Suisun Marsh Salinity Gates Pilot Study

Project Description

Prepared for:

California Department of Water Resources

March 2018

Prepared by:

GEI Consultants

Consulting Engineers and Scientists

Suisun Marsh Salinity Gates Pilot Study

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Abbreviations and Acronyms

ADP	adaptive management planning
BO	Biological Opinion
DBW	Division of Boating and Waterways
DWR	Department of Water Resources
EC	electric conductivity
fps	feet per second
Gates	Suisun Marsh Salinity Control Gates
IEP	Interagency Ecology Program
NMFS	National Marine Fisheries Service
USCG	U.S. Coast Guard
USFWS	US Fish and Wildlife Service

Chapter 1. Introduction

1.1 Background

1.1.1 Delta Smelt Resiliency Strategy

California Department of Water Resources (DWR) is evaluating the feasibility of implementing Action #4 in the *Delta Smelt Resiliency Strategy* (Resources Agency, 2016) which calls for summer operation of the Suisun Marsh Salinity Control Gates as described below:

> ***Linkage to Conceptual Models***
>
> This management action is proposed as an alternative to the *Summer Outflow Augmentation* action described above and would benefit juvenile and sub-adult life Delta Smelt stages. The primary Habitat Attribute that would be affected is Food Availability.
>
> ***Summary of Action***
>
> DWR will operate the Suisun Marsh Salinity Control Gates to reduce salinity in the Suisun Marsh during summer months. This management action may attract Delta Smelt into the high-quality Suisun Marsh habitat and reduce their use of the less food-rich Suisun Bay habitat. This management action would need to be monitored closely to ensure it does not result in unintended salinity changes in Suisun Bay, the Sacramento/San Joaquin River confluence region, or key water quality compliance/export locations.

1.1.2 Permits

Operation of the Suisun Marsh Salinity Control Gates (Gates) was evaluated in the 2009 National Marine Fisheries Service (NMFS) Biological Opinion (BO) (2008/09022) and 2008 U.S. Fish and Wildlife Service (USFWS) BO (81420-2008-F-1481-5) for the *Long-Term Operations of the Central Valley Project and State Water Project*. Telemetry studies conducted from 1998 through 2004 identified a significant improvement in salmonid passage when the boat locks were left open. As a result, the MNFS BO mandate that the boat locks remain in the open position while the flashboards are in place.

DWR currently holds a permit for operation and maintenance for Gates with the San Francisco Bay Conservation and Development Commission (Permit 1984.004.007md) which is valid through April 1, 2020. DWR will apply for a minor amendment to authorize this work under the current permit.

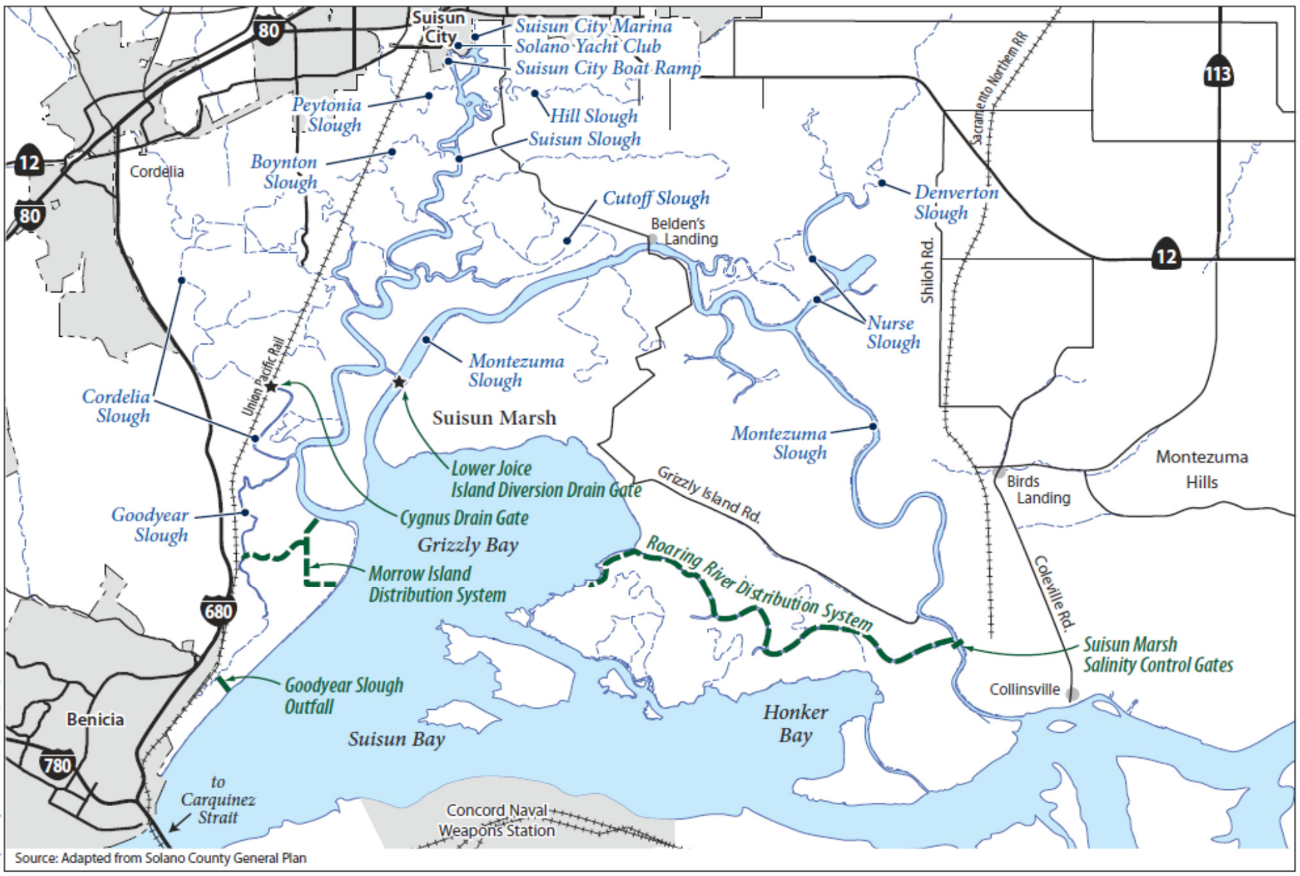
1.2 Pilot Study Summary

DWR proposes to undertake a Pilot Study which involves operating the Gates in August 2018, 2019, and 2020, depending on suitable conditions within the Suisun Marsh as determined by DWR modeling. Overall, the effort represents a modest change to normal operations of the Suisun Marsh Salinity Control Gates. DWR will monitor the Pilot Study operations to determine if it is effective at enhancing Delta smelt habitat in select locations throughout the Suisun Marsh. The results of the Pilot Study will help inform both the efficacy of summer Gates operations on improving Delta Smelt habitat and will also support development and permitting of a more permanent operations plan, as needed.

Chapter 2. Suisun Marsh Salinity Control Gates Operation

The Gates, which aid in reducing salinity throughout the Suisun Marsh, are in the eastern portion of Montezuma Slough approximately 3 miles north of Collinsville (**Figure 1**). The Gates are one of the four initial facilities (outlined in the *Suisun Marsh Preservation Agreement of 1987*) and began operating in November 1988.

Figure 1. Suisun Marsh Vicinity Map



Source: ICF

The Gates are a structure that consist of radial gates, flashboards, and a boat lock. Currently, the Gates begin tidally-operating in early October, depending on salinity, and may continue through the end of May. This period is referred to as the control season. During the control season, the radial gates are lowered during the flood tides and opened during the ebb tides (i.e., tidally operated), flashboards are installed, and the boat lock is operated as-needed for passing vessels. Outside of the control season, the radial gates remain open (allowing unrestricted tidal flow), the flashboards are removed, and the operation of the boat lock is not needed. **Table 1** summarizes the typical operations of the Gates.

Table 1. Typical Gates Operations

	Period	Radial Gates	Flashboards	Boat Lock
Control Season	October – May	Tidally-operated*	Installed	Operated
Non-Control Season	June – September	Open	Removed	Not Operated

Note:
* Depends on salinity.

Understanding how the Gates work requires an understanding of the hydrology of Montezuma Slough without the Gates. Montezuma Slough runs in a semicircular route from the Sacramento River–San Joaquin River confluence downstream to Grizzly Bay. During flood tide, flow typically goes from west to east depending upon the magnitude of Delta outflow, where the flow from Grizzly Bay is dominant. By convention, this flow direction is considered to be negative. At high tide, a slack water condition typically occurs, and the flow slows to zero. Then, as ebb tide begins, flow goes from east to west, where the flow from the Delta is dominant. This flow direction is considered positive. At low tide, a slack water conditions once again occurs, with the flow slowing to zero. The process then repeats.

The Gates control salinity by allowing tidal flow from the Sacramento River into Montezuma Slough during ebb (outgoing) tides but restricting the tidal flow from Montezuma Slough during flood (incoming) tides. The Gates cause a net inflow (approximately 2,500 cubic feet per second) of low salinity Sacramento River water into Montezuma Slough. When sensors detect a velocity of -+0.1 feet per second (fps) the Gates automatically close. Some higher saline water from Grizzly Bay does enter Montezuma Slough, but far less than if the Gates were open. As the flood tide proceeds, a stage differential builds between both sides of the Gates, with the higher stage occurring on the western side. The highest differential occurs at high tide. As the ebb tide proceeds, the stage on the eastern side of the Gates becomes dominant. When the sensors read that the eastern side is 0.3 feet higher than the western side, the Gates are opened, allowing the less saline Delta outflow to flow into Montezuma Slough.

Operation of the gates is currently determined by trigger salinities at monitoring stations throughout Suisun Marsh, to meet salinity targets, set by the State Water Resources Control Board in *Water Right Decision 1641* (D-1641). If salinity is expected to exceed targets, DWR operates the Gates until salinity is sufficiently lowered. If salinities are low relative to the standards, the Gates remain in the open position.

Chapter 3. Modelling Results

In March 2018, the Bay-Delta Office of DWR conducted modeling with real-time data to determine if conditions are suitable for the Pilot Study operations (**Attachment A**). The results indicated that the 2017-2018 water year is expected to be classified as "below normal" and operating the Gates in August 2018 would result in a minimal 5% increase of electric conductivity (EC) at Jersey Point. DWR has tentatively determined that 30,000 acre-feet would be needed to offset an increase in EC. This water could come from reducing Delta exports and/or additional water releases from upstream reservoirs. DWR will coordinate with NMFS and State Water Contractors to ensure water is made available to mitigate the effects of the Pilot Study operations.

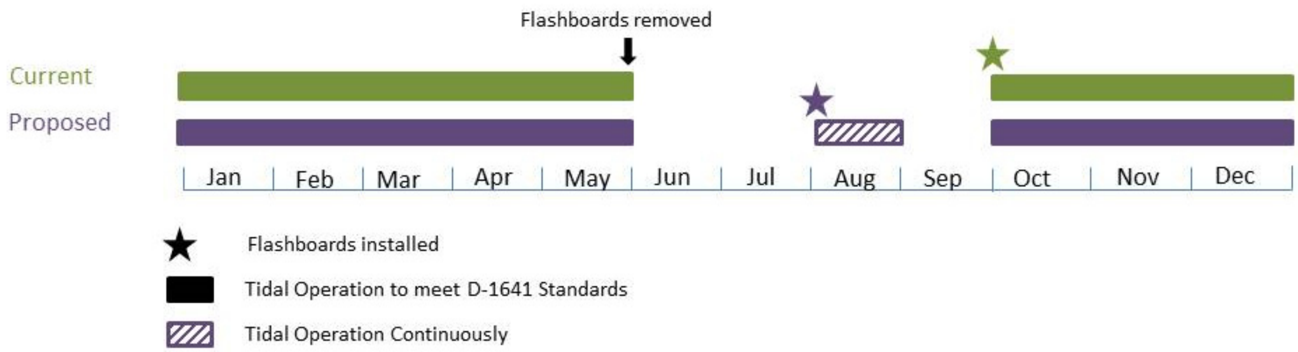
Chapter 4. 2018–2020 Pilot Study

4.1 Operations

For 2018, DWR proposes to operate the Gates for the duration of August. One of the three radials gates will be operational (i.e., one radial gate will be removed for refurbishment and the space sealed with logs). DWR modeling results (**Attachment A**) indicate that there is a minor reduction in efficiency (approximately 6%) with operating two radial gates as opposed to three radial gates. Because the water year is expected to be classified as "below normal," conducting the Pilot Study in August 2018 is ideal.

The implementation of the Pilot Study in 2018 includes removal of the flashboards after normal operation is complete (i.e., no later than the end of May), and re-installation of the flashboards early (i.e., prior of August 1) to allow for an added operational period (**Figure 2**). Unless conditions require September operations (which is highly unlikely), the flashboards will remain in during September, but the Gates will remain in the open position until normal operation resumes in October.

Figure 2. Proposed 2018 Operational Schedule for the Pilot Study



For 2019 and 2020, DWR may operate the Gates in August depending on various criteria. DWR would only operate the Gates in "below normal" or "above normal" water years (i.e., DWR would not operate the Gates in August during "wet," "dry," and "critical" water years). Also, DWR would conduct modeling to determine flow efficiency, anticipated EC results, and anticipated water releases. Finally, DWR would assess the 2018 operations (see Section 4.2, "Monitoring and Assessment") and consider incorporating alternative operation schedules (e.g., 1 week on and 1 week off) or outflow augmentation schedules (e.g., timed with spring-neap cycle) for 2019 and/or 2020.

4.2 Monitoring and Assessment

DWR's Draft Work Plan for Monitoring and Assessment (**Attachment B**) and the State Water Contractors' A Template and Guide for Adaptively Managing Operations of the Suisun Marsh Salinity Gates to Benefit Delta Smelt (**Attachment C**) describe the basis and design for monitoring and evaluation of the Pilot Study. Monitoring will begin in July to capture baseline conditions before the start of the proposed Project. Monitoring will also continue from August to October to capture the full temporal range of the proposed Project's effects. DWR will collect data from three new zooplankton sampling stations, 17 Summer Townet stations (California Department of Water Resources), 10 Environmental Monitoring Program stations (Interagency Ecology Program [IEP]), and 12 water quality monitoring stations (California Data Exchange Center). Through adaptive management planning (ADP), DWR will assess the data and coordinate with the Collaborative Science and Adaptive Management Program and IEP to develop future actions and operations. The AMP was designed in accordance with Department of Interior guidelines for design and implementation of adaptive management strategies. DWR would conduct monitoring and assessment activities during the 3-year Pilot Study regardless if the Gates are operational in August.

Chapter 5. Summary of Anticipated Effects

5.1 Water Quality

The Pilot Study operations will improve water quality conditions in the Suisun Marsh during summer and perhaps early fall. Through monitoring and coordination with stakeholders, DWR will ensure that current water quality standards (e.g., D-1641) and guidance agreements (e.g., Contra Costa Water District) are met.

5.2 Fish

The proposed Project is specifically designed to improve habitat conditions for Delta smelt (*Hypomesus transpacificus*) by increasing habitat connectivity and food web interactions in the Suisun Marsh and parts of Suisun Bay. By similar logic, the proposed Project may also improve habitat conditions for other native fishes, such as longfin smelt (*Spirinchus thaleichthys*), Sacramento splittail (*Pogonichtys macrolepidotus*) and rearing juvenile salmonids. The proposed Project is not expected to have any effect on emigrating juvenile Chinook salmon (*Onchorhyncus tshawytshca*) and/or steelhead (*O. mykiss*) because none have been found to be present in the upper estuary. Moreover, the proposed Project would not affect adult Chinook salmon (winter, spring, fall or late-fall run) migration because Suisun Marsh is not a migratory corridor. Early migrating adult fall run Chinook could possibly occur in the project area with effects similar to those described for normal fall operations of the Gates. Based on conversations with NMFS, there does not appear to be sufficient information to determine if green sturgeon (*Acipenser medirostris*) would occur in the Suisun Marsh at this time. Only three Green sturgeon have been caught in the UC Davis Suisun Marsh Sampling Program, representing over 30 years of sampling.

5.3 Wetlands

Suisun Marsh is well-recognized as a major center for managed wetlands in northern California. Based on initial conversations with land managers, DWR expects that improved salinities will have beneficial effects to managed wetlands.

5.4 Recreation

Montezuma Slough is a navigable waterway. During the salinity control season (September–May), DWR installs flash boards across the 70-foot wide maintenance channel and operates a 20-foot wide boat lock (daily from 7 a.m.–5 p.m.) which allows boaters to pass the Gates. Outside of the salinity control season, flash boards are removed providing a boat passage through the channel. Before the installation and removal of the flashboards, DWR will notify the California Division of Boating and Waterways (DBW) and U.S. Coast Guard (USCG). DBW will publish the information in their boating news publication and on their website. USCG will publish the information in the Local Notice to Mariners.

Chapter 6. References

California Department of Water Resources. Draft Work Plan for Monitoring and Assessment of Propose Suisun Marsh Salinity Control Gates Action, 2018-2020.

DWR. See California Department of Water Resources.

National Marine Fisheries Service. June 4, 2009. Final Biological Opinion and Conference Opinion on the Long-Term Operations of the Central Valley Project and State Water Project. Available: http://www.westcoast.fisheries.noaa.gov/central_valley/water_operations/ocap.html. Accessed on February 9, 2018.

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U.S. Bureau of Reclamation. April 21, 2014. Final Environmental Impact Study/Final Environmental Impact Report for the Suisun Marsh Habitat Management, Preservation and Restoration Plan. Available: https://www.usbr.gov/mp/nepa/nepa_project_details.php?Project_ID=781. Accessed on February 9, 2018.

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USFWS. See U.S. Fish and Wildlife Service.

Attachment A. March 2018 Modeling Results for the Suisun Marsh Salinity Control Gates Pilot Study

March 2018 Modeling Results for the Suisun Marsh Salinity Control Gates Pilot Study by DWR Bay-Delta Office

March 12, 2018

Question 1: What are the estimates of a preliminary forecast model on impact of 2018 summer re-operation on water quality (WQ) at Jersey Point?

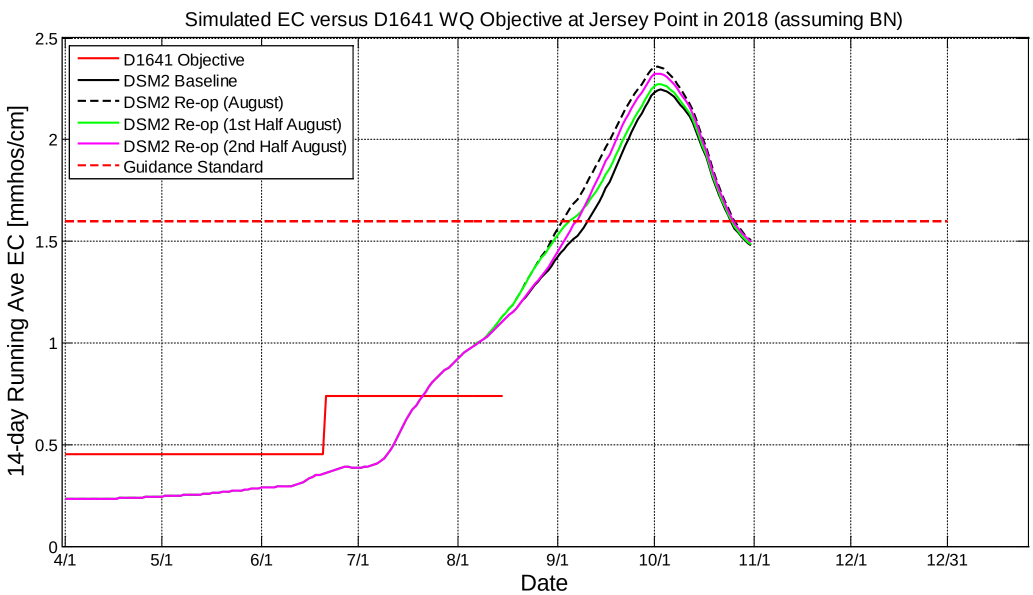
a) Configuration

1.Hydrology (primarily based on O&M January 2018 forecast)	
Boundary inflows	monthly converted to daily (month-end/start treated with conservative spline)
	East flows: break into Consumnes, Calavaras, Mokelumne with 1:2:2 (planning ratio based on historical averages) Yolo bypass, Bar Slough use 0
Delivery	monthly converted to daily (month-end/start treated with conservative spline)
	Contra Costa Canal (CCC): break into Rock Slough, Victoria, Discovery with 2012 (BN) monthly ratio
DICU	Delta sum break to nodes by ADICU
	splice of BDO historical 1922-2014, OM recent 2014-2017, OM forecast 2018
Martinez downstream stage	astronomical stage
2. Facilities operation (primarily based on forecast from all stakeholder agencies)	
Delta Cross Channel	O&M 2018 forecast monthly percentage applied with OPEN priority on weekends
Clifton Court Forebay Gate	O&M 2018 forecast, using Priority 2
South Delta Temporary Barriers	BDO south Delta 2012 historical (lack forecast for later time of 2018)
Suisun Marsh Salinity Control Gates	Assuming **3** gates in operation (will consider 2 gates next)
3. Water Quality (EC) (primarily generated from planning/forecast scripts in house)	
Martinez downstream	produced from Martinez stage and O&M provided NDO (AN & BN), by Martinez EC generator (2014 calibrated)

San Joaquin	Flow-EC regression from previous forecast study
All others inflows	constant values as planning study (<200, I.e. almost fresh)
DICU	constant values (monthly)

Assumption→ 2018: below-normal year

b) Results



Changes (from baseline simulation, in %) in peak EC:

Jersey Point 2018 (assuming BN):

re-op in August: 5.0% increase;

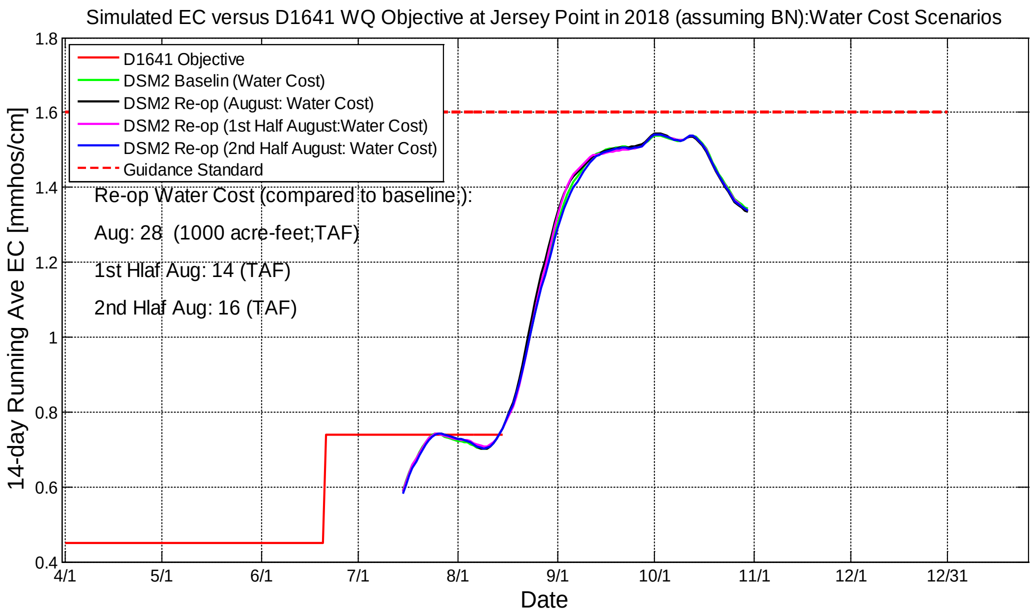
re-op in 1st half of August: 1.2% increase;

re-op in 2nd half of August: 3.6 % increase

[guidance standard exceeded in all scenarios]

Question 2: What is the estimated water cost of gate re-op in August 2018 to comply with the standards at Jersey Point?

a) baseline and all three re-operation scenarios (after water cost):



Water cost (compared with baseline simulation) to comply with standards:

Jersey Point 2018 (assuming BN):

re-op in August: 28 TAF (i.e., 1000 acre-feet);

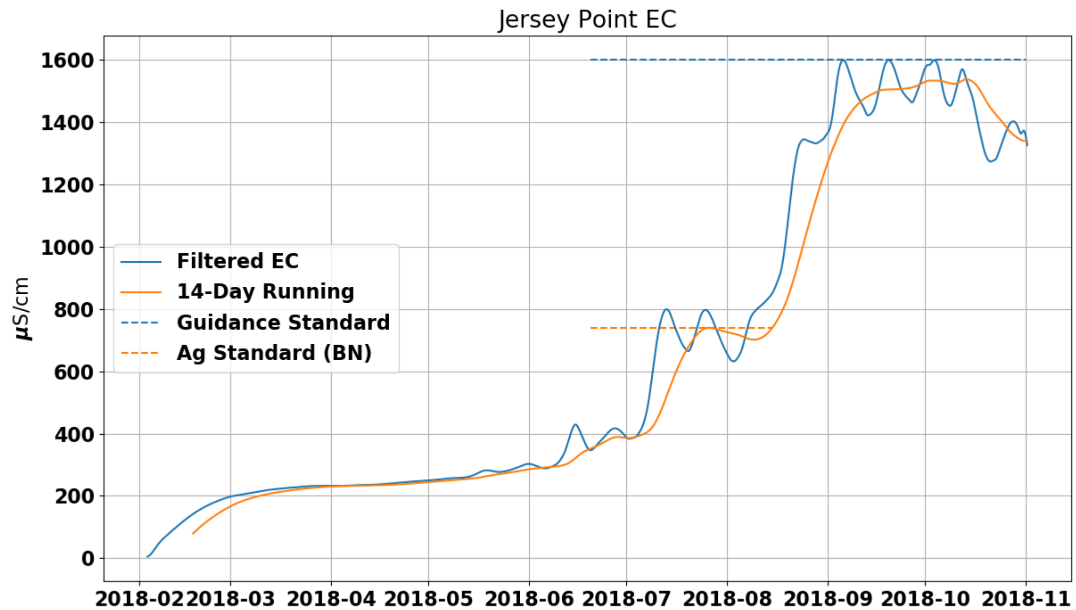
re-op in 1st half of August: 14 TAF;

re-op in 2nd half of August: 16 TAF.

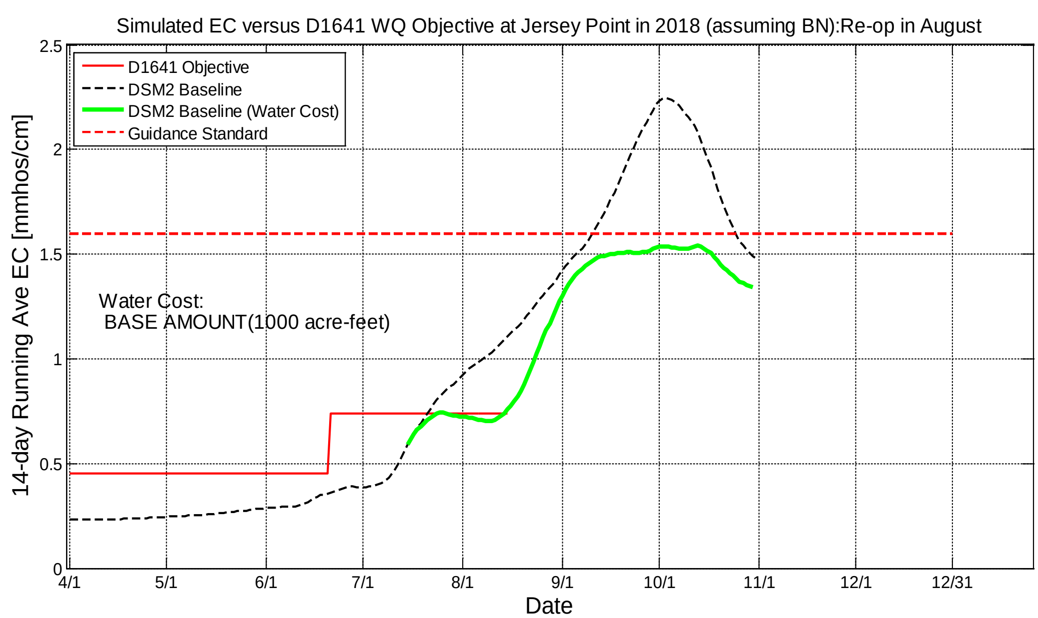
March 12, 2018

b) baseline 2018

Water cost analysis:

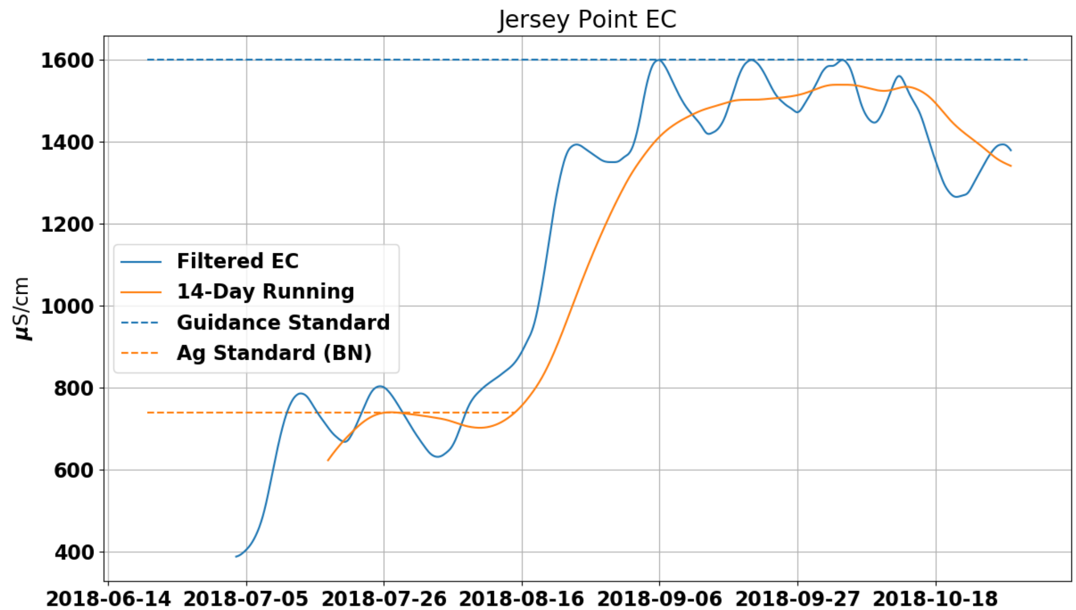


Before and after water cost:

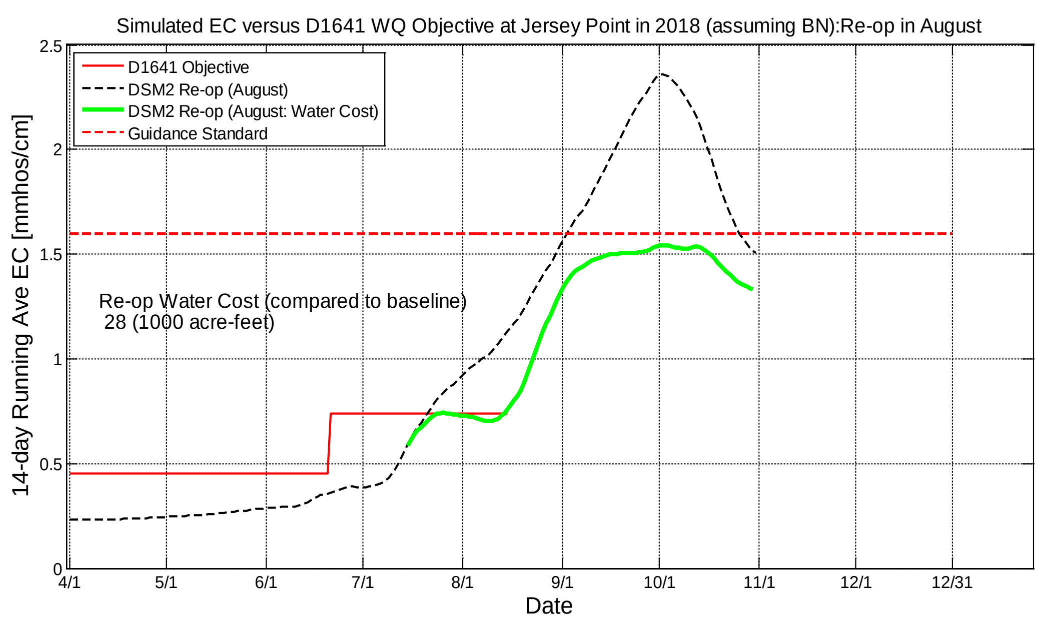


c) re-operation in August 2018

Water cost analysis:

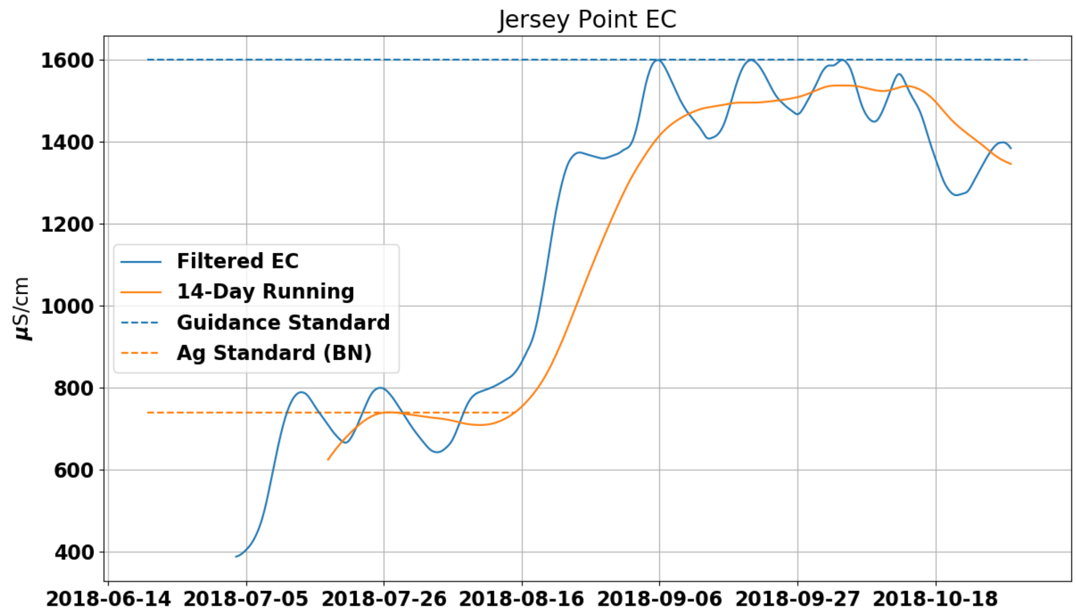


Before and after water cost:

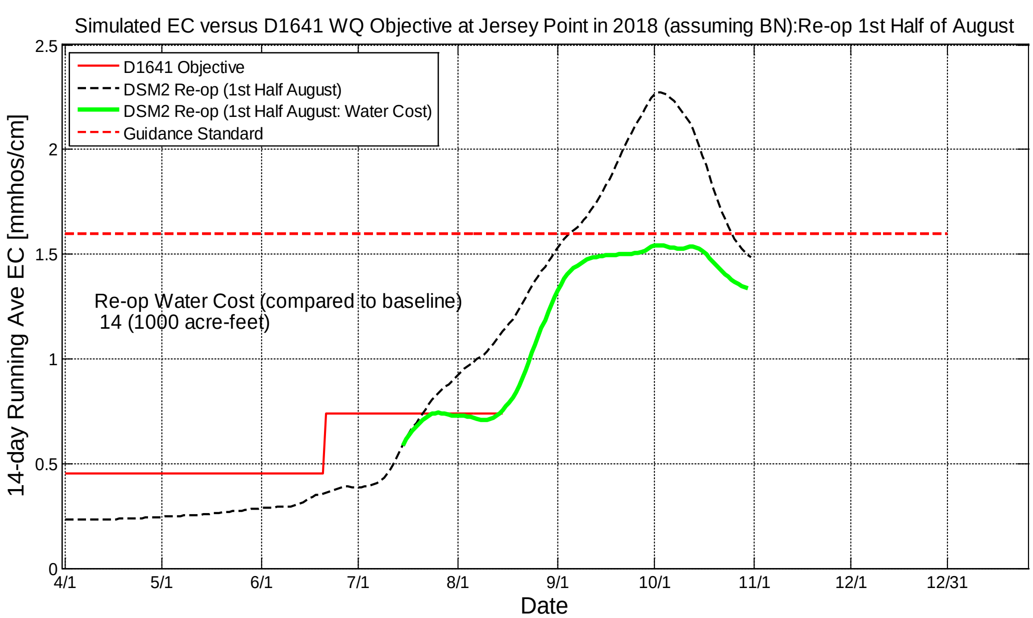


d) re-operation in 1st half of August 2018

Water cost analysis:

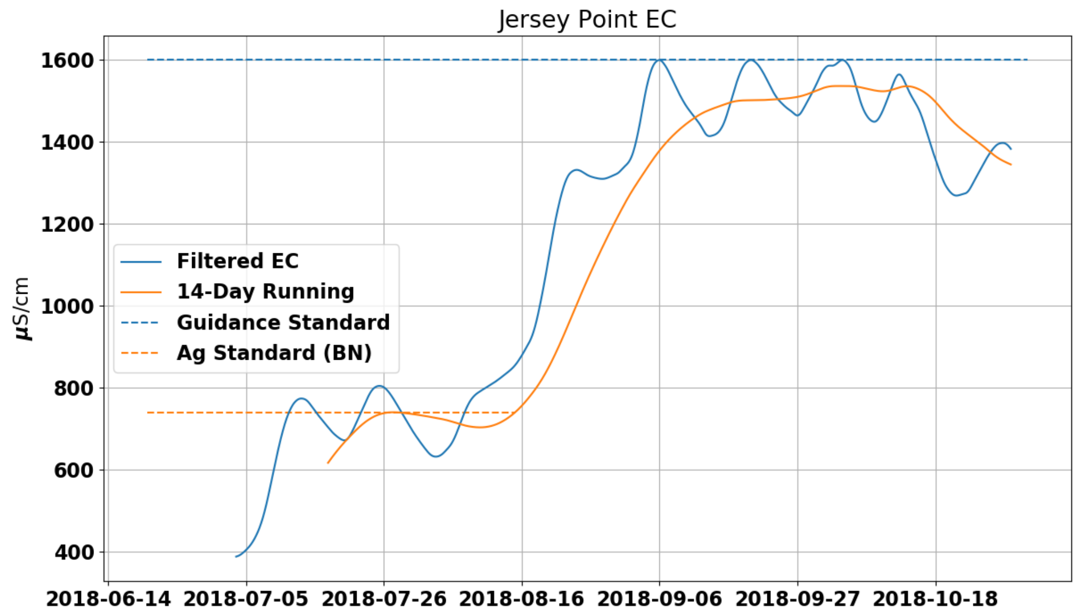


Before and after water cost:

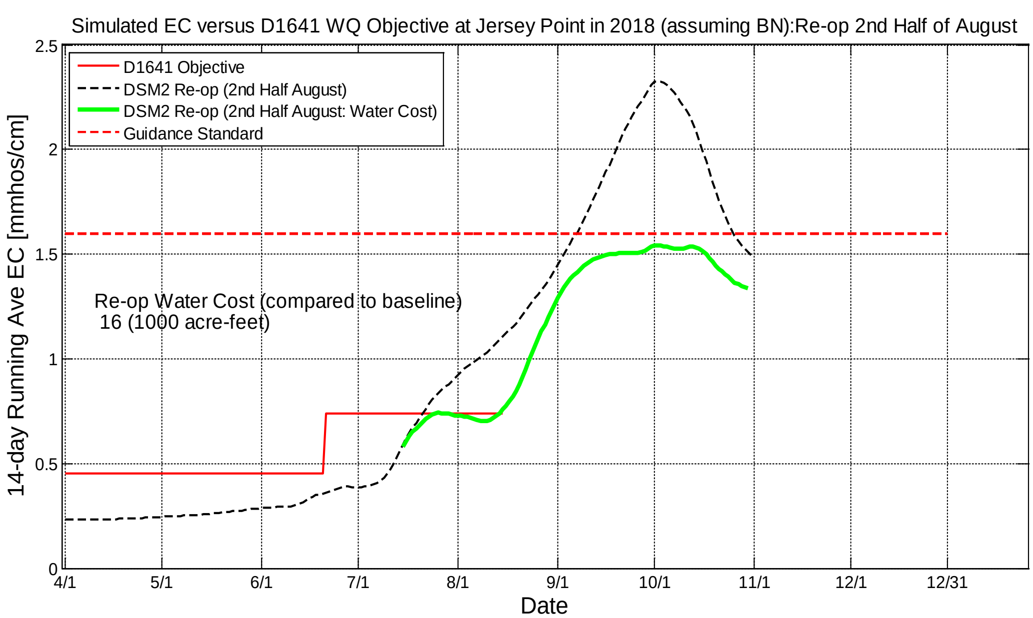


e) re-operation in 2nd half of August 2018

Water cost analysis:



Before and after water cost:



Question 3: What is the flow efficiency if only two gates are in operation (assuming that the third radial gate is removed for refurbishment and the space is sealed with logs)?

Re-operation Period	Mean NSL Flow (cfs)		Flow Efficiency
	3 gates open	2 gates open	
August 2018	2,010	1,887	93.9%
1st Half of August 2018	2,041*	1,914*	93.8%
2nd Half of August 2018	1,981*	1,863*	94.0%
August 2012	2,038	1,908	93.6%
August 2005	2,044	1,918	93.8%

*semi-monthly average flow at NSL; other flows in monthly average in August.

Next steps:

1) refine forecast model configuration using updated forecasts (e.g., latest hydro forecasts)

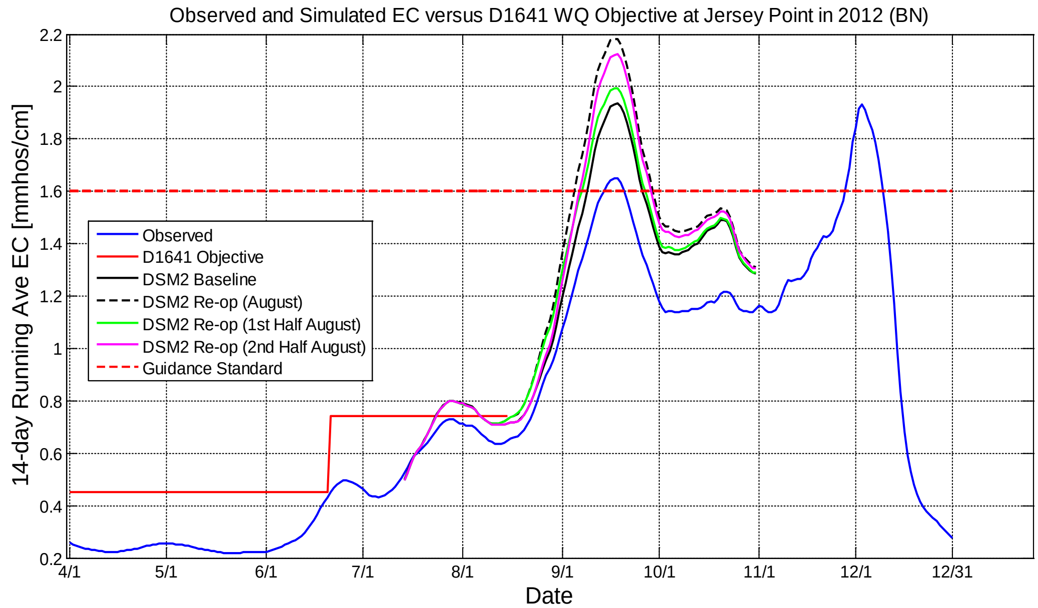
2) re-run forecast model water cost analysis with 2 gates (rather than 3) in re-operation

3) look at additional locations (e.g. Mallard)

4) look into above-normal year assumption

Appendix: 2012---a historical perspective

Question A1: What would be the impacts on water quality if the gates are re-operated in a different way (e.g., gates in operation only for two weeks in August versus the entire month as originally planned), if history (2012, BN) is any indication?



