How important are food web interactions in establishing a productive and resilient California Delta?

An assessment of the scientific information needed to improve management actions

Delta Independent Science Board

Draft Prospectus

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Motivation

Food web interactions are central in understanding how environmental drivers and management actions affect the abundances of individual species (Lathrop et al. 2002; Jordán et al. 2006; Naiman et al. 2012; Bunnell et al. 2014; de Mutsert et al. 2016; Townsend et al. 2019). While both top-down and bottom-up food web processes can be at play concurrently, traditional management is generally focused on how an individual driver or a combination of drivers (e.g. flow and temperature) affect the abundance of a single species of interest. Nevertheless, there is substantial evidence from other large aquatic ecosystems that food web interactions have strong effects on fish abundances, and we suspect that may be the case in the Sacramento-San Joaquin Delta (hereafter, the Delta).

The Delta, as an evolving ecosystem, is expected to experience significant modifications resulting from climate change, sea level rise, major flooding and storms, invasive species, water supply diversions, shifts in land use, restoration actions, and a growing human population (Norgaard 2021). Understanding and predicting how socio-ecological processes affect the abundances of fish species of interest and ecosystem resilience (e.g. sustainability) are at the core of Delta management and are critical to achieving the coequal goals (Delta Stewardship

Council and Delta Science Program 2022). Here, we propose to examine whether quantitative understanding of food web interactions can advance the ability to predict fish species abundances as a function of changing environmental and social drivers, especially management actions.

Understanding food web interactions and developing a food web model for the Delta were key recommendations from both the Strategic Science Needs Assessment (DPIIC and Delta ISB 2021) and the Delta Independent Science Board's (Delta ISB) Non-Native Species Review (Delta ISB 2021). Developing a quantitative understanding of food web interactions are directly relevant to evaluating the impact of management actions aimed at supporting fish populations under climate and other system changes. There is, however, a basic need to evaluate existing information on Delta food webs, identify informational gaps impeding progress, and link resulting knowledge to improve management actions. The Delta ISB believes that having knowledge of basic ecosystem processes across trophic levels will improve management actions, ones that may not be predictable by focusing on single-species responses to environmental drivers.

Various aspects of food web interactions have been previously examined in the Delta, but a quantitative understanding of major food web processes should be further explored. For instance, the role of striped bass as a predator for native fishes (e.g., Delta smelt and juvenile Chinook salmon) has conflicting results, with some studies pointing to striped bass as a generalist predator (Grossman et al. 2016), and others showing that during specific seasons and environmental conditions striped bass feed primarily on native species (Brandl et al. 2021). Prey switching is evident in several fishes across seasons and habitat gradients, such as between densely or sparsely vegetated sites (Whitley and Bollens 2014), but the capacity and frequency of prey-switching across the food web, which could change what we know about food web connections on different temporal or spatial scales, has not fully been explored. Moderate densities of non-native, submerged aquatic vegetation was shown to increase the habitat for juvenile largemouth bass, but larger fish were found at all densities of vegetation (Conrad et al. 2014), indicating the importance of including life history in examining food web interactions. Several studies describe changes in community assemblages due to various abiotic stressors, different habitats, or ecosystem gradients in the Delta (Feyrer and Healey

2003; Young et al. 2018). Other gaps in knowledge that have been identified include the role of terrestrial predators (reptiles, birds, and mammals) in fish predation and a need to understand anti-predator behaviors (Grossman et al. 2016).

Despite an abundance of foundational knowledge of species interactions and environmental drivers in the Delta, they have not been adequately linked and incorporated into models used to guide management actions (Brown et al. 2016; Sturrock et al. 2022). One of the primary tools for evaluating effects of environmental drivers on species abundance and interactions is food web modeling. Food web models can serve as a repository of current understanding of species predator-prey relationships and environmental effects on reproduction, growth and survival. Further, they provide details of interactions and connections among species that reveal the likely responses of species' abundances to future changes (e.g., Osakpolor et al. 2021; Naman et al. 2022). Although the responses of individual fish species to water flow, salinity, and temperature are modeled in the course of evaluating management strategies of some fish species (Michel et al. 2021), the secondary responses of one group of fishes to changes in abundances of other species groups has largely been ignored. Importantly, quantitative models with predictive capabilities are the most beneficial in that they can evaluate the influence of environmental and management changes on multiple future scenarios. Predictive models would provide managers with understanding of the aquatic ecosystem as a whole and, via trophic interactions, how a change in the abundance of one species may cause changes in the abundance of other species.

Existing assessments of food resources rely heavily on models of primary producers and their immediate consumers (e.g., phytoplankton and zooplankton) (Jassby 2003; Cloern et al. 2016). While these organisms serve as the primary food source of the fish at the base of the food web, the level and the direction of responses by individual species to changes in prey resources are often dependent on species-specific food web interactions. Overall, this "bottom up" approach emphasizes the effects to the ecosystem rather than recognizing the potential for the "top down" effects of large predators. The Delta ISB believes it is important that this review prioritize gaps and techniques to improve the representation of upper trophic levels, especially fishes.

Our goal is to assess the importance of food web interactions in the Delta, and to identify where improved understanding and tools (e.g. primarily food web models) might substantially improve predictions of species' responses to environmental drivers and management actions. This review will evaluate the degree to which the inclusion of food web interactions can benefit and facilitate multi-species management in the Delta and whether available data and science can support the development of such tools. Topics include:

- Evaluate the comprehensiveness of the existing knowledge about upper trophic-level food web interactions
- Identify gaps in data and understanding needed to develop and implement upper-trophic level food web modeling or similar tools
- Determine the potential management applications of upper-trophic level food web models

The review will draw on scientific and subject-matter experts from within and outside the Delta. Together they will assess the existing data and knowledge that could inform and improve fish management from an ecosystem perspective. They will articulate gaps in knowledge of trophic interactions and identify tools that could be employed to support the predictive management and the resiliency of the Delta ecosystem.

