doc	2.1	C. Ambrose/A. Cranford	Recommend the entire Section 2 be moved to 1.3 and move 1.3 to later in the document.	[AWS] This may be warranted, but I will leave this to the WRMP team to see if they would like to pursue this revision. [LL] Could be modified if deemed necessary by the WRMP TAC or SC, but will require additional time & costs to restructure the document..	No, but the SOP is a living document and these changes can be added at a later date when the program moves into the implementation phase if needed.
12/15/2022	separate doc	2.1	C. Ambrose/A. Cranford	It appears this section is introducing the WRMP Science Framework, a workshop, and participants. It would be more helpful for the reader if this entire section is moved upfront in the background section to provide context to the final recommendations and a sequence of events. It would also be helpful to know where this document fits into Figure 3.	[AWS] This may be warranted, but I will leave this to the WRMP team to see if they would like to pursue this revision. [LL] Could be modified if deemed necessary by the WRMP TAC or SC, but will require additional time & costs to restructure the document..	No, but the SOP is a living document and these changes can be added at a later date when the program moves into the implementation phase if needed.
12/15/2022	separate doc	2.4	C. Ambrose/A. Cranford	Recommend the management questions of 4A and 4B and the goals are restated here. It's not clear if 2.4.1 - 2.4.3 are management questions or a goal.	[LL] WRMP Guiding and Management Questions are listed in Section 2.2.1. There are no WRMP "Goals", so these should be clear now. To add clarity, Section 2.4 now begins with "The FFH workgroup identified three fish-specific monitoring goals that will provide data that are critical for addressing Management Questions 4A & 4B of the WRMP."	Yes
12/15/2022	separate doc	3.1.4	C. Ambrose/A. Cranford	The scientific name for green sturgeon is incorrect. The scientific name listed is for white sturgeon. It should be Acipenser medirostris instead.	[AWS] fixed.	Yes
12/15/2022	separate doc	3.2.1 thro	C. Ambrose/A. Cranford	The data metrics describe water quality rather than habitats. Section 3.4 defines habitat types but it's not clear which habitat metrics are being monitored to inform the management question 4A (e.g. "how habitats…are changing overtime"). If water quality data are being used as a surrogate for habitats this should be described.	[LL] Other work groups will be monitoring variation in marsh geomorphology.	yes, in part
12/15/2022	separate doc	3.3 and S	C. Ambrose/A. Cranford	Sections 3.3 through Section 4 should be merged and all information under one header. These two sections are redundant and we recommend describing methods, recommendations, and justifications for each gear type all in the same section.	[AWS] This may be warranted, but I will leave this to the WRMP team to see if they would like to pursue this revision. [LL] The document was structured in this fashion to provide separation between sections where high-level details regarding each speicific consideratin are outlined, and where reviewers can find specific recommendations and justifications. To adess this comment, Section 4 now includes direct links to each relevant subsection within Section 3, thus improving clarity and ease of use when additional information is needed regarding a specific recommendation. The overall structure of the document could be modified if deemed necessary by the WRMP TAC or SC, but may reduce clarity and would require additional time & costs.	yes, in part

12/16/2022	separate doc	3.3 and S	C. Ambrose/A. Cranford	There have been a number of monitoring reviews (IEP Long Term Monitoring Review and Design Team Final Report - See folder) which evaluated various studies, gear types, and approaches for improving efficiencies. Please refer to these reviews to ensure that recommendations within this document are consistent with the latest information regarding effective monitoring approaches.	[LL] These have been reviewed and recommendations are largely in agreement, given the sampling constraints and FFH Goals listed.	yes, in part. Documents were reviewed but not referenced specifically in SOP. Can be added later in the implementation phase if needed.