Changes (from baseline simulation, in %) in peak EC:

Jersey Point 2012 (BN):

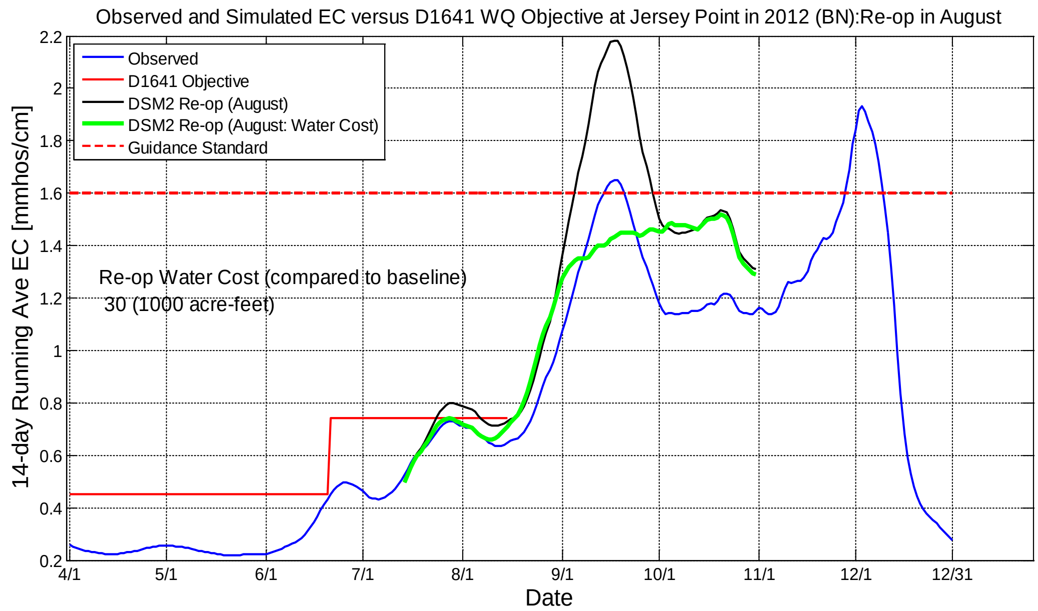
re-op in August: 12.8% increase;

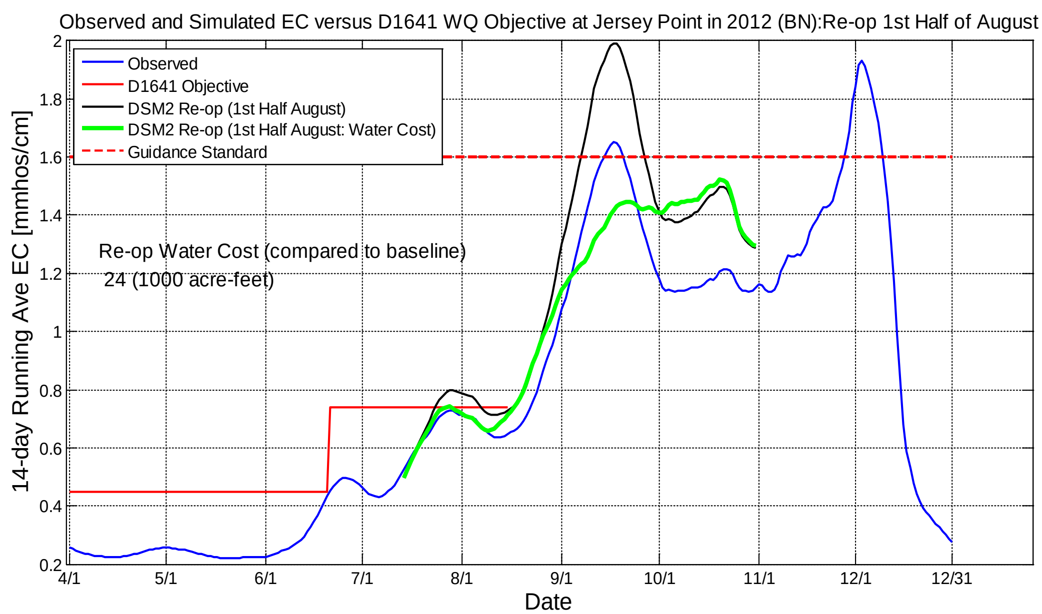
re-op in 1st half of August: 2.9% increase;

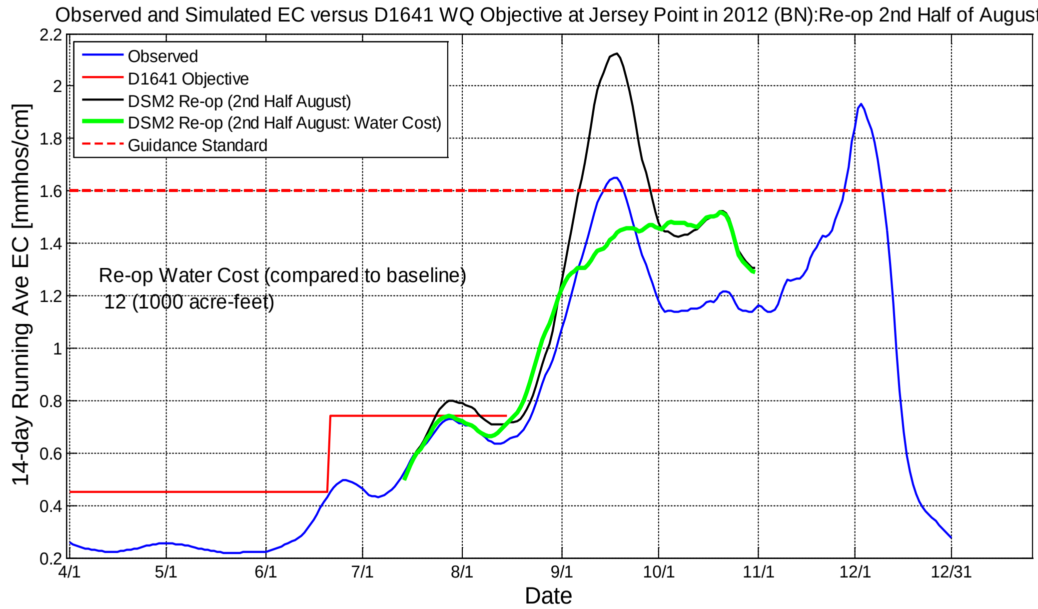
re-op in 2nd half of August: 9.6% increase

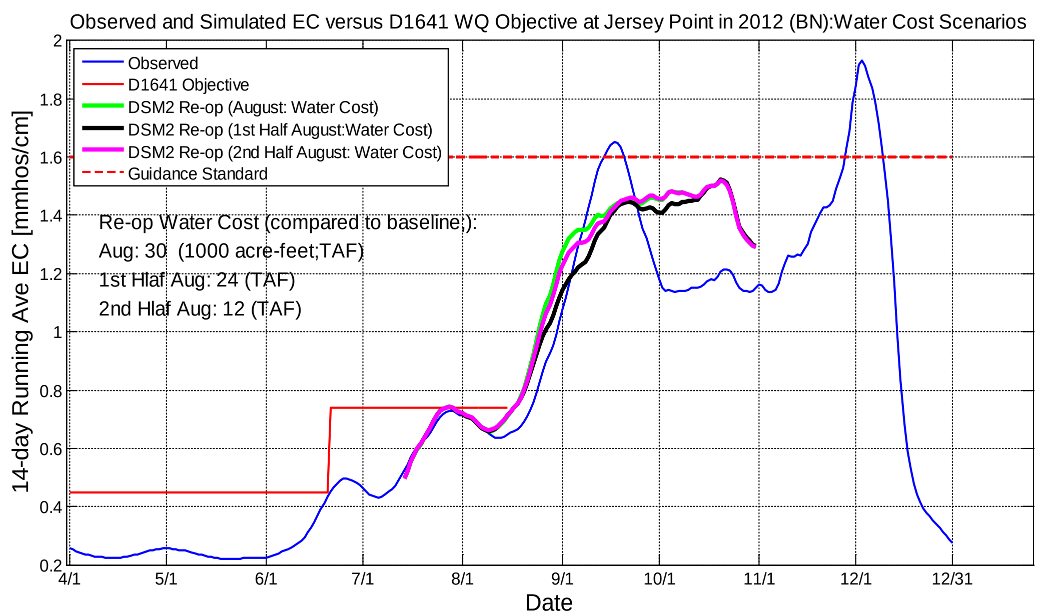
[guidance standard exceeded in all scenarios]

Question A2: What is the estimated water cost for those re-op scenarios to comply with the standards, if history (2012, BN) is any indication?









Water cost (compared with baseline simulation) to comply with standards [preliminary]:

Jersey Point 2012 (BN):

re-op in August: 30 TAF (i.e.,1000 acre-feet);

re-op in 1st half of August: 24 TAF;

re-op in 2nd half of August: 12 TAF.

Attachment B. Draft Work Plan for Monitoring and Assessment of Proposed Suisun Marsh Salinity Control Gates Action, 2018-2020

Work Plan for Monitoring and Assessment of Proposed Suisun Marsh Salinity Control Gates Action, 2018-2020

By Department of Water Resources Division of Environmental Services

Team members: Ted Sommer, Louise Conrad, Ted Swift, Michal Koller

February 9, 2018

Figures

Tables

Abbreviations

20-mm	20-mm survey
AMP	Adaptive management plan
BiOp	Biological Opinion
BPUE	Biomass per unit effort
CDFW	California Department of Fish and Wildlife
CDWR	California Department of Water Resources
CVP	Central Valley Project
Delta	Sacramento-San Joaquin Delta
DSRS	Delta Smelt Resilience Strategy
FLaSH	Fall low salinity habitat
FMWT	Fall Midwater Trawl
HSG	Habitat Study Group
IEP	Interagency Ecological Program
LSH	Low salinity habitat
LSZ	Low salinity zone
MAF	Million acre feet
MAST	Management, Analysis, and Synthesis Team
NRC	National Research Council
NTU	Nephelometric turbidity unit
OMR	Old and Middle River
POD	Pelagic organism decline
PSU	Practical Salinity Unit
RPA	Reasonable and Prudent Alternative
SFE	San Francisco Estuary
SKT	Spring Kodiak trawl
SRDWSC	Sacramento River Deep Water Ship Channel
SSC	Suspended sediment concentration
Suisun Bay	Suisun Bay and associated embayments
SWP	State Water Project
SWRCB	State Water Resources Control Board
USFWS	U.S. Fish and Wildlife Service

TNS	Summer townet survey
UCD	University of California at Davis
X2	The location of the near-bottom 2 PSU salinity isohaline measured in kilometers from the Golden Gate, following the river channel

Introduction

The following work plan describes the basis and design for monitoring and evaluation of a potential management action during drier seasons of the year (e.g. Summer-Fall) to benefit the Delta Smelt *Hypomesus transpacificus,* a federal and state listed species endemic to the San Francisco Estuary (Figure 1). Specifically, we propose to operate the Suisun Marsh Salinity Control Gates (SMSCG) in summer to improve salinity and habitat conditions for Delta Smelt. The concept of altering outflow and operations to benefit rearing stages of Delta Smelt is not new. Action 4 of the Biological Opinion (BiOp) on the Long-Term Operational Criteria and Plan for coordination of the Central Valley Project (CVP) and the State Water Project (SWP) (USFWS 2008) explicitly directs augmentation of Delta outflow during the fall to improve fall habitat for Delta Smelt, when the water year is above normal. Since the BiOp, there has been increased interest in targeted flow & habitat actions during other times of During spring/summer of 2016 the Delta Smelt Resiliency Strategy (DSRS) (CNRA 2016) was circulated and a final draft released in July 2016. The DSRS is a science-based document to voluntarily address both immediate and near-term needs of Delta Smelt, and promote their resiliency to drought conditions as well as future variations in habitat conditions. The document relies on concepts from a new conceptual model of Delta Smelt ecology (IEP-MAST 2015) and articulates a suite of actions that could be implemented in the next few years to benefit Delta Smelt. Included in these actions was pilot operation of the SMSCG in summer to improve salinity and habitat conditions for Delta Smelt. This action was included as part of a suite of other actions such as aquatic weed removal, flow-related experiments (North Delta Food Web, Summer Flow Augmentation), and habitat restoration (CNRA 2016).

the year.

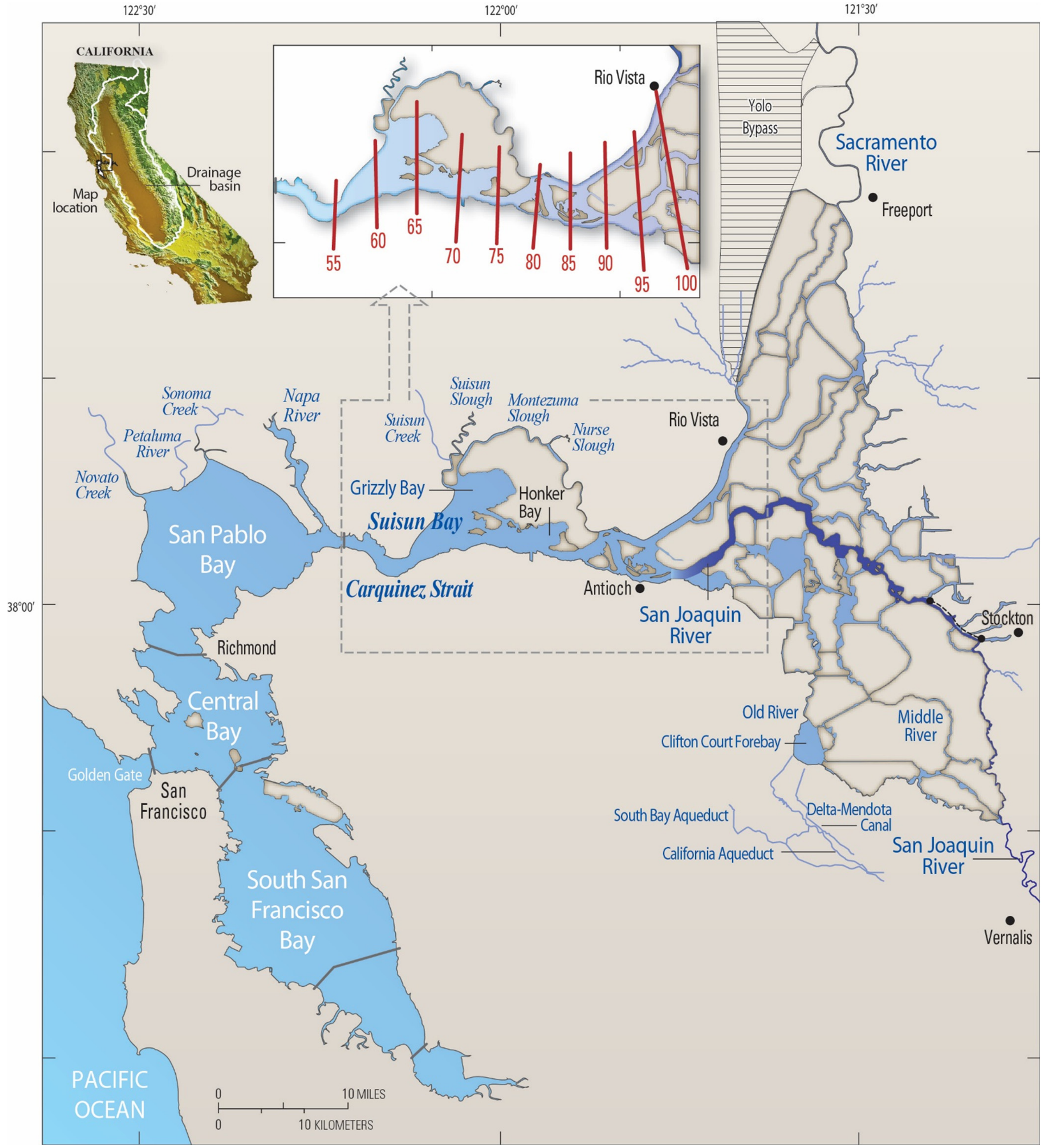


Figure 1. San Francisco Bay Estuary. Also shown are locations corresponding to different values of X2, which is the horizontal distance in kilometers from the Golden Gate up the axis of the estuary to where tidally averaged near-bottom salinity is 2 (adapted from Jassby and others, 1995).

Purpose and Scope

For this work plan we focus on a management action in which SMSCG are operated in summer to improve salinity and habitat conditions for Delta Smelt. This action is conceptually related to the companion North Delta Food Web Project, where dry season flows will be increased through the Yolo Bypass for the purposes of improving food web conditions for Delta Smelt. The SMSCG project also has linkages to Action 4 of the BiOp, which also seeks to improve Delta Smelt habitat during the drier fall months. As will be described later in this document, the SMSCG and the other actions noted above area all considered as part of the Collaborative Adaptive Management Team (CAMT's) efforts to provide guidance for flow and habitat actions under the BiOp and the DSRS. Since all the actions listed above are related to flow manipulations, the monitoring and evaluation covered in this plan will be included as part of the Interagency Ecological Program's Flow Evaluation Project Work Team (IEP FLoAT), an open forum to coordinate many of the proposed actions. Hence, there is substantial overlap between the current work plan for SMSCG and the monitoring and evaluation reports prepared by IEP FLoAT for other actions such as Fall X2 (e.g. Brown *et al*. 2017).

This work plan has 3 major objectives. The first major objective is to develop a set of hypotheses to assess regarding the expected effects of SMSCG operations on ecological conditions and Delta Smelt in the upper SFE. The second major objective is to provide an integrated work plan for monitoring and assessment studies that provide the data needed for evaluation of the hypotheses, including testing of corresponding predictions. The third major objective is to begin to put the expected results of the action into context within the larger body of knowledge regarding the SFE (Figure 1) and in particular the upper SFE, including the Sacramento-San Joaquin Delta (Delta) and Suisun Bay and associated embayments (Suisun Bay) (Figure 2).

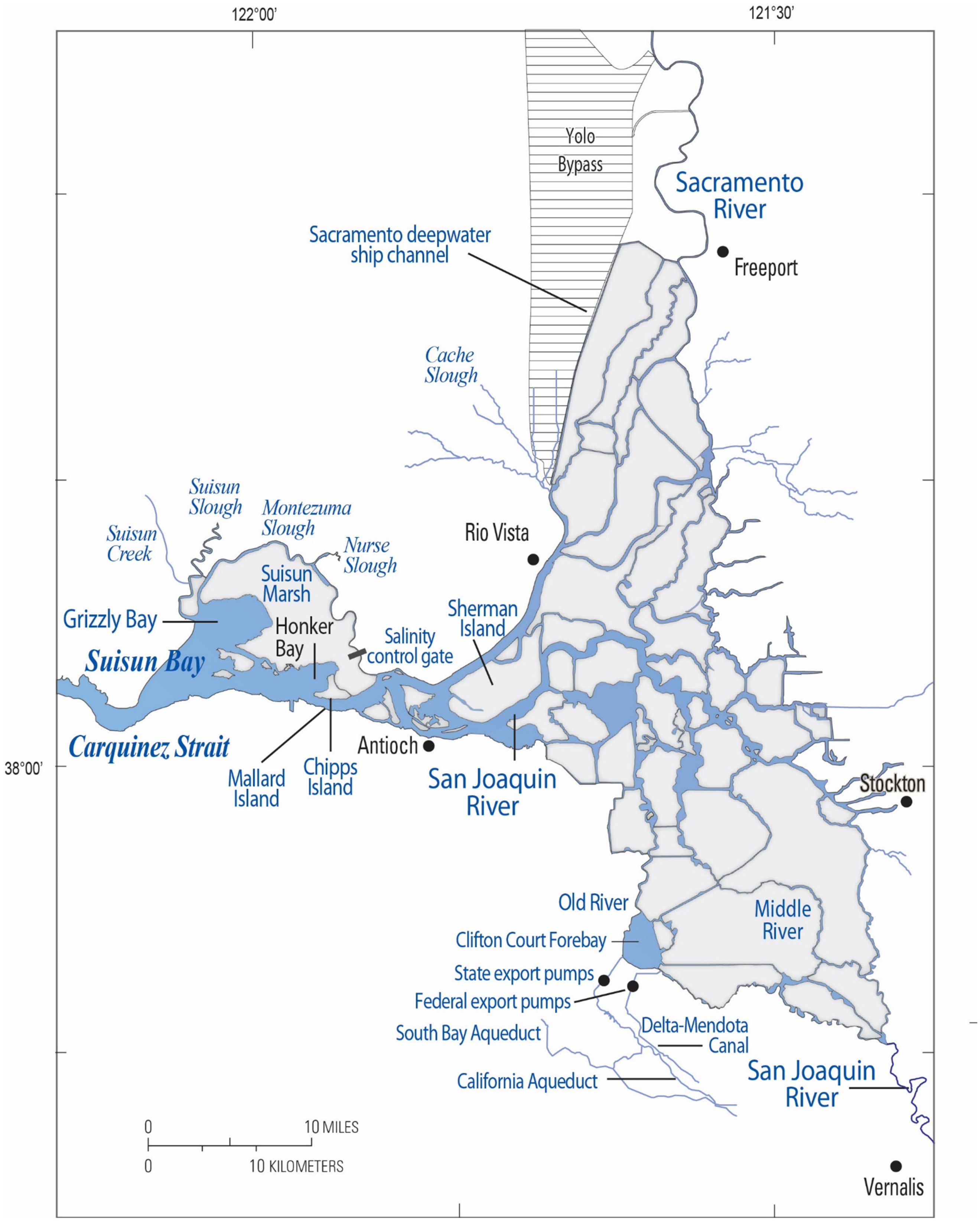


Figure 2. Sacramento-San Joaquin Delta, Suisun Bay, and associated areas (from IEP-MAST 2015).

The overall focus this work plan is on Suisun Marsh and Suisun Bay: however, we also include the freshwaters upstream of the low salinity zone (LSZ – see below) in the North Delta, and the LSZ to put the habitat needs of Delta Smelt into a broader context. Note that this geographical emphasis does not mean that downstream areas are unimportant for Delta Smelt. For example, Delta Smelt can tolerate higher salinities (Komoroske et al. 2016) and it is well known that the Napa River region represents key habitat for this species (Merz et al. 2011).

The North Delta includes the Sacramento River from Freeport to the area between Rio Vista and Decker Island and various sloughs and waterways to the west of the Sacramento River. The Cache Slough Complex extends north of the confluence of Cache Slough with the Sacramento River to the upper extent of tidal influence (Figure 3). Because our effort is focused on Delta Smelt and its habitat, the LSZ is defined as the area of the upper SFE with salinity ranging from 0.5 to 6 PSU, consistent with recent reports and conceptual models (Brown et al. 2014, IEP-MAST 2015). This is generally considered a core part of the distribution of Delta Smelt (Bennett 2005), although fish also occur outside this core range (Feyrer et al. 2007, Kimmerer et al. 2009, Merz et al. 2011; Sommer et al. 2011a). The geographic boundaries of the LSZ are dynamic both seasonally and among years, because periods of high outflow push the LSZ seaward, but in drier periods the LSZ is located further inland. Therefore, we also consider fresher and more brackish waters to the extent needed to understand both Smelt responses and the role of the LSZ.

Because the current project is proposed to begin in Summer 2018, this period and months that immediately precede and follow that season are the focus of this work plan. However, IEP monitoring and other studies have been ongoing in the SFE for many years providing the opportunity to put the current work plan into a broader temporal context. In fact, this broad perspective is likely critical to understanding how flow augmentation can contribute to the protection and recovery of Delta Smelt. This report represents the first step in addressing this broader scope.

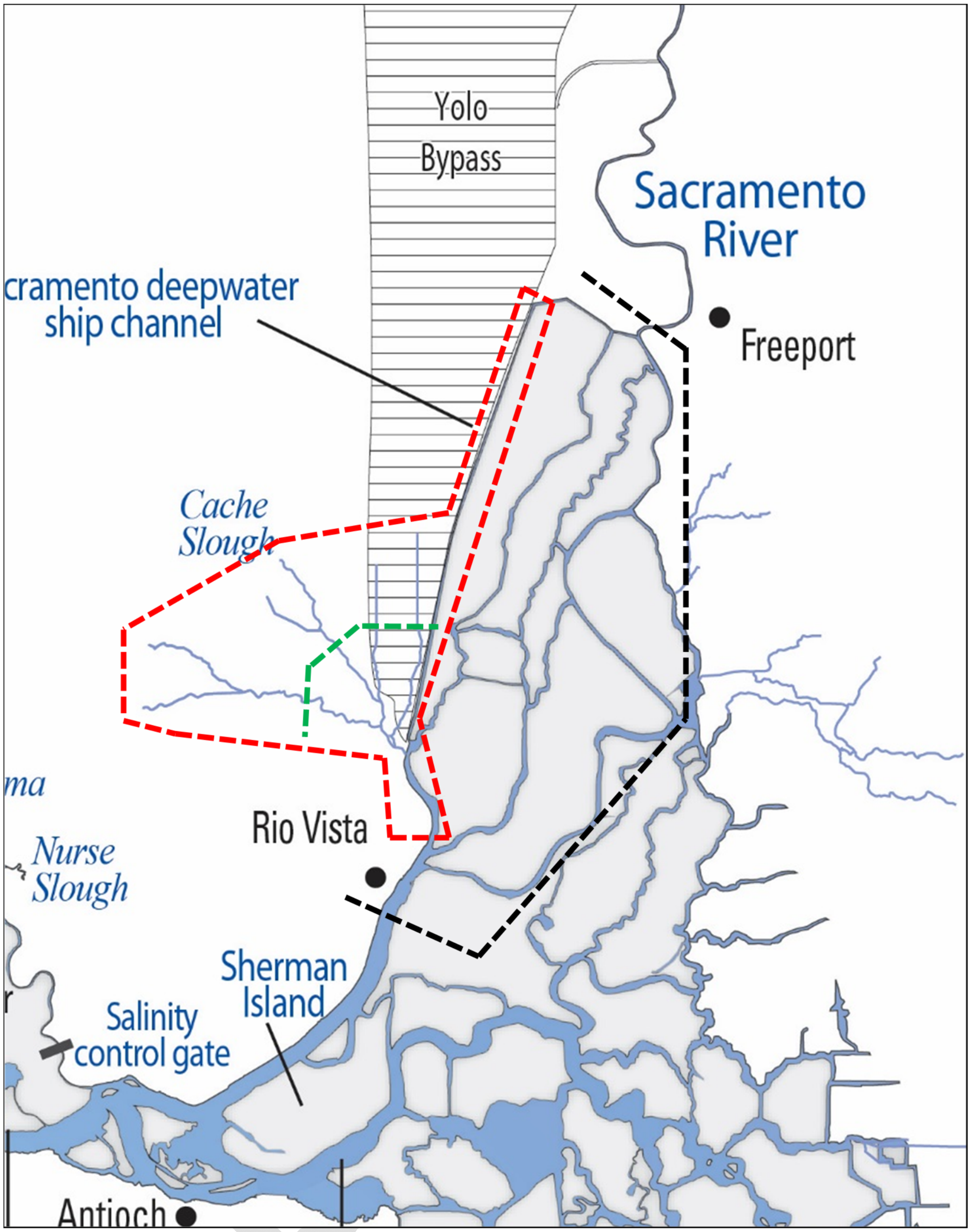


Figure 3. Regions of the North Delta. The black dotted line defines the north, south, and eastern extent of the North Delta as defined for this work plan. The red dotted line encloses the Cache Slough Complex. The green dotted line is an approximation of the division between the northern and southern Cache Slough Complex.

Background

Delta Smelt

In this section we summarize some general information about Delta Smelt biology for readers that are unfamiliar with the species. Details of factors believed to be affecting the biology of Delta Smelt are discussed extensively in additional sections of this work plan. Early information on the Delta Smelt population was collected as part of sampling and monitoring programs related to water development and Striped Bass *Morone saxatilis* management (Erkkila et al. 1950, Radtke, 1966, Stevens and Miller 1983). Striped Bass is an exotic species but supported a popular and valuable sport fishery when development of the CVP and SWP began (Moyle 2002). These early monitoring efforts, subsequently consolidated with other activities under the auspices of the IEP, provided sufficient information on the decline of Delta Smelt (Fig. 4) (Moyle et al. 1992) to support a petition for listing under the federal Endangered Species Act, which resulted in the species being listed as threatened in 1993 (USFWS 1993). Reclassification from threatened to endangered was determined to be warranted but precluded by other higher priority listing actions in 2010 (USFWS 2010). The species status was changed from threatened to endangered under the State statute in 2009 (California Fish and Game Commission 2009). Subsequent declines in the Delta Smelt in concert with three other pelagic fishes (Figure 4) caused increased concern for avoiding jeopardy and achieving recovery of Delta Smelt. These declines are often referred to as the Pelagic Organism Decline (Sommer et al. 2007, Baxter et al. 2008, 2010).

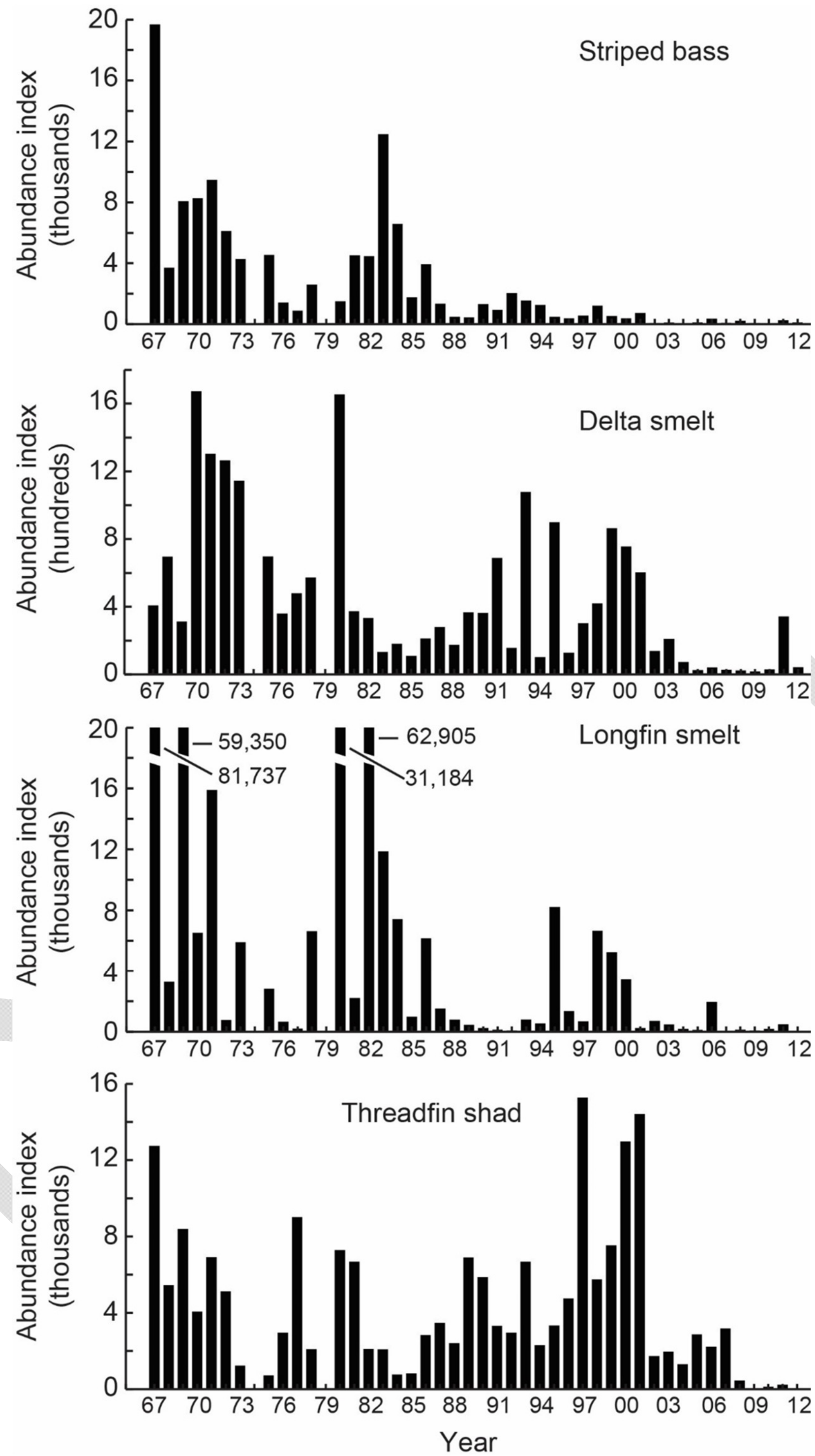


Figure 4. Trends in abundance indices for four pelagic fishes from 1967 to 2010 based on the Fall Midwater Trawl, a California Department of Fish and Game survey that samples the upper San Francisco Estuary. No sampling occurred in 1974 or 1979 and no index was calculated for 1976. Note that the y-axis for longfin smelt represents only the lower 25% of its abundance range to more clearly portray the lower abundance range (from IEP-MAST 2015).

The Delta Smelt is endemic to the upper SFE (Moyle et al. 1992, Bennett 2005). Delta Smelt is a slender-bodied fish typically reaching 60–70 mm standard length (SL) with a maximum size of about 120 mm SL. Delta Smelt feed primarily on planktonic copepods, mysids, amphipods, and cladocerans. Many Delta Smelt complete the majority of their life cycle in the Low Salinity Zone (LSZ) of the upper estuary and use the freshwater portions of the upper estuary primarily for spawning and rearing of larval and early post-larval fish (Figure 5) (Dege and Brown 2004, Bennett 2005); however, some Delta Smelt do complete their entire life cycle in freshwater and some appear to complete their entire life cycle in brackish water (Bush 2017). The continued global existence of the species is dependent upon its ability to successfully grow, develop, and survive in the SFE. The current range of juvenile and sub-adult Delta Smelt encompasses the Cache Slough Complex, and Sacramento River in the North Delta, the confluence region in the western Delta, and Suisun Bay (Figure 6). They also occur in the Napa River estuary in wetter years. Historically, juvenile and sub-adult Delta Smelt also occurred in the central and southern Delta (Erkkila et al. 1950), but they are now rare during the summer and fall months (Bennett 2005, Nobriga et al. 2008, Sommer et al. 2011a). Juvenile and sub-adult Delta Smelt occur mostly in the LSZ, with a center of distribution around salinity1-2 (Swanson et al. 2000, Bennett 2005, Sommer et al. 2011a). While some Delta Smelt complete their entire life cycle in fresh water, a large portion of the spawning population appears to rear in the LSZ (Bush 2017). Delta Smelt are generally not found at salinity above 14; however, with acclimation some can survive full seawater (Komoroske et al. 2014) for a short time. Komoroske et al. (2016) suggested that the physiological costs to Delta Smelt of living outside the low salinity zone, particularly at higher salinities, are energetically expensive and may preclude long-term occupancy of higher salinity water.

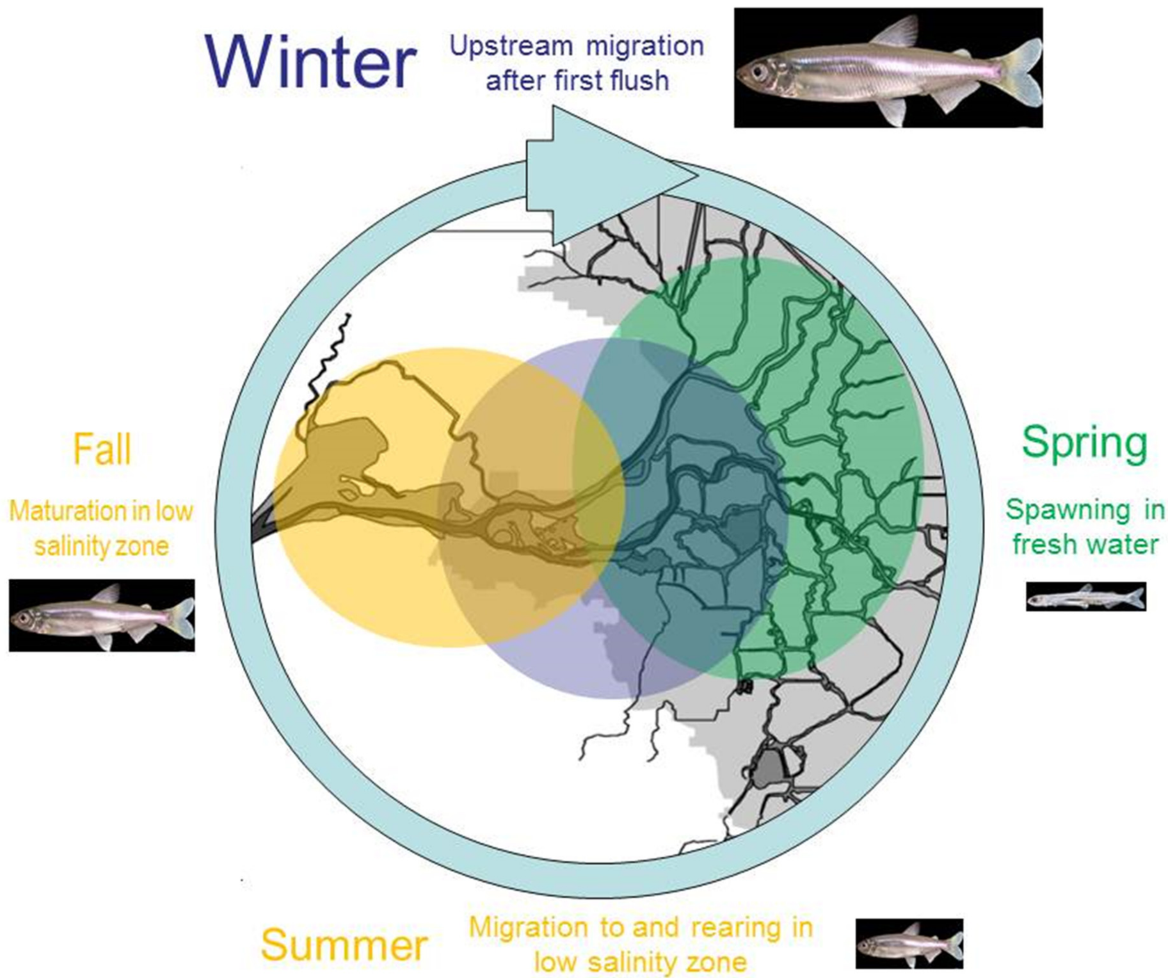


Figure 5. Simple conceptual diagram of the Delta Smelt annual life cycle for the dominant Low Salinity Zone rearing and the upper Delta spawning life history (modified from Bennett, 2005).

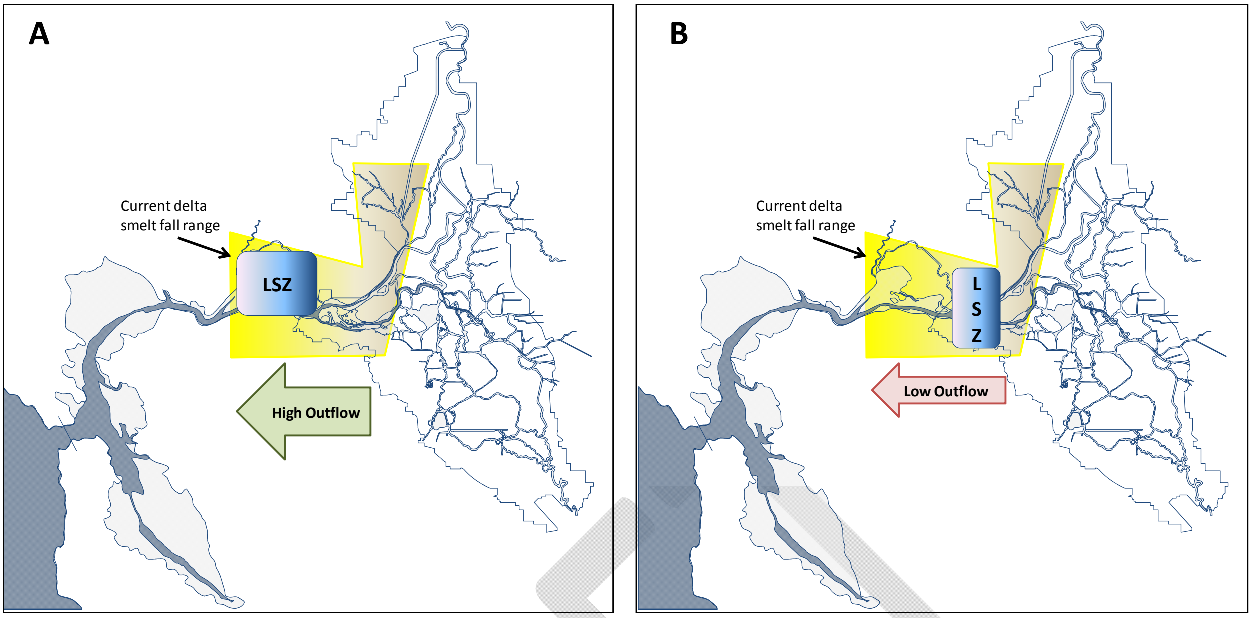


Figure 6. In the fall, Delta Smelt are currently found in a small geographic range (yellow shading) that includes the Suisun Bay, the river confluence, and the northern Delta, but most are found in or near the low salinity zone (LSZ). A: The LSZ overlaps the Suisun Bay under high outflow conditions. B: The LSZ overlaps the river confluence under low outflow conditions (from Reclamation, 2012).

Upstream movement of maturing adults generally begins in the late fall or early winter with most spawning taking place from early April through mid-May (Bennett, 2005; Sommer et al. 2011a). Not all maturing fish move up into the Delta to spawn and the movements to maturation and spawning areas can be thought of as a more general movement into freshwater areas (Murphy and Hamilton 2013). Many larval Delta Smelt move downstream with tidal or riverine flow until they reach favorable rearing habitat in the Low Salinity Zone (Dege and Brown, 2004). As noted earlier, some fish remain in freshwater, upstream areas including the Cache Slough complex and the lower Sacramento River year-round (Sommer et al. 2011a, Bush 2017). A very small percentage of Delta Smelt survive into a second year and may spawn in one or both years (Bennett 2005)

Summer physical habitat has been described by Nobriga et al. (2008) with summer (June-July) distribution of Delta Smelt determined by areas of appropriate salinity but also with appropriate turbidity and temperatures. Similarly, Feyrer and others (2007, 2010) found the distribution of Delta Smelt to be associated with salinity and turbidity during fall months (September-December). Kimmerer et al. (2009), Sommer et al. (2011a), and Merz et al. (2011) expanded on these studies by examining the habitat associations and geographic distribution patterns of Delta Smelt for each of the major IEP fish monitoring surveys. Manly et al. (2015) found that Delta Smelt were associated with some specific geographic regions in the fall, and Bever et al. (2016) found Delta Smelt associated with metrics of hydrodynamics (e.g., average water column velocity) in Suisun Bay during the fall. Overall, these studies demonstrated that most Delta Smelt have a center of distribution near the 2 isohaline, but many shift during winter and spring months when spawning and early development occur over a broader region including upstream freshwater sloughs, as well as the downstream Napa River in wet years.

Fisch (2011) determined that individuals inhabiting freshwater areas were not genetically unique relative to Delta Smelt captured from other regions of the system; rather, there is a single, panmictic Delta Smelt population in the estuary. Although not conclusive, this finding suggests that freshwater resident Delta Smelt do not form a separate, self-sustaining population. Rather, it seems likely that the life history of Delta Smelt includes the ability to rear in fresh water if other factors are favorable; however, the absence of Delta Smelt from riverine non-tidal habitats upstream of the Delta suggests that there are limits on freshwater residence.

Although abundance of Delta Smelt has been highly variable, there is a demonstrable long-term decline in abundance (Figure 4; Manly and Chotkowski 2006, USFWS 2008, Sommer et al. 2007, Thomson et al. 2010). The decline spans the entire period of survey records from the completion of the major reservoirs in the Central Valley through the POD (pelagic organism decline) (IEP-MAST 2015). Statistical analyses confirm that a step decline in pelagic fish abundance marks the transition to the POD period (Manly and Chotkowski, 2006, Moyle and Bennett 2008, Mac Nally et al. 2010, Thomson et al. 2010, Moyle et al. 2010) and may signal a rapid ecological regime shift in the upper estuary (Moyle et al. 2010, Baxter et al. 2010). The decline of Delta Smelt has been intensively studied as part of an IEP effort to understand the POD decline (Sommer et al. 2007, Baxter et al. 2010). The POD investigators have concluded that the decline has likely been caused by the interactive effects of several causes, including both changes in physical habitat (e.g., salinity and turbidity fields) and the biotic habitat (i.e., food web). This conclusion was generally supported by a recent independent review panel (NRC, 2012) and recent literature reviews (IEP-MAST 2015, Moyle et al. 2016, Brown et al. 2016).

A wide variety of statistical approaches have been applied to studies of Delta Smelt in the SFE. Various forms of regression and multiple regression models have been widely applied (e.g., Manly and Chotkowski 2006, Feyrer et al. 2010, Miller et al. 2012). General additive models have been used to identify important abiotic habitat factors (Feyrer et al. 2007, Nobriga et al. 2008). Additional models include Bayesian change point models (Thomson et al. 2010) and a Bayesian-based multivariate autoregressive model of Delta Smelt fall abundance (Mac Nally et al. 2010). Adaptive management calls for the use of quantitative models when available. Importantly, these studies differed widely in methodology and objectives and rarely evaluated the same environmental factors. As a result, they often reached alternative conclusions about the direct or indirect importance of the same environmental factor on the species.

Life cycle models that quantify and integrate many aspects of Delta Smelt biology are expected to provide results that will help guide outflow management and other management actions in the coming years. Maunder and Deriso (2011) developed a statistical state–space multistage life cycle model to evaluate the importance of various factors on different life stages of Delta Smelt. Another life cycle model developed by Newman et al, currently under development, has a state-space structure similar to Maunder and Deriso (2011). It differs from the Maunder and Deriso model in three critical ways: (1) the model is spatially explicit, so that management actions can be assessed at a local level, (2) the temporal resolution is finer, a monthly time step, and (3) data from more fish surveys are being used to fit the model (Ken Newman, written communication, 2012). A numerical simulation model has also being developed (Rose et al. 2013a,b). The life cycle models and numerical simulation model could be used to evaluate hypothesized associations in conceptual models as the SMSCG project develops.

Conceptual Model

As a follow-up to the fall low-salinity habitat studies (Brown et al. 2014), the IEP established the Management, Analysis and Synthesis Team to develop a new conceptual model for Delta Smelt Biology (IEP-MAST 2015). In this workplan, we use the original framework of the FLaSH conceptual model, which includes stationary abiotic habitat components, dynamic abiotic habitat components, dynamic biotic habitat components, and Delta Smelt responses (i.e., pelagic recruitment; Figure 7). We use the IEP-MAST conceptual model (IEP-MAST 2015) and subsequent literature (e.g., Moyle et al. 2016) to identify habitat components that likely are important to Delta Smelt in the summer (Figure 8) and fall (Figure 9) and to identify likely Delta Smelt biological responses. In contrast to the FLaSH approach, which focused on the characteristics of the Low Salinity Zone as it moved through the estuary in response to flow, we put our FLOAT conceptual model in the context of the fixed geography of the region because the SMSCG project is expected to affect only the Marsh and nearby areas. The idea that specific locations may be preferred by Delta Smelt has also received recent support in the literature (Merz et al. 2011, Bever et al. 2016, Manly et al. 2015).

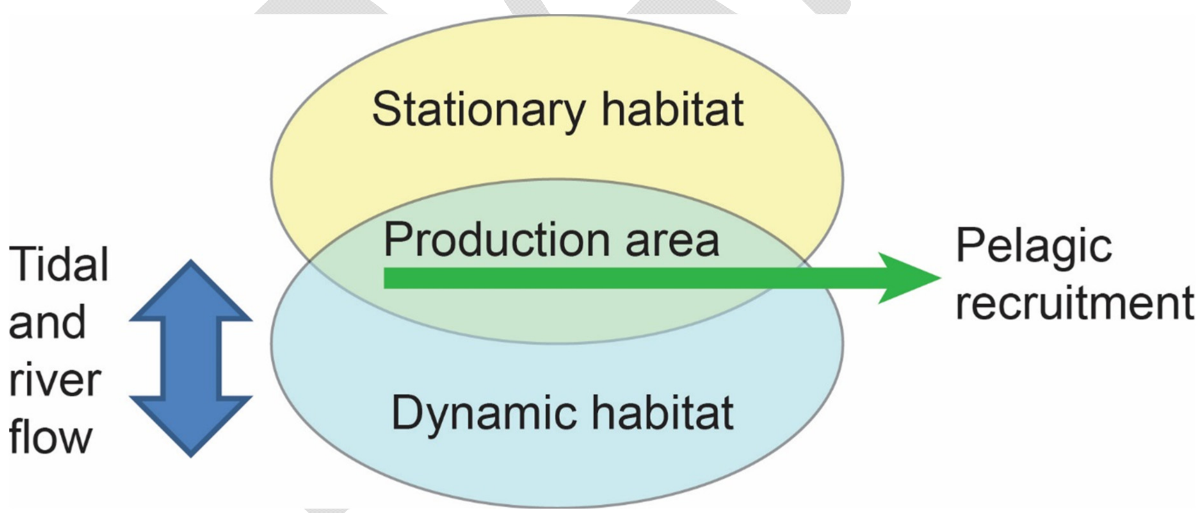


Figure 7. Illustration showing estuarine habitat conceptual model (modified from Peterson 2003).

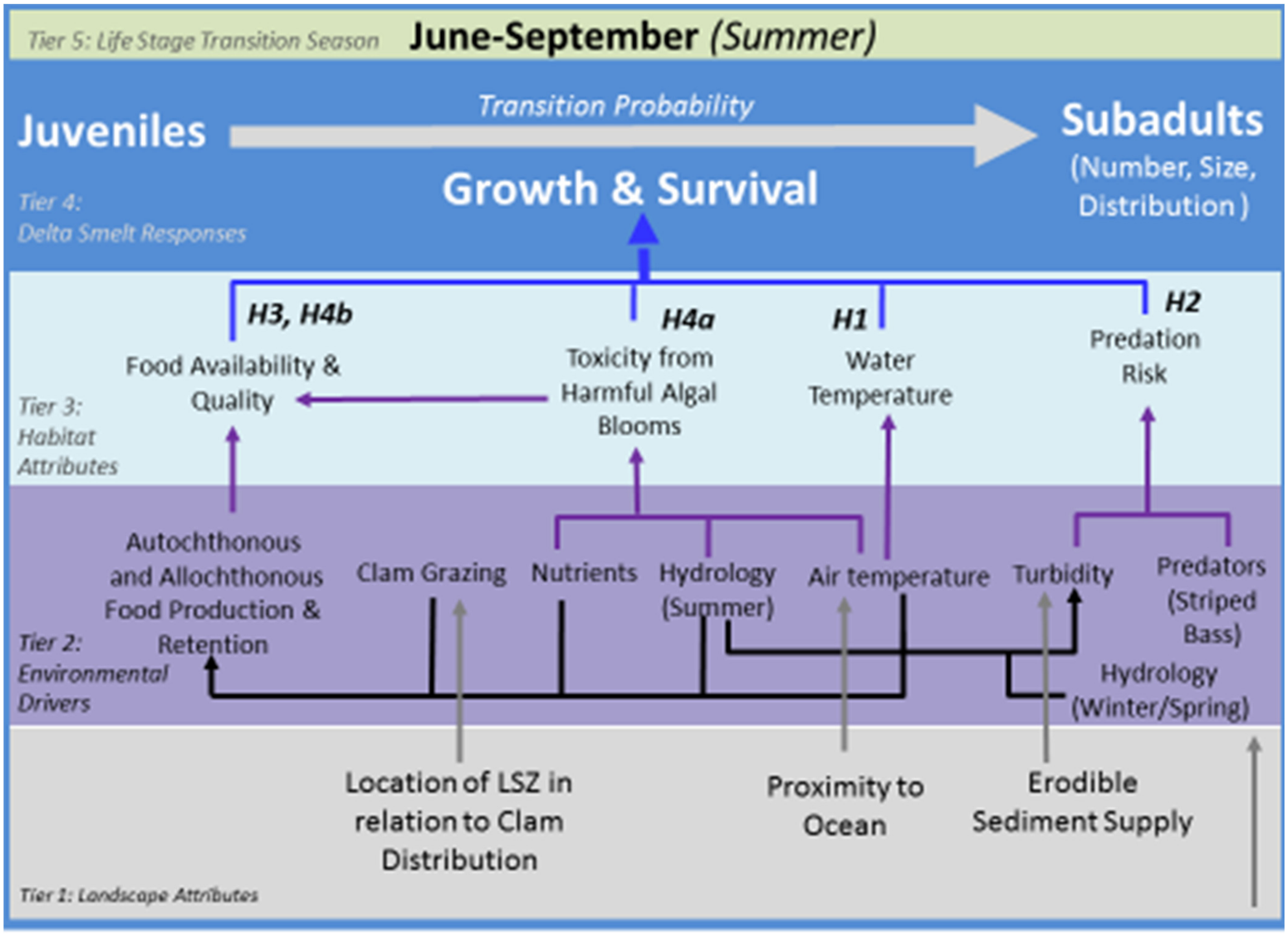


Figure 8. Summer conceptual model for Delta Smelt (from IEP-MAST 2015).

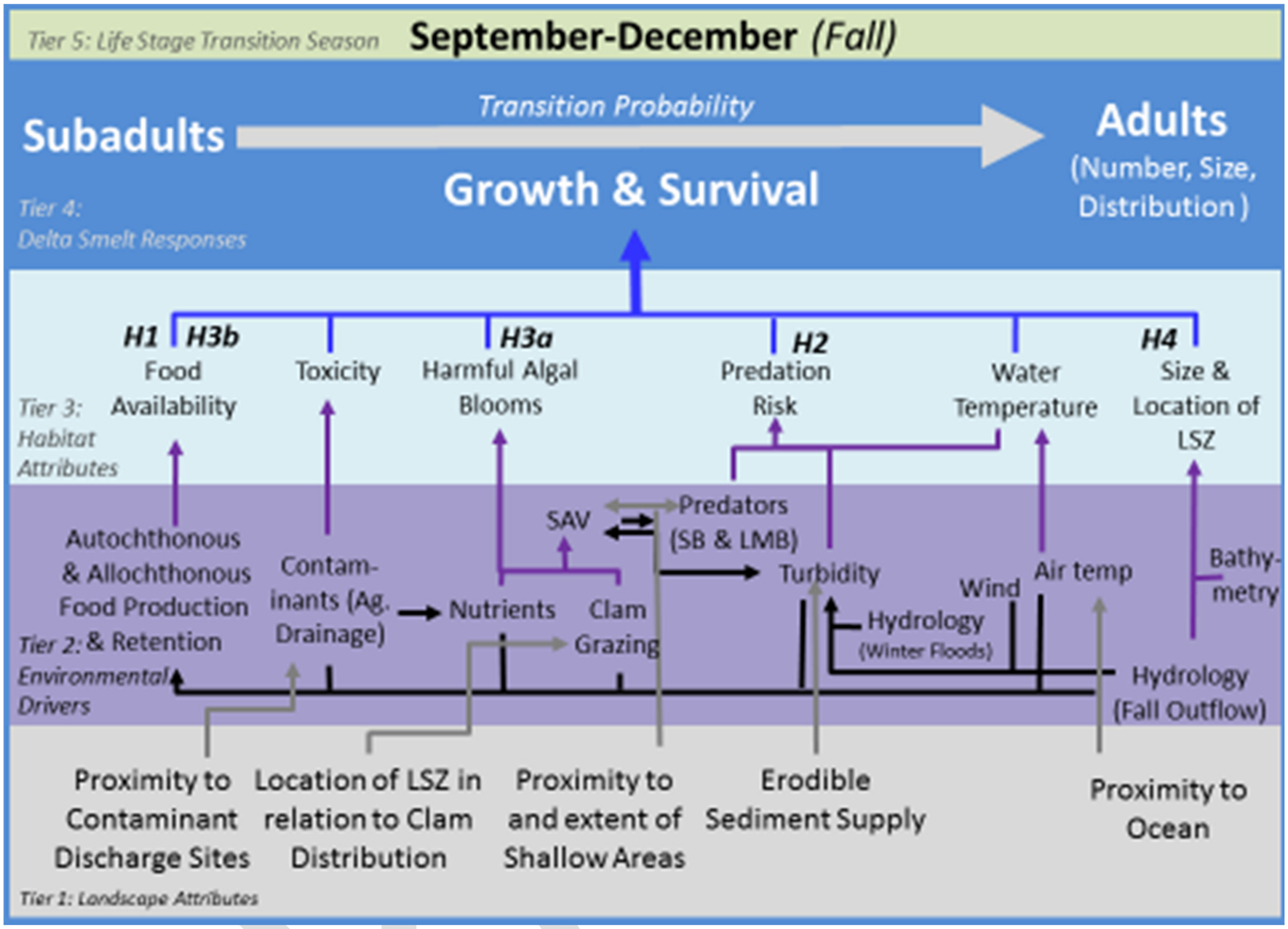


Figure 9. Fall conceptual model for Delta Smelt (from IEP-MAST 2015).

For a detailed description of the DS-MAST conceptual model, readers should refer to the original report (IEP-MAST 2015). For the purposes of this workplan we use the seasonal conceptual models for summer (Figure 8) and fall (Figure 9). Note that the DS-MAST conceptual models only show the processes considered most important to Delta Smelt in each particular season, as determined by the authors at that time. This determination also included operational considerations, such as the likelihood that flow augmentations or pumping restrictions would be considered. For the current work plan, we first considered the processes included in the DS-MAST conceptual models but also considered other processes that might be affected by SMSCG action. The DS-MAST conceptual models do include a tier of Landscape Attributes which was meant to capture the effects of fixed geographic characteristics on the dynamic abiotic and biotic attributes of the system summarized in the Environmental Drivers tier. Because the actions being considered in the work plan are very geographically specific, a more specific geographic conceptual model was developed for the FLoAT actions than was used for the DS-MAST conceptual model (Figure 10).

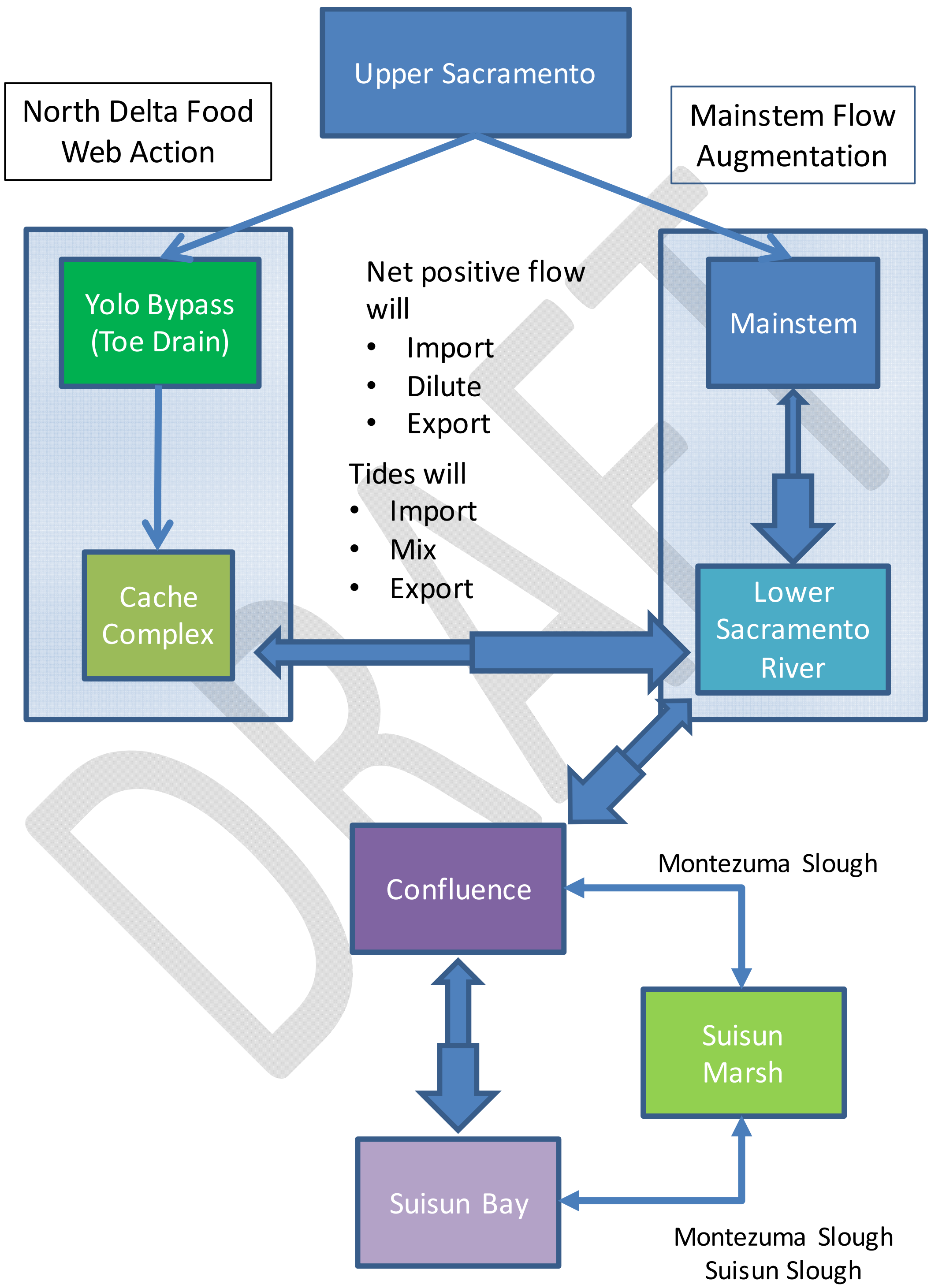


Figure 10. Box model for the geographic area of interest, and key upstream reaches.

The FLoAT geographic conceptual model (Figure 10) focuses on the specific routes for additional flow being considered under a the SMSCG and North Delta food web actions, and other potential Flow Augmentation Actions.

The water flow in Suisun Marsh exhibits several patterns affected by tidal action and net river flow. At the eastern end of the marsh water can enter through the eastern end of Montezuma Slough which connects to the confluence region (Figure 2), or from the west through Suisun Slough or the western end of Montezuma Slough at Grizzly Bay (Figure 2). Daily tidal cycles cause water in Montezuma Slough to travel a significant fraction of the slough length. When river discharge is high, net flow is westward through Montezuma Slough. During low river flows. tidal energy tends to create a small net eastward flow in Montezuma Slough, drawing in relatively saline water from the west (Fischer et al. 1979). As described in the BiOp, the SMSCG are currently operated in fall to freshen marsh channels. The general approach during operational periods is to open gates during ebb tide and close gates during flood tides. These operations essentially tidally pump water into Suisun Marsh from the confluence region by allowing freshwater into the marsh during ebb tides, then closing the gates to keep the water from getting "pushed out" by more saline high tides.

Hypotheses/Predictions

A key to the adaptive approach is to develop a suite of expected responses from dynamic habitat drivers and biological responses at multiple levels of the ecosystem during the target summer and fall period for SMSCG operations. Those expectations about dynamic habitat drivers and biological responses are presented below for each type of action. In the current work plan, we use data from past and present monitoring and research programs to help formulate predictions.

Our general approach in formulating the predictions was to review the processes and interactions depicted in the conceptual model, evaluate the available information, and make a judgment about whether each prediction was reasonable. For the purposes of this work plan, we consider summer as being defined by June–August and Fall as only September-October due to the specific timing of a relevant and related action, Action 4 in the USFWS Biological Opinion (FWS 2008--fall outflow action). The summer and fall periods in the conceptual models overlap (Figures 8 and 9) because they are partially defined on the basis of Delta Smelt life stages, which are continuous and can vary from year to year based on environmental conditions and fish vital rates, such as growth rates. We fully recognize that there may be interactions between the SMSCG action and other manipulations such as the North Delta Food Web Action. However, for the purposes of this effort we focus on expected changes from the SMSCG project. The effects of multiple concurrent or serial actions will require a more complex approach, making it harder to evaluate the individual contribution of SMSCG operations.

Suisun Marsh Salinity Control Gate Action

The general hypothesis is that reducing salinity in Suisun Marsh is beneficial for the Delta Smelt population for reasons discussed earlier. Here we describe the expected responses in two types of habitat components (Stationary, Dynamic) and for Delta Smelt.

Stationary abiotic habitat components

There are four key stationary habitat components that differ between the Sacramento River, the river confluence region and Suisun Bay and may affect habitat quality and availability for Delta Smelt. In addition, they all vary within each region, and change over time in response to dynamic drivers, albeit much more slowly than the dynamic habitat components. For example, bathymetry and erodible sediment supply can change as more sediment is transported into the region and deposited or eroded and flushed out to the ocean. Contaminant sources and entrainment sites are added or eliminated with changes in land and water use. Although we make predictions for several abiotic habitat components, we note that most would not change either regionally or in the Low Salinity Zone under the action (Table 1).

Table 1. Predicted responses relative to base conditions (i.e. similar periods without SMSCG operations). Predicted outcomes for the SMSCG Action assuming a change in gate operations during summer of dry-below normal years. Extreme wet and very dry years are excluded from the predictions because the SMSCG action is unlikely under those conditions.

Variable (Aug-Oct)	Predictions Relative to Base		
Habitat Conditions	**Full Low Salinity Zone (Dynamic Location)**	**Suisun Marsh Region (Montezuma Sl, Grizzly Bay, Honker Bay)**	**River Region (Confluence area to Rio Vista)**
Average Daily Net Delta Outflow	Higher	Higher	Higher
San Joaquin River Contribution Outflow	Neutral	Neutral	Neutral
Surface area of the fall LSZ	Higher	Higher	Neutral
Hydrodynamic Complexity	Higher	Neutral	Neutral
Salinity	Neutral	Lower	Neutral
Average Wind Speed	Neutral	Neutral	Neutral
Average Turbidity	Neutral	Neutral	Neutral
Average Ammonium Concentration	Neutral	Neutral	Neutral
Average Nitrate Concentration	Neutral	Neutral	Neutral
Non-Smelt Food Web Responses			
Average Phytoplankton Biomass (excluding *Microcystis*)	Higher	Neutral	Neutral
Contribution of Diatoms to Phytoplankton Biomass	Higher	Neutral	Neutral
Average *Microcystis* Biomass	Neutral	Neutral	Neutral
Calanoid copepod biomass in the LSZ	Higher	Neutral	Neutral
Cyclopoid copepod biomass in the LSZ	Higher	Neutral	Neutral
Bivalve biomass	Neutral	Neutral	Neutral
Bivalve survival	Neutral	Neutral	Neutral
Bivalve growth	Neutral	Neutral	Neutral
Fish assemblage	Different	Different	Neutral
Delta Smelt (DS) Responses			
DS caught at Suisun power plants	0	0	0
DS in SWP & CVP salvage	0	0	0
DS distribution	Westward	Westward	Westward
DS growth, survival, and fecundity in fall [a]	Higher	Higher	Neutral
DS health and condition in fall	Better	Better	Neutral
DS Recruitment the next year	Better	Better	Better
DS Population life history variability	Better	Better	Better

Bathymetric complexity: Differences in bathymetry and spatial configuration between the three regions affect nearly all other habitat features and interact strongly with the prevailing dynamic tidal and river flows to produce regionally distinct hydrodynamics. Overall, the Suisun Bay and the Marsh region targeted in the SMSCG action are more bathymetrically complex than the river. Hence, these differences are reflected in our regional predictions. Extensive shallow, shoal areas in the Suisun Bay are considered particularly important. The river confluence area is more constrained and channelized but is still influenced by areas with some complexity, such as the shallow waters and tidal wetlands around Sherman Island and Decker Island. The upper Sacramento River upstream of Decker Island is deep and highly constrained and changes character above the confluence of Cache Slough where it becomes narrower and more riverine; although it is still highly constrained.

Erodible Sediment Supply: The amount and composition of the erodible sediment supply is an important factor in the regulation of dynamic suspended sediment concentrations and turbidity levels in the water column. Suisun Bay features extensive shallow water areas such as Grizzly and Honker Bays that are subject to wind waves that resuspend bottom sediment and increase turbidity relative to the confluence (Ruhl and Schoellhamer, 2004). The contribution of organic material to the erodible sediment supply in Suisun Bay and the river confluence and its role is uncertain, so we don't not make specific regional predictions. The upper Sacramento River likely functions more as a conduit for suspended sediment since it is leveed and maintained, at least partially, to convey flood flows during winter storms.

Contaminant Sources: The large urban areas surrounding the estuary and the intensive agricultural land use in the Central Valley watershed and the Delta have resulted in pollution of the estuary with many chemical contaminants (Brooks et al. 2012, Johnson et al. 2010). Many of these pollutants (e.g. heavy metals, pesticides) can be toxic to aquatic organisms (Fong et al 2016). Sources of contaminants in these broad regions are quite extensive, including but not limited to the mothball fleet, duck pond management, refineries, waste water treatment plants, integrative pest management, industrial and agricultural chemicals, and storm drains. The largest wastewater treatment plant in the Delta, the Sacramento Regional Wastewater Treatment Plant (SRWTP), discharges effluent with high amounts of ammonium, pyrethroid pesticides, and other pollutants into the Sacramento River near the northern border of the Delta. The large Contra Costa wastewater treatment plant also discharges substantial amounts of ammonium and other pollutants into the western Suisun Bay near Carquinez

Strait. Ammonium has been found to suppress nitrate uptake and growth of phytoplankton in the Delta and Suisun Bay (Dugdale et al. 2007). Stormwater runoff is a significant and seasonal problem with toxicity detected in Delta Smelt critical habitat (Weston et al 2014). Aquatic weed and vector control programs directly apply pesticides to the Suisun/Delta. Intermittent accidental spills also occur, for example the Kinder Morgan Diesel Fuel Oil Spill in Suisun Marsh in 2004. In addition to chemical pollution, blooms of the toxic cyanobacteria like *Microcystis aeruginosa* have become a common summer occurrence in the central and southern parts of the Delta, including the river confluence and the eastern edge of the Suisun Bay (Lehman et al. 2008, 2010). Because *Microcystis* can produce potentially toxic microcystins and is considered poor food for secondary consumers, it is considered a biological contaminant. Overall, we predict that contaminants and toxic blooms will be more of an issue in regions upstream of Suisun Bay. This prediction is consistent with work from Hammock et al. (2015), in which histopathological examinations of Delta Smelt tissue from fish collected from Suisun Marsh, Suisun Bay, and the Cache Slough Complex showed the greatest evidence of contaminant exposure in the Cache Slough Complex.

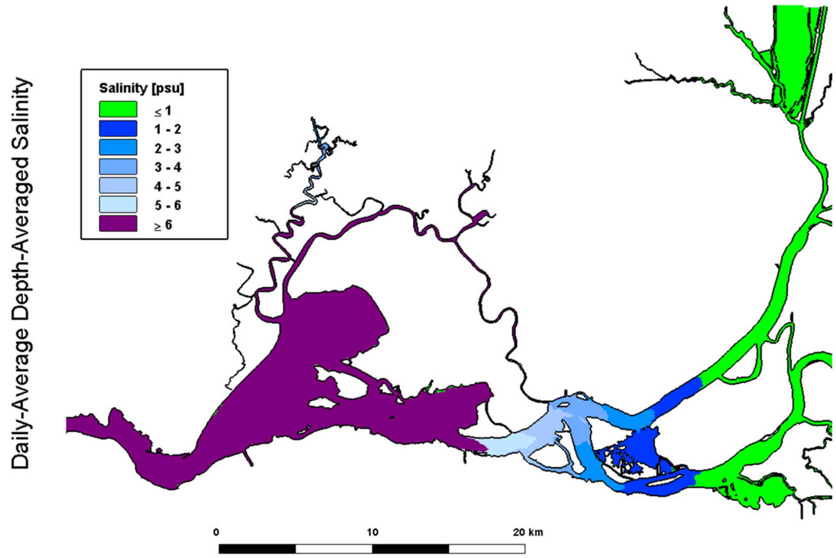
Entrainment sites: Entrainment sites include agricultural water diversions and urban water intakes throughout the Delta and Suisun Bay, the state and federal water project pumps in the southern Delta (fig. 3), and two intermittently-operated power plant cooling water intakes in the Suisun Bay (in Pittsburg and Antioch). Entrainment can cause direct mortality in fish screens, pumps, or pipes (Grimaldo et al. 2009; Castillo et al. 2012), and it can cause indirect mortality due to enhanced predation or unsuitable water quality associated with diversion structures and operations (Arthur et al. 1996; Feyrer et al. 2007; Moyle et al. 2010). Direct entrainment of Delta Smelt in the summer-early fall months covered by the SMSCG action are most likely to occur at local agricultural diversions and perhaps North Bay Aqueduct. Hence, we predict that entrainment will be modest overall, but with potential for greater effects upstream of Suisun Bay given the larger number of diversions.

Predictions for dynamic abiotic habitat components

There are a number of dynamic components that change in magnitude and spatial configuration at daily, tidal, seasonal, and interannual time scales. Their interactions with each other and with stationary habitat components determine the extent and location of production areas for estuarine species. There are eight major dynamic abiotic habitat components to consider. Predictions are summarized in Table 1.

Total Delta outflow and San Joaquin River contribution in the summer-fall The interaction of ocean tides with inflows from tributary rivers is the main dynamic driving force in estuaries and determines outflow to the ocean. The estuary is located in a Mediterranean climate zone with highly variable precipitation and river flow patterns (Dettinger, 2011). Winters are generally wet and summers are dry, but there is large interannual variability. Only a small amount of San Joaquin River water is actually discharged to the ocean in all but the wettest years. This is especially true in the summer and fall months, when only a very small fraction of Delta outflow is contributed by water from the San Joaquin River. Thus, the prediction is that the proposed action will not change the contribution of San Joaquin River flows in summer. With regard to Total Delta Outflow, operation of the SMSCG during the summer is expected to result in a slight upstream shift in X2. The reason is that operation of the SMSCG during summer would essentially direct more freshwater into the marsh rather than along the main open water region of the estuary, i.e. the Sacramento-San Joaquin River main stem or Deep Water Ship Channel. Hence, there would be slightly less freshwater flow to shift X2 downstream in the main stem. Based on this effect, we predict that the Total Delta Outflow would not change under the SMSCG action unless additional flow is provided to compensate for the X2 shift. Under the later scenario, as reflected in the current Project Description, there would be a modest increase in Total Delta Outflow during August and part of September to keep X2 in the same region it would be without the SMSCG reoperation action. We do not expect that this additional outflow would come from the San Joaquin River.

Location and extent of the fall Low Salinity Zone. Under the static summer-fall outflow regime that has been typical for the POD period (Brown et al. 2014), outflows throughout much of the fall are always low and salinity intrudes far to the east (X2 > 80 km), causing the LSZ to be constricted to the confluence of the deep Sacramento and San Joaquin river channels (Figure 12). When X2 is more seaward, the LSZ includes more of Suisun Bay (Figures 13 and 14). Based on initial modeling studies, it appears that operations of the SMSCG in August will increase the amount of habitat conducive to Delta Smelt in the Suisun Marsh and Bay, specifically Grizzly Bay. The degree to which this will change depends substantially on water year types. In general, the effect is greatest in drier water years and modest in above normal years. The same is true for the predicted effect of the SMSCG operations on LSZ. Specifically, SMSCG operations are expected to result in a modest increase the area of the LSZ in drier years and a very slight increase in above normal years. Moreover, the action would substantially increase the proportion of the LSZ that it located in Suisun Marsh.



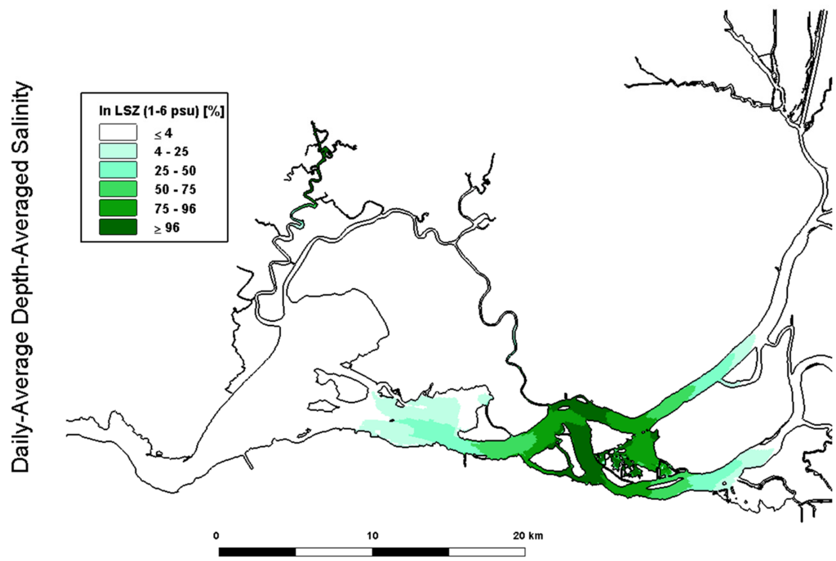
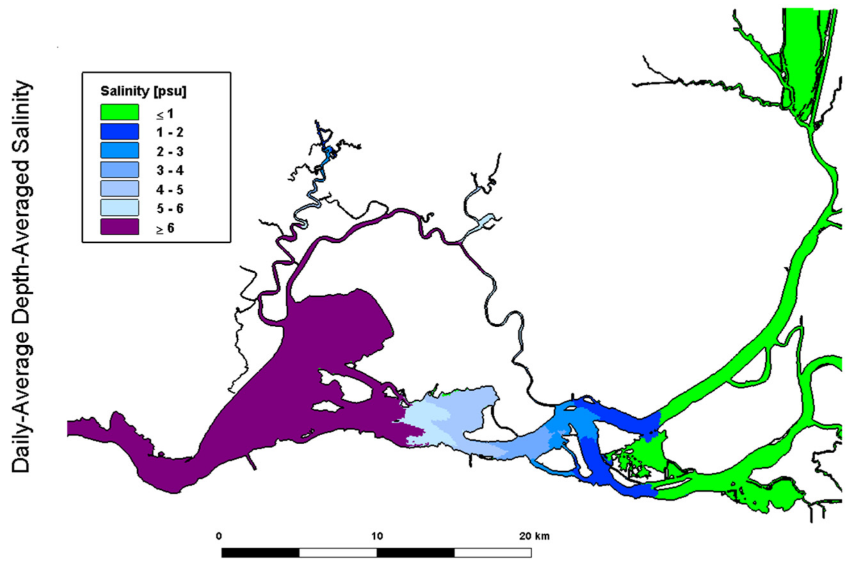


Figure 11. Location and extent of the fall Low Salinity Zone.



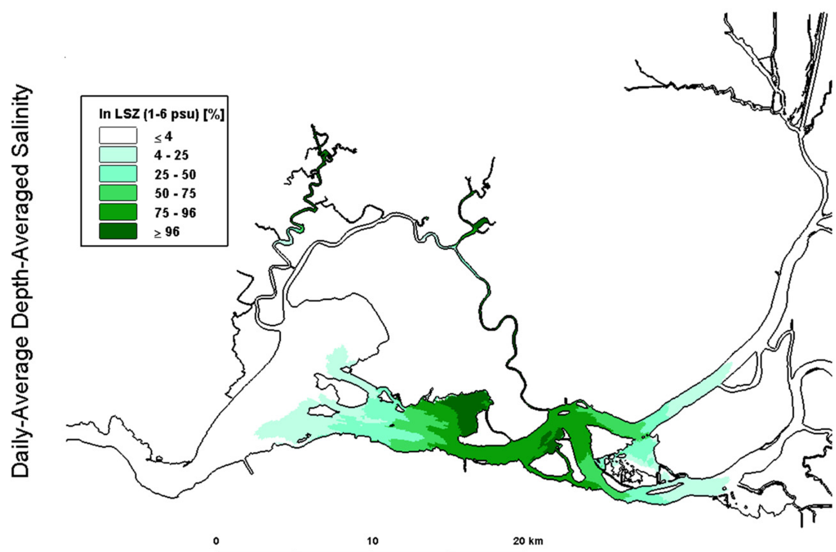


Figure 12. Low Salinity Zone located further west.

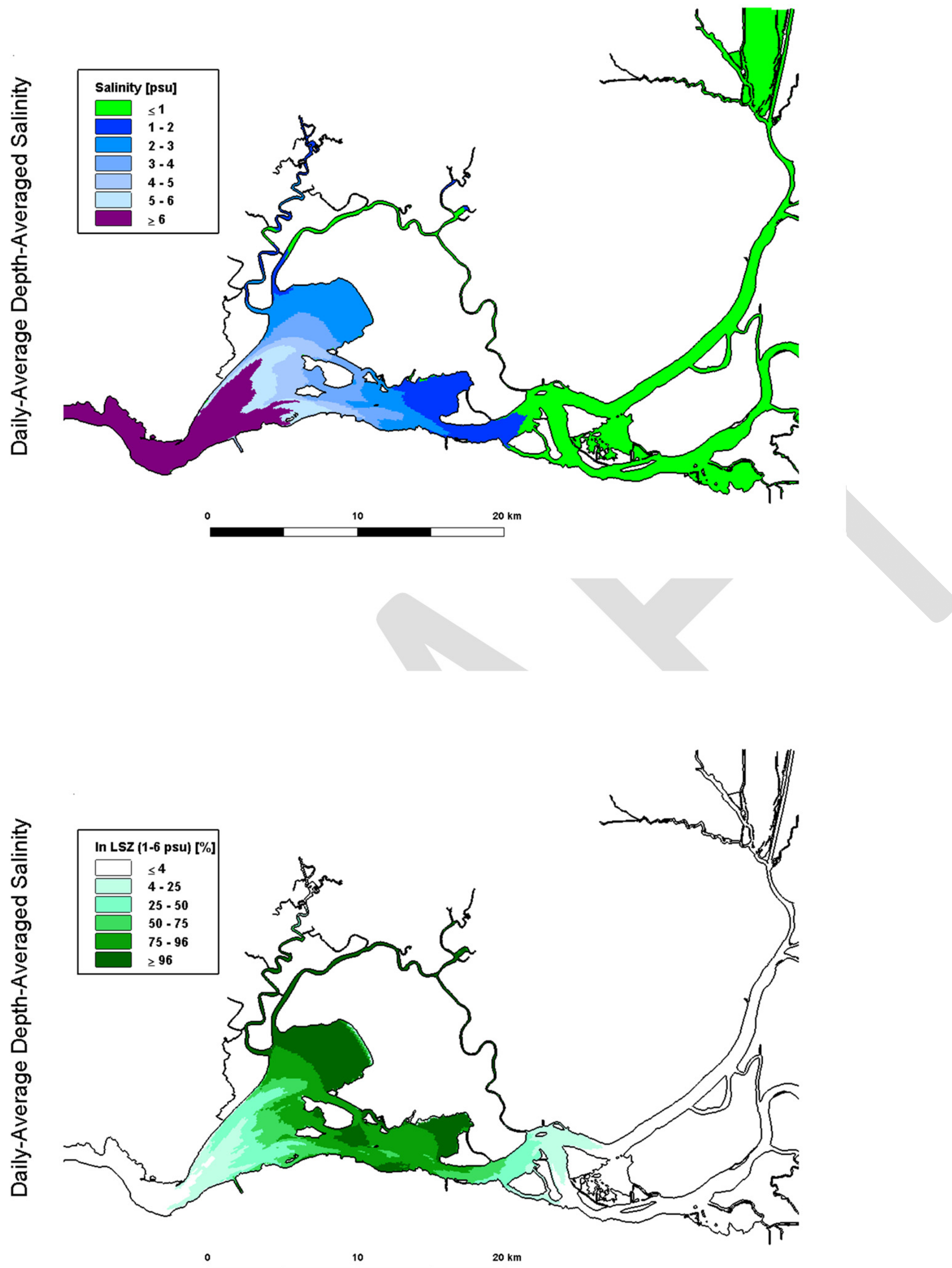


Figure 13. Location and extent of the Low Salinity Zone under very fresh high flow conditions.

Hydrodynamic complexity in the LSZ. The basic idea behind the idea of hydrodynamic complexity is habitat heterogeneity within the LSZ (Brown et al. 2014, Bever et al. 2016). It is hypothesized that when the LSZ is located in Suisun Bay, there is more shoal habitat available, connections with Suisun Marsh are possible, and there is greater likelihood of gyres and eddies forming. Conceptually, this provides a greater array of habitat types for Delta Smelt to utilize for resting, feeding, and other activities. Hydrodynamics are primarily driven by the interaction of dynamic river flows, and ocean tides with stationary bathymetry and spatial configuration of channels. With respect to the movement of water masses through the estuary, hydrodynamics in the estuary are generally understood and have been modeled with a variety of tools (MacWilliams et al. 2016). There remains much uncertainty, however, about the interaction of hydrodynamics with the stationary habitat components in Suisun Bay, the river confluence region, and the Sacramento Rivers and their combined effect on other dynamic habitat components including turbidity, contaminants, and biota. The diverse configurations of shoals and channels and connections to Suisun Marsh produce complex hydrodynamic features such as floodtide pulses in Grizzly Bay (Warner et al. 2004), tidal asymmetry (Stacey et al. 2010), lateral density fronts in Suisun cutoff (Lacy et al. 2003), and multiple null zones and turbidity maxima (Schoellhamer and Burau, 1998, Schoellhamer, 2001). In contrast, the river confluence area has simpler bathymetry that lacks extensive adjacent shallow embayments. Large, shallow freshwater embayments (flooded islands) exist in the central and northern Delta, but are outside of the region overlain by the LSZ. The hydrodynamics of the Sacramento River are less well known but Delta Smelt are commonly captured around Decker Island which provides some habitat complexity. We predict that the proposed SMSCG action will increase hydrodynamic complexity because more of the LSZ will be located in Suisun Marsh and Bay.

Wind speed Strong winds from the north and west are characteristic of Suisun Bay and the Delta. On average, wind speeds are high throughout most of the year including summer-early fall, but lower in mid to late fall. The interaction of wind with river and tidal flows and the erodible sediment supply drives the resuspension of erodible bed sediments. Wind-wave resuspension is substantial in the shallow bays of the Suisun Bay (Ruhl and Schoellhamer, 2004) and flooded islands in the Cache Slough Complex (Morgan-King and Schoellhamer 2013) and helps maintain generally high suspended sediment concentration and turbidity levels in these areas. In contrast, wind likely plays a less important role in suspending sediments in the deep channels of the river confluence. We hypothesize that wind speeds would be higher over the LSZ as it is shifted into the open Suisun Bay. Operation of the SMSCG could therefore result in a very slight increase in mean wind speeds, but the change is likely to be below detection limits. We therefore predict no change in wind speeds in the LSZ or other regions under the proposed SMSCG action.

Turbidity: Turbidity, often measured as Secchi depth in the Delta, has been found to be an important correlate to Delta Smelt occurrence during the summer (Nobriga et al. 2008) and fall (Feyrer et al. 2007). Turbidity during the winter also appears to be important as a cue for the spawning movements (Grimaldo et al. 2009; Sommer et al. 2011a). Turbidity is assumed to reduce predation risk for Delta Smelt as it does for other fishes but no direct experiments or observations exist to support the hypothesis. In the SFE, turbidity is largely determined by the amount of suspended inorganic sediments in the water (Cloern 1987, Ganju et al. 2007, Schoellhamer et al. 2012), although organic components may also play a role (USGS 2008). Sediment particles are constantly deposited, eroded, and resuspended, and are transported into, within, and out of the estuary. The amount of sediment that is suspended in the water column depends on the available hydrodynamic energy, which determines transport capacity, and on the supply of erodible sediment. Strong turbulent hydrodynamics in Suisun Bay caused by strongly interacting tidal and riverine flows, bathymetric complexity, and high wind speeds continue to constantly resuspend large amounts of the remaining erodible sediments in large and open shallow bays of Suisun Bay. Suisun Bay thus remains one of the most turbid regions of the estuary. Turbidity dynamics in the deep channels of the river confluence and Sacramento River are driven more by riverine and tidal processes while high wind and associated sediment resuspension has little if any effect (Ruhl and Schoellhamer 2004, Schoellhamer et al. 2016). By contrast, wind wave resuspension is relatively high during summer in open water areas of Suisun Bay. This difference is also consistent with preliminary analyses by W. Kimmerer (SFSU, pers. com.) that suggest that turbidity in the LSZ is higher when fall X2 is further downstream and the LSZ overlaps Suisun Bay. As discussed above with regard to wind speed, there may be slight improvements in turbidity since more of the LSZ will be located in Suisun Bay and Marsh, but we don't expect to observe a detectable change in turbidity.

Contaminant Concentrations and Nutrients: Chemical contaminants from agricultural and urban sources that are present in the estuary include pyrethroid pesticides, endocrine disruptors, and many traditional contaminants of concern (Kuivila and Hladik 2008, Johnson et al. 2010, Brooks et al. 2012). Some regions of the upper estuary are also enriched with the nutrient ammonium (Johnson et al.

2010; Brooks et al. 2012). In the late summer and early fall, blooms of the cyanobacteria *Microcystis aeruginosa* can produce toxic microcystins (Lehman et al. 2010). Agricultural contaminants are delivered into the LSZ from winter to summer in storm-water run-off, rice field discharge, and irrigation return water (Kuivila and Hladik, 2008). The amount and types of agricultural contaminants that reach the LSZ vary seasonally, with more inputs from winter to summer than in the fall (Kuivila and Hladik 2008). Urban and industrial pollution from wastewater treatment plants and industrial discharges (including ammonium and nitrate) occurs more steadily throughout the year, although the amount of contaminant-containing urban storm-water run-off is largest in the winter and spring. In the fall, pollutant loading from stormwater is generally negligible and lower river flows mobilize fewer sediment bound contaminants than in other seasons. Control programs for species in the Suisun/Delta directly apply pesticides in and around water. In addition, legacy contaminants due to accidental spills or land can contaminate the habitat. The factors governing nutrient and contaminant transport are extremely complex. For the purposes of this work plan our initial prediction is that the proposed action will not change contaminant or nutrient concentrations. However, given that flow could potentially be increased somewhat to offset the upstream shift in X2 (see above), there may be a very slight decrease in contaminant or nutrient concentrations due to dilution.

Predictions for dynamic biotic habitat components:

Estuarine fishes seek areas with a combination of dynamic and stationary habitat components that are well suited to their particular life histories. In addition to abiotic habitat components, fish habitat also includes dynamic biological components such as food availability and quality and predator abundance.

Food availability and quality Food production in estuaries is a dynamic process that involves light, nutrients, algae, microbes, and aquatic plants at the base of the food web and trophic transfers to intermediate and higher trophic levels including invertebrates, such as zooplankton and benthic invertebrates, and vertebrates such as fishes and water birds. As in many other estuaries, higher trophic level production in the open waters of the Delta and Suisun Bay is fueled by phytoplankton production (Sobczak et al. 2002). However, there is a growing recognition that marsh carbon contributes substantially, particularly in Suisun Marsh and the North Delta (Young 2017). In contrast to many other estuaries, however, the SFE has overall low phytoplankton production and biomass (Cloern and Jassby 2008). Phytoplankton production in the estuary is highly variable on a seasonal and interannual basis

(Jassby et al. 2002, Cloern and Jassby 2010). The SFE also has a large amount of spatial variability in food production and food web dynamics (Brown et al. 2016). Food webs Suisun Bay and the Delta have also been affected by species introductions (Brown et al. 2016). Estuaries and rivers often have dynamic food and biogeochemical "hot spots" (Winemiller et al. 2010) that persist in one location for some time or move with river and tidal flows. There also are usually areas with low food production and biomass. The temporal and spatial variability of food production, biomass, and quality in estuaries is the result of the interaction of dynamic drivers such as biomass and nutrient inputs from upstream, estuarine hydrodynamics, salinity, turbidity, and trophic interactions with stationary habitat components such as the bathymetric complexity and spatial configuration of a particular geographic area. Food resources for Delta Smelt in the summer-fall LSZ vary considerably on many spatial and temporal scales. *Microcystis* became abundant in the estuary starting in 2000 coincident with the POD (Lehman et al. 2005). The hepatotoxic microcystins that are often within this cyanobacterium has been found in many components of the food web (Lehman et al. 2005). Although *Microcystis* is a freshwater cyanobacterium, blooms can extend into Suisun Bay and the LSZ and the toxin microcystin associated with cyanobacteria in the SFE have been detected in the shellfish of San Francisco Bay (Gibble et al. 2016). *Microcystis* can have food web effects through impacts on calanoid copepods and cladocera, which are sensitive to *Microcystis* in the diet and microcystins dissolved in the water column (Ger et al. 2009, 2010a, b). If blooms expand in scope and duration there may be more concern regarding direct effects of toxins on fishes and other organisms. Many uncertainties remain about the dynamics of food resources at the small scales important to individual feeding Delta Smelt, which ultimately contribute to Delta Smelt survival, growth, and health in the fall. Uncertainties also remain regarding the relative importance of food subsidies from upstream regions, off-channel habitat and food produced in the LSZ. Subsidies of biomass from the San Joaquin River have been hypothesized to be important to the LSZ, when flows are sufficient to transport biomass downstream. Species invasions associated with extreme salinity intrusions during droughts have greatly altered the composition of the invertebrate community in the LSZ, with uncertain effects on Delta Smelt.

Overall, food quantity and quality may be higher for Delta Smelt if the LSZ is in Suisun Bay and Suisun Marsh than if it is in the river confluence. Like the channels of the Cache Slough Complex (Sommer et al. 2003, DWR, In review; Fred Feyrer, unpublished data), marsh channels tend to have relatively higher levels of phytoplankton and zooplankton (Rob Schroeter, UC Davis, unpublished data). We therefore predict that production of phytoplankton (including diatoms) will increase under the proposed action as the LSZ incorporates more shoals as it moves into Suisun Bay, and more long residence-time habitat in Suisun Marsh. There may be slight regional (e.g. Suisun, River) changes in phytoplankton concentration and species composition as flow is increased under the proposed action. Similarly, the biomass of *Microcystis* might be reduced slightly in the LSZ and the target regions under the proposed action with modest flow increases. The salinity control gates provide flow control flexibility, and in principle *Microcystis* growth could be modulated by adaptively managing marsh water flow.

With regard to zooplankton, we predict that the increases in phytoplankton in the LSZ under the proposed action would support corresponding increases in zooplankton. Similarly, increased overlap between the LSZ and marsh channels would provide zooplankton with additional terrestrial/wetland sources of carbon (e.g. Young et la. 2017). As for phytoplankton, there would be no regional change in zooplankton levels in the Suisun or the River areas.

Clam grazing The primary bivalve grazer in the Sacramento River is *Corbicula*, and the primary bivalve grazer in Suisun Bay is *Potamocorbula* during the target study period (Greene et al. 2016; Figure 15). The confluence region has a mixture of the two. *Corbicula* is generally food limited in the Delta (Foe and Knight, 1985) suggesting grazing rates can increase in response to increased food availability.

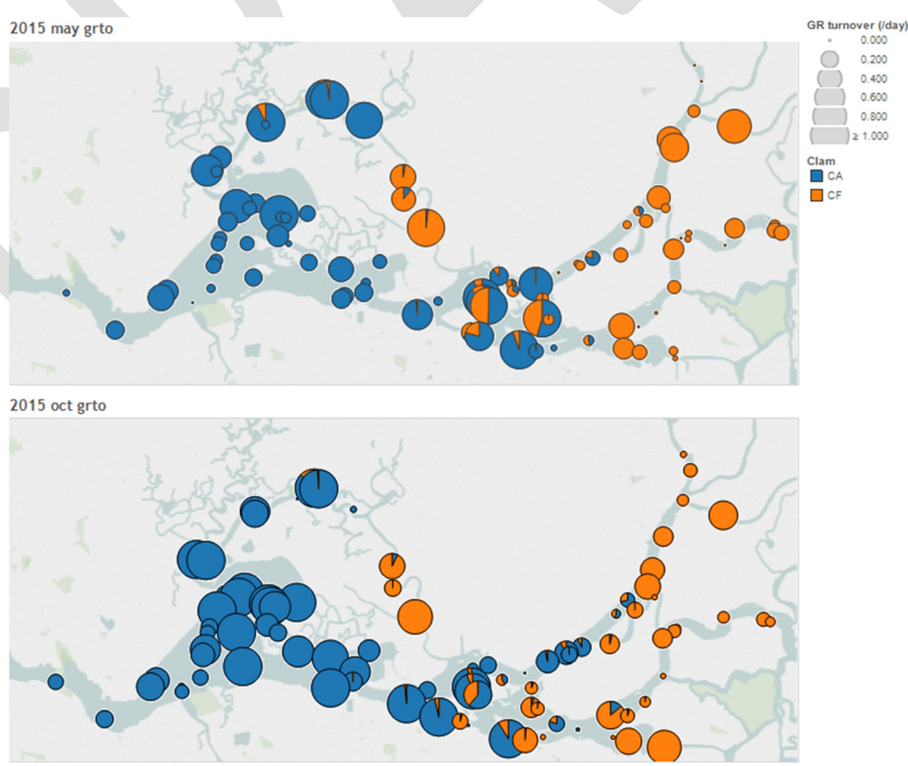


Figure 14. Distribution of *Corbicula* (CA) and *Potamicorbula* (CF) in the western Delta and Suisun Bay region.

Bivalve biomass and grazing rate vary temporally and spatially. In general, higher flows tend to limit the upstream recruitment of *Potamocorbula*. This in turn can facilitate a downstream shift in *Corbicula* (Peterson and Vaysierres 2007). Our prediction is that there will be little change in overall grazing rate, growth, survival and biomass in the LSZ and either of the two study regions. However, we also predict that there may be localized improvements survival and growth of Corbicula in marsh channels that are freshened by the SMSCG action.

Predation and competition. As for other actions being considered by IEP FLoAT (Brown et al. 2017), we chose not to make predictions about predator abundance and distribution or predation rates with respect to predation on Delta Smelt or other fishes. Data evaluation during the FLaSH study (Brown et al. 2014) and a general review of fish predation in the Delta (Grossman 2016) have found the available data to be insufficient to reach conclusions. To our knowledge, the situation has not changed sufficiently to warrant predictions. Similarly, we do not make predictions about competition since there are no data we are aware of establishing competition as a strong driver in the decline or present low abundance of Delta Smelt. Developing special studies to evaluate these processes would certainly be appropriate.

Although we make no specific predictions about the effect of the action on predation and competition, there is some expectation that the management action may result in least modest change the fish assemblage due to the shift in the distribution of the salt field and perhaps other constituents. The change is most likely to occur in the Suisun Region, but there may also be some shifts in assemblage in the LSZ.

Predictions for Delta Smelt responses

Delta Smelt will likely respond in several ways to outflow-related habitat changes such as SMSCG operations. Specifically, access to areas of greater bathymetric complexity such as those found in the Suisun Bay and Suisun Marsh (Bever et al. 2016) likely offers multiple advantages to Delta Smelt, although many uncertainties regarding the mechanisms that link Delta Smelt responses to outflow conditions and the position of the LSZ remain. Note also that the responses of Delta Smelt may be muted depending on the status of the population and conditions in other seasons. For example, severely low adult abundance is likely to generate relatively low egg production. Even with good summer and fall survival, poor conditions in winter could affect adult maturation and winter and spring conditions can affect hatching and larval survival. the increase in the 2011 Delta Smelt abundance index compared to years in the 2000s (Figure 4) suggests that the Delta Smelt population is still resilient and able to respond to favorable conditions, but low population levels in 2017, a wet year, could substantially limit the efficacy of management actions.

Distribution: Prior to their spawning movements in the winter, Delta Smelt are commonly found in the LSZ (Feyrer et al. 2007, Sommer et al. 2011a). Older life stages of Delta Smelt may not require the same high turbidity levels that larval Delta Smelt need to successfully feed, but are most likely able to discriminate level and types of turbidity (and salinity) to find waters that contain appropriate prey resources and that will provide some protection against predation. A less saline Suisun Bay (e.g., Figure 14) ensures Delta Smelt access to a larger habitat area that overlaps with the more bathymetrically complex Suisun Bay with its deep channels, large shallow shoal areas, and connectivity with Suisun Marsh sloughs. We predict that the center of distribution of the Delta Smelt population, excluding the Cache Slough Complex will move westward into Suisun Marsh with the proposed action.

Growth, survival and fecundity Distribution across a larger area with high turbidity and more food, when the LSZ overlaps the Suisun Bay and Marsh, may help Delta Smelt avoid predators and increase survival and growth. Distance from entrainment sites and locations where predators may congregate (artificial physical structures, scour holes in river channels, *Egeria* beds) may also help increase survival. Increased growth should result in greater size of adult Delta Smelt and greater fecundity of females, since number of eggs is related to length (Bennett 2005). Our prediction is that these metrics will improve with increased access to Suisun Marsh under the proposed action; however, data presented by Hammock et al. (2015) suggest this might not be the case.

Health and condition: The same mechanisms listed for growth, survival and fecundity, can affect health and condition. Improved health and condition at the beginning of the spawning period may increase the likelihood of spawning success and frequency by females. In addition, a larger habitat area may help Delta Smelt avoid areas with high concentrations of contaminants. Again, we predict that these metrics will improve with greater access to Suisun Marsh under the proposed action; however, as noted above, Hammock et al. (2015) present some contradictory data.

Recruitment in the next spring: Overall, our prediction is that improvements in the factors listed above will lead to increased distribution, abundance, and reproductive potential of the Delta Smelt population and greater recruitment in the following spring. However, Delta Smelt need to find suitable spawning and larval rearing habitat upstream of the LSZ for reproductive potential to result in successful recruitment in the spring. In addition to preceding summer conditions, successful spring recruitment thus requires suitable winter and spring conditions for migration, gamete maturation, spawning success, and larval rearing. These habitat conditions depend on the interplay of a different set of stationary and changing dynamic habitat features. Only if habitat conditions are met year-round will Delta Smelt be able to successfully maintain their life history and genetic diversity. For example, a large population of subadult fish present in fall 2011 did not result in a large cohort of preadults in 2012, likely because of poor survival in spring and summer (Brown et al. 2014).

Adaptive Management Approach

The proposed action would be conducted in August 2018 and would be used to inform potential future actions and operations. The adaptive management planning (AMP) and activities will be led by DWR, and guided by management input from the Collaborative Science and Adaptive Management Program (CSAMP) and science input from Interagency Ecological Program (IEP). Both of these organizations already are providing leadership on flow-actions as proposed under the Delta Smelt Biop (FWS 2008) and the Delta Smelt Resiliency Strategy. CSAMP relies on a management level team, the Collaborative Adaptive Management Team (CAMT) to conduct its oversight and review activities. Because the range of hypotheses and data needs associated with an AMP was likely to be broad, CAMT in cooperation with IEP perceived the need for a science-based group to address the technical aspects of the effort. The IEP Flow Alteration Project Work Team (IEP FLoAT) was established to address those scientific needs. An additional and important source of guidance is the Suisun Marsh Preservation Agreement Environmental Coordination Advisory Team (ECAT), a multi-partner group established to provide guidance on projects with Suisun Marsh.

In 2017, much of the focus of CAMT/CSAMP and IEP FLoAT was the planning and evaluation of a fall X2 action as required under the 2008 BiOp (FWS 2008). Although no specific AMP was generated for 2017 activities, the approach relied largely on an earlier version of an AMP (USBR 2012) developed in conjunction with studies of high flow effects on low-salinity habitat of Delta Smelt in 2011 (Brown et al. 2014). That AMP was designed in accordance with the Department of Interior guidelines for design and implementation of adaptive management strategies (Williams et al. 2009). All adaptive management strategies share a cyclical design including: 1) problem assessment, including development of conceptual and quantitative models; 2) design and implementation of actions; 3) monitoring of outcomes; 4) evaluation of action outcomes; and 5) adjustment of the problem assessment and models in response to learning from the previous actions (Figure 16). This process might result in the modification of previous actions or consideration of new actions to address the identified problems.

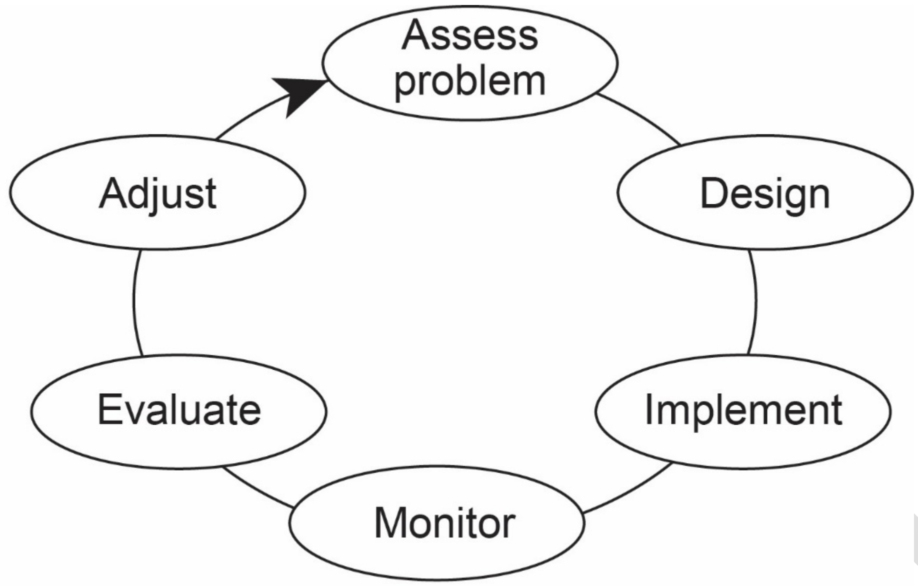


Figure 15. The adaptive management cycle (modified from Williams and others, 2009).

We propose that the SMSCG action incorporate a similar adaptive management approach, using many of the same institutions and metrics. In addition, the State Water Contractors funded the preparation of a guidance document for adaptive management focusing on many of the design and statistical considerations for the SMSCG action (Attachment 1). Hence, this document will be used as a resource in the design and AMP of the SMSCG work.

Coordination

A key part of the AMP will be outreach and coordination of the work. As noted above, the primary vehicle for coordination will be the CAMT and IEP FLoAT PWT. The former includes a strong complement of agencies, non-government organizations, and public water agencies, and the latter represents a public forum for all parties interested in the projects. In addition, IEP FLoAT PWT members will provide periodic briefings to the ECAT (see above), which was designed specifically to help coordinate Suisun Marsh activities. Activities through 2017 included the following:

September 2017: ECAT – overview of project.

November 2017: CSAMP – overview of project as part of DSRS briefing.

December 2017: CAMT, IEP FLoAT – overview and progress report.

In the near-term there are also planned presentations to water project operators, CAMT Delta Smelt Scoping Team and IEP FLoAT about initial modeling results for the alternatives.

Monitoring and Evaluation

The monitoring and evaluation program for the SMSCG action will leverage existing, routine monitoring surveys, supplementing them as necessary, to evaluate the predictions detailed in Table 1. Sampling locations are shown in Figure 16, and the existing surveys that will inform the monitoring program for each of the predictions listed in Table 1 are described in Table 2. See the following section for a description of how measurements will be evaluated against "Base" conditions.

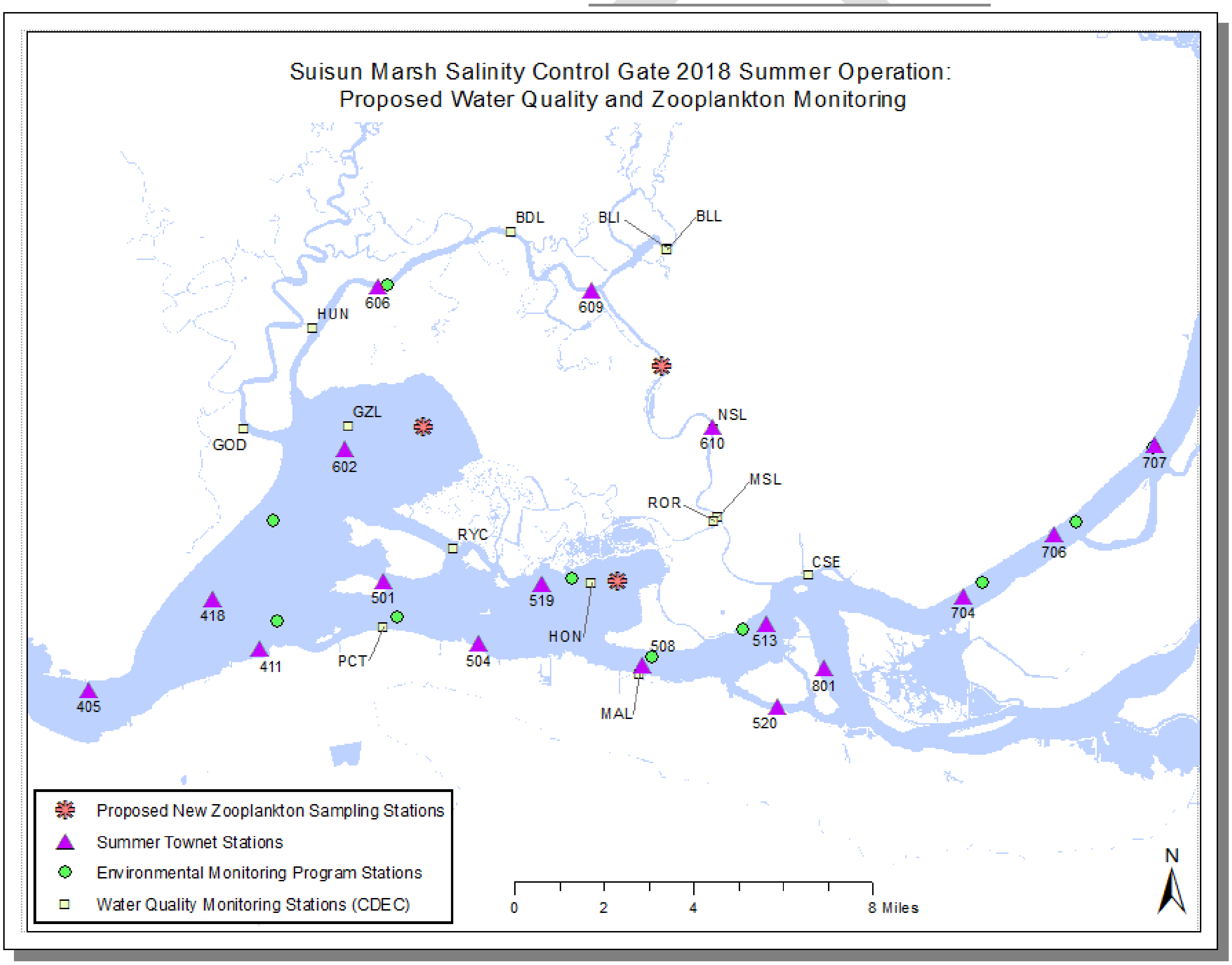


Figure 16. Suisun Bay region existing and proposed monitoring and sampling locations.

As with the predictions, the monitoring plan is organized by regions for predicted effects of the SMSCG action (Suisun Marsh and River Regions), and by the LSZ, which has a dynamic location depending on hydrological conditions. The monitoring plan will cover the July – October period in 2018, in order to capture baseline conditions before the action occurs in August, and the full temporal range of the action's effects (through October).

A key tool in these evaluations will be the use of UnTrim 3-D model which has been used in the development of this project (see companion Project Description document). This model has been successfully used to develop indicators of hydrodynamic complexity and to estimate the area and location of the LSZ (Bever et al. 2016).

The LSZ, Suisun Marsh, and lower Sacramento River region are already relatively well-monitored by routine and long-standing IEP surveys such as the Environmental Monitoring Program (*http://www.water.ca.gov/iep/activities/emp.cfm*), which collects water quality, phytoplankton, zooplankton and benthic invertebrate samples on a monthly basis. The California Department of Fish and Wildlife operates the Summer Townet Survey (https://www.wildlife.ca.gov/Conservation/Delta/Townet-Survey), which collects zooplankton and fish samples at all stations shown in Figure 16, on a biweekly basis in July and August. In September, the Townet Survey is replaced by the Fall Midwater Trawl, (https://www.wildlife.ca.gov/Conservation/Delta/Fall-Midwater-Trawl), which operates on a monthly basis and also collects zooplankton samples in addition to fish sampling. Similarly, UC Davis conducts the Suisun Marsh Fish Sampling Program, a year-round monthly survey of the Suisun Marsh Region (https://watershed.ucdavis.edu/project/suisun-marsh-fish-study). Finally, the DWR Suisun Marsh group and the DWR Real-Time water quality monitoring group maintain a number of water quality gauging stations in the LSZ and Suisun region. The SMSCG monitoring plan will supplement existing surveys in order to achieve biweekly zooplankton sampling in the LSZ and the Suisun Marsh and River regions in September and October, as well as ensure sufficient spatial coverage of continuously collected variables for water quality, and chlorophyll-*a*, (chl-a) a common surrogate for phytoplankton biomass density.

In addition to the EMP invertebrate surveys described above, the study will include a special UC Davis study to examine vital rates for invasive clams. The approach will test the use of caged clams to evaluate growth and survival over the course of the study in multiple locations in the Suisun Marsh region. Such cages are a common tool in ecological studies, but have not been widely used in the SFE. The species composition (e.g. *Corbicula fluminea*; *Potamocorbula amurensis*) of each cage will be adjusted based on EMP monitoring data for the ambient benthic community. Details will be provided in a companion study plan.

Table 2. Data sources with current status of data collection.

Variable	**Full Low Salinity Zone (Dynamic Location)**	**Suisun Marsh Region (Montezuma Sl, Grizzly Bay, Honker Bay)**	**River Region (Mainstem from Confluence area to Rio Vista)**
Abiotic Habitat			
Average Daily Net Delta Outflow	Dayflow	Dayflow	Dayflow
San Joaquin River Contribution Outflow	Dayflow	Dayflow	Dayflow
Surface area of the fall LSZ	Modeling (Anchor QEA)		
Hydrodynamic Complexity	Modeling (Anchor QEA)		
Average Wind Speed		Blacklock (CDEC)	
Turbidity, Salinity	*Discrete:* Biweekly, existing STN/FMWT stations + 3 additional stations.	*Discrete:* Biweekly, existing STN/FMWT stations + 3 additional stations. (*n* = *8*)	*Discrete:* Biweekly, STN/FMWT stations, from confluence up Sac River to Station 711 (*n* = *5)*
	Continuous: Existing Stations + 1 new station in Grizzly Bay	*Continuous:* Existing Stations (GOD, HUN, BDL, NSL, MSL, HON, TYC, PCT) + 1 new station in Grizzly Bay	*Continuous:* Existing stations PCT, MAL, CSE, RVB
Ammonium, Nitrate + Nitrite Concentrations	All EMP Stations, monthly	EMP, monthly: D7, NZ032, NZS42	EMP, monthly: D4, D22
Biotic Habitat			
Chlorophyll-*a*	*Continuous:* Existing Stations + 1 new station in Grizzly Bay	*Continuous:* Existing Stations (GOD, HUN, BDL, NSL, MSL, HON, TYC, PCT) + 1 new station in Grizzly Bay	*Continuous:* Existing stations PCT, MAL, CSE, RVB
Average Phytoplankton Biomass (excluding Microcystis)	EMP Stations, monthly	EMP Stations (*n* = *3)*, monthly	EMP (n = 2), monthly:
Contribution of Diatoms to Phytoplankton Biomass			

Microcystis Presence/Absence	EMP Stations, monthly; STN/FMWT stations, biweekly + 3 additional stations	EMP Stations (n = 3), monthly; STN/FMWT stations, biweekly + 3 additional stations (n = 8)	EMP (n = 2), monthly: STN/FMWT stations, biweekly (n = 5)
Calanoid copepod biomass in the LSZ			
Cyclopoid copepod biomass in the LSZ			
Bivalve biomass	EMP Stations, Special Study (UCD)	EMP, monthly: D7	EMP, monthly: D4
Bivalve survival & growth	Special Study (UCD)	Special Study (UCD)	None
Fish Community	STN/FMWT/EDSM	Suisun Marsh Survey	STN/FMWT/EDSM
Delta Smelt (DS) Responses			
DS caught at Suisun power plants	Existing Monitoring	Existing monitoring	Existing Monitoring
DS in SWP & CVP salvage	Existing Monitoring	Existing monitoring	Existing Monitoring
DS distribution	STN/FMWT/EDSM	STN/FMWT/EDSM	STN/FMWT/EDSM
DS growth, survival, and fecundity in fall [a]	STN/FMWT/EDSM (otoliths)	STN/FMWT/EDSM (otoliths)	STN/FMWT/EDSM (otoliths)
DS health and condition in fall	STN/FMWT/EDSM	STN/FMWT/EDSM	STN/FMWT/EDSM
DS Recruitment the next year	STN/FMWT/EDSM	STN/FMWT/EDSM	STN/FMWT/EDSM
DS Population life history variability	STN/FMWT/EDSM (otoliths)	STN/FMWT/EDSM (otoliths)	STN/FMWT/EDSM (otoliths)

Data analysis and synthesis

Data analysis and synthesis will be led by the IEP FLoAT Management Analysis and Synthesis Team (FLoAT MAST), which, like the IEP FLoAT PWT, is composed of state, federal, and non-governmental scientists. Much of the approach will be similar to the descriptive and multivariate methods that the team is using to evaluate the predictions as compared to years when the action was not conducted (“Base”). An additional part of the analysis will include looking at 2018 conditions before, during, and after the action. The latter approach is particularly important for selected new water quality sensors, zooplankton stations, and clam vital rates for which there is no historical record.

As described above, a key element of this work will be UnTrim modeling to provide a high-resolution evaluation of how habitat conditions changed under the action. Additional modeling (e.g. biological, life cycle) will also be considered based on guidance from team members and oversight groups. Hence, the FLoAT MAST will provide updates and presentations to the IEP FLoAT PWT, and to CAMT as appropriate.

Many of the specific analyses used in the synthesis will be similar to the approach used by Brown et al. (2014) and IEP MAST (2015) including graphical comparisons of the study period in relation to recent (e.g. Early Summer 2018) and historical data (e.g. 1987-Present). Many of the key statistical and design considerations are discussed in Appendix A. However, we do not expect that sample sizes for Delta Smelt Responses (Table 2) will be large enough for statistically robust analyses because of extremely low abundance. For this reason, much of the evaluation will be based on habitat conditions. The overall assessment will rely largely on a *weight of evidence* approach that includes the responses of diverse metrics (e.g. Brown et al. 2014).

Deliverables

A range of deliverables will be provided to suit the needs of different audiences. For technical audiences, our products will include at least two presentations at major conferences (e.g. 2019 IEP Annual Meeting, 2020 Bay-Delta Science Conference). Written products will include a major technical report (e.g. Brown et al. 2014) and draft manuscripts for one or more publishable manuscripts, if appropriate. Our goal is to have each of these completed by Summer 2019. For broader audiences including managers, stakeholders, and the public, we will prepare short summary documents (e.g. one-page fact sheets) to support oral presentations.

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Attachment C. A Template and Guide for Adaptively Managing Operations of the Suisun Marsh Salinity Gates to Benefit Delta Smelt

A Template and Guide for Adaptively Managing Operations of the Suisun Marsh Salinity Control Gates to Benefit Delta Smelt

State Water Contractors

San Luis and Delta Mendota Water Authority

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Executive summary

This document provides a suggested roadmap for developing an Adaptive Management (AM) Plan for the Operations of the Suisun Marsh Salinity Control Gates (SMSCGs), which can serve as a foundation upon which the Department of Water Resources (DWR) may build an AM Plan.

As a targeted management action in support of the California's Delta Smelt Resiliency Strategy (CNRA 2016), DWR intends to test the ability of operations of the SMSCGs to reduce salinity in Montezuma Slough and Suisun Marsh during summer months to improve delta smelt habitat conditions in the Suisun Marsh. This presents an opportunity to use an active adaptive framework to test the hypothesis that lower salinity conditions enhance habitat quality for delta smelt. The rare structure of this managed system allows levers to be pulled in a relatively controlled setting and while the benefits to delta smelt in this particular area may be small, the broader applicability to delta smelt conservation could be substantial. This roadmap for SMSCGs AM relies on three essential planning considerations that combine to assure that the implemented management action is informed by the best available science:

1. Any management action that will be taken is supported by a **structured decision making** (SDM) process that has considered the benefits and costs of that action to delta smelt, the ecological communities that support it, water quality, recreation, and other values by applying input from all experts and stakeholder interests in a decision-analysis framework. SDM helps make trade-offs associated with alternative gate operations explicit.
2. The selection of a management-action scenario will be informed by an **effects analysis** that is driven by management objectives, accurately represents the ecological mechanisms acting on delta smelt and its habitats, employs quantitative models that link the management action to expected ecological outcomes, and specifies management-action thresholds that will trigger the salinity-gates management response.
3. The **monitoring** protocol attending the implemented management action will be designed to have sufficient statistical rigor to detect an effect on delta smelt and its habitat from the management action. Monitoring efforts must be efficiently administered, have effective data management procedures, and be adequately funded. Improving survey effectiveness will be a key goal of salinity gates operations targeting delta smelt.

A three-phase approach to the developing and implementing an AM plan is presented.

In Phase 1 – *Process Priming* – foundational steps would be taken to initiate the process framework, including integrating AM into a broader decision making framework (SDM), establishing or clarifying institutional arrangements, and specifying funding sources.

In Phase 2 – *Technical Priming* – an effects analysis would be initiated, high-benefit, low cost baseline monitoring identified and initiated, and a series of management experiments designed and undertaken to establish evidence that would empirically test hypotheses linking operations of the Suisun Marsh Salinity Control Gates, to habitat quality as measured as food availability and salinity, and delta smelt performance.

In Phase 3 – *Initial Decision Making and Long Term Adaptive Management* – the results of management experiments would be used, alongside additional ecological and socio-economic information, to inform the initial selection of a preferred management action using the SDM framework developed in Phase 1. Over time, as more is learned about the system, the selection of a preferred management action may change in response to changes in administrative, ecological, economic, and social factors.

The document is organized into three sections:

Section 1 discusses adaptively managing delta smelt using the salinity gate operations as a structured decision making process. It considers seven steps in the SDM process – clarifying the scope and process, defining objectives and performance measures, developing management alternatives, estimating consequences, addressing uncertainties, evaluating trade-offs and selecting a management alternative, and monitoring and assessment. It discusses fast and slow learning in an adaptive management framework.

Section 2 discusses effects analysis, which is used to predict the impacts of management actions on delta smelt. It presents a conceptual ecological model and conceptual management model, and discusses translating them into quantitative assessment capabilities. It discusses management goals, objectives, and metrics in the context of gate operations, environmental factors, and species responses in Suisun Marsh. Section 2 considers supporting data and information, potentially useful model frameworks, modeling and data needs, and identifying management questions.
It discusses evaluating monitoring data in relation to management hypotheses.

Section 3 considers monitoring design and analytical issues and focuses on catch-per-unit effort (CPUE) as the program's essential response variable in assessing treatment effects. It identifies a set of testable hypotheses that explore relationships between salinity, food availability, and delta smelt occupancy and performance. It presents methods for estimating delta smelt abundance, estimating catchability, environmental covariate modeling, and data collection. Section three offers a step-by-step process for conducting management experiemnts accompanied by a rigorous monitoring program.

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1 Structured Decision Making and planning context

1.1 Introduction

This document provides a suggested approach or roadmap for the development of an Adaptive Management Plan for the Operations of the Suisun Marsh Salinity Control Gates (SMSCG) – it can be referred to as an adaptive management template. It has been written by external consultants with knowledge and expertise in some, but not all, of the key areas required to develop such a plan; as such it should be considered a template to be adapted for use by those who would own it, implement it, and participate in it – not least because doing so requires resolution of myriad design choices that can be made only with appropriate regulatory authority and content expertise in delta smelt and in related issues.

This can be one of the first steps towards implementing the State of California's Delta Smelt Resiliency Strategy (CNRA 2016). The Resiliency Strategy identifies actions that have the potential to improve habitat conditions for delta smelt. The Resiliency Strategy includes near-term actions aimed at creating better physical habitat, more food, and higher turbidity, along with reduced levels of predators, aquatic weeds, and harmful algal blooms. It is intended that management actions that are deemed feasible and are implemented will together improve the current status of the species.

As the Resiliency Strategy observes that Suisun Marsh on the western edge of Sacramento-San Joaquin Rivers Delta contains suitable delta smelt habitat, but notes that delta smelt are sensitive to salt at higher levels in the estuary. By reducing salinity in the marsh during the dry summer months, conservation planners hope to attract smelt to what is hypothesized to be higher-quality habitat than that in adjacent Suisun Bay. However, many aspects of delta smelt's needs and preferences remain uncertain, despite decades of research and efforts to construct conceptual ecological models. These uncertainties represent a common challenge for delta smelt management throughout its range in the Sacramento-San Joaquin Delta.

Fortunately, the location of the SMSCG in the context of the constrained physical geography of Suisun Marsh (and, in particular, Montezuma Slough) creates an opportunity to consider manipulating the gates in ways that could facilitate the empirical testing of hypotheses relating to cause and effect relationships between delta smelt and a range of environmental variables. The transferable learning gathered in this system could contribute to constructing a more comprehensive effects analysis to inform broader management decisions targeting delta smelt and its habitats into the future.

1.2 Approach to developing an adaptive management plan

In the context of large and complex river systems, adaptive management benefits from the presence of three features:

First, is a foundation in a **structured decision making (SDM)** planning process that clarifies the scope, timing, resourcing and institutional opportunities and constraints that affect the range of actions that might potentially be implemented, and that ultimately helps decision makers evaluate preferred alternatives by explicitly describing the benefits and costs of actions to delta smelt, the ecological communities that support it, water quality, recreation, and other values. Through an SDM process, the often difficult ecological and socio-economic 'balancing' decisions that must be tackled by management are treated as a primary organizational framework.

Second, SDM processes require information on the *predicted* consequences of actions on delta smelt and other issues. Although in this case estimating the impacts on these other issues is relatively straightforward, the ability to predict the consequences of actions on delta smelt is anything but. For this reason, predicted impacts on delta smelt should be informed by an **effects analysis** that is driven by management objectives, accurately represents the ecological mechanisms acting on delta smelt and its habitats, employs quantitative models that link the management action to expected ecological outcomes, and specifies management-action thresholds that will trigger the salinity-gates management response.

Third, AM requires that management actions can be accurately monitored, and the findings compared to predictions to validate the predictive model and to learn over time. The **monitoring** protocol attending the implemented management action must be designed to have sufficient statistical rigor to detect an effect from the management action. Monitoring efforts must be efficiently administered, have effective data management procedures, and be adequately funded. Improving survey effectiveness will be a key goal of this work.

1.3 Structured decision making

The core steps of a decision process based on SDM and AM are shown in Figure 1. The steps are discussed briefly in the context of this AMP.

Step 1: Clarify the scope and process

The Suisun Marsh Salinity Control Gates (SMSCG) are located at the entry to Montezuma Slough at the southeast corner of Suisun Marsh (Figure 2).

Figure 1 -- *Core steps of structured decision making and adaptive management with this plan's work phases.*

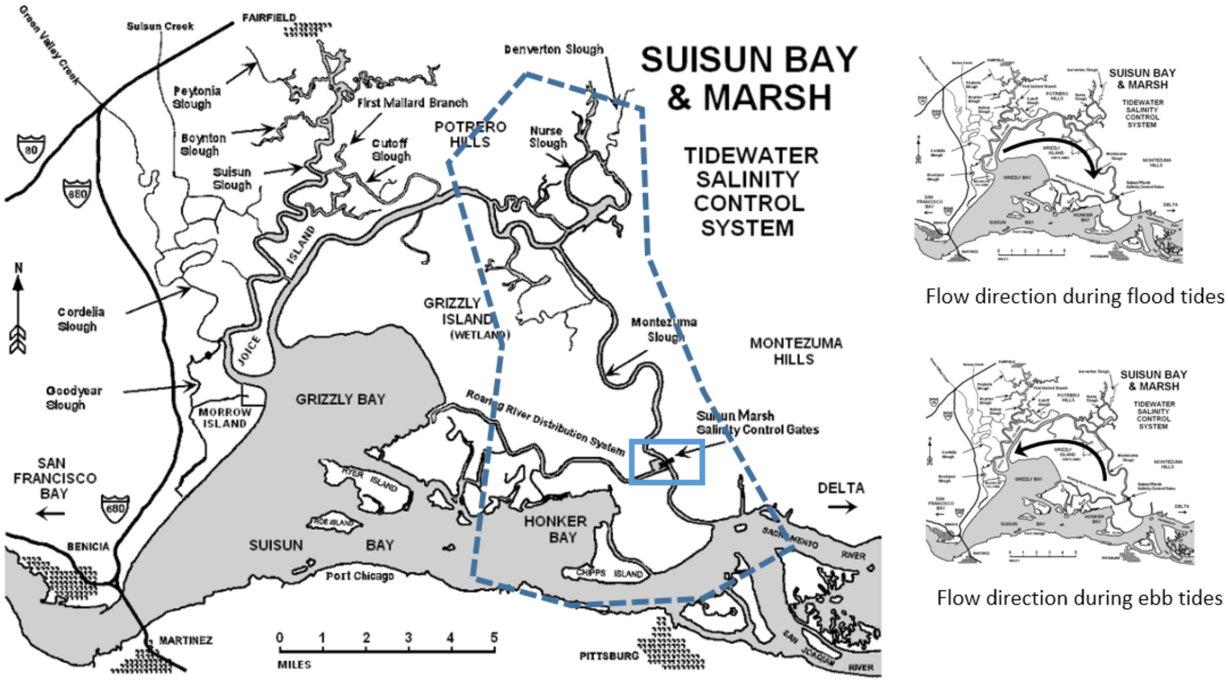

Figure 2 -- *Location of the SMSCGs and tidal flow directions in Montezuma Slough (from http://www.wikiwand.com/en/Suisun_Marsh).*

The facility comprises three main structures: a set of retractable radial gates, a set of removable flashboards, and a boat lock (Figure 3). The SMSCG can reduce salinity in and around Montezuma Slough if they are closed when higher-salinity water from Grizzly Bay would otherwise flow clockwise through the slough during flood tides and are opened during ebb tides to allow freshwater flows to move counter-clockwise through the slough. This 'freshwater pumping' operation is effective only between September and May (depending on hydrology and when ebb flows have a lower volumetric flow rate) and when flashboards are in place. Currently, the gates are operated approximately 10-20 days a year in September and October as needed to meet water quality objectives for managed wetlands in the Marsh. In the remainder of the year, the flashboards are removed and the gates are left open. For a more in-depth discussion on the ecological and social complexities of Suisun Marsh, see Moyle et al. (2014).

Purpose

The purpose of this AM Plan is three-fold:

- To provide a long-term framework through which operational decisions for the Suisun Marsh Salinity Control Gates can be made by DWR and stakeholders in ways that are explicitly mindful of their consequences on ecological, social and economic factors.

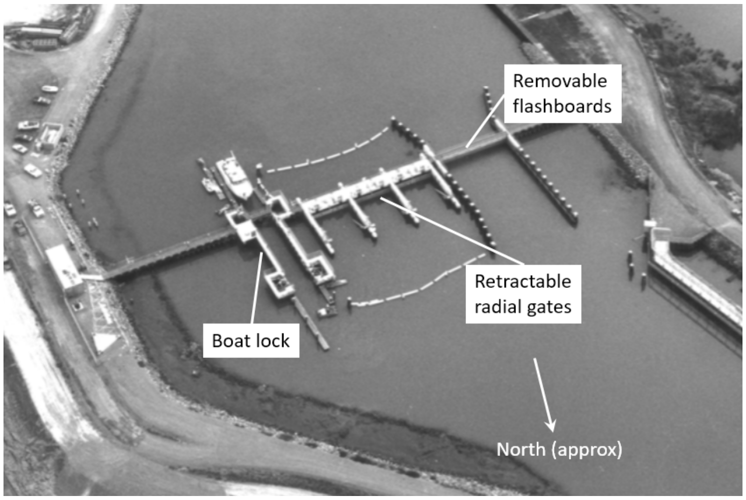

Figure 3 -- *Facility configuration (from http://www.cwemf.org/Asilomar/ChrisEnright.pdf).*

- In performing the necessary scientific studies required to inform 1 above to generate transferrable scientific knowledge that can be applied to other situations in the region.
- In developing 1 and 2 above, provide an example upon which other adaptive management plans could be modeled.

Goals and phases

The AM Plan has the following goals:

1. To implement Phase 1 (see below) by [Date to be set by DWR – February 2018?]
2. To implement Phase 2 by [Date to be set by DWR – May 2018?]
3. To implement Phase 3 by [Date to be set by DWR]

This document advocates a three-phase approach to developing and implementing an adaptive management plan.

<u>Phase 1 – Process priming (planning)</u>

The intent of Phase 1 is to create and clarify the planning framework as drafted in this Section. This includes confirming the purpose of the plan, developing a governance structure and determining executive ownership of the plan, clarifying what is in and out of scope, identifying and securing funding mechanisms, and articulating roles and responsibilities. Phase 1 also includes developing an approach to decision making (a proposed approach is described below) and developing a <u>detailed plan</u> for Phase 2 effects analysis, baseline monitoring, and systematic experimentation.

As an outcome of this planning phase, DWR will have:

- Confirmed plan ownership, source(s) of funding, governance structure, and clarity about roles;
- Confirmed scope;

- Confirmed a Phase 2 work plan, including key technical tasks, engagement tasks, and timelines;
- Addressed budgets, technical resources; and,
- developed Terms of Reference to guide the process.

Phase 2 – Technical priming (initial experimental phase)

Phase 2 can be thought of as the first time through the adaptive management loop to address critical uncertainty and update models and assumptions. In this phase, scientists and other experts would finalize the experimental and monitoring approach, largely driven by the goals and objectives established in Phase 1. An effects analysis would be initiated (Section 2) and 'no-regrets' baseline monitoring would be identified and initiated if possible. Further monitoring may be initiated based on emerging needs from the effects analysis (Section 3). Monitoring and focussed experiments could be designed and undertaken to establish evidence that would empirically evaluate or test ecological hypotheses including:

H_{01} The abundance of delta smelt differs significantly between adjacent areas of Suisun Marsh and Suisun Bay (adjacent areas outside and inside of the SMSCGs).

H_{02} Food availability for delta smelt differs significantly between adjacent areas of Suisun Bay and Suisun Marsh.

H_{03} Manipulation of the SMSCGs, which when open may reduce Suisun Marsh salinities, can directly alter the availability of food and indirectly the abundance of delta smelt in Suisun Marsh.

H_{04} Salinity determines the spatial-temporal distribution and local abundance of delta smelt in Suisun Marsh.

H_{05} The site-specific abundance of delta smelt is correlated with species composition and abundance of prey in Suisun Bay and Suisun Marsh.

H_{06} Food availability and salinity are correlated in Suisun Bay and/or Suisun Marsh.

H_{07} Food availability is the limiting environmental factor that determines spatial distribution and local abundance of delta smelt in Suisun Marsh.

H_{08} Some other physical or biotic factor(s) are the limiting factors that determine landscape occupancy by and/or local abundance of delta smelt in Suisun Marsh.

H_{09} The abundance of delta smelt varies significantly by meso-habitat type.

The intent of this phase is to ultimately process the empirical findings of gate-operations experiments and finalize approaches for predicting the consequences of different management alternatives.

Phase 3 – Initial decision making and long term adaptive management

In Phase 3, the results of these initial experiments would be used, alongside additional ecological and socio-economic information, to inform the initial selection of a preferred management regime using the structured decision making framework discussed here. This would include defining an array of plausible management alternatives to examine from an SDM perspective and creating a consequence table to understand and explore management trade-offs across alternatives. After an initial decision is made on a preferred operating alternative, it will be important to design and implement continued monitoring and plan decision update cycles. Over time, as more is learned about the system, this selection of a preferred management alternative may change in response to changes in administrative, ecological, economic, and social factors.

Scope

Spatial scope

The spatial scope of the plan will be limited to the following areas (approximately outlined using the dotted line in Figure 2):

- The terrestrial-aquatic interface along Montezuma Slough, including the areas east, west, and north of Nurse Slough.
- The area immediately to the south of the gates, to the east and west of Montezuma Slough toward the rivers confluence and San Pablo Bay.

Management action scope

The scope of management actions considered under this plan will be limited to operational regimes involving the SMSCG facility (i.e., potential changes only to operations of the radial gates, use of the flashboards, and boat lock operation). No actions that involve physical changes to the area described above will be considered in the scope.

The significance of the use of the boat lock on the ability of the SMSCG to control the salinity gradient in Montezuma Slough is not fully understood. It is known that significant reductions in salinity in the slough can be achieved by SMSCG operations even when the boat lock is left open when not in use, as is currently the case (C. Enright, personal communication). However, it may be that significantly greater salinity control could be achieved if the boat lock were to be closed when not in use during the operational season. Furthermore, because operation of the boat lock is dependent on traffic, operations may have the potential to complicate the experimental design. Boat lock operation decisions may possibly be influenced also by anadromous fish passage concerns, an issue discussed below. A decision will need to be made early in the plan's development about whether, and if so how, boat lock operations should be treated within the scope of an adaptive management plan.

Related decisions and initiatives

Other ongoing initiatives have the potential to alter the background conditions for this plan. For example, the delta smelt Resiliency Strategy coordinates various activities intended to promote the resiliency of delta smelt (California Natural Resources Agency, 2016), and some of these could have the potential to confound experiments employing the salinity gates if care is not taken. Additionally, substantial "habitat" restoration is planned for the region affected by the SMSCG operation. The potential may exist at some point in the future to coordinate the discharge of stored freshwater in duck ponds adjacent to Montezuma Slough to create a 'freshwater flush' of water in the slough. However, this is not physically possible using the current infrastructure, and so is considered outside the scope of this plan. Once empirical relationships between salinity and other physical factors on delta smelt and other endpoints have been better established, future managers will be in a better position to consider the relative merits of such an action.

Additionally, the activities under this plan are subject to legal and regulatory constraints too numerous to list here, but to which the designers of this plan must be fully familiar. Of specific note at the initial planning stages, however, are the following:

- **Flexibility to change SMSCG operations:** The degree of regulatory flexibility that exists around the ability to trial different gate operations should be clarified.
- **US Fish and Wildlife Service (USFWS) restrictions on delta smelt take:** The plan's spatial scope is entirely within an area designated as critical habitat for delta smelt under the federal ESA (USFWS 2017) and there are restrictions on experimental take of delta

smelt. It will be critical to fully explore and define this constraint prior to the development of experimental design.

- **Achievement of existing water salinity targets must not be compromised:** Water salinity targets set by the State Water Resources Control Board are assumed to continue. If operations affect the anticipated achievement of these targets, water resource managers must take appropriate actions to ensure the targets are upheld.

Plan ownership

The ownership of the Plan should be clearly defined. It is currently assumed that DWR is the plan owner and bears sole responsibility for implementing the plan and its associated funding and spending. DWR will engage and consult with regulatory partners as required and with a limited set of interested stakeholder groups in an advisory capacity.

Sources of funding

Funding for the AM plan has not yet been identified.

Funding for the action is expected to be limited to planning, effects analysis development, monitoring costs, and labor costs associated with increased flashboard installation and removal.

Governance structure

Careful consideration should be given to planning for the involvement of government agencies, key interested parties, and the public in Plan development, including established collaborative processes such as CSAMP. The approach to engagement may be different for different parties due to the nature of their interests, the extent to which they may be affected, and their capacity to participate. An effort should be made at this stage to identify the parties that will be key to successful implementation, and attention given to how best to meaningfully involve them early and on an ongoing basis to obtain buy-in for the findings of the plan. Some non-signatory parties may be invited to participate, either as observers, participants, or core decision making members. Others may be invited to participate via various working groups struck to address components of Plan development. And others may simply be invited to participate in periodic one-on-one meetings, focus group meetings, or public information sessions. Regardless of which model is selected, decision makers are encouraged to ensure the on-going involvement of partners as a means of improving transparency and ultimately of securing broad-based support for the Plan. A possible governance structure for the plan is provided in Figure 4.

DWR would be responsible for setting policy directions and priorities, for selecting management objectives, and for making key high-level decisions regarding operation regimes for the gates, and prioritizing management experiments.

<u>Steering Committee</u>

A Steering Committee could be valuable to guide the Project Manager when non-trivial issues emerge. Membership in this committee would include the most critical parties with interests in the operation of the gates, and would likely include representatives from DWR, State Water Contractors (SWC), USFWS, CA Department of Fish and Wildlife (CADFW), SWRCB, NMFS, and Suisun Resource Conservation District (SRCD).

<u>CAMT - Stakeholder Advisor</u>

A stakeholder advisory role is helpful to establish where there may be public interests that need to be represented in the governance structure but are not represented effectively by agencies or organizations already included. In this case, CAMT may serve this function.

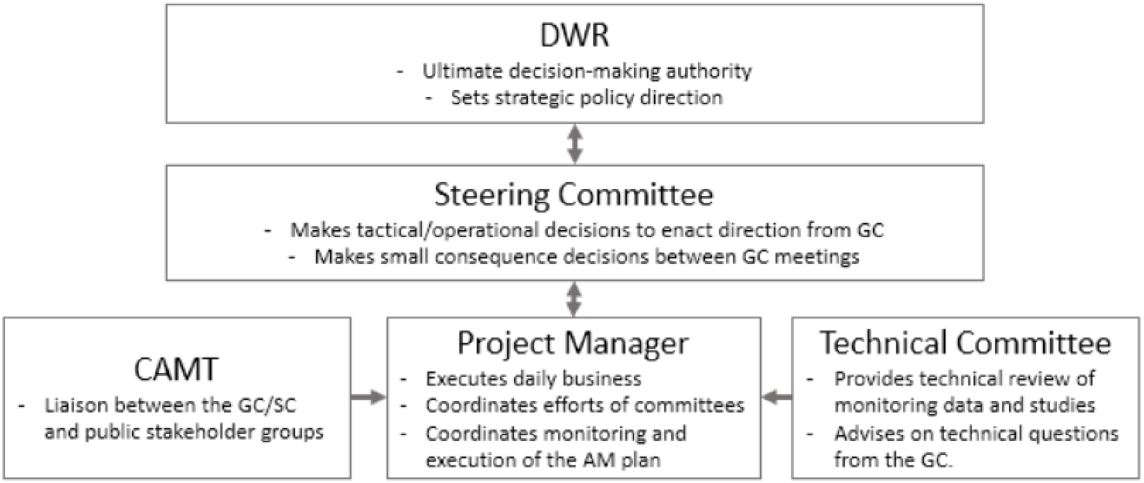

Figure 4 -- A possible governance structure for a Suisun Marsh AM program.

<u>Technical Committee</u>

Technical decisions should be handled separately from policy-level questions, and ideally by a group of technical experts. In an adaptive management context, these sorts of technical questions might relate to how to express and prioritize management questions and ecological hypotheses, study designs for testing competing hypotheses, coordinating monitoring programs, and interpretation and utilization of monitoring and focused study results.

This group should involve technical staff from some of the organizations represented on the Governance Committee, including DWR, SWC, USFWS, and SWRCB, and also include technical experts from other organizations and academic partners.

Table 1 identifies an initial (and likely incomplete) list of interested parties, their key interest in the operation of the SMSCG facility, and proposes a likely role in the process.

Step 2: Define objectives and performance measures

At the core of the integrated planning process is a set of well-defined objectives and performance measures that clarify “what matters” – the things that people care about that could be affected by the decision. Together, objectives and performance measures drive the development of creative alternatives, and become the framework for comparing alternatives.

Potential objectives for this plan

Key objectives related to this planning initiative are likely to reflect a range of interests. These draft objectives are intended to be revised and clarified through Phase 1 of implementation and the nature of cause and effect relationships that connect SMSCG operations and the objectives will be investigated systematically in Phase 2. The objectives will then be used to guide the choice of management actions in Phase 3 once the degree of uncertainty surrounding the effects of alternative salinity gate operational regimes can be effectively characterized.

Table 1 -- *Potential participation, roles and responsibilities.*

Interested Party:	Key Interest:	Possible Role[1]:
State Water Contractors (SWC)	Water contractor. Interested in smart and efficient use of freshwater upstream.	Advisory
San Luis & Delta-Mendota Water Authority	Water contractor. Interested in smart and efficient use of freshwater upstream.	Notified
Contra Costa Water District	Water contractor. Interested in more freshwater in the Bay (for primarily drinking water purposes).	Advisory
Solano County Water Agency	Water contractor. Interested in smart and efficient use of freshwater upstream.	Notified
CA Department of Water Resources (DWR); Suisun Marsh Program (SMP)	Operator of the SMSCGs; ongoing evaluation, monitoring, and planning role for Suisun Marsh	Decision making
CA State Water Resources Control Board (SWRCB)	Developed the salinity standards, and interested in their enforcement.	Advisory
CA State Department of Fish & Wildlife (CADFW)	Own and manage refuges in and around Suisun Marsh; likely interested in actions that affect these areas.	Advisory
Cal EcoRestore (CA Agency of Natural Resources)	Involved in Delta-wide restoration activities. Interested in coordination with Suisun Marsh activities.	Notified
Delta Stewardship Council, Delta Science Program	Responsible for coordinating management actions in Suisun Marsh, and ensuring consistency of on-going initiatives, and coordinating applied research across agencies involved in the management of Suisun Marsh.	Notified
National Marine Fisheries	Responsible for Chinook salmon, steelhead, and green sturgeon protection (ESA-listed species).	Technical and Regulatory
State and Federal Water Contractors Agency (SFWCA)	An umbrella group for various water agencies that receive water from the Delta. Has program areas for addressing Delta issues: Science Research and Review, Delta Governance and Ecosystem	Technical

[1] Possible roles are as follows: Advisory to decision makers, Decision making, Technical support, Notified of decisions.

Interested Party:	Key Interest:	Possible Role[1]:
	Restoration. SFCWA dedicates its resources in each area to achieve co-equal goals for water supply and promoting a healthy ecosystem.	
Suisun Resource Conservation District (SRCD)	Advocate for local recreational/hunter interests.	Advisory
US Fish and Wildlife Service (USFWS)	Responsible for delta smelt protection (ESA-listed species).	Technical and Regulatory
US Army Corps of Engineers (USACE)	Supply permit for gate operations (including experimental alternatives), and involved with management of waterways that affect wetlands.	Advisory
US Bureau of Reclamation (USBOR)	Interested in federal water projects, and responsible for supporting mitigation efforts in Suisun Marsh.	Notified
US National Marine Fisheries Services (NMFS – NOAA)	Involved in activities affecting anadromous fish passage.	Notified
UC Davis	Home to researchers with on-going involvement in Suisun Marsh and strong technical expertise.	Technical

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Delta smelt

Context: The effects of SMSCG operations on species abundance, distribution, fecundity, or population growth are likely to be primary considerations.

Potential objective(s): Increasing delta smelt distribution and abundance are two likely objectives. While estimating abundance is particularly difficult for this species, several suitable proxies may exist that could be developed into adequate performance measures.

Figure 5 shows a simplified influence diagram for key factors that are hypothesized to influence delta smelt abundance *as they relate to the scope of this plan*. Factors such as contaminants, predators and competitors are important only insofar as they have the potential to be part of a causal link between the SMSCG, salinity, and delta smelt. They are thus considered, sub-objectives, since they are subservient to the objective under consideration, delta smelt.

Technical objectives for delta smelt will be developed as part of the effects analysis discussed in Section 2.

Potential PM(s): Because direct measures of smelt abundance are problematic for various reasons discussed in Section 5, proxies such as food availability and

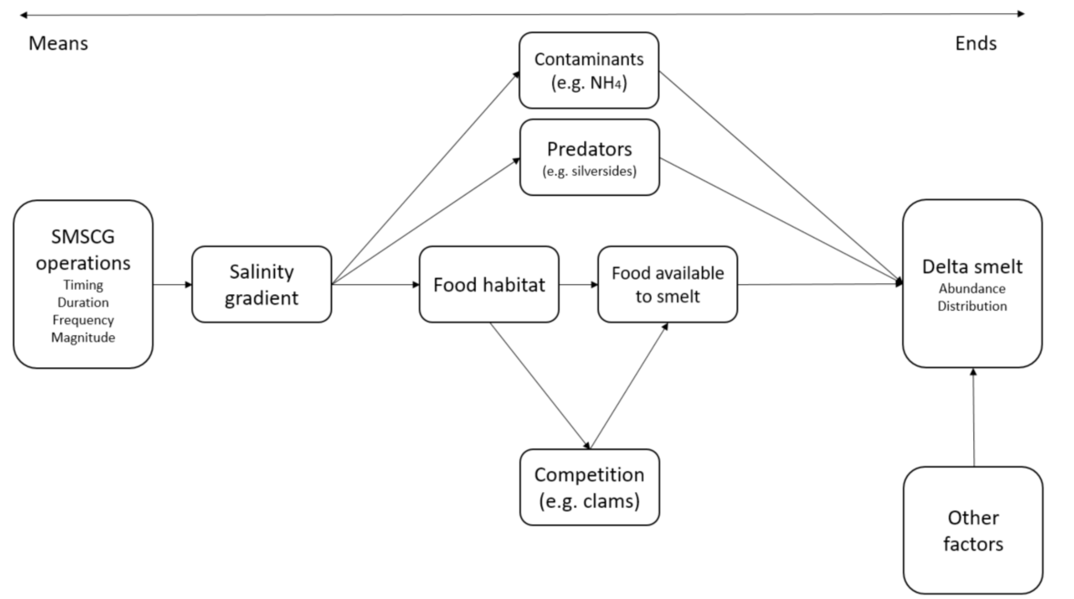

Figure 5 -- *Illustrative, simplified, potential influence diagram for delta smelt.*

predator/competitor abundance may need to be used instead, while water chemistry and food availability may be used as proxies for distribution. Learning more about the role that SMSCG operations play in influencing these factors will be an important outcome from the first two phases of the AM program, and could heavily inform the development of reliable performance measures.

Considerations for predicting consequences: The analytical approach to this task is discussed in detail in Section 2.

Water management actions

Context: If salinity concentration constraints are in danger of being exceeded, and if SMSCG operations are not to be compromised, one of two responses may be necessary from the water exporters:

1. Water project exports could be reduced, which would create more freshwater outflow towards Suisun Marsh; or,
2. Additional water could be released from upstream reservoirs to flush the eastern side of the Marsh with fresh water.

In either case, these actions would come at a financial cost to the water exporters. The exact nature of how the exporters would decide how to increase flow of freshwater to the marsh is complex and outside the scope of this document.

Potential objectives(s): All else equal, the water exporters wish to “minimize the economic impacts of SMSCG operations” on their activities.

Potential PM(s): Impacts on water exporters might best be estimated in terms of dollars per year or Acre-Feet. Since wide inter-annual variation might be expected, this value could be represented in various statistical ways, including expected value, median, and percentile estimates.

Considerations for predicting consequences*:* Modeling efforts to support this kind of analysis are currently available within DWR.

Anadromous fish passage

Context: Anadromous fish (salmonids and sturgeon) move through Suisun Marsh and Montezuma Slough, and the SMSCG have the potential to negatively affect their passage if the radial gates, flashboards and boat lock are all closed. However, this is unlikely to be an issue because:

- Although, there is some evidence that gate operations can affect adult salmon movements in fall, the typical time when the gates are used (T. Sommer, Personal Communication), most of the operations considered here are earlier than this. There might be some adult salmon in the area in late August, but a gate-induced delay would be unlikely.
- Under current operating regimes, the radial gates, flashboards and boat lock are never all closed. There would need to be a compelling reason to propose doing so under this plan, in which case, anadromous fish passage implications should be reconsidered.

Potential objective(s): "Minimizing negative impacts of operations to anadromous salmon passage" is one way of framing this objective.

Potential PM(s): A potential performance measure to characterize this effect might be to minimize days of the salmonid migration season (or proportion of days) with inadequate anadromous salmon passage.

Considerations for predicting consequences: [To be discussed during actual plan development]

Recreational boat access

Context: As with fish passage, the degree to which recreational boating access will be affected in this plan depends on whether the boat lock operations are considered part of the experimental design. Boats use the Montezuma Slough boat lock, but this is only a consideration when the gates are operational. Before considering this further, more inquiries should be undertaken to establish the realistic scale of impact, and whether the issue is of sufficient significance.

Potential objective(s): "Minimize negative impacts of SMSCG operations to recreational boating" is one way of framing this objective.

Potential PM(s): There could be many ways to characterize this, including average wait time for boat passage, or, as with recreational hunting, a constructed scale could be developed to capture a range of impacts to boating interests.

Considerations for predicting consequences: DWR maintains logs of boat lock usage throughout the operational period. Based on these historical records, estimates could be then made by a suitable DWR expert (for example, a SMSCG operations manager) on how many boat trips might be affected under different operational regimes.

Learning

Context: In some adaptive management contexts, "learning" is specified as its own objective. To the extent that the eventual decision maker might be willing to compromise benefits to an objective (e.g., delta smelt) for an increase in the amount of learning that can happen, then it may appropriate to specify 'Learning' as an independent objective. Further discussion on this issue is required.

These objectives should be refined through the course of Phase 1, during which other objectives may be identified. Additional objectives may be refined through the decision process. It is assumed here that there is no potential for significant effects of gate operations (positive or negative) on waterfowl hunting, though this may not be the case. Also, for example, water contaminants resulting from mosquito spraying or the introduction of treated water, may be considered relevant.

Step 3: Develop alternatives

Alternatives are the various actions or strategies that are under consideration. In this case, the alternatives are different operating regimes for the SMSCG.

In Phase 2 of the work plan, the actions undertaken for experimental purposes are simply that; they are not 'alternatives' in any real sense because the purpose of Phase 2 is to better understand the links between cause and effect between the SMSCG operations and the objectives. However, for the purposes of discussion, the gate operations will be referred to as 'alternatives' regardless of the Phase.

In Phase 3, once the cause and effect links are better known, the alternatives will be specific prescriptions for how the SMSCG should be operated under the range of variation in conditions that are expected, and the task will be to find which alternative provides what decision makers consider to be the 'best balance' of impacts across the range of objectives considered.

Alternatives in this case are defined as a complete description of SMSCG operations. Two bookend alternatives, one defined by a configuration where the SMSCG are open under all conditions (subject to agreed constraints), and the second where they are closed under all conditions, could be evaluated first. Subsequently, other gate configurations that vary in **timing** (how long the gates are closed), **duration** (how many days per year the gates are operational), **frequency** (how many times per tidal cycle the gates are closed), and **magnitude** (how far open or closed the gates are) could be evaluated.

Rather than selecting random combinations of these factors, it would be preferable to define potential operational regimes with a purpose or strategy in mind. For example, one strategy might be to wait for a natural event that delivers a relatively strong freshwater ebb flow through the gates, and then close the gates for a period of 7 to 10 days to 'trap' the freshwater in place and prevent the backwatering of saline water on the flood tide. This strategy might be hypothesized to be more favourable to the growth of food habitat – a hypothesis that could be tested empirically.

Another alternative explored in Phase 2 might be to do precisely the opposite and to hold more saline water. This may be valuable as a learning experience and may be necessary to 'move the dial' to test and calibrate monitoring efforts. There may be concerns about the impacts of such an operation on waterfowl and fish passage, underlining the importance of having a strong stakeholder outreach of some kind during that work.

Further suggestions for alternatives should ideally come from knowledgeable scientists.

Step 4: Estimate consequences

In Phase 2 of the plan (i.e. as part of the effects analysis development and experimental monitoring), the consequences of operations on ecological endpoints may be studied directly. During Phase 3, once cause and effect relationships are better understood, the consequences of various alternatives can be predicted to enable decision makers to consider the trade-offs between them across all the objectives and to select a preferred regime.

In general, predictive models can take a variety of forms; they can be quantitative or qualitative, and they can be driven by data, expert judgment, or a combination of the two. Expertise may come from scientific, traditional, or local knowledge sources. Where expert judgment is used, best practices to ensure objectivity and transparency should be used. In addition to dealing with common biases and explicitly characterizing uncertainty, these practices include documenting methods and assumptions and encouraging peer review. Some potential approaches for estimating consequences for the SMSCG were summarized as part of the discussion of each possible objective in Step 2. Consequences are often best summarized in a consequence table.

Consequence tables summarize the estimated consequences of each alternative on each objective, as reported by the performance measures.

Step 5: Address critical uncertainty

At this step, decision makers address four questions concerning the uncertainties in the table:

- Does the uncertainty effect, or have the potential to effect, decision making?
- Can it be reduced, either in the short term or the long term?
- What options are available for reducing it?
- What is the value of the information that will be gained?

While many uncertainties will exist, it is important to distinguish between those that affect decision making and those that do not. Some uncertainties may be of scientific interest, but do not affect which alternative is preferred. For example, a predictive model may be imperfect due to uncertainty in an input parameter value, and may provide only coarse approximations. If this uncertainty is expected to affect each alternative equally, it may not affect their relative ranking, and therefore will not help with choosing between alternatives (thus, it is not important to reduce that uncertainty).

Various forms of “Value-of-Information” analysis can be performed to assess the benefits of reducing uncertainty. This can be particularly useful for defining which uncertainties matter most for performance measures and/or comparing alternative monitoring/experimental designs.

Step 6: Evaluate trade-offs and select an alternative

Although structured decision making processes often find several win-wins (i.e., alternatives that perform well on multiple objectives), most decision problems will be characterized by trade-offs of some sort. In Phase 3, it should be expected that decision makers will need to make explicit choices about which alternatives are preferred, based on predicted performance. They are asked to do this based on their own preferences and their understanding about the preferences of others (which they will have learned about through the process). An illustrative consequence table for this plan might look like that presented in Figure 6.

Interest	Units	Dir	Ref Alt	Alt 2	Alt 3	Alt 4	Alt 5	Alt 6
Delta Smelt								
Performance measure	Units	H	100	70	80	120	200	280
Anadromous fish passage								
Performance measure	Units	H	10	8	6	3	12	2
Boat passage								
Performance measure	Units	H	10	3	4	15	2	12
Water export constraints								
Performance measure	Units	L	100	120	80	90	150	90

Legend
Better than selected
Worse than selected
Selected

Figure 6 -- *Core steps of structured decision making and adaptive management with this plan's work phases -- Illustrative consequence table*

In this simplified, illustrative figure, point-value numbers are shown. Typically, sometimes higher numerical values are preferred over lower ones (all else equal) and sometimes the opposite is true. In the figure, higher numbers for smelt are preferred, for example, but lower values for water export constraints are preferred. For this reason, it is common practice to employ some form of color-coding scheme, as used here, where red cells highlight numbers that are worse than any focus alternative (in this case, 'Reference Alternative (Ref Alt)' is the basis of comparison), and green cells show performance that is better than the focus alternative.

In this simple illustration, Alternative 2 is worse than 'Ref Alt' in all respects, and no trade-offs exist. A hypothetical Alternative 6, meanwhile, shows improvements in performance for delta smelt, boat passage and water export constraints, but a reduction in performance of anadromous fish passage.

Key questions may emerge at this stage. Are the trade-offs clear enough that an informed choice can be made? If not, it may be necessary to go back and refine the estimation of consequences. The table promotes discussions around optimizing alternatives – in this case, could Alternative 6's definition be adjusted to improve fish passage without excessively compromising the other objectives? Often the exploration of trade-offs leads to a clearly preferred solution. Even when it does not, the structured exploration of trade-offs and documentation of areas of agreement and disagreement will, at minimum, inform decision makers and help to identify a more broadly acceptable set of recommendations or management actions.

Step 7: Monitor and review

This final step occurs as part of implementation, but it's important to consider what's needed for effective monitoring and review at the time of developing recommendations. The focus at this stage is on what learning is needed to improve future decision making and how best to ensure that it happens. The challenge is to implement the decision in a way that reduces uncertainty, improves the quality of information for future decisions, and provides opportunities to revise and adapt based on what is learned. In some cases, there may be a focus on strengthening management or institutional capacity to make better decisions in the future, and recommendations may include actions related to human resources (for example, training local community members in monitoring methods) or institutional capacity (for example, building trust and partnerships, developing systems for tracking and storing data, etc.).

1.4 Iterate: Fast and slow learning

Learning occurs at different rates in different decision contexts. A fast learning cycle is possible when monitoring occurs over a short period of time (1-3 years), and learning can be used to update models, refine estimates of consequences, and revise management actions without reconvening a full decision process. However, in many resource management contexts, the time required to reduce ecological uncertainties is measured in decades rather than years. By the time models can be updated, many things may have changed, including new legal or policy constraints, new stakeholders to involve, and new management alternatives to consider. A slow learning cycle requires that the review of new learning circle back to the start, by clarifying the current decision context and proceeding through each step of the framework.

Together, these core principles and steps of structured decision making and adaptive management constitute the basis for the development of recommended management plans. Further discussion of this is provided in an Appendix.

2 Developing an effects analysis in support of adaptive management of delta smelt using the Suisun March Salinity Control Gates

2.1 Introduction

The fundamental purpose of an effects analysis is to apply the best available science to characterize quantitative relationships between alternative management actions and expected outcomes for delta smelt and its habitat, the managed resources (Murphy and Weiland 2011). We offer here a general prescription for conducting an analysis of effects operations of the Suisun Marsh Salinity Control Gates on delta smelt performance in affected areas of Montezuma Slough and adjacent waterways in Suisun Marsh (Figure 7). Additionally, the general structure of this chapter can be used to guide the development of effects analysis for other management applications and other species of interest.

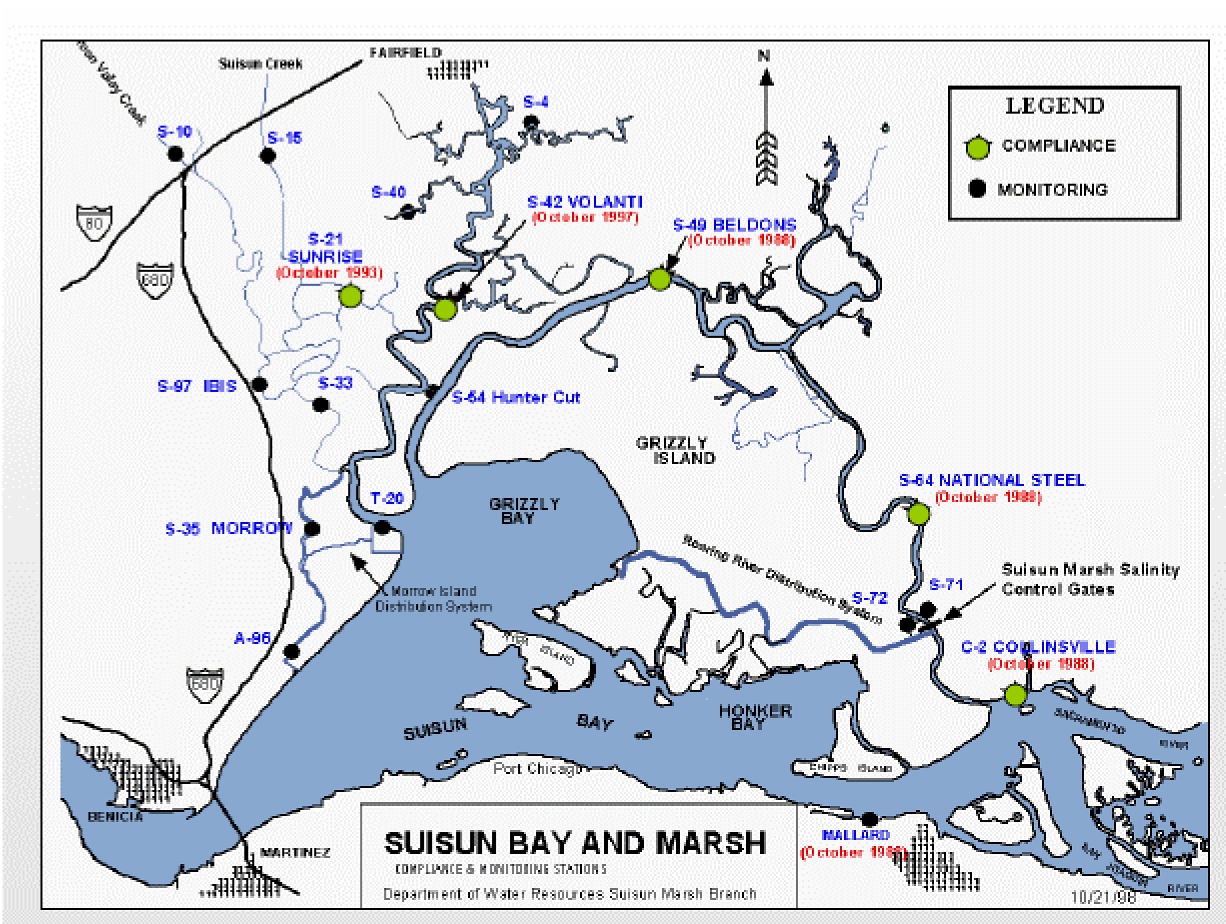

Figure 7 -- *Map of Suisun Bay and Suisun Marsh with identification of the salinity control gates and Montezuma Slough (adapted from Enright 2008).*

A formal effects analysis, embedded within a management and decision-making framework, includes the following components (e.g., Figure 8):

Problem formulation - This initial activity defines the proposed management action, spatial domain of interest, and desired outcomes for delta smelt and habitat. This step focuses on developing a conceptual ecological model that describes the biological and physical relationships and mechanisms that functionally relate potential management actions to likely outcomes.

Collection of reliable scientific information - The first step in the effects analysis requires gathering relevant available data, results from analyses, and findings from those analyses that relate candidate management actions to delta smelt and its habitat, and each to the environmental stressors that are thought to impact the species. This initial step defines an initial range of management actions that are possible and realistic.

Critical assessment and synthesis of data and analyses - Step 2 in the effects analysis identifies relevant models and other analytical tools that can be used to

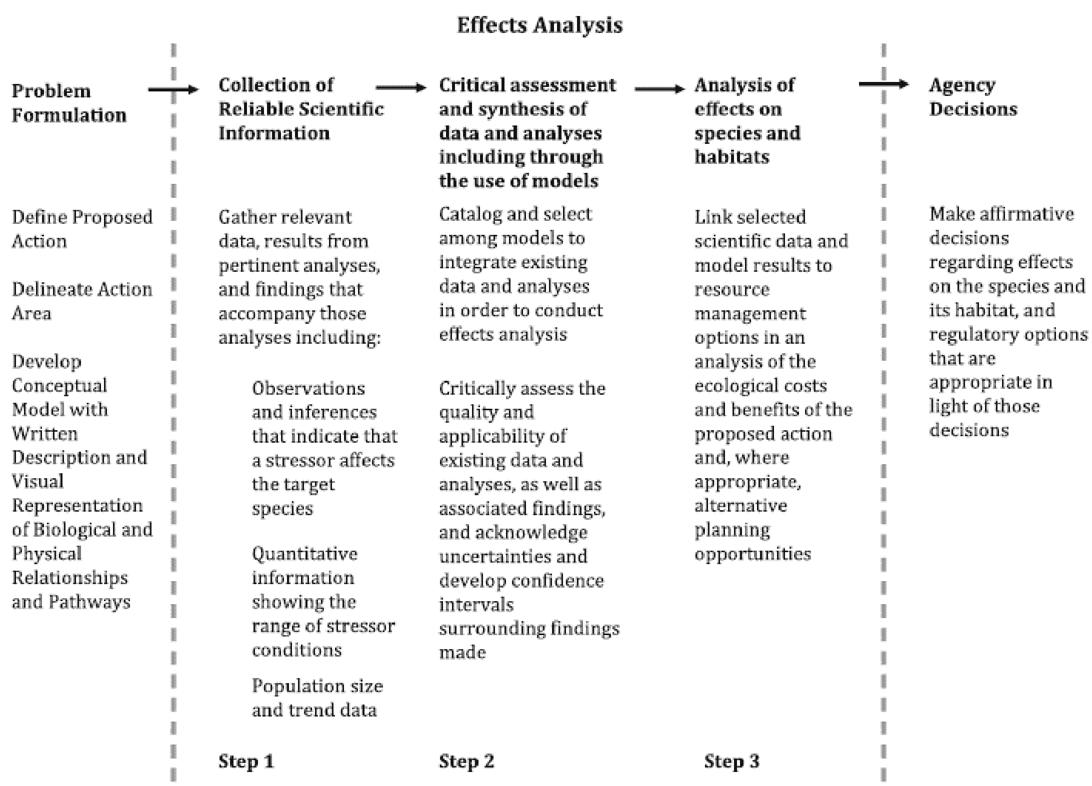

Figure 8 -- *Structured effects analysis (from Murphy and Weiland 2011).*

examine the data collated in Step 1. Step 2 strives to characterize uncertainties associated with key findings.

Analysis of effects on species and habitats - Step 3 connects the results of analysis and modeling to specific resource management actions, including an assessment of ecological costs and benefits associated with proposed alternative management actions.

Supporting agency decision-making - Completion of the three steps that constitute an effects analysis should provide support to decision-making regarding the expected outcomes of implemented management actions on the species of interest and its habitat.

The resulting causal understanding generated by an effects analysis based on "best available science" is used to (1) identify management actions that might effectively and economically achieve the desired outcomes for species and their habitats, (2) design specific implementations of the selected actions to maximize desired outcomes, and (3) contribute to the design effective monitoring programs for evaluating the performance (actual outcomes) of implemented management actions (Murphy and Weiland 2016).

2.2 Designing and implementing an effects analysis for delta smelt and the SMSCG

The following provides an outline or template for an effects analysis for operation of the Suisun Marsh Salinity Control Gates (SMSCG). The effects analysis begins with the development of a consensus conceptual ecological model (CEM) for delta smelt populations in the Montezuma Slough, Suisun Marsh, and adjacent areas of Suisun Bay and the Delta. The conceptual model illustrates known or hypothesized relationships between different broad-scale environmental drivers, meso-scale physical factors, more localized habitat attributes, and corresponding delta smelt population dynamics.

The CEM prefaces the presentation of a corresponding conceptual management model (CMM). The CMM characterizes the relationships between gate operations, habitat extent and condition, and delta smelt population responses.

The template begins to prescribe how the CMM can be translated to an operational model, that is, a calculus for projecting quantitative population responses to specific schedules of control gate operations. The template can be fleshed out into a comprehensive effects analysis for operating the salinity control gates.

2.3 Montezuma Slough lower-trophic level production

The impacts of alternative salinity gate operations on the associated production of phytoplankton (Jassby 2008) and zooplankton (Rose et al. 2013, Figure 9) might become important endpoints in indirectly assessing the effects of salinity management on delta smelt or surrogate species. If the salinity gate operations impacts plankton production (either positively or negatively), inferences might be drawn concerning possible indirect food web effects on the production of delta smelt.

2.4 Clearly stated management goals, objectives, and metrics

The overall usefulness of an effects analysis is determined by the clarity of stated management goals and objectives, which identify and describe the desired management outcomes.

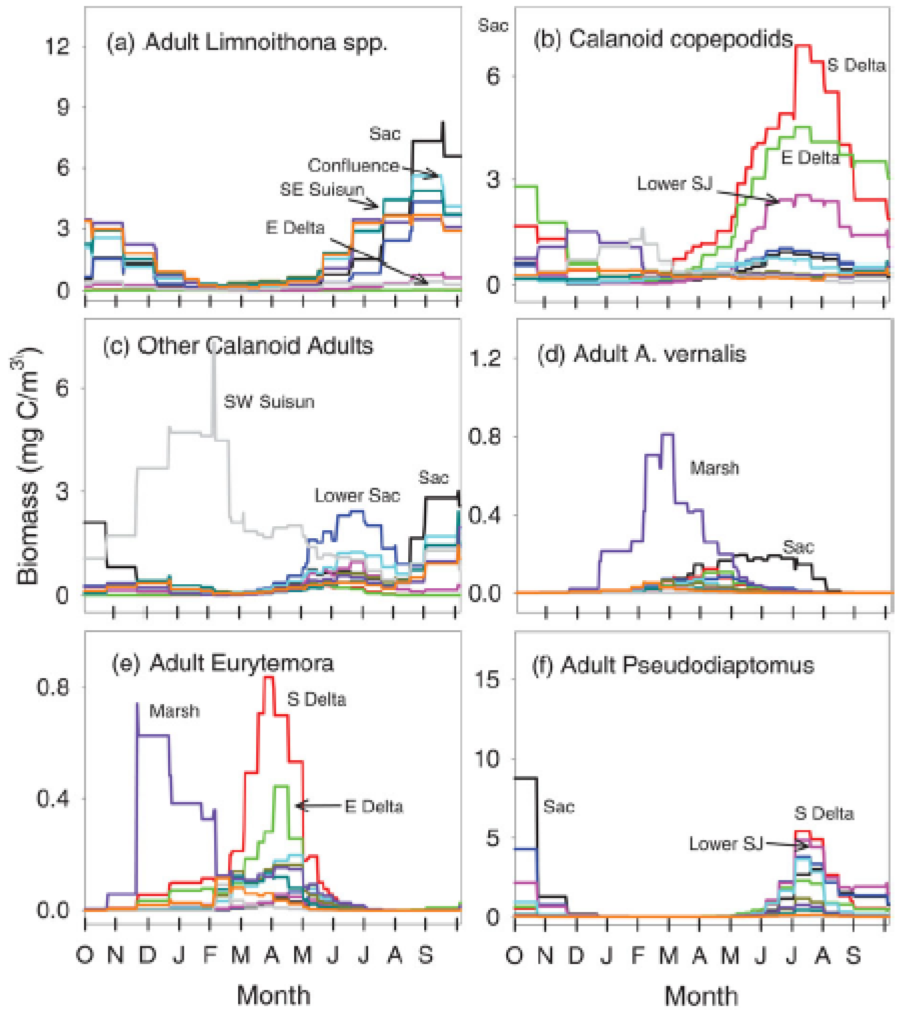

Figure 9 -- *Seasonal values of zooplankton biomass for the upper estuary under low flow conditions (taken from Rose et al. 2013).*

Management goals and objectives for delta smelt in Montezuma Slough could include:

- Achieving a population size and age distribution of delta smelt consistent with historical conditions before installation of the salinity control gates and prior to more recent assertions of a population in decline,
- Establishing a self-sustaining population with a growth rate (λ) that varies around a value of 1.0,
- Preserving, restoring, and creating habitat distribution, extent, and quality in the Suisun Marsh and Montezuma Slough area affected by salinity gates operations sufficient to support those population goals and objectives.

Given well-defined management goals and objectives, the challenge in developing an effective effects analysis lies in identifying and describing measures (metrics) that can be used to evaluate quantitatively the outcomes of implemented management actions in relation to the goals and objectives. Identifying useful metrics for delta smelt in constructing an effects analysis is challenged by institutional constraints on directly monitoring this species. Absent permission to collect delta smelt, unequivocal characterization of the size of the demographic unit in the project area, and its spatial and temporal distribution, and growth rate will be all but impossible.

Permitting constraints to measuring delta smelt directly might require a hierarchical approach to defining metrics that might justifiably include (1) population metrics specified for a surrogate species (perhaps longfin smelt), (2) measures of lower-trophic-level productivity in Suisun Marsh and Montezuma Slough upon which delta smelt depend either directly or indirectly, and (3) water quality parameters that directly characterize habitat capacity for delta smelt or influence lower-trophic level productivity and/or community structure.

2.5 Suisun Marsh Salinity Control Gates management action

The management actions relevant to this effects analysis focus on the operation of the Suisun Marsh Salinity Control Gates (Enright 2014). Well-stated management goals and objectives should be complemented by correspondingly well-specified management actions in developing a useful effects analysis. The challenge lies in identifying and describing SMSCG management actions that can lead unequivocally to desired measurable responses in the managed resources and associated metrics.

The implemented management action will define the timing, frequency, and duration of opening and closing the salinity gates to achieve desired anticipated outcomes for delta smelt, surrogate species, or lower-trophic level productivity.

One approach to exploring the potential outcomes of gate operations on selected metrics is to examine the expected management implications of not opening the gates at all or alternatively operating continuously with the gates completely open. These two extreme, “bookend” management scenarios can help understand the theoretical strength of the management action and the reasonableness of expecting any measurable responses within the range of potential schedules for gate operations. Examination of these bookend management actions could also help in determining the level of effort (and sampling design) required to reliably measure changes in the response metrics for less extreme schedules for gate operations. Importantly, if the bookends scenarios are not expected, upon detailed analysis (see operational model development below), to produce measurable responses with sufficient statistical power to support structured decision-making, implementing any schedule for operating the control gates to manage delta smelt populations would seem inadvisable – or at least not supported by the best available science.

2.6 Conceptual ecological model for delta smelt

The conceptual ecological model (CEM) captures the salient aspects of the basic ecology of the delta smelt based on known life history attributes, field biology and ecology, laboratory studies, resulting data and informed analyses, and models (Figure 10).

The larger-scale environmental drivers identified in the CEM include climate, geology, and land-use. Climate and geology define the larger-scale, longer-term environmental context that delineates opportunities to expand and enhance delta smelt habitat in the broadest sense (the existence, physical topology, and seasonal dynamics of Suisun Marsh and Montezuma Slough).

The larger-scale drivers influence more localized physical factors that directly determine habitat quality and availability relevant to delta smelt. These physical factors include river flows, tides, runoff, inundation, and geomorphology specific to Suisun Marsh and Montezuma Slough. These physical factors provide a more localized context that can influence the outcome of different

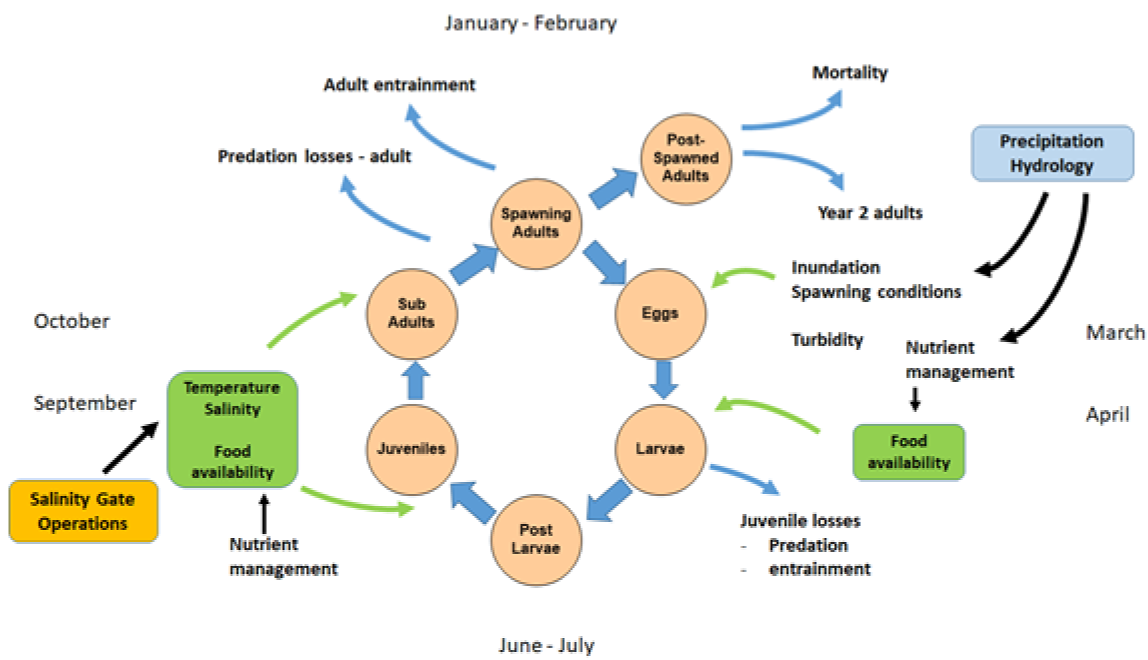

Figure 10 -- *A conceptual ecological model (CEM) for delta smelt that illustrates key environmental drivers, physical factors, smelt life history, and biological processes which influence smelt population dynamics in relation to proposed operation of the salinity gates in Montezuma Slough.*

schedules for operation of the salinity gates. Understanding quantitatively the (potential) influences of these factors on the expected outcomes of gate operations on delta smelt population dynamics and habitat conditions can provide valuable information for designing management alternatives. Importantly, infrequent, large-scale inundation of Suisun Marsh might be an overlooked or under-emphasized, but likely is a key influence on the viability of delta smelt in Suisun Marsh. The CEM habitat attributes influenced by the listed physical factors comprise salinity, current velocity, water depth, turbidity, and nutrient concentrations. Developing functional relationships between operation of the salinity gates and associated values of those habitat attributes is fundamental for projecting quantitatively the anticipated population response of delta smelt to alternative operations of the salinity control gates.

Habitat extent and quality defined by the attributes identified in the CEM determines three key biotic responses: reproductive opportunities for delta smelt, a forage (prey) base available to delta smelt, and predation pressures experienced by delta smelt. The biotic responses relate directly to delta smelt reproductive success, survival of early and adult life stages, and ultimately the distribution and abundance of delta smelt is Suisun Marsh and Montezuma Slough. Developing a useful effects analysis will depend on establishing quantitative relationships between changes in the identified habitat attributes and associated values of these biotic response variables.

2.7 Conceptual management model for the salinity gates and delta smelt

A conceptual management model (CMM) incorporates the CEM and focuses schematically on key relationships between basic ecology, management actions, and the expected species response to operations of the salinity gates. The CMM retains the broader-scale environmental context defined by geology, land-use, and climate. To this context, the CMM additionally recognizes the legal, economic, and socio-political drivers that can importantly shape management actions. Both sets of broader-scale drivers can directly impact proposed operations of the salinity gates. The CMM underscores the observation that the additional anthropocentric drivers are assumed to only influence key physical factors through operation of the salinity gates.

The legal requirements of specified salinity values at certain times and locations in Suisun Marsh may constrain the design of management prescriptions of gate operations directed at achieving the species goals and objectives. Economic and socio-political drivers of gate operations might include implications of managed flows on waterfowl that utilize the marsh and the associated impacts on recreational hunting.

The management action, operation of the salinity gates, directly affects flows through Montezuma Slough, and correspondingly affects salinity and related environmental (habitat) factors (e.g., velocity, depth, turbidity, and nutrient concentrations. The habitat factors are presumed to determine biotic responses and species performance identical to the CEM (Figure 11).

2.8 Translating CEMs and CMMs to quantitative assessment capabilities

One principal benefit of developing CEMs and CMMs lies in translating these conceptual models to models that can compute the expected responses of identified metrics to alternative management actions. This translation will inevitably make use of a variety of approaches, including quantitative analysis of experimental results; analysis of field monitoring data; derivation of empirical (statistical) relationships, functions, or mathematical formulations; and construction of simple demographic population models, more complex individual-based models, or food web/ecosystem

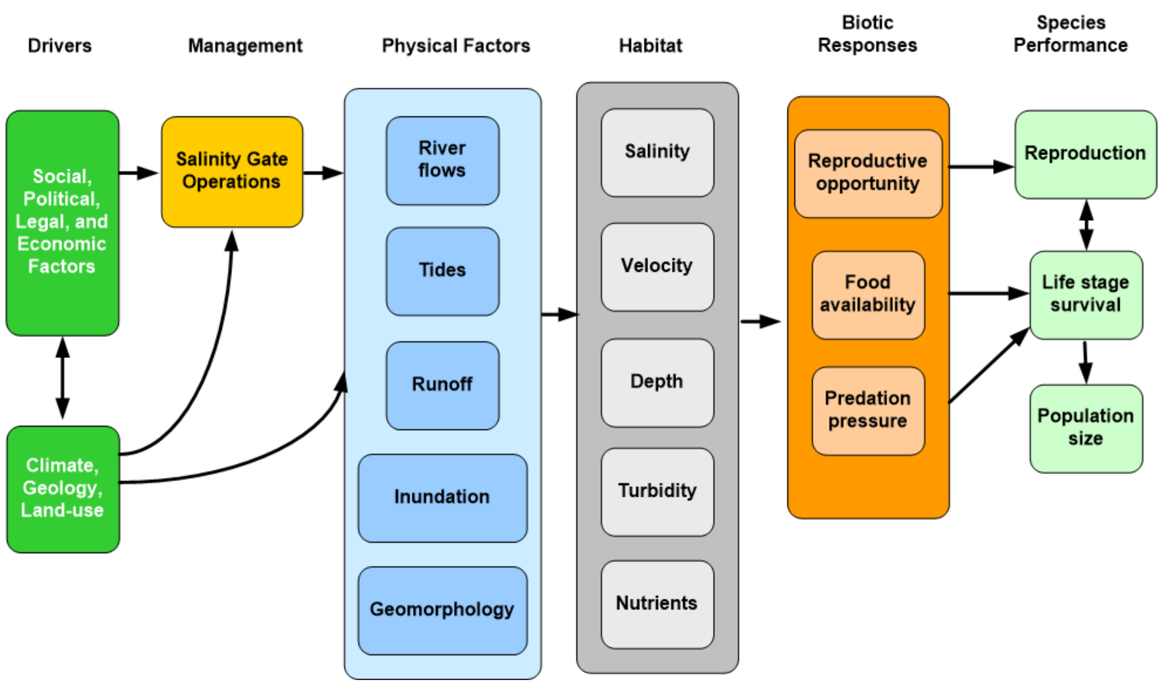

Figure 11 -- *Conceptual management model (CMM) for salinity gate operations and delta smelt.*

models, as well as informed judgment. Importantly, the translation develops the "management-response" relationships without which management (adaptive or otherwise) is not possible. The accuracy and reliability of the management-response functions will in large part determine the success of an adaptive management approach to structured decision-making. Absent management-response functions, ecosystem experimentation is the only recourse.

When completed, the operational model will permit estimation, using a sequence of interrelated calculations, of the anticipated delta smelt population responses to specific proposals for operating the salinity gates. The anticipated population responses (explicitly including associated uncertainties) become the focus of monitoring and further analysis within the adaptive management framework.

2.9 Gate operations, environmental factors, species responses in Montezuma Slough

An important initial step in translating the CMM to an operational model lies in developing a quantitative description of a proposed management action (that is, temporal pattern of salinity gates operations) in terms of resulting physical factors (for example, spatial-temporal values of salinity and similarly affected water-quality parameters) that can serve directly as independent values in forcing functions used ultimately to project the anticipated species individual responses (in terms of individual growth, survival, or fecundity) and corresponding population dynamics.

Physical factors and habitat attributes

Following the translation of specific plans for operating the salinity gates to expected changes in physical factors, corresponding changes in specific habitat attributes need to be estimated in relation to managed impacts on the controlling physical factors.

For example, Figure 12 illustrates differences in salinity (specific conductivity) downstream from the salinity control gates one day before operating the gates and 10 days after operation. The maximum difference is about 6 mm hos/cm at about 17 km upriver from the A96 monitoring station – a salinity difference of ~4 psu. Similar summaries for other water-quality parameters (including N, P, dissolved oxygen, turbidity) should be developed to support the effects analysis for operation of the salinity gates.

Habitat attributes and biotic responses

The next step in CMM translation consists of developing quantitative relationships between values of habitat attributes and the resulting impacts on biotic responses, including changes in opportunities for reproduction, altered food availability, and shifts in predation pressures. Figure 13 illustrates a simple functional relationship between the value of a habitat factor (e.g., X_i) and a corresponding modifier for a biotic response. The simple trapezoidal function defines a tolerance range (X_1-X_4) of habitat factor values for a hypothetical biological response (e.g., survival, growth, reproduction) and a smaller interval of values (X_2-X_3) that equate to optimal conditions for the habitat factor in relation to the biological response. The effects analysis should construct a set of relationships that map multiple habitat factors onto a set of key biological responses related to the species objectives. Integrating across managed changes in habitat factors (particularly salinity management) and corresponding biotic responses provides a quantitative estimate of the benefits likely afforded by a management action. In practice, the simple relationship illustrated by Figure 13 might be replaced by a more complicated nonlinear function (see Thornton and Lessem 1978). The biotic response variables might be actual physiological rates or values of demographic parameters (such as mortality and fecundity) that replace the simple [0-1] response modifiers (for example Figure 14).

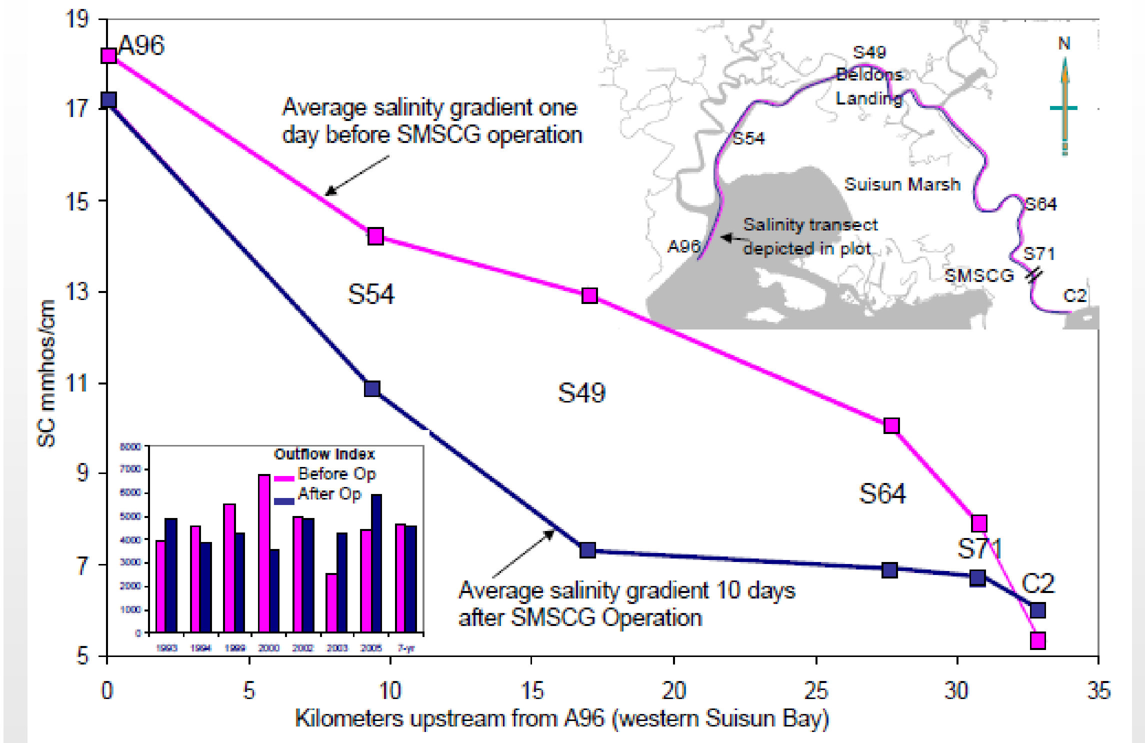

Figure 12 -- *Effects of salinity gates operations ("signal") on conductivity values for Montezuma Slough (Adapted from Enright 2008).*

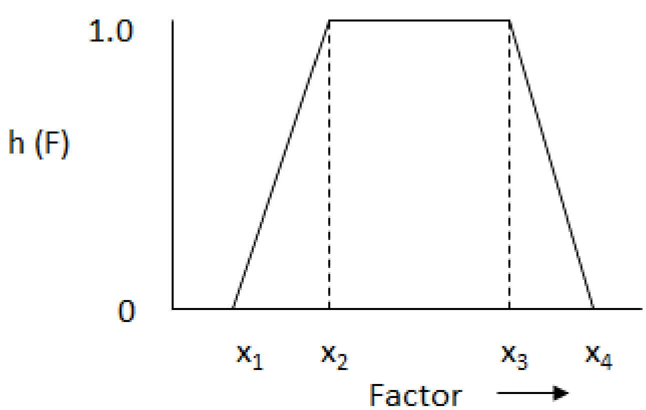

Figure 13 -- *Example of simple habitat suitability function that can be used to translate physical-chemical habitat attributes (e.g., temperature, salinity) to a modifier for a biotic response (e.g., survival, growth, reproduction). Values of X_1 and X_4 define a range of tolerance; X_2 and X_3 define a range of optimal habitat quality for the biological response.*

Biotic responses and species performance

The final step develops the relationships between magnitudes of biotic response and direct population-level effects of managing salinity gate operations. The example CMM focuses on reproduction, survival of early and adult life stages, and the corresponding implications for population growth (λ) and population size. Completion of this final step describes potential management actions as corresponding alterations in habitat attributes that translate initially to associated biological responses and finally to consequent quantitative species responses.

2.10 Short-cutting the CMM translation

It might prove possible to coalesce some of the steps, depending on interest in the intermediate variables (e.g., physical factors, habitat attributes), and develop more direct relationships between a proposed schedule for gate operations and impacts on delta smelt population dynamics. For example, if management has less interest on the impacts of gate operations on flows through Montezuma Slough, emphasis might be focused on obtaining direct estimates of changes in salinity and turbidity (in time and space) associated with gate operations.

Alternatively, it might prove feasible and economical to work backwards in developing functional relations between reproductive success and life stage survival (which largely determine λ and population size) and critical values of biotic responses (e.g., food availability) and habitat attributes (e.g., salinity, turbidity) that respond in predictable ways to salinity gate operations. Working backwards from an understanding of key biotic and demographic responses to a subset of intermediate physical factors and habitat attributes affected by gate operations can reduce the dimensionality (the number of necessary quantitative relationships) of the operational model and correspondingly reduce sources of uncertainty associated with projected population impacts of specific schedules for gate operations and economize future model applications.

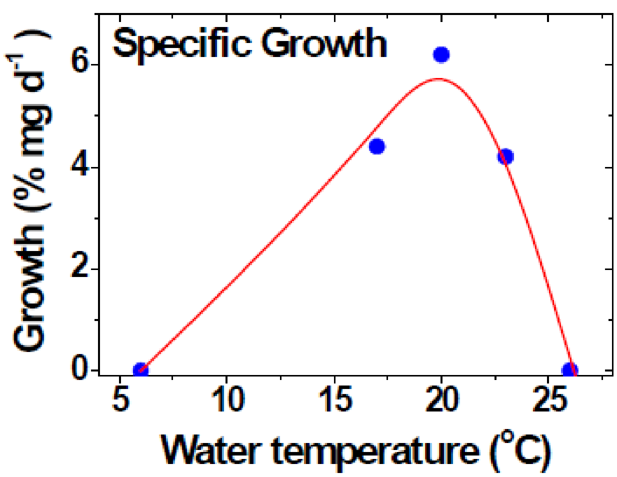

Figure 14 -- *Specific growth rate of juvenile delta smelt as a function of water temperature (After Baskerville-Bridges et al. 2004 as cited in Bennett et al. 2008).*

2.11 Supporting data and information

Habitat attributes might be directly related to delta smelt population metrics using available data and statistical methods (Nobriga et al. 2008, Feyrer et al. 2007, Bennett 2005). Simple regression, or more complicated multivariate analyses can be used to derive empirical management-response functions to be used in quantitatively examining the likely outcomes for delta smelt (or surrogate species or plankton productivity) for proposed alternative schedules for operating the control gates. For example, Baskerville-Bridges et al. (2004) were able to develop a non-linear function relating juvenile delta smelt growth rate to water temperature (Figure 14). Indirect manipulations of water temperature through operations of the salinity gates could be translated into associated changes that could be expected for juvenile growth rate using this function.

In performing an effects analysis, the following environmental data should be identified and collated for the upper estuary, with emphasis on Montezuma Slough:

- Physical data (e.g., flows, velocities, depths, temperature, salinity) for Montezuma Slough
- Water-quality data (e.g., nutrients, dissolved oxygen, ammonia)
- Biological data (e.g., food web structure, invasive species)

Potentially useful models

Models can be used to augment empirical (data-driven) approaches to deriving the critical management-response functions. Several examples include:

- Demographic population models (e.g., Maunder and Deriso 2011)
- Bioenergetics and individual-based models (e.g., Rose et al. 2013)
- Food web/ecosystem models (e.g., Bartell et al. 2010, 2013)

In addition, nutrient-phytoplankton-zooplankton models (see Cloern 2006) might be used to develop functional relationships between salinity gate operations, associated impacts on nutrient (particularly N) concentrations, and production of phytoplankton and zooplankton prey resources for delta smelt.

The selected model(s) need to translate the input salinity values to associated changes in delta smelt responses, for example,

- The demographic model would compute changes in entrainment mortality for different life-stages of delta smelt (Maunder and Deriso 2011). These managed salinity-driven adjustments to mortality rates would then alter the modeled population dynamics of the smelt.
- The individual-based model uses salinity to determine the movement and location of individual smelt of different age classes (Rose et al. 2013). The smelt, as a result of the salinity-driven movements, then experience local conditions (e.g., temperature, food availability), which subsequently influence growth, survival, and reproduction.
- The food web model uses input values of salinity to adjust the overall population growth rates for delta smelt and other food web components (e.g., competitors, predators). The model computes the direct and indirect food web impacts of salinity management on delta smelt population dynamics (e.g., Bartell et al. 2010).

Modeling and/or data needs

Additional modeling studies and data collection might be required to characterize system responses to gate operations not previously examined. To inform an effects analysis, each scenario for gate operations should provide:

- Values of flow, current velocity, and water elevation (or depth) at downstream monitoring stations – perhaps hourly average values two days before, during, and two days after a gate operation action; values at depths sampled at each monitoring station, or averaged over the water column, if possible.
- Values of salinity, pH, water temperature, turbidity, and dissolved oxygen at same locations and time scales as above.
- Dissolved inorganic P and N, and ammonium, at the same locations scales as above, but perhaps daily average concentrations over the water column
- Chlorophyll$_a$ concentrations at same locations scales as above, but perhaps daily average concentrations; noting that those values might be augmented by remotely sensed surface chlorophyll concentrations, depending on data availability
- Grab samples for phytoplankton and zooplankton, same locations, perhaps one sample per day, again integrated over the water column.

Depending on time and resources, it might prove useful to summarize modeling results at 0.5 or 1.0-km intervals from the control gates to S54 (Hunter Cut) or A96 (Goodyear Slough). Model results summarized for the locations corresponding to monitoring stations S71 (Roaring River), S64 (National Steel), and S49 (Beldons) could also be instructive through comparisons with data available from these locations.

The results of additional modeling scenarios could provide input values to models of delta smelt population viability, models of delta smelt habitat capacity (measured as volume x time) for condition exhibiting selected habitat-quality criteria (including optimal salinity, temperature, turbidity), and models of lower-trophic level productivity directly relevant to delta smelt growth.

2.12 Developing management questions

An effects analysis provides the opportunity to address alternative management actions as management questions that can be answered through formal statistical analyses or otherwise quantitatively evaluated. Example questions include --

- Will operation of the salinity gates to reduce salinity in the Suisun Marsh during summer months benefit juvenile and sub-adult delta smelt through increased food availability compared to Suisun Bay (CNRA 2016)?
- Can the salinity gates be operated to produce favorable (that is, low salinity) regimes during certain periods that the survival, growth, or reproduction of delta smelt inhabiting Suisun Marsh and Montezuma Slough are increased?
- Can the salinity gates be operated to produce less-favorable salinity regimes for species that compete with delta smelt for food resources when those are limited?
- Can the salinity gates be operated to produce salinity regimes that are less favorable for predators of delta smelt?

The previous example questions translate into potentially different schedules (i.e., frequency, timing, magnitude, and duration) for operating salinity gates. Corresponding hypotheses that can guide evaluation of the premise that strategic operations of the salinity control gates can benefit delta smelt include –

- H_{01} The abundance of delta smelt differs significantly between adjacent areas of Suisun Marsh and Suisun Bay (adjacent areas outside and inside of the SMSCGs).
- H_{02} Food availability for delta smelt differs significantly between adjacent areas of Suisun Bay and Suisun Marsh.
- H_{03} Manipulation of the SMSCGs, which when open may reduce Suisun Marsh salinities, can directly alter the availability of food and indirectly the abundance of delta smelt in Suisun Marsh.

Evaluating those hypotheses using best available scientific information and data generated by project-specific monitoring offers the opportunity to address hypotheses that have implications for conservation planning beyond the salinity gates action area, including.

- H_{04} Salinity determines the spatial-temporal distribution and local abundance of delta smelt in Suisun Marsh.
- H_{05} The site-specific abundance of delta smelt is correlated with species composition and abundance of prey in Suisun Bay and Suisun Marsh.
- H_{06} Food availability and salinity are correlated in Suisun Bay and/or Suisun Marsh.
- H_{07} Food availability is the limiting environmental factor that determines spatial distribution and local abundance of delta smelt in Suisun Marsh.
- H_{08} Some other physical or biotic factor(s) are the limiting factors that determine landscape occupancy by and/or local abundance of delta smelt in Suisun Marsh.
- H_{09} The abundance of delta smelt varies significantly by meso-habitat type.

2.13 Description and implementation of selected management action(s)

Selected management action alternatives should be implemented at appropriate scale to produce outcomes (values of the metrics) that can be unequivocally or at least statistically related back to the management actions. The previous monitoring of "normal" gate operations on associated values of salinity in Montezuma Slough demonstrates a readily measured gradient (e.g., Enright 2014). However, the challenge remains to relate any "managed" changes in salinity (and other correlated water quality parameters) to delta smelt population responses.

The previous considerations demonstrate that the design of an actionable management alternative should proceed in parallel with the design of its monitoring program. Working backwards from basic understanding and experience with sampling protocols (e.g., gear types, sampling procedures, sample processing, kinds of data produced), required monitoring resources, and attendant costs, management actions can be designed to increase (maximize) the opportunity to measure species or habitat responses with sufficient statistical power to usefully inform structured decision-making (i.e., adaptive management).

2.14 Evaluating monitoring data in relation to management hypotheses

An effects analysis for operation of the salinity gates should outline the methods for comparing the results of monitoring the outcomes of management actions to designated metrics within the context of previously developed management hypotheses and associated decision criteria. Given the range of relevant management hypotheses, methods would be developed to evaluate the effects of gate operations on

- Direct measures of data pertinent to demographics and population dynamics of delta smelt in Montezuma Slough,
- Measures of data describing demographics and population dynamics for a surrogate species (e.g., longfin smelt),
- Data quantifying the spatial and temporal production of zooplankton prey and indirectly relevant phytoplankton production, and
- Water quality parameters (e.g., salinity, temperature, ammonia, and nutrients) that can be used to define habitat quality and availability for delta smelt in Montezuma Slough.

Univariate and multivariate parametric analyses, non-parametric tests, computationally intensive methods (e.g., bootstrapping), and Bayesian methods might all usefully contribute in evaluating the monitored responses of gate operations for the above-mentioned categories of response variables.

2.15 Prescription for adapting management actions

An effects analysis for operation of the salinity gates should specify how evaluation of monitoring data in relation to management hypotheses will be used to inform the adaptive management process. Assuming a management hypothesis-driven framework for adaptive management of salinity gate operations, the following approach might facilitate such an evaluation

Fail to reject hypothesis: continue with current action(s) and monitoring

Under these circumstances, the results of the analysis of the monitoring data are consistent with the expected and desired outcomes of the implemented and monitored management action. The structure decision-making process would argue for continued implementation and monitoring of the current management action. There might be some modifications to the implementation if the supporting science is sufficient to fine-tune the management action to increase the overall effectiveness of the management action in relation to the management goals and objectives.

Reject hypothesis: adapt management actions

Alternatively, evaluation of the monitoring results might indicate that the expected outcomes of an implemented management action are not being realized. These circumstances might suggest the following steps to redress the situation:

- Revise CEMs and supporting methods and models
- Revise current management hypotheses and associated actions
- Develop alternative hypotheses and associated actions
- Implement a selected alternative management action and continue AM

2.16 Summary

Successful completion of an effects analysis will generate the necessary management-response functions to project the expected outcomes of a proposed schedule for operating the salinity gates. The effects analysis will facilitate the design of alternative management actions and provide the technical means to evaluate proposed alternatives in relation to achieving management goals and objectives concerning delta smelt and its supporting habitat. The effects analysis will identify and characterize key sources of uncertainty associated with the management-response function. These uncertainties can be used in evaluating the likely outcomes of alternative management actions.

3 Monitoring in support of adaptive management of delta smelt using the Suisun Marsh Salinity Control Gates

3.1 Introduction

The Delta Smelt Resiliency Strategy intends to decrease salinity in Suisun Marsh to increase habitat extent and quality for delta smelt. The Suisun Marsh Salinity Control Gates (SMSCGs), which can be operated to restrict flood-tide flow of higher-salinity water from Grizzly Bay into Montezuma Slough, allow resource managers to increase net inflow of fresh water in portions of the Suisun Marsh (see Figure 15). An essential element in the adaptive management plan for operations of the SMSCGs is the monitoring scheme, which must be able to assess the performance of gate operations by differentiating effects of the management actions from background environmental variation and impacts on the species from environmental stressors that will affect delta smelt.

This section expands the discussion of monitoring recognizing that ongoing delta smelt monitoring appears inadequate to resolve the population status and trend in the species, nor has it allowed management planners to draw strong inference regarding the causes of delta smelt population declines. Survey sampling carried out using larger craft and relatively deep-water gear are ineffective in sampling portions of the project area. Accordingly, we present here a new approach to data collection that is informed by the conceptual ecological model presented in Section 2, the published literature regarding landscape areas occupied by delta smelt, and knowledge of delta smelt experts. Combined with the statistical approaches used by Newman and Polansky, we propose that the Enhanced Delta Smelt Monitoring program as currently designed, expanded to sample the breadth and diversity of “meso-habitats” (habitat strata) occupied by delta smelt, be implemented in a sampling scheme to evaluate a set of nine management-relevant hypotheses that test the premises for SMSCGs action as presented in the Delta Smelt Resiliency Strategy.

3.2 Overview of environmental monitoring

The following paragraphs briefly outline the basic principles of successful and defensible environmental monitoring programs. Previous critiques of environmental monitoring programs have found them to be characterized by inadequate attention to qualitative and quantitative design issues (Noon, 2003, Gitzen et al. 2012). We agree with this assessment and here go into detail discussing the components of the monitoring program to assess the effects of the salinity-gate-operations “experiments” and to provide support for an adaptive management program for delta smelt in portions of Suisun Marsh. First, we provide a broad overview of the key components of defensible environmental monitoring programs, including general principles and design/analytical considerations. Then we present rationale for using a design-based approach to monitoring and include considerations for sampling design, response variable selection, and assessing treatment effects.

General principles

Monitoring programs must be efficiently administered, adequately funded, supported by the clients of the monitoring program, have effective data management procedures and regular reporting schedules. However, our focus here is on the essential analytical components for environmental monitoring. There is a strong consensus in the scientific literature on

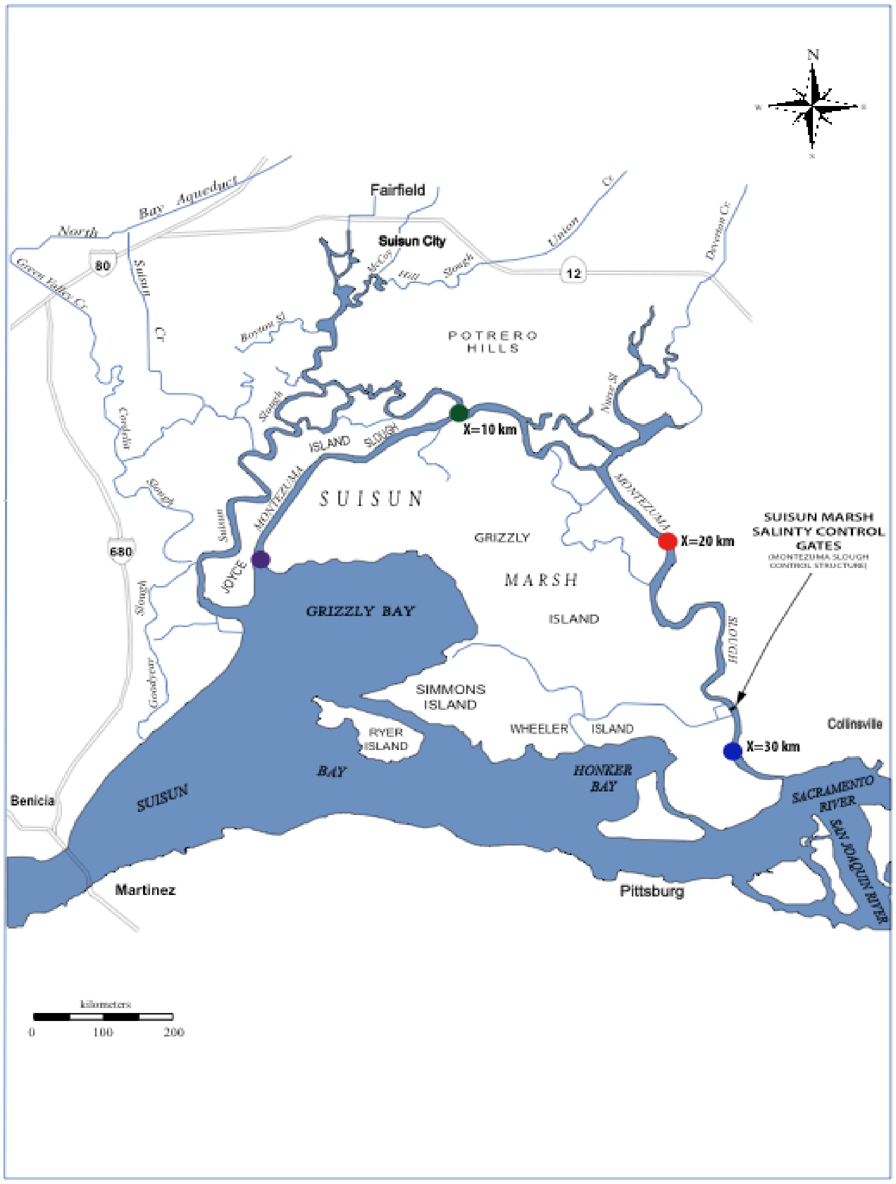

Figure 15 -- *The Suisun Marsh Salinity Control Gates are operated to decrease salinity in Suisun Marsh during summer months. The management action can be carried out accompanied with strategically designed monitoring to test multiple hypotheses that relate the performance of delta smelt and its zooplankton prey to salinity and other abiotic and biotic environmental factors.*

the essential components of monitoring programs designed to assess status and trend. Components relevant to the operation of the salinity gates include:

1. Specify objectives in terms of measurable attributes. The objectives of the salinity gates experiments are to evaluate the response of delta smelt to changes in salinity to the extent that can be facilitated by operations of the salinity gates. DWR will operate the

Suisun Marsh Salinity Control Gates to reduce salinity in the Suisun Marsh during summer months. It is hypothesized that this management action will attract delta smelt into “high-quality Suisun Marsh habitat” from areas of lower habitat quality and reduce use by delta smelt of less food-rich Suisun Bay habitat. Employing the design and methods outlined below, the outcomes from these management experiments would be closely monitored to evaluate the nature of the population-level response of delta smelt to the management action.

2. Identify the monitoring state variables (e.g., indicators) and why they were selected. Assessing the effects of the salinity gates experiments will focus primarily on estimating pre-adult and adult delta smelt abundance in various meso-habitat types within Montezuma Slough, channels and tributaries feeding and joining the slough, and areas outside directly adjacent to the salinity gates in Suisun Bay. The monitoring state variable will be delta smelt catch-per-unit-effort (CPUE) index, which is detailed in the following sections.

3. State the spatial and temporal domain (sampling frame) of the population of interest (that is, the sample frame). Sampling to estimate monitoring state variables will be focused within Montezuma Slough, the area affected by operation of the gates. The temporal extent of the experiments will reflect the length of time the gates are open and the magnitude of flow into the slough. The timing of inflow, flow magnitude, and flow duration will be design factors in the flow experiments n_0 and delta smelt CPUE will be the primary response variable.

4. State the type of change to detect. The primary objective of the experiments is to evaluate the population-level response of delta smelt to changes in salinity (primary factor) and secondary factors (food, predators, and water quality and other physical attributes of habitat that may vary with gates operations) that may affect population size and distribution. The experiments will test a major hypothesis that delta smelt populations are limited by salinity levels and that changing the spatial distribution of salinity domains can lead to increases in delta smelt abundance in Suisun Marsh.

5. Specify the magnitude of effect to detect effect size (essential for sample design decisions). This key component of an effective monitoring scheme will determine the number and spatial distribution of sample units. This is a policy decision that will have to be made by the management agencies.

Conceptually, we can think of the task of determining a sample size as –

$$\Pr(|\hat{N} - N| > d) < \alpha$$

Where, $\hat{N} =$ estimated delta smelt abundance

$N =$ true, unknown abundance

$d =$ maximum, acceptable difference between truth and the estimate (effect size is $\leq$ d)

$\alpha =$ probability the difference exceeds d

If $\hat{N}$ is an unbiased, normally distributed estimator of N, then, $\dfrac{\hat{N} - N}{\sqrt{\mathrm{var}(\hat{N})}}$ has a standard normal distribution, z. The inequality is solved if we choose n larger enough so that

$z\sqrt{\text{var}(\hat{N})} \leq d$. Given an estimate of the $\text{var}(\hat{N})$ based on the sample data, and letting z denote the $\alpha/2$ point of the standard normal distribution, then an estimate n_0 of the required sample size is

$$n_0 = \frac{z^2\alpha^2}{d^2}$$

6. Following (5) specify desired precision for the trend estimate (this requires pilot data and a components of variance analysis). The $\text{var}(\hat{N})$ decreases with increasing sample size n, so this calculation can be done as part of the previous step. Note that trend estimates are most relevant to the adaptive management program.

7. Generate estimates of uncertainty. The catch-per-unit-effort estimators developed below are associated with variance estimators.

Criteria listed below are applicable to components of the adaptive management program and not specific to estimating the outcomes of the salinity gates experiments. These require decisions by the lead agency regarding management action responses to ambient conditions and identification of decision criteria upon which management actions are initiated or terminated.

8. Specify 'trigger point' (thresholds) that will lead to a management response
9. Specify the management action that will occur
10. Determine (monitor) the effects of the management actions
11. Update design as needed (adaptive monitoring)

Design and analytical issues

The above steps are important, but program components cannot compensate for inadequate attention to design and analytical issues. Specifically, the survey design and associated statistical model(s) to be used for analysis must be decided upon early in the process. Given specific monitoring state variables (indicators), sampling objectives, such as desired statistical power, effect sizes, variance components, and statistical precision require a priori identification of specific statistical methods. Failure to do this makes it impossible to perform basic sample size calculations and to allocate optimally sampling effort across time and space. Rigorous and responsive monitoring design ensures that limited project funding is used in the most efficient way.

To clarify the components of variance concept, we assume a design in which each sample unit (site) is visited in each of a set of years. Given this assumption, the key components of variation are (see Urquhart 2012):

- Spatial components: variation among sample units (sites); treated as a random effect in an ANOVA model
- Temporal components: how much the state variable varies from year-to-year across all sample units; treated as a random effect
- Space by time interaction: how much the state variable changes across time within a sample unit independent of changes in other sample units
- Error variance

Partitioning the total variance is expressed as: $\sigma^2_{Total} = \sigma^2_{site} + \sigma^2_{time} + \sigma^2_{site\ x\ time} + \sigma^2_{error}$

To estimate trend, we must first assume a model for how the response variable (e.g., value of an index of delta smelt CPUE at sample unit i) changes over time. For example, if we assume a simple linear time-trend model for the indicator, y, our model is:

$$y_{ij} = \mu + S_i + T_j + \varepsilon_{ij}$$

where,

$y_{ij} =$ the value of the state variable at site i in year j

S_i = effect of site i

T_j = effect of year j; {j = 1, 2, … , t}

$\varepsilon_{ij} =$ error term

Then our estimation model for a linear trend, assuming a common trend across sample sites, is:

$$\hat{y}_{ij} = \beta_0 + \beta_{1j} + \varepsilon_{ij}$$

where,

β_1 estimates trend

$\beta_0 + \beta_1(t+1)/2$ estimates 'status'

The null and alternative hypotheses of interest are, respectively: H_0: E[β_1] = 0; H_a: E[β_1] $\neq$ 0. That is, to detect trend we test the null hypothesis that no trend is present in the indicator (delta smelt abundance or a proxy measure) against the alternative hypothesis that a trend is present. The ability of a monitoring program to detect trend when it is truly present is referred to as its statistical power.

The best source of information for a component of variance analysis is from preliminary survey data, which for delta smelt is available for the SMSCGs project area. Those preliminary data also provide information essential for sample-size calculations and determination of an optimal sampling design.

Using design-based monitoring

Background on design- and model-based monitoring

There are two broad categories of environmental monitoring programs—design-based and model-based. Both require that the target population and the sample frame be clearly defined to avoid the potential for confounding perceived project effects arising from changing frame errors. Programs that use design-based inference use the selection probabilities of the sample units to calculate an estimate for the statistical population and provide estimates of uncertainty. In contrast, programs that use model-based inference assume an a priori statistical model for the distribution of indicator values and do not require a probability based sample design. The following discussion develops this distinction further.

In a designed-based view, the observable value (Z) for the indicator attribute at each sample site *i* (or Z_i) is a fixed quantity. In this case it could be the index of delta smelt abundance. Any probabilistic process that may have produced Z_i is unknown and irrelevant. The probabilistic component of the data arises from the sample design itself (i.e., a simple random sample with equal probability of inclusion for each sample unit).

In contrast, in a model-based view, Z_i is a random variable—a random realization from a statistical model, such as a normal, with mean μ and variance σ^2. The values Z_1, Z_2, …, Z_N at any time t are just one outcome of many possible outcomes under the statistical model. Under this model, the sample design that provides the data is irrelevant.

In the design-based view, if the goal is to estimate the population mean, then we simply compute:

$$\hat{\bar{Z}} = \frac{1}{n}\sum_{i=1}^{n} Z_i$$

Even if the entire population, N, had been sampled and the mean was based on a census, the estimate provides no insights to μ since we have observed only one realization from the statistical distribution. Generally, n << N, there is uncertainty about both the realized mean (due to sampling variance) and the parameters of the statistical model that generated the Z's.

In contrast to a design-based approach, if we use a model-based approach and re-compute the mean, as above, from the sample of size n (where the sample design is irrelevant) then the expected value of the sample mean is:

$$E\left[\hat{\bar{Z}}\right] = \mu$$

Designed-based inference makes three assumptions: 1) the values, Z_i, that are measured at each sample unit are fixed quantities; 2) the only source of error in the population estimate is due to sampling variation -- that is, no distributional assumptions are made about the data; and 3) all values are measured perfectly.

In contrast to designed-based, model-based inference assumes: 1) there is some statistical process that generated the observed data—the super-population model; 2) we have an approximating model—that is, an a priori hypothesis that we can translate into a well-defined model; 3) our approximating models lies close to truth. In general, analyses for model-based programs are considerably more complex than for design-based programs.

Many environmental attributes, including species abundances and densities, are likely generated by dynamic processes. Because of their inherent dynamics, measured indicator values have two sources of uncertainty — uncertainty arising from the sampling process and uncertainty about the underlying statistical processes that generate the observed values. Thus, model-based designs may seem most appropriate because they better characterize the generating process for the indicator values. However, based on our knowledge of environmental monitoring programs, design-based approaches are most common. The primary reason is that there seldom is sufficient knowledge of the system to develop a strong a priori hypothesis about the statistical generating model for the data. The generating process is likely to be extremely complex due to the complexity of natural systems, particularly those in human-modified systems disturbed by human drivers. It is usually difficult to identify all of the un-modeled (and unknown) environmental factors that affect the assumed statistical model for the data.

In practice, many environmental monitoring programs are a hybrid of design-based and model-based components. For example, in wildlife and fishery studies, estimating the abundance, and temporal trend in abundance, of a harvested species is a common objective (Pollock et al. 2002). In this case, abundance in sample unit *i* is most often assumed to be fixed during the survey period (designed-based), but it is recognized that abundance is estimated with error. As a result, an observation model is adopted to model uncertainty in the measurement process. This model estimates the probability of detection, *p*, conditioned on the animal's presence in the sample unit.

Based on the number of animals counted in a sample unit (C_i), the adjusted estimate of abundance is then given by: $\hat{N}_i = \frac{C_i}{\hat{p}}$

We find the above estimate of abundance, adjusted for imperfect detectability, to be highly relevant to estimates of the abundances of delta smelt, because fish capture (catchability) is a function of fish size. Unbiased estimates of delta smelt abundance will require estimates of $\hat{p}$.

Inference to the target population

The goal of environmental monitoring programs is to make inference to the status and trend of the entire target population based on a sample of that population. Making inference to indicators values at un-sampled locations is inherently a model-based task. If the program for indicator estimation is model-based to begin with, then extrapolation from the sample data to un-sampled locations is more direct than for designed-based programs.

Because design-based monitoring is grounded in a random sample design, wherein all potential sampling units have a non-zero inclusion probability, inferences can be made to the entire sample frame. However, this extrapolation is not spatially explicit — that is, it does not allow prediction at the scale of un-surveyed sample units. However, extrapolation to this scale can be accomplished by measuring one or more covariates at the sample locations. This is followed by estimating a statistical model that relates spatial variation in the indicator values (such as an index of delta smelt abundance) — for example, by means of multiple regression — to the covariates. Prior knowledge, or measurement, of the covariate values at the un-sampled locations allows one to predict (with uncertainty) indicators values throughout the study area.

A designed-based approach

Below, we outline design-based approaches to monitoring. This is because the questions addressed in the salinity gate experiments concern current (actual) status and trend in delta smelt populations over time and space—descriptions of sample data. Concerns about future dynamics are not based on a specific causal model of the Bay Delta ecosystem but on the assumption that delta smelt population trends result from human activity and management decisions. This design is consistent with the ongoing CDFW delta smelt-monitoring program and the methods proposed by the USFWS (Newman 2008).

Sampling design

A major design decision is the selection of sampling times and sites. All monitoring programs have goals that require linking observations taken at different times or sites into summary statistics, such as means or trends, which can help determine management actions. In addition, measurements must be taken so as to allow a measure of the reliability of these estimates. In a design-based approach, sample units are selected using a spatially random process. Sites where the indicator value(s) is measured can be referenced in space and time as Z(s, t). The full set of Z(s, t) values is assumed fixed though unknown. Uncertainty in the estimate of $\overline{Z}$, for example, depends on the variation of the full set of Z(s, t) values, and the chance associated with the random (s, t) selection.

We usually don't know the spatial and temporal components of variance, σ_{Site}^2 or σ_{Time}^2 (or σ_{Int}^2). However, we will have some management objective that prioritizes one over the other. For example, we expect abundance of delta smelt to vary by mesohabitat type so that we may want habitat specific estimates of abundance and trend. On average, Z values will differ less between sites that are closer together, so the region can be divided into strata and an appropriate number of sites randomly selected from each stratum. In addition, we may want sites within strata to be as independent as possible. So, we may use a spatially balanced design to select sample locations, such as generalized random-tessellation stratified (GRTS; Stevens and Olsen 2004).

General principles of simple and stratified random sampling

Assume that the control and treatment areas (in this case the area inside and outside of the salinity gates) have been partitioned into many potential sample units. To estimate the abundance of delta smelt over the entire area, we first draw a random sample of *n* units. These *n* units comprise the sample. If we took another sample of size n for comparison, we would select another random sample. Hypothetically repeating this process hundreds of times, the variation in the mean number of fish per unit would demonstrate the concept of sampling variation.

We define the following terms:

N = total number of units in the whole population

n = number of units in the sample

y_i = the particular observed value in unit i

μ = population mean = the average number of individuals in a unit taken from the total number of units N in the whole population (**parameter**)

$\overline{y}$ = sample mean = average number of individuals in a unit taken from a sample = estimate of population mean (**estimator**)

T = population total = true total number of individuals in population (**parameter**)

$\hat{T}$ = estimate of population total (**estimator**)

$\sigma^2 = \text{var}(y_i)$ = true population variance of all the y_i (**parameter**)

$\sigma = \sqrt{\text{var}(y_i)}$ = true population standard deviation of all the y_i (**parameter**)

$s^2 = \hat{\text{var}}(y_i)$ = estimate of the population variance of all the y_i (**estimator**)

$s = \sqrt{\hat{\text{var}}(y_i)}$ = estimate of the standard deviation of all the y_i (**estimator**)

To assess the precision of our estimates ($\overline{y}$ and $\hat{T}$) we use the following:

$\hat{SE}(\overline{y}) = \sqrt{\hat{\text{var}}(\overline{y})} = \sqrt{s^2/n}$ = Standard error of the mean

$\hat{SE}(\hat{T}) = \sqrt{\hat{\text{var}}(\hat{T})}$ = Standard error of the total

Simple random sampling

With simple random sampling, *n* units are selected from the entire area with each unit having an equal probability of being included in the sample.

An estimate of the population mean is simply the average of the observed counts (y_i) in each of the selected quadrats:

$$\overline{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$$

Where, s^2 is calculated with the usual variance equation,

$$s^2 = \frac{1}{n-1}\sum (y_i - \bar{y})^2$$

An estimate of the variance of the sample mean is calculated with the following equation:

$$\hat{\text{var}}(\bar{y}) = \frac{N-n}{N} \cdot \frac{s^2}{n}$$

Note: $\frac{N-n}{N}$ is called the finite population correction, which is used to adjust the variance estimate in cases where the total population is small (i.e. n is a small portion of N).

Normally, we are interested in the square root of the variance, the standard error of the mean:

$$\hat{S}E(\bar{y}) = \sqrt{\hat{\text{var}}(\bar{y})}$$

Estimating the population total:

$$\hat{T} = N \cdot \bar{y}$$

With associated variance given by,

$$\hat{\text{var}}(\hat{T}) = N^2 \cdot \hat{\text{var}}(\bar{y})$$

$$\hat{S}E(\hat{T}) = \sqrt{\hat{\text{var}}(\hat{T})}$$

A measure of the confidence we have in the precision (1-α = 0.95) of our estimate is given by the confidence interval:

Population total: $UCL = \hat{T} + 1.96 \cdot SE(\hat{T})$ and $LCL = \hat{T} - 1.96 \cdot SE(\hat{T})$

Stratified random sampling

With stratified random sampling, the study area is divided into two or more spatial strata based on the expected value of the parameter being estimated. For example, we are estimating the abundance of a species that differentially utilizes a variety of different habitat types; we then want to stratify based on habitat type. Our a priori expectation is that abundance will be more similar in two sample units drawn at random from the same stratum then if selected from different strata. Each stratum then becomes a “mini-study-area" of its own, with a sample size that may or may not be the same as that chosen for the other strata.

We define the following terms:

L = total number of strata

N_h = total number of units in stratum h

N = total number of units in the study area: $N = \sum_{h=1}^{L} N_h$

n_h = number of units sampled from stratum h

$\overline{y}_h$ = mean # animals per unit in stratum h

$s_h^2 =$ variance in mean number of animals per quadrat in stratum h

An estimate of the mean number of animals per sample unit (stratified sample):

$$\overline{y}_{st} = \frac{1}{N}\sum_{h=1}^{L} N_h \overline{y}_h$$

An estimate of the variance of the mean number of animals per sample unit is given by:

$$\text{var}(\overline{y}_{st}) = \frac{1}{N^2}\sum_{h=1}^{L} N_h^2 \left(\frac{N_h - n_h}{N_h}\right)\left(\frac{s_h^2}{n_h}\right)$$

Estimating the population total:

An estimate of the population total (T) is obtained by adding the individual population total estimates for all the strata,

$$\hat{T} = \sum_{h=1}^{L} N_h \overline{y}_h$$

With associated variance given by:

$$\hat{\text{var}}(\hat{T}) = \sum N_h (N_h - n_h) \cdot \frac{s_h{}^2}{n_h}$$

$$\hat{S}E(\hat{T}) = \sqrt{\hat{\text{var}}(\hat{T})}$$

A measure of the confidence (1-α = 0.95) we have in the precision of our estimate is given,

$$UCL = \hat{T} + 1.96 \cdot SE(\hat{T}) \text{ and } LCL = \hat{T} - 1.96 \cdot SE(\hat{T})$$

Response variable selection: Using catch per unit effort (CPUE) data

There is a long history of surveying for (sampling) delta smelt throughout the Bay-Delta ecosystem with samples taken multiple times per year. The FMWT survey, for example, primarily focuses on estimating catch per unit effort as an index of delta smelt abundance. The assumption is that changes in the CPUE index, before and after treatment experiments, will reflect the response of delta smelt the population to manipulation of the gates.

CPUE is generically defined as,

$$C_t = qEN_t$$

$$\frac{C_t}{E} = qN_t = CPUE_t$$

Where, $C_t =$ the number of fish caught during sampling occasion t

$N_t =$ true unknown population abundance at time t

$E =$ effort (volume of water sampled and assumed constant over time)
$q =$ catchability (probability that a fish exposed to the sample device is caught)

Because catch is the product of abundance and catchability, trends in CPUE over time can reflect changes in abundance, catchability, or both. Unfortunately, the relationship of the $CPUE_t$ index to the true population size N_t is unknown, because catchability (*q*) is generally not estimated in the delta smelt monitoring program. In addition, *q* is expected to vary with the size of individual delta smelt (by fish length), by the mesh size of the sampling gear, and across time and space (give the distinct characteristics of meso-habitat types and seasonal uses of them by delta smelt). We believe this is a significant data limitation that needs to be addressed to make reliable inferences to delta smelt status and trend, and to make better use the CPUE data; for example, to derive estimates of unknown parameters for a population model. That data limitation, and how it can be addressed, is discussed below.

Example: Including catchability in the CPUE metric using simple random sampling

To illustrate how catchability, q, can be incorporated into estimates of abundance (and total population size), we simplify the above discussion by assuming that the trawl surveys are carried out with constant effort so that the area or volume in each sample is equal. In addition, we suppose that we are referring to a single meso-habitat type. In this case, we define the following variables,

N = total number of sample units in a given meso-habitat type
n = number of units selected at random from N
C_i = true number of fish in sample unit i
c_i = the number of fish caught in sample unit i
$\tau = \sum_{i=1}^{N} C_i$ = total population size in a given meso-habitat type
q = catchability (detection) probability in a given meso-habitat type
$\hat{C}_i = c_i / q$ = estimate of the number of fish actually in sample i

In this case, c_i is a binomial random variable with expected value $E(c_i) = C_1 / q$. With a simple random sample of n units, and $\overline{c} =$ the mean counts across all n samples, an estimator of the population total is

$$\hat{\tau} = N\frac{\overline{c}}{q}, \text{ with variance, } \operatorname{var}(\hat{\tau}) = N^2\left[\left(\frac{N-n}{n}\right)\frac{s^2}{q^2 n} + \left(\frac{1-q}{q^2 N}\right)\overline{c}\right]$$

With s^2 = the sample variance of the observed c_i-values.

For further reading, see Thompson (2012, pages 219-220).

Assessing treatment effects

Assessing the effects of the treatment – the experimental manipulation of the salinity gates – requires a careful research design. The critical components of true experiments include: 1) impact and control sites, 2) a random selection of sample units in both impact and control locations, and 3) replication to adequately estimate variance components and to have sufficient statistical power to detect a treatment effect. A note on the use of terminology; the term “treatment” is inclusive and refers to whether a site experiences a Control environment or an Impact environment. “Period” or “time” refers to samples taken either before or after the experimental treatment.

The discussion below is a broad overview of the experimental design components we believe are best suited to the proposed gate operation experiments. Our discussion cannot be comprehensive—essential computation details are not included. The details of the design, its implementation and subsequent analysis, will require consultation with a professional statistician (perhaps with members of the Newman-Polansky team at FWS). A recommended set of readings on the details of design and analysis of the experimental data can be found in Underwood (1993, 1994, 1996) and Stewart-Oaten (1996a, 1996b), and Stewart-Oaten and Bence (2001).

We recommend that assessment of the environmental impacts of the salinity gates experiments be evaluated using a Before-After-Control-Impact (BACI) design (Stewart-Oaten 1996a, 1996b, Underwood 1993, 1994). In this design, measurements are taken at the impacted site(s) and at the control site(s) both before and after the experiment occurs. If this design is feasible, it will provide more reliable insights than a simple Before-After comparison of sample sites solely within Montezuma Slough and Suisun Marsh. It is more reliable to have control sites because a change in the response variables may occur independently of any experimental manipulation because of temporal effects—that is, changes may have occurred over time unrelated to the experiment. For example, salinity levels may change between the before and after periods and the response may be related to natural changes in flow rather than changes due to gate manipulation.

By establishing one or more control sites (where presumably no effect of an experiment will be experienced), the temporal change that occurs in the absence of the impact can be measured. As a result, the observed change in the difference in delta smelt CPUE, for example, over time is evidence of an environmental impact. In the following, we focus on changes in the mean value of candidate response variables (CPUE, salinity, turbidity, etc.) for the most part using CPUE as the example response variable.

In the discussion below, we assume that the data consist of estimated abundances (from net hauls) of delta smelt taken at a set of times Before the experiment and at another set of times After in the experimental location (Montezuma Slough) and at (a set of) control sites not affected by the experiment. We recognize that delta smelt abundance will not be the only response variable of interest. However, the BACI design outlined below should be widely applicable to other response variables (including food and predators).

The designs discussed below largely rely on differences among means—here the mean difference-in-the difference in delta smelt abundance between Before and After periods. Tests for differences among means are most common in these designs. However, other parameters could be chosen. For example, the amplitude of population fluctuations might be important and tests could be conducted on the equality of variances, Before versus After (Underwood 1991).

A key assumption of BACI designs is that the system is in a dynamic equilibrium before and after the impact and that response to the impact is rapid. This assumption is illustrated in Figure 16 (based on Schwartz 2015).

It is expected that opening the salinity gates will result in system change. As discussed previously, a key aspect of the experimental study to address early on is the magnitude of change (effect size) to be detected. That is, what magnitude of change in any of the response variables is deemed to be biologically significant to delta smelt? Note that this a biological, not statistical, decision but one with high relevance to the design of the study. A final caveat is relevant: drawing inferences from the results of BACI designs must be done carefully. The reason is that the impact sites are not chosen at random and, as a result, these are not true experiments.

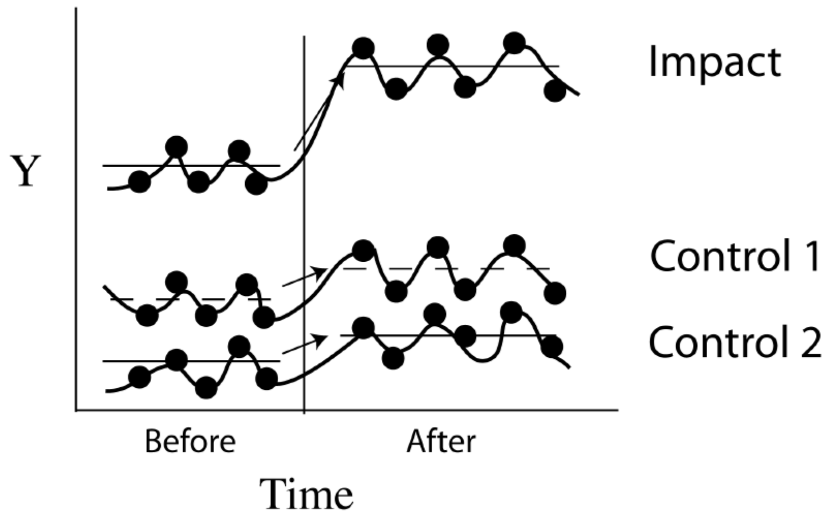

Figure 16 -- *Example before-after, control-intervention (BACI) experimental design, from Schwarz (2015).*

Measurements of any of the possible response variables of interest (e.g., delta smelt abundance, salinity, turbidity, smelt prey abundance, etc.) will be characterized by two broad sources of variation over time—temporal and spatial. At any point in time, spatial variation occurs at two levels—between impact and control areas, and within each of these areas. Spatial variation at a given point in time, within the impact and control areas, is estimated by sampling multiple sample units. These measures are subject to sampling variation—variation arising from taking a random sample of the populations of interest with an attempt to minimize measurement error.

Non-BACI design

For discussion, we initially consider a non-BACI design that lacks control sample locations. In this design, "effect" of the experimental treatment (opening the salinity gates) is the difference between smelt abundance at the experimental site(s) after the experiment relative to what it would have been in the absence of the experiment. In this scenario, we assume that multiple sites (spatial replicates) are sampled at multiple times both before and after experimental manipulation of the salinity gates. If sample locations are selected according to some type of random selection (that is, a spatially balanced sample), inference can be made to the entire experimental area. However, because opening the gates is likely to create a gradient in the value of many (possibly even all) response variables along a linear gradient running the length of Montezuma Slough and into the upper Suisun Marsh, an a priori stratification of the affected area is necessary. In this case, a random selection of sites within each stratum will be required.

In general, designs involving multiple sample times are most efficient if samples are taken at pre-determined times with equal temporal spacing between samples (to increase precision -- see Stewart-Oaten and Bence 2001). At each sample time, spatial replicates are needed to get reliable estimates of the mean values of the response variables and the spatial variation among replicates. However, a limiting feature in this design is the number of temporal replicates before and after impact. Before and after comparisons are often based on mean values because repeated measures of the same sample units over time are pseudo-replicates, and cannot be treated as independent observations (Hurlbert 1984).

In a simple example (Figure 17), we have three sample periods before and three after opening the flood gates. At each time period, three trawl samples are taken and a mean count of delta smelt is computed for each tine period across the three trawls (averaging over the pseudo-replicates). There will be a total of six means, three before and three after. In this case, the before and after periods can be compared with a two-sample t-test assuming either equal or unequal variances. The estimated difference in the means between the two periods is of most interest. The null hypothesis being tested is that the mean abundance before (B) treatment is equal to the mean Effect size can be estimated by a multiple comparison test procedure and a confidence interval computed for the effect size to see if it includes zero. An effect size confidence interval that does not include zero suggests a significant treatment effect.

There are two sources of variation in this experiment. First is the temporal variation among sample times. Second is the spatial (residual) variation among sample units within a time period. The spatial component of variation can be reduced by gathering more samples within each individual time period. However, having more spatial replicates has no impact on the time-to-time random variation.

The above, non-BACI design can be expanded to include replicate Before and After locations (Figure 18). Having multiple before and after replicates will greatly increase the ability to detect any treatment effects arising from opening the salinity gates. Averages are taken across the pseudo- replicates measured in each combination of time by Before (and After) replicate. The diagram in Figure 19 illustrates the simple case of two Before and two After replicates but these can be increased to any number. In this design, the count in pseudo-replicate i is nested within abundance after (A) treatment: $H_0 : \overline{x}_B = \overline{x}_A$. time j, time is nested within replicate (1 or 2), and replicate is nested within period (before or after). As before, period represents the difference in the mean count before and after opening of the salinity gates.

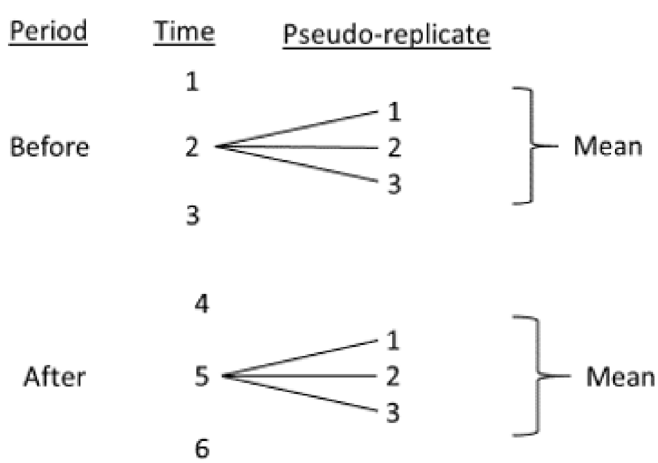

Figure 17 -- *Example design for a Before-After experiment lacking control plots. In this example, samples are taken three times Before impact and three times After impact. At each time of sampling, there are three spatial replicates.*

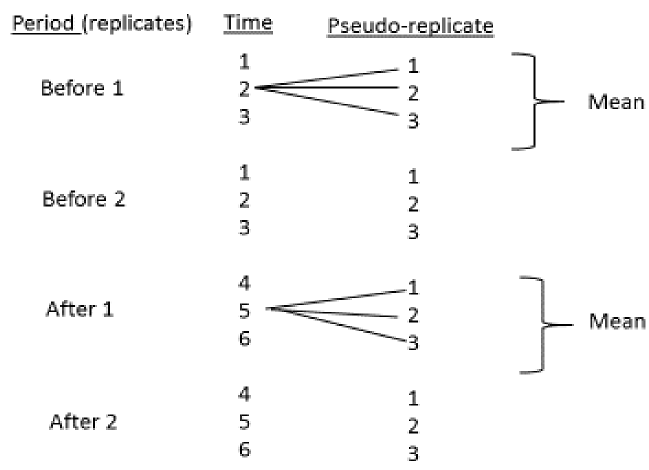

Figure 18 -- *Non-BACI design with replicate Before and After samples. In this example, samples are taken three times Before impact at two locations and three times After impact at two locations. At each time of sampling, there are three spatial replicates.*

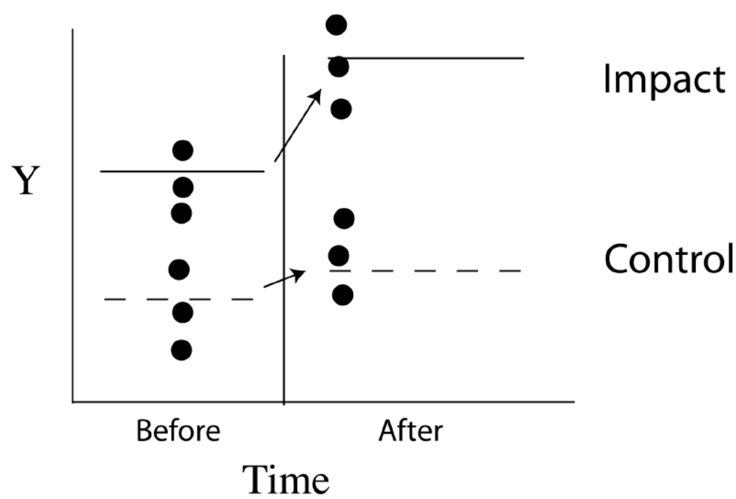

Figure 19 -- *Simple BACI design. Dots represent spatial replicate samples Before and After opening of the flood gates. Figure reproduced from Schwarz (2015).*

The analysis of data derived from this experimental design is readily understood. For example, if the analyses estimate mean delta smelt abundance (and related covariates) at the experiment site from the Before data (E_B) and again from the After data (E_A), the experimental effect is estimated by the difference between these two estimates ($E_B - E_A$) using a t-test. The main concern is the possibility of strong temporal correlations in the time series, which would introduce a bias into the hypothesis tests (Bence et al. 1996). The usual approach to test for first-order autocorrelation is to compute the Durbin-Watson statistic.

There are four sources of variation in a salinity-gates-operations experiment, and not all are separable when the analysis is done using counts averaged across trawls within a time period. First, is time-to-time variation, which may represent movement of fish among sample units arising from unknown random effects. Second, replicate-to-replicate variation, which may reflect spatial variation within Montezuma Slough and Suisun Marsh. Third, is replicate-time interaction, where the replicates may show different trends across time. Fourth, is trawl-to-trawl (sample-to-sample) variation, which measures the variation in the count over different areas of the sample frame. Unfortunately, when time averages are analyzed, the last two variance components cannot be separated.

BACI design including control sites: One time before and one time after

We now introduce one or more control sites not exposed to the effects of opening the salinity gates. The simplest BACI design is where there is just one period of measurement before the gates are open and one period after opening (Figure 20). Evidence of a treatment effect is a non-parallel response over time between the control and treatment sites in terms of the response variable (e.g., delta smelt CPUE). BACI control sites are not experimental controls in the usual sense of experimental designs (Stewart-Oaten and Bence 2001). They do not need to be chosen randomly. In fact, they should be deliberately chosen so as to be as similar as possible to the treatment sites in all regards except for exposure to the treatment. Control sites should share common sources of temporal variation with the impact sites (Stewart-Oaten and Bence 2001).

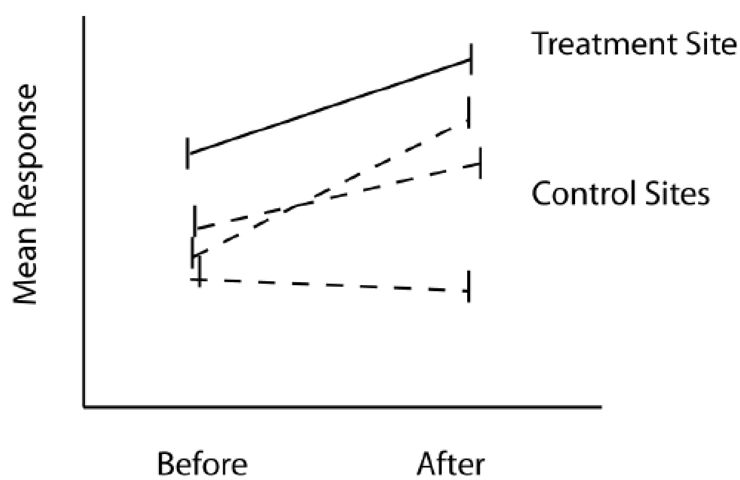

Figure 20 -- *Conceptual diagram of a BACI design with multiple control sites. Figure reproduced from Schwarz (2015).*

With both control (C) and impact (treatment, T) sites, effect size has a specific interpretation. Effect size is the mean estimated effect calculated from difference between the average Before (B) and After (A) mean differences (Bence et al. 1996):

$$\text{BACI effect} = (\mu_{CA} - \mu_{CB}) - (\mu_{TA} - \mu_{TB})$$

In general, for BACI designs two issues must be considered before selection of the sample units. First, sample units should be far enough apart that they can be considered independent. Second, in some cases it may be important that no sample unit is measured repeatedly over time. For example, units measured only before or after impact may be needed to provide variance components necessary for some hypothesis tests (Schwartz, 2015). In addition, the BACI models discussed here implicitly assume that both locations (Control and Impact) are being measured at the same time. This may not always be logistically feasible. In these cases, more complex designs are needed (see Underwood 1991, 1992).

If separate sample units are measured in the two periods, this analysis is a straightforward two-way ANOVA, also called a two-factor completely randomized design. One factor is treatment—that is, sample sites located within Montezuma Slough and affected by operation of the gates (impact sites) and sites not affected by gate operation (control sites). The second factor is period, Before or After gate operation. The hypothesis of interest is whether there is a significant interaction between period (Before vs After) and treatment (Impact vs Control). H_0: No significant time*treatment interaction. The model fit to the response variable (Y) is:

Y = Treatment + Time + Treatment*Time,

where, Treatment = either the control or impact site, Time = before or after impact, and Treatment*Time measures the BACI effect.

This design has some significant limitations, primary in terms of the scale of inference. The spatial replicates in treatment and control sites are likely to be pseudo-replicates and inference is restricted to the specific set of control and treatments sites. Also, there is only one time period of measurement, one set of measurements before and one after the experiment. Given these limitations, broader inferences to treatment effects are not justified.

An obvious extension to the single control-site design is to include multiple control sites. It is unlikely that a single control sites will reflect the true spatial variation in the response variable that occurs outside of the area affected by operation of the salinity gates. This is particularly true given that spatial replicates at a single site are probably pseudo-replicates. In addition, having multiple control sites makes it less likely that any observed differences between control and impact sites are a result of the specific control site chosen.

Similar to previous designs, in this design the analysis is based on partitioning the variation in the data attributable to different sources: period (Before vs After), treatment vs control, site-to-site variation within the multiple control sites, site by period interactions, and trawl-to-trawl variation. After a more complex set of variance partitioning steps than in previous designs, the null hypothesis test comes down to that in simpler designs—that is, is the mean difference between before and after periods in the fish count metric, for example, the same for control and treatment groups. This is analogous to a two-sample t-test.

BACI design: Multiple times before and after

Expanding the BACI design to include multiple time periods before and after a salinity gate action (experiment) allows one to detect more nuanced responses to the experimental treatment. For example, it may be that the response to opening the flood gates is characterized by a time-lag --that is, significant changes in the response variables do not occur until the systems has been exposed to the environmental change for some period of time. The converse may also be true --an initial strong rapid response that is attenuated over time.

The general form of the design is shown in Figure 21 for the case of one treatment site and one control site. In this example, there is variation attributable to spatial variation at a given sample time (two spatial replicates illustrated), time-to-time variation in both before and after periods at both treatment and control sites, and evidence of a site (treatment or control) by time (Before or After) interaction. These various sources of variation are illustrated in Figure 22.

As for many BACI designs, there are multiple ways to analyze these data. Many of these designs are easily understood as analogous to two-sample t-tests; however, the analyses, and variance components calculations, can be quite complex and will require collaboration with a statistician. For example, assume that samples taken at control and experimental sites are paired in time, and for each time period the difference in the response variable between the paired samples are calculated. If there are multiple control sites, the control component of the differences can be averaged first. These differences are computed separately for the Before and After periods. The null hypothesis that the mean differences are equal before and after the experiment can be tested against the alternative hypothesis that they are not equal. Rejection of the null leads to the conclusion of a significant experimental effect.

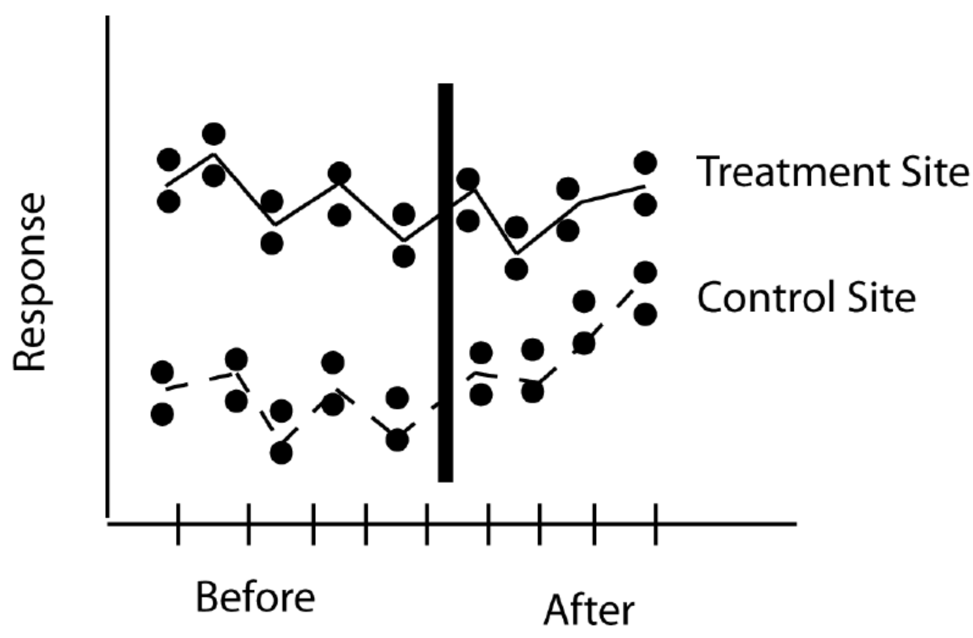

Figure 21 -- *Conceptual diagram of a BACI design with multiple measurements before and after the experiment with single treatment and control sites. Figure reproduced from Schwarz (2015).*

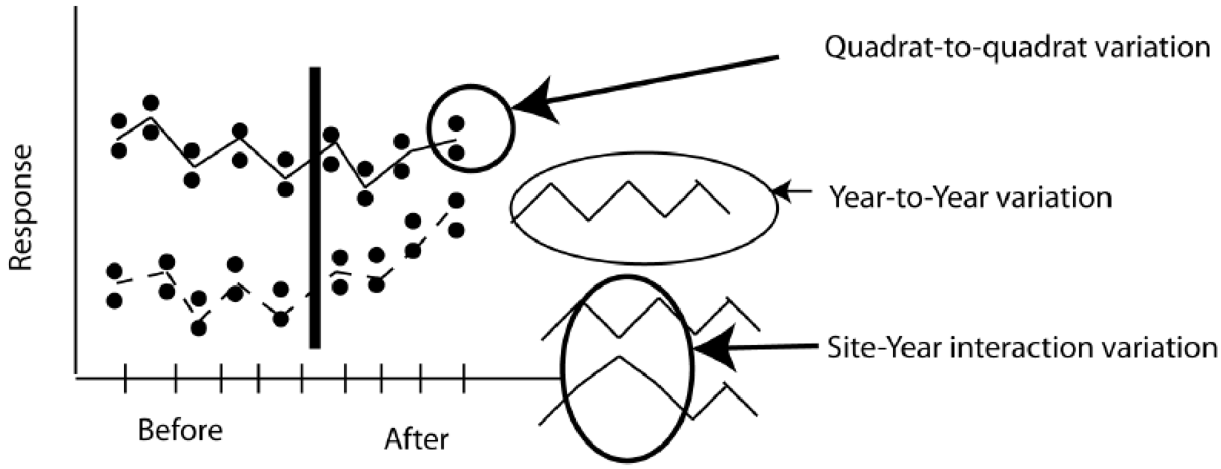

Figure 22 -- *Conceptual diagram of a BACI design with multiple measurements Before and After the experiment with single treatment and control sites. The figure illustrates the sources of variation (variance components) in the experiment. Figure reproduced from Schwarz (2015).*

An example BACI design

There are many possible BACI designs involving various combinations of control and impact sites, number of time periods before and after impact, and number of replicate samples taken at each site (control or impact) by time combination. An example design (Schwartz 2015) is shown in Figure 23. Note that the number of sample units does not have to be equal across impact and control areas, and the number of time periods before and after do not have to equal.

Gradient BACI design

BACI designs can be extended to include “gradient" effects where there may be multiple impact locations. In this case, it is necessary to model the effect at a site as a function of its distance from the experimental treatment. This design may be applicable to the effects of the salinity gates experiments where the magnitude of the response in delta smelt abundance, salinity, or turbidity (for examples) may vary as a function of distance from the gates. This design change may be accompanied by difficult modeling problems arising from spatial and temporal correlation in treatment effects.

However, establishing a series of sites at varying distances from the control gates should reveal important insights in terms of environmental factors that affect delta smelt abundance and vary as a function of distance from the gates. Such sites would not be replicates, but their locations along Montezuma Slough may be important for assessing the scale of the treatment effect and assessing causal relationships. An example application of a BACI design to gradient impacts is found in Ellis and Schneider (1997).

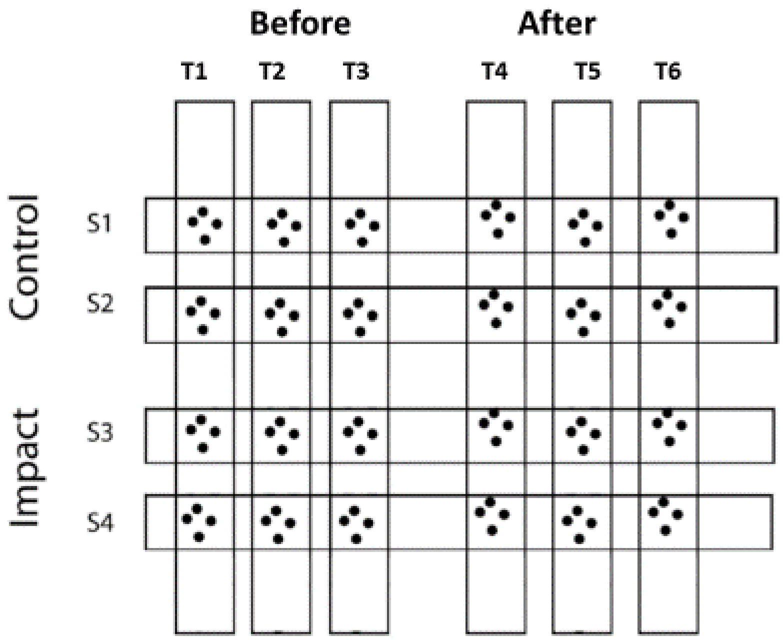

Figure 23 -- *An example of a possible BACI design including two Control and Impact sites, three time periods Before and After the experimental Impact event, and three replicate sample units at each Time by Treatment combination. Figure reproduced from Schwarz (2015).*

BACI power analysis

Deriving an initial estimate of statistical power -- the probability of rejecting the null hypothesis when it is false -- is a key step in designing a BACI experiment. A power analysis is usually needed in order to estimate sample size requirements before implementing the experiment. Sample size can include the number of replicates in each site-by-time combination, the number of control sites, and the number of time periods before and after the treatment. How these are optimally allocated depends on the variance components as discussed above. The calculations can be complex but fortunately software tools are available to aid in these calculations. For example, R package "emon" (Barry and Maxwell 2017) has an easy to use application, given initial estimates of three of the following components:

- The α-level—the probability of failing to reject a false null hypothesis
- Variance components
- Sample size (generally, most important are the number of time periods Before and After treatment)
- The effect size to be detected

The variance components are often the most difficult to estimate *a priori* and may require a pilot study. In BACI designs, these components include site-to-site variance (variance between Control and Impact locations), time-to-time variation, site-by-time interaction variance, and within time-site variation (spatial variance among sample units at a point in time).

3.3 Application to the salinity gates experiments

This section provides our proposed approach to expanding the Enhanced Delta Smelt Monitoring Program to evaluate SMSCGs management hypotheses. We propose nine different management hypotheses and build on the statistical approaches used by Newman (2008) and Polansky et al. (in press) to estimate delta smelt abundance by meso-habitat type. We then discuss methods for estimating catchability, co-variate modeling, and environmental data collection.

Hypotheses to test

Operation of the salinity gates affords an opportunity for adaptive management of delta smelt in a small portion of its range guided by an action that allows several hypotheses with delta-wide management implications to be evaluated. The following hypotheses can be evaluated with strategically placed sampling sites, and a sampling scheme that gathers data on appropriate physical and biotic factors, and delta smelt abundance (CPUE) throughout its habitats in the planning area during summer months.

- H_{01} The abundance of delta smelt differs significantly between adjacent areas of Suisun Marsh and Suisun Bay (adjacent areas outside and inside of the SMSCGs).
- H_{02} Food availability for delta smelt differs significantly between adjacent areas of Suisun Bay and Suisun Marsh.
- H_{03} Manipulation of the SMSCGs, which when open may reduce Suisun Marsh salinities, can directly alter the availability of food and indirectly the abundance of delta smelt in Suisun Marsh.
- H_{04} Salinity determines the spatial-temporal distribution and local abundance of delta smelt in Suisun Marsh.
- H_{05} The site-specific abundance of delta smelt is correlated with species composition and abundance of prey in Suisun Bay and Suisun Marsh.
- H_{06} Food availability and salinity are correlated in Suisun Bay and/or Suisun Marsh.
- H_{07} Food availability is the limiting environmental factor that determines spatial distribution and local abundance of delta smelt in Suisun Marsh.
- H_{08} Some other physical or biotic factor(s) are the limiting factors that determine landscape occupancy by and/or local abundance of delta smelt in Suisun Marsh.
- H_{09} The abundance of delta smelt varies significantly by meso-habitat type.

Reduced salinity in Suisun Marsh helps mitigate the impacts of water projects and may increase habitat availability and habitat quality for delta smelt. When gates are open on the ebb tide, water level is ~0.3 ft greater than 'downstream' water level and flow into the Slough may be as high as ~2,800 cfs. The salinity response to SMSGC operation creates a salinity gradient in the Slough ranging from ~5 SC (near the gates) to ~19 SC (entering Suisun Bay) mmhos/cm. Gate operations also affect the position of the X2 salinity threshold in Suisun Bay.

Methods for estimating delta smelt abundance

Ongoing delta smelt population surveys

Several sample designed-based surveys are conducted each year estimate to estimate pre-adult and adult delta smelt abundance. The Fall Mid-water Trawl (FMWT) survey occurs during September – December each year at a set of fixed stations. It began in 1967 and, until recently, was the primary survey used to assess delta smelt abundance and trend. The Summer Tow-net (STN) trawl survey begins in June and runs into August using a fixed station design. This survey samples age 0 and age 1+ fish. Many or all of the stations in the STN are the same as stations used in the FMWT. The 20mm Survey is designed to sample for larval and juvenile delta smelt. It generally begins in March and runs into June. The spring Kodiak Trawl (SKT) begins in December-January and runs into April. It is designed to capture adult Delta smelt and provides an estimate of the size of the spawner population. In combination, these four survey types provide abundance estimates for the key life-history stages of delta smelt—larvae, juvenile, age 0 and older fish, and the spawning population. None of the trawl surveys employ gear or sampling procedures that are likely to generate representative samples of delta smelt in the project area inside the SMSCGs.

Estimating delta smelt abundance by meso-habitat type

The following methods section develops sampling and estimation principles that are generally applicable to all the various delta smelt surveys. The methods discussed closely parallel those developed by Newman (2008) for the FMWT surveys and Polansky et al. (in press) for SKT surveys.

Definition of terms:

i denotes meso-habitat type, $i = 1, 2, \ldots, k$

j denotes seine haul,

k denotes the number of meso-habitat types

n_i denote the number of seine hauls taken in meso-habitat type i,

v_{ij} denotes the volume (m^3) sampled by haul j in meso-habitat type i,

v_i denotes the total volume sampled in meso-habitat type i

V_i denotes total volume (m^3) of meso-habitat i within the selected study section

E_i denotes effort expended in meso-habitat type i,

C_{ij} denotes the catch of delta smelt in haul j in meso-habitat type i,

C_i denotes the total catch in meso-habitat type i,

q_i denotes "catchability" in meso-habitat type i (probability that a fish present in the area of a seine haul is captured),

D_i denotes density (fish per m^3) of delta smelt in meso-habitat type i,

N_i denotes abundance of delta smelt in meso-habitat type i

The estimators address all delta smelt age classes though age 0 fish are expected to be dominant. Given the above definitions, the total number of delta smelt (N) present in all k mesohabitat types within a selected study section of Montezuma Slough would be

$$N = \sum_{i=1}^{k} D_i V_i$$

and, the densities (fish/m^3) of delta smelt within a selected study section, across all meso-habitat types, would be

$$D = \frac{N}{\sum_{i=1}^{k} V_i} = \frac{\sum_{i=1}^{k} D_i V_i}{\sum_{i=1}^{k} V_i}$$

The expected number of fish caught in tow *j* in meso-habitat type *i* is,

$$C_{ij} = q_i v_{ij} D_i$$

where effort is, $E_{ij} = v_{ij}$ and the proportion of meso-habitat type *i* sampled is, $\gamma_i = v_{ij} / V_i$

The expected total number of fish caught in meso-habitat type *i* is,

$$C_i = \sum_{j}^{n_i} C_{ij}$$

The aggregated catch metric across all *k* meso-habitat types is,

$$C = \frac{\sum_{i}^{k} \sum_{j}^{n_i} C_{ij}}{\sum_{i}^{k} \sum_{j}^{n_i} v_{ij}}$$

The average density estimate in meso-habitat type *i* is,

$$\hat{D}_i = \frac{\sum_{j}^{n_i} C_{ij}}{\sum_{j}^{n_i} v_{ij}}$$

The estimated abundance in meso-habitat type *i* is,

$$\hat{N}_i = \hat{D}_i V_i$$

and, the aggregate abundance estimate across all meso-habitat types is,

$$\hat{N}_{total} = \sum_{i}^{k} \hat{N}_i = \sum_{i}^{k} \hat{D}_i V_i$$

For the expected value of this aggregated CPUE measure to be directly proportional to the true density (or abundance) of delta smelt over the entire selected unit, *as is required for a valid and useful "index"*, the following conditions must be met:

1. Catchability must be identical for all k meso-habitat types (i.e., $q_1 = q_2 = \ldots = q_k = q$), **or** estimated by meso-habitat type; and,
2. The total area seined over the n_i hauls within each meso-habitat type must be the same proportion, γ , of the total area of each meso-habitat type, **or** effort must be estimated by meso-habitat type.

Catchability is a key component of the various delta smelt monitoring programs that has not been consistently estimated. Catchability is expected to vary by gear type, mesh size of trawl nets, behavioral responses to sampling, meso-habitat type, and where in the water column sampling occurs. One key source of sampling bias arises from the interaction of mesh size and fish size. For a given mesh size, catchability is expected to increase rapidly with fish length (see Newman 2008: Figure 3).

A stratified sample design for Montezuma Slough

The distribution of delta smelt populations in the San Francisco Bay Estuary ecosystem is highly heterogeneous in both space and time. A number of distinct meso-habitat types are used by delta smelt, and smelt densities are believed to vary by these type. Key meso-habitat types to consider for sampling (not all of which may occur within Montezuma Slough and Suisun Marsh) include:

- OWS -- Open water in bays and channels, near-surface and light-penetrating zone
- OWB -- Open water in bays and channels, near-bottom and below the light-penetrating zone
- MWS -- Mid-water locations in dead-ended and inter-connected sloughs
- FSW -- Second- and third-order dendritic watercourses feeding channels and sloughs
- SHO -- Shoals and shallow areas, absent submerged aquatic vegetation
- SLZ -- Bathymetrically diverse locations in the sub-littoral zone, including drop-off circumstances from shorelines, shoals, and shallow situations
- FMP -- Seasonally inundated floodplains and marsh plains

One of the key uncertainties regarding delta smelt biology is the degree to which densities vary by meso-habitat type and their relations to the species' life history. Experiments to be conducted in MZ Slough provide an excellent opportunity to tests various competing hypotheses about habitat selection in delta smelt. As a result, we propose that sampling be stratified initially by meso-habitat type. With stratified random sampling, the study area is divided into multiple strata that are subsequently sampled using simple random sampling within each stratum.

Extending the above discussion, we describe design-based, meso-habitat-specific total abundance estimates from CPUE data (see Newman, 2008 and Polansky et al., in press). The design assumes that at least two tows are taken within each meso-habitat (i.e., $n_i \geq 2$) in order to get an estimate of within habitat variance.

$$Var(\hat{N}_i) = \frac{v_i^2 s_i^2}{\left((1/n_i)v_i\right)^2 n_i}$$

where, $s_i^2 = \frac{\sum_j^{n_i}(C_{ij} - \hat{D}_i v_{ij})^2}{n_i - 1}$ is the variance of the count within each mesohabitat type.

The variance estimate for the total abundance is,

$$Var(\hat{N}_{total}) = \sum_{i=1}^{k} Var(\hat{N}_i)$$

Assuming that estimates of $\hat{N}_i$ and $\hat{N}_{total}$ are log-normally distributed, methods to compute confidence intervals for the abundance estimates are described in Polansky et al. (in press).

Identifying meso-habitats and estimating meso-habitat-specific volumes

The abundance estimation methods above are based on volumetric expansions of the density estimates. To apply these methods to multiple meso-habitat strata, estimates are required of the volume of water in each meso-habitat occupied by delta smelt. The first step to acquiring volume estimates is to map the spatial distribution of meso-habitat types within MZ Slough to derive an estimate of area for each meso-habitat. To compute a volume, a second step is required for each meso-habitat type—that is, to specify the depth of water used in each type. Polansky et al. (in press) used a depth of 2 meters but this may not be appropriate for all meso-habitat types, particularly shoal and floodplain habitats.

The seven delta smelt meso-habitats identified above have been mapped across the extent of the Sacramento-San Joaquin Delta and adjacent portions of the eastern San Francisco Estuary; the mapped areas include the project areas affected by operations of the Suisun Marsh Salinity Control Gates (a portion of the full Delta meso-habitats map appears as Figure 24). A preliminary interpretation of the mapped data suggests that five of the seven delta smelt meso-habitats occur inside of the salinity gates (Figure 25 and Figure 26). All seven of the meso-habitats, including two open-water habitats, would be included in a sampling footprint that extends outside of the gates. Note that three meters serves as the lower limit of shoals and shallows, a depth that roughly represents the light-penetrating zone. We recognize that the depth zone is a survey sampling determination, not a designation that will be apparent on our habitat-strata map. Shoals and shallows do not exist where the substrate from the shoreline directly drops through three meters to the bottom. That bathymetric situation is identified as the sub-littoral zone. First- through third-order channels are not designated by width, but by geographic arrangement.

The Newman-Polansky study group is in the early stages of considering how volumes might be calculated for delta-smelt-utilized depths in the water column in the more circumscribed and bathymetrically complex portions of the Delta. Within the project area, it is the sub-littoral zone, determining certain meso-habitat-specific volumes required for unbiased abundance estimates may prove challenging.

Estimating catchability

The importance of estimating catchability to adjust the CPUE index to achieve unbiased estimates of N_t by meso-habitat type is discussed above and in Newman (2008).

Catchability is also relevant to acquiring a more complete understanding of the life history of the delta smelt. Biases introduced by spatial and temporal variation in catchability across meso-habitat types affect estimates of CPUE and undermine the ability to detect treatment effects. For example, using CPUE index values that have not been adjusted for length-dependent catchability can result in erroneous conclusions regarding population structure and dynamics with implications for management (Breton et al. 2013).

Several methods are commonly used to acquire estimates of catchability by meso-habitat type for fishes. These include:

Combining traditional seine-based survey methods with more intensive capture and removal methods (e.g., via electro-shocking). The latter estimates are more accurate (if extensive numbers of removals are made in each unit) and can be used to calibrate the CPUE index methods using ratio estimates. Two variables must be estimated: CPUE based on traditional survey methods and 'true' abundance (N_{True}) based on removal methods.

Conducting gear selectivity studies (see Newman 2008) where traditional seining methods and mesh sizes are augmented by finer mesh seines that presumably sample all fish exposed to the seine (i.e., they are non-selective sampling devices). The latter estimates are more accurate and can be used to calibrate the CPUE index methods. Two variables must be estimated: CPUE based on traditional survey methods and $\hat{N}_{True}$ based on the fine-mesh seine assumed to be non-selective with respect to fish size.

Removal methods

We propose that the challenge of estimating meso-habitat-specific catchabilities can be partially addressed by comparing meso-habitat-specific CPUE (an index of meso-habitat-specific fish density) based on traditional seine surveys to meso-habitat-specific estimates of density based on closed population removal methods. We recognize that removal methods may only be feasible in certain meso-habitat types—that is, those that are shallow or can be effectively electro-shocked. Our recommended approach rests on two critical assumptions. First, we assume that seine catchability, though unknown, is relatively constant within a given meso-habitat type, if sampling in this habitat type is conducted under similar environmental conditions. Second, we assume that the numbers of fish present within enclosures used for removal method estimation are equal to the numbers originally present within the areas of the enclosures so that the removal method estimates of abundance allow approximately unbiased estimation of meso-habitat-specific density. (The second assumption should be rigorously "tested" in a realistic field setting.)

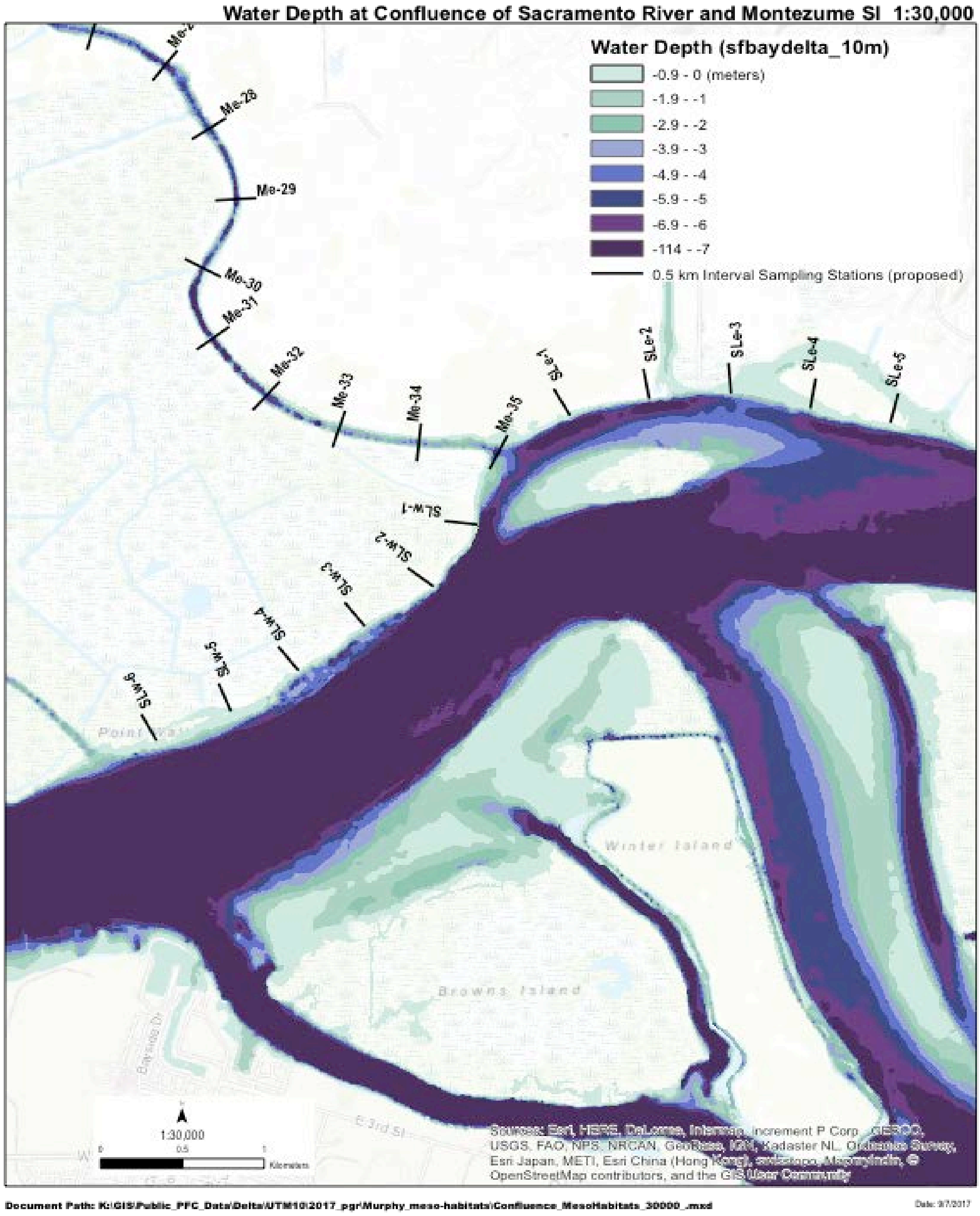

Figure 24 -- *Channel depth and shoreline inclination around the confluence of Montezuma and Nurse sloughs indicate bathymetric heterogeneity that includes multiple delta smelt habitat strata.*

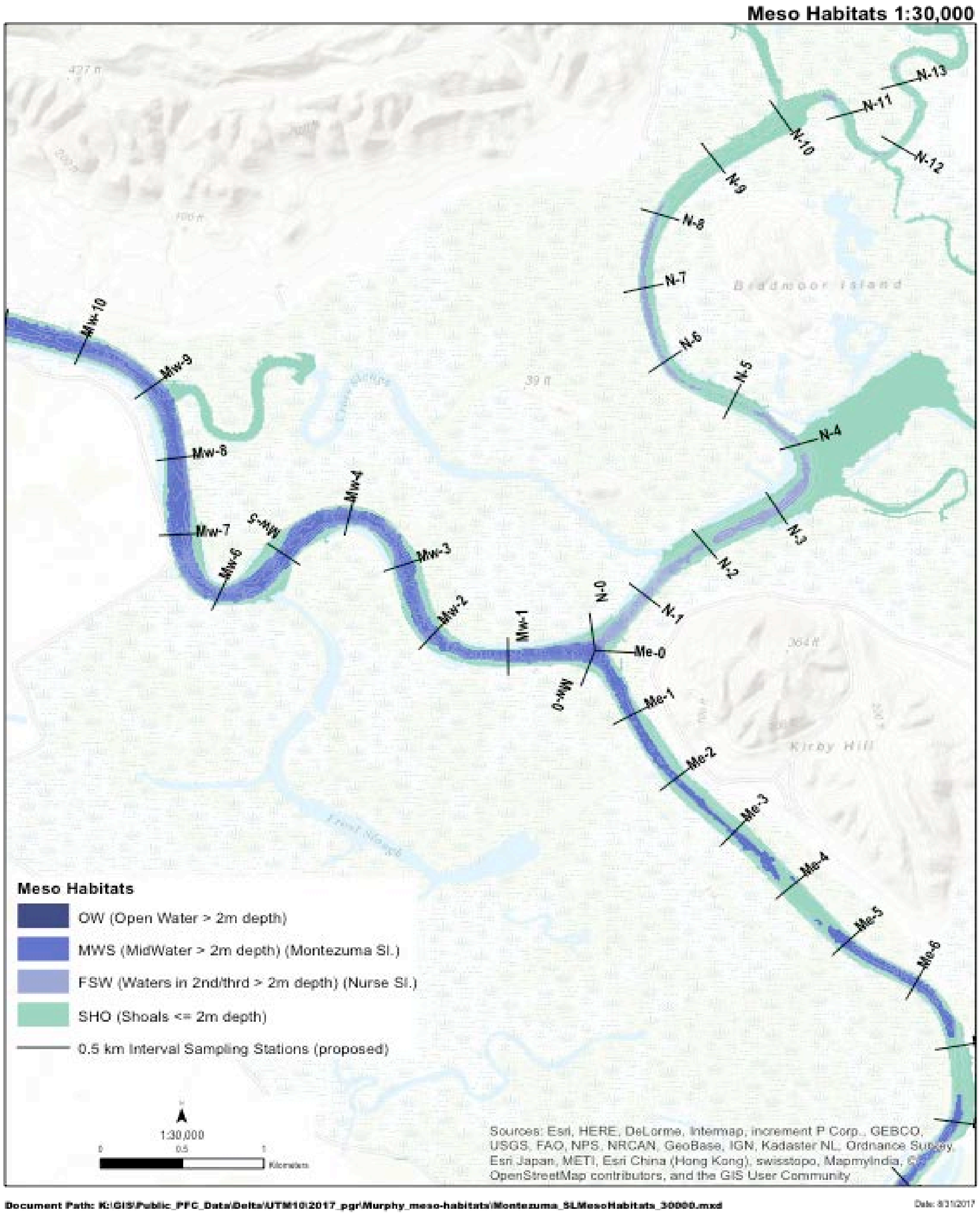

Figure 25 -- *Distribution of three delta smelt meso-habitat types at and around the confluence of Montezuma Slough and Nurse Slough. Potential survey stations at 0.5 kilometers apart appear to offer ample opportunity to sample each of the meso-habitats. The fourth meso-habitat type (open water) is found outside of the Suisun Marsh Salinity Control Gates.*

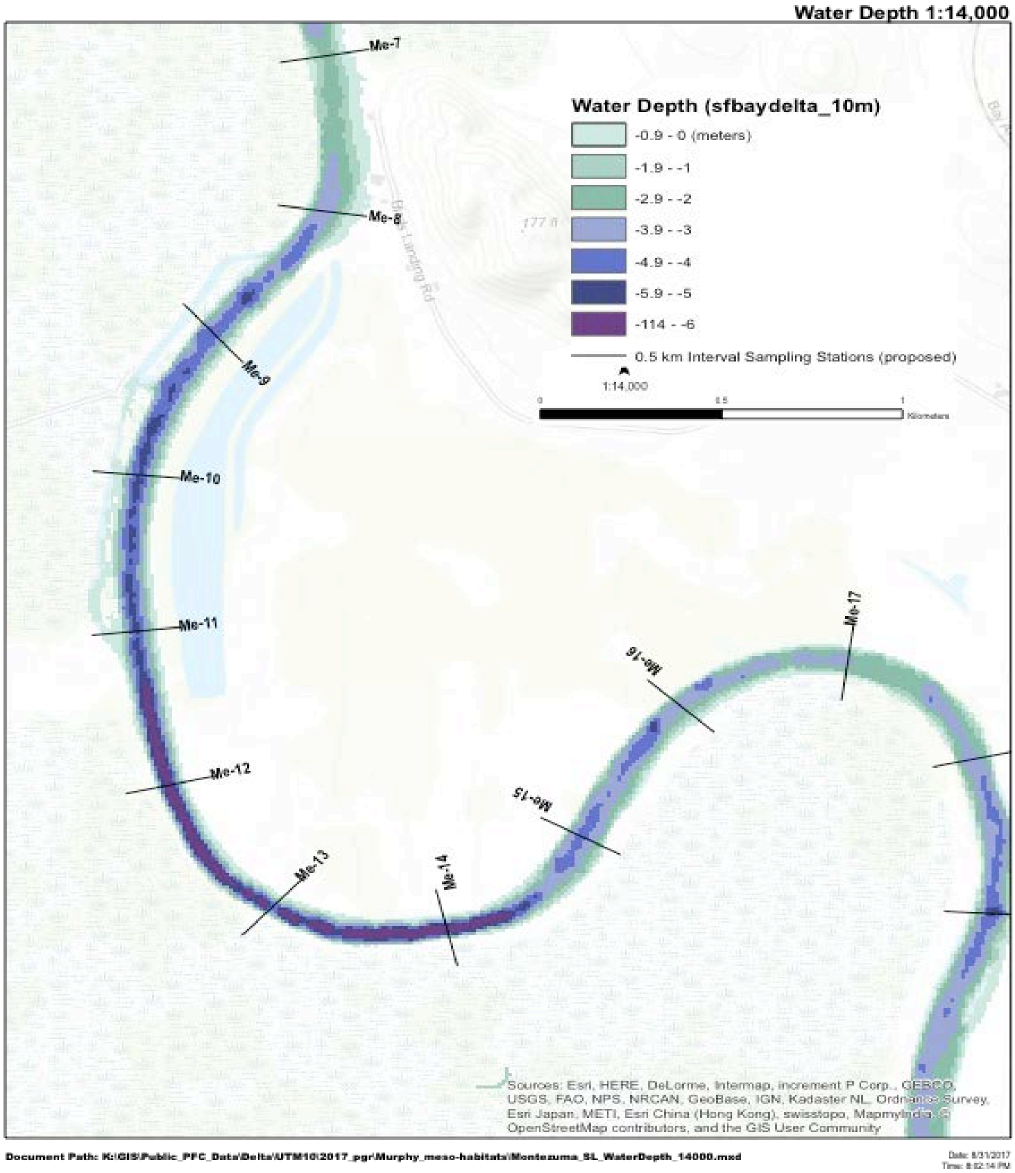

Figure 26 -- *Another reach of Montezuma Slough (a slough increment that includes kilometer 23 – see Figure 17 to place on the Suisun Marsh landscape), showing diversity of depth, shoals, and bathymetric diversity representing multiple delta smelt habitat strata.*

In the population estimation surveys, *n* random locations within a given meso-habitat type (within a primary sampling units) are selected and enclosures are deployed over these selected locations. The abundance of fish within these enclosures is estimated using removal method estimation based on multiple-pass electro-fishing (Zippin 1958, Otis et al. 1978). If estimates of abundance within enclosures are of high accuracy, they can be combined across enclosures within meso-habitat types and then divided by the total volume of all sampled enclosures, thereby generating an estimate of fish density (fish per m^3) in a given meso-habitat type. This estimate of delta smelt density will be approximately unbiased if capture electro-fishing probability is high and at least three removals are taken.

Thus, the expected value of the meso-habitat-specific CPUE value should be meso-habitat-specific catchability times density, whereas the removal method sampling would generate a nearly unbiased estimate of actual density. Therefore, the ratio of meso-habitat-specific CPUE to the estimated meso-habitat-specific density should provide a good estimate of meso-habitat-specific catchability (q).

The approximate variance of the estimated q can be estimated via Taylor series approximation. Based on the variance of the ratio of two independent random variables, the approximate variance is,

$$v\hat{a}r(\hat{q}) = \left(\frac{(CP\hat{\hat{U}}E)^2}{\hat{\hat{N}}^2} \right) \left(\frac{s_{CPUE}^2}{(CP\hat{\hat{U}}E)^2} + \frac{s_N^2}{\hat{\hat{N}}^2} \right)$$

Where, s_{CPUE}^2 is the variance in the CPUE index computed across sample units, and s_N^2 is the variance associated with the removal estimate of N.

Gear selectivity methods

Typical seine hauls impose a size-selectivity though their mesh size. If the mesh size is "too large", then many small fish will pass through the mesh of the net and not be captured. Only fish of a size (length or diameter) that cannot squeeze through the net will be caught. To understand this kind of gear selection, envision the net passing through a group of fish and comparing the size distribution of fish retained relative to all fish actually exposed to the gear. In Newman (2008), two nets are fished in parallel, one with a very fine code-end that is assumed to retain "everything" and another that has the normal size code-end mesh size. Length distributions of fish collected by the two gears are compared to allow estimation of a physical "gear selection curve". For trawls, these are typically logistic-like in shape. Comparison of length frequencies of fish collected in the two gears should allow generation of a size selection curve for the seine gear under the (reasonable, but difficult to test) assumption that the (passive) net gear is non-selective with respect to size of fish. A fitted selection curve can in turn be used to adjust length frequency data accounting for size-dependent catchability. Importantly, if different gear types are used in different meso-habitats, then gear-selectivity studies may need to be done separately by meso-habitat.

Survey design and computation methods for adjusting the CPUE metric for imperfect detectability using gear selectivity methods are provided by Newman (2008).

Factors affecting sampling efficiency and catchability

Standardized sampling protocols have not yet been developed to maximize sampling efficiency across diverse habitat strata and delta smelt life stages. However, lessons can be learned from investigators who have sampled shallow and bathymetrically diverse areas of the Delta, with a focus on larvae and early juvenile life stages. Monitoring salinity gates operations in an experimental framework that tracks delta smelt responses through their complete life cycle requires a diversity of habitat-strata-specific sampling techniques and gears using multiple platforms (boat sizes and types and manual seine engagement where practicable.

These include:

Open-water shallow circumstances (OWS)

- *Adult life stage* (beach seines and purse seines)
- *Juvenile life stage* (push net)
- *Larval life stage* (ring net)

Open-water benthic circumstances (OWB)

- *Adult life stage* (trawl net, not oblique, different than mid-water trawl
- *Juvenile stage* (trawl net, not oblique, different than mid-water trawl)
- *Larval stage* (ring net)

Mid-water slough situations (MWS)

- *Adult life stage* (trawl net, not oblique, different than mid-water trawl, maybe a fyke net)
- *Juvenile life stage* (trawl net, not oblique, different than mid-water trawl, maybe a fyke net)
- *Larval stage* (ring net)

Second- and third-order feeder sloughs (FSW)

- *Adult life stage* (from Cramer-style platform boat)
- *Juvenile life stage* (from Cramer-style platform boat)
- *Larval stage* (ring net)

Shoals and shallow areas (SHO)

- *Adult life stage* (without aquatic vegetation, Cramer-style platform boat; with vegetation, enclosure nets with beach seine depletion)
- *Juvenile life stage* (without vegetation, Cramer-style platform boat; with vegetation, enclosure nets with beach seine depletion)
- *Larval stage* (ring net)

Bathymetrically diverse locations in the sub-littoral zone (SLZ)

- *Adult life stage* (from Cramer-style platform boat)
- *Juvenile life stage* (from Cramer-style platform boat)
- *Larval stage* (ring net)

Floodplains and marsh plains (FMP)

- *Adult life stage* (beach seines or fyke nets)
- *Juvenile life stage* (beach seines or fyke nets)
- *Larval stage* (fyke net)

Covariate modeling

For managers involved in the conservation of the delta smelt, the ultimate goal is to "recover" the species to the point at which it can be delisted from the Endangered Species Act (ESA). Studies of any fish or wildlife population begin with questions about the species' abundance, distribution and "status" -- is the population stable, declining or increasing? Before initiating any management actions to affect a population of interest, it is important to first have some initial estimates of the abundance of the population. This has been the approach taken in studies of delta smelt where the primary emphasis has been on estimating the status and trend of the population using a catch-per-unit-effort-based (CPUE–based) index of abundance. However, a time series of abundance estimates (or annual indices of abundance) does not, by itself, provide any explanation for why the population may be increasing or decreasing, and does not provide information on the underlying demographic processes that drive population dynamics.

The limitations of abundance estimates alone for providing insights to inform conservation efforts for declining species are discussed in Newman et al. (2014). The primary state variable for assessing the effects of environmental variation and management actions on delta smelt has been count-based, CPUE metrics—proxy indices of the true, but unknown abundances (N_t) in any given year t. However, even if the state of the system were known without error (all $N_1, N_2, \ldots, N_t$ values known with certainty for all t years), these data alone would tell managers nothing about the underlying processes that gave rise to the realized abundances. To understand past dynamics of delta smelt populations, and to predict future states of the population, requires that managers better understand the causal environmental factors that directly, or indirectly, generated the realized population states.

Estimating the relationships between environmental variables, particularly those that can be altered by management practices, and delta smelt distribution and abundance is an important research priority. Previously published studies have related temporal and spatial variation in the CPUE index to multiple environmental and hydrologic factors, including several within the purview of managers. Previous covariate modeling, however, has been inconsistent in identifying consistent environmental correlates of delta smelt abundance. However, collectively these previous studies provide guidance on candidate covariate selection.

We have previously identified the key covariate to include as a candidate predictor of spatial variation in delta smelt abundance—meso-habitat type. Given adjustment for differential catchability by meso-habitat type, insights to habitat-based difference in density may be the single most important insight provided by the salinity gates experiments. The ecological role of each meso-habitat component is acknowledged to at least some degree by most of the literature, although there is no agreement on the relative importance of all components for production rates, growth rates, or survival rates at various life-history stages.

We recommend that the adjusted CPUE metric be modeled as a function of broad-scale hydrologic variables, meso-habitat type, food resources, and abiotic factors that may vary across meso-habitat types (e.g., salinity, turbidity, water depth, local flow rates, etc.). By including covariates that vary by time and by space, an appropriate statistical model would allow CPUE to be temporally and spatially dynamic. Some of these studies have been implemented in the field, as observational studies taking advantage of natural temporal and spatial variation in the covariates. Understanding should be accelerated, however, by experiments conducted under controlled conditions using changes in fresh water flow magnitude and duration made possible by differential operation of the salinity gates.

A partial list of candidate covariates, roughly in priority order, based largely on previously published studies, includes:

- Turbidity
- Salinity
- Prey (depends on life stage; zooplankton and crustaceans), can be collected with CB nets or pumps
- Tidal stage when sampling occurs
- Time of the year (association with delta smelt life-history stages)
- Water temperature
- Depth of trawls (using a HOBO sensor on net)
- Time of day
- Predators (all fish species that occur in the sampling frame)
- Water velocity
- Submerged aquatic vegetation density

Mixture-models for estimating covariate relationship

We provide only a very brief discussion of mixture models here. These models seem appropriate to the delta smelt CPUE (survey) data because many sample units have zero fish captures, but when fish are captured in a sample unit, delta smelt abundance can vary over several orders of magnitude. Mixture models (e.g., combining binomial and lognormal distributions) have been shown to be very effective in modeling ecological count data with many zero observations (e.g., White 1978, Fletcher et al. 2005, Martin 2005). For example, in fisheries, mixture models have been used extensively to model CPUE data as part of the Rio Grande silvery minnow recovery program (Dudley et al. 2016).

For the silvery minnow, logistic regression was used to model the probability that a sample unit was occupied (CPUE $\geq$ 1, CPUE = 0), and the lognormal model was used to estimate the count data given a sample unit was occupied. Models provide estimates of four parameters for each time of sampling—probability of occurrence (ψ), mean and standard deviation of the lognormal distribution (μ and σ), and estimated fish density. General linear models can then be used to incorporate covariates, as fixed effects, into the models where a logit link can be used for ψ and log links for μ and σ ($\beta_0 + \beta_1$ x covariate with the corresponding link function).

Environmental-variable data collection

A YSI Sonde (Model EXO) could be used to continuously record environmental variables while sampling for fish. Each observation will be stamped for date, time, and location (lat-long). Continuously measured environmental variables will include water temperature, barometric pressure, conductivity, dissolved oxygen, turbidity, pH, chlorophyll-a, and blue-green algae. Data-collection techniques and instrumentation can follow well-established sampling protocols and procedures that have been employed elsewhere in the Bay-Delta.

Depth can be recorded continuously by a Sonar/GPS device. Depth observations will be stamped for date, time and location (lat-long) allowing them to be associated with fish captures. Additional spatial habitat covariates, including distance to shore, shoreline vegetation, and other variables, may be assessed by aligning biological sampling dates-times and locations (lat-long) with available spatial data.

Macro-zooplankton sampling may utilize a 12.5” diameter Clarke-Bumpus net made from 0.160mm mesh nylon cloth. The net will taper to 50mm at the cod-end where a polyethylene bottle screened with 0.140mm mesh wire cloth will collect captured organisms. Samples will be preserved in 10% formalin with Rose Bengal dye to aid in separating organisms from detritus and algae. Macro-zooplankton samples will be sampled as frequently as every five minutes during continuous fish sampling.

Micro-zooplankton sampling can utilize a 12V siphon pump to run 1 to 5 gallons of water through 35 micron mesh plankton net fitted with a cod-end for sample collection. Samples will be preserved in 10% formalin with Rose Bengal dye to aid in separating organisms from detritus and algae. Micro-zooplankton samples will be sampled as frequently as every five minutes during continuous fish sampling.

3.4 Implementing experiments

Key components to address prior to conducting experiments

Above, we have outlined, and discussed, the key components and topics we believe need to be addressed prior to initiating the salinity gates experiments. These topics include:

- *Selecting the response variable(s).* The hypotheses to be evaluated following implementation of the sampling design specifically address the relationship between temporal and spatial variation in the abundance of delta smelt and their zooplankton food (prey) to variation in salinity. The focus above has been primarily on delta smelt CPUE and derived parameters of delta smelt density and abundance. Food abundance/density will be concurrently assessed. The sampling protocol can easily be extended to other candidate response variables and environmental stressors.
- *Adjusting the CPUE index to account for measurement error.* The focus above was on meso-habitat and gear-specific estimates of catchability.
- *Selecting a sample design.* We proposed a stratified random sample design were the strata are the most important meso-habitat types used by delta smelt. This part of the research will provide important insights into density differences among meso-habitat types independent of a BACI type experiment. It may be most informative to conduct the BACI 'experiments' separately by meso-habitat type.
- *Selecting an experimental design.* We proposed a type of BACI design be implemented in order to clearly identify the occurrence and magnitude of treatment effects from the salinity gate experiments. We recommend that the BACI analysis be conducted overall and separately by meso-habitat type.
- *Relating observed treatment effects to environmental covariates by fitting regression-based models.* These models would estimate putative causal relationships between CPUE-derived parameters (abundance, density), for example, and environmental factors.

A recommended step-by-step process for conducting an experiment

In the following, we outline the steps that need to be followed to conduct the salinity gates experiments. To get initial estimates of the "treatment effect size", we recommend "ramping up" the treatment to full extent in the initial set of experiments — that is, keeping the gates open for a long period of time. A ramp-up is required to overcome uncontrolled environmental variation and sampling variation.

1. Map the meso-habitat types within Montezuma Slough. Multiple meso-habitat types are well represented in the salinity gates project area. Note the boundaries of the meso-habitats may change dynamically with variations in flow and tidal stage. This is a significant complication that needs to be incorporated into the sample design.

2. To ensure that samples are widely distributed within each meso-habitat type, conduct spatially balanced sampling (Stevens and Olsen 2004, Olsen et al. 2012) within each type. To estimate the time-by-treatment (Control or Impact) variance component, at least two replicate samples per meso-habitat, per time period will be required. One possible sample design within Montezuma Slough is based on fixed survey stations separated by ~0.5 kilometers. This spacing should encompass all key meso-habitat types and be exposed to the full range of the impacts generated by experimental operation of the salinity gates. Survey stations should be spaced sufficiently far apart so they can be considered independent (this should be informed by expert input).

3. Estimate the volume for each meso-habitat type used by delta smelt. This will require defining the depth of water within the water column utilized by Delta smelt, measured from the surface downward. As discussed in (1), volumes are likely to be affected by flows and tidal stage.

4. Select the appropriate sampling gear (gear type and mesh size) for the specific meso-habitat type being sampled.

5. Estimate catchability, separately by meso-habitat type to have an unbiased estimate of density or abundance.

6. Determine the environmental covariates to be measured, at the scale of the individual sample unit (trawl), to be associated with the response variable(s) estimated at this scale (CPUE, density, abundance, prey abundance, etc.).

7. Consider conducting experiments across and at various times within seasons to coincide with the different critical aspects of the delta smelt's life history stages (recruitment, larvae, juveniles, sub-adults).

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A coda – The overall adaptive management philosophy and approach

Adaptive management (AM) involves more than making ad hoc changes to management in response to observed phenomena. Rather, it is a systematic approach to understanding and managing uncertainty in natural resource management decisions. Originally developed in the 1970s by Holling (1978) and Walters (1986), the concept has intuitive appeal and has been applied to a wide variety of resource management challenges. At its core, formal AM involves exploring alternative management actions, making explicit predictions of their outcomes, selecting one or more to implement, monitoring to see if the actual outcomes match those predicted, and then using these results to learn and adjust future management plans and policies. While the steps of adaptive management can vary, it is this structured and rigorous approach to learning and its application to management decisions that defines it.

Rather than being implemented in isolation, adaptive management is increasingly designed within the context of a structured decision making (SDM) process (Runge et al 2011). Based in the decision sciences, SDM is a systematic approach to identifying and evaluating policy and management alternatives and making difficult choices that are characterized by both trade-offs and uncertainties. Some practitioners view AM as a special case of SDM wherein recurring decisions are made under uncertainty. Viewed this way, AM adds to the steps of an SDM process; those additional steps emphasize tasks related to addressing uncertainty, updating of models, and iteration.

Structured decision making helps management planners come to a solution by working through a series of steps. Participants in SDM begin by clarifying the planning or decision making context – what's the decision, who's the decision maker, what's in and out of scope, how should the technical analysis and the consultation process be structured, and who needs to be involved. They then define a clear set of management objectives, or "things that matter" that are affected by the decision at hand. These typically include a range of ecological, social, and economic considerations. Concise performance measures – specific metrics that are used to estimate and report the consequences of management alternatives on the objectives – are identified. A range of creative management alternatives are identified. The performance, or consequences of these alternatives are estimated using predictive models. Participants carefully examine the trade-offs across management objectives; they will iteratively refine the alternatives seeking win-win outcomes, but usually there are some value-based trade-offs. A range of analytical and deliberative tools may be used to help in the selection of a preferred alternative. Multi-attribute analysis tools may be used to assess and compare the "utility" or total value of different alternatives to aid in selection. Almost every natural resource management decision involves uncertainty, and the implementation of a preferred alternative is usually accompanied by resource monitoring to validate the actual performance of the management action against predicted performance, or to evaluate hypotheses or assumptions used in predictive modeling. Given the dynamic and changing nature of information, values, and institutional contexts, structured-decision-making adherents advocate that processes for formal review be established at the time the decision is made; this is often critical for reaching consensus on a recommended alternative.

A formal approach to adaptive management may be called for when the uncertainty associated with one or more of the consequence estimates substantially impedes decision making – that is, difficulty is encountered in selecting an alternative because uncertainty makes it unclear which alternative is preferred. In such cases, it's useful to think of AM as adding steps to the decision making process. Decision makers are faced with four key tasks -- 1) to confirm that uncertainty affects the selection of a management action, 2) to explore whether the uncertainty can be reduced, 3) to develop options for reducing it, and 4) to determine whether the benefits of learning outweigh the costs of learning. Next, it is important to confirm that the uncertainty affects decision making. There are many uncertainties; under AM, those that affect decision making are a higher priority for further investigation than those that do not.

Once a critical uncertainty is identified, the first question to ask is whether the uncertainty can be reduced within the time-frame of the decision being considered. Some uncertainties can be readily reduced with a short-term program of study. If this is the case, the decision process could be paused while studies are implemented to reduce the uncertainty. This may be done through literature review, modeling, field research, or the formal use of expert judgment, when data are not otherwise available. If the uncertainty cannot be resolved using these methods within the time available, then the uncertainty is a candidate for an adaptive management approach.

Consequences are estimated using predictive models. Uncertainty is formalized and expressed via the development of alternative models representing hypotheses about the relationship between management actions and performance measure outcomes. Each model, or hypothesis, is assigned a weight reflecting the probability or degree of belief that it is the true hypothesis. Following evaluation and selection, a preferred management alternative is implemented, along with monitoring to reduce critical uncertainty. When new information is available from monitoring, models are updated. Bayesian methods are used to increase the probability. or degree of belief in models, that is consistent with the observed response and decrease the degree of belief in others.

Learning occurs at different rates in different decision contexts, depending on ecological and institutional considerations. For some decisions, responses to treatments occur rapidly and key uncertainties may be reduced in just a few seasons or years. In such cases the learning is used to update models and new management actions may be selected and implemented without reconvening a full decision process. This fast-learning cycle has been termed “single loop learning” (Conroy and Peterson 2013). However, in many resource management contexts, the time required to reduce key ecological uncertainties is measured in decades rather than years. In such cases, by the time models can be updated, many things will have changed. In addition to new information about predictive modeling assumptions, there may be new legal or policy constraints, new stakeholders that need to be involved, new management objectives arising from new stressors or changes in social values, and new management alternatives that need to be considered. In such cases, a whole new cycle of decision making is triggered. This slower learning cycle is sometimes termed “double-loop learning.” It should be expected that double-loop may attend the management of delta smelt in Suisun Marsh.