Audience

This review is intended for managers, researchers and policy-makers across the Delta that are developing or using models to inform management of fish or aquatic ecosystems. We will be asking who could benefit from integrated knowledge of species-specific trophic interactions to improve projections of how species' abundances and the ecosystem respond to changes. The focus is on determining how and where existing knowledge of species interactions and their impact on upper trophic levels can inform management decisions and their tradeoffs. The review is anticipated to generate information and recommendations used by those conducting water management and ecosystem restoration, including water management agencies, natural resource agencies, nonprofit organizations, and Delta community-based organizations.

Inputs to the Review

Literature Review:

We will draw upon a mixture of primary and gray literature, local and non-local experts, and resources from previous work conducted by Delta agencies and groups [e.g., National Center for Ecological Analysis & Synthesis (NCEAS) food web modeling group (e.g., Rogers et al. 2022) and the 2022-2026 Science Action Agenda (Delta Stewardship Council and Delta Science Program, 2022)]. Delta-relevant literature searches and previous research will inform the themes, structure, and speaker list for a two-day workshop.

Stakeholder Discussions:

We will conduct discussions with local management leaders, non-governmental organizations (NGOs), and other stakeholders. The purpose of the discussions is to tailor the workshop with themes of particular relevance in the Delta. Our initial set of potential management questions (see below) and the speaker list, structure, and content of the workshop will be refined by obtaining local knowledge through targeted group discussions. We will also seek public comment on the prospectus during scheduled public meetings.

Food Web Workshop:

The Delta ISB will host a two-day workshop, which will consist of integrated panels of scientists, managers, decision-makers, and stakeholders with substantial experience in food web dynamics, ecology, and key management concerns within the Delta. Additionally, experts from other relevant ecosystems will provide examples of how food web models and better understanding of species interactions have been successfully applied to fundamental management problems in other large ecosystems (e.g. the Great Lakes, Columbia River, Chesapeake Bay, Gulf of Mexico, freshwater lakes). The workshop will help identify the science, data, and modeling required to develop a set of tools that can be applied to understanding the potential response of native species to management actions and multi-species interactions in an evolving Delta system. Examples of fundamental questions include:

1. What are the important food web interactions affecting predictions of how restoration, climate change, and changes to system management (e.g., flow rates or other environmental drivers) impact the abundances of key native species?
2. How could a quantitative understanding of food web interactions improve the design of performance metrics used for upper trophic levels in the Delta?
3. How will changes in food resources at lower trophic levels (e.g. phytoplankton and zooplankton) increase food resources for species of interest?
4. Can one predict how current or future invasive species may impact native fish abundances or survival?
5. What are the critical inputs (e.g. data) and outputs to a food web model that could help make predictions?
6. What level of complexity does a Delta food web model need to have (e.g. What temporal and spatial scales are important for successful management solutions)?
7. What could food web models reveal about the indirect effects of management choices on endangered species living in the Delta?

The workshop will include a series of discussions with expert panels drawn from fisheries management, non-profit organizations, academic institutions, and other stakeholder groups focused on the following tentative themes:

- The most important food web interactions in the Delta (e.g. those that can be used to improve the impacts of management decisions).
- The state of current tools used in the Delta to address management questions related to native species and species interactions
- The management applications of food web models at the ecosystem scale
- Recommendations for future science priorities and essential information

Breakout groups focused on scientific and informational needs will follow expert panel discussions. Those discussions will form the basis of recommendations provided in the review.

Timeframe

Target Date	Benchmark
April 2023	Prospectus finalized
June 2023	Finalize workshop agenda and invite speakers.
July 2023	Finish literature review, annotated bibliography Open registration for workshop
August 2023	Host workshop
January 2024	Release draft workshop summary report for public comments
Spring/Summer 2024	Finalize summary report and findings

Related reviews

Some studies of food web interactions (predation, competition, and so forth) in the Delta are cited above. There are relatively few concrete examples where specific species interactions or upper trophic level conditions are incorporated into management models (Bryndum-Buchholz et al., 2020). A few reviews of conceptual or empirical models of the Delta food web include:

- Rogers/Bashevkin, et al. 2022. Evaluating top-down, bottom-up, and environmental drivers of pelagic food web dynamics along an estuarine gradient.
- Durand, J. R. 2015. A Conceptual Model of the Aquatic Food Web of the Upper San Francisco Estuary. *San Francisco Estuary and Watershed Science*, 13(3). https://escholarship.org/uc/item/0gw2884c
- Brown et al., 2016. Food Webs of the Delta, Suisun Bay, and Suisun Marsh: An Update on Current Understanding and Possibilities for Management. San Francisco Estuary and Watershed Science. https://escholarship.org/uc/item/4mk5326r
- Osakpolor et al., 2021. Mini-review of process-based food web models and their application in aquatic-terrestrial meta-ecosystems. Ecological Modeling. https://doi.org/10.1016/j.ecolmodel.2021.109710

- Bauer, M. 2010. An Ecosystem model of the Sacramento-San Joaquin Delta and Suisun Bay, California, USA. Master's Thesis, California State University, Chico.

These reviews have identified important abiotic and biotic drivers for food webs, determined that both bottom-up and top-down drivers are important for the Delta, depending on the location, and found that the role of environmental drivers is equal to or greater than the trophic forcing for the Delta. We will build on these reviews by identifying new opportunities for applying multi-level species interactions within the Delta into management. Previous reviews have focused on phytoplankton, zooplankton, and bottom-up limits/drivers with respect to overall food resources for native fishes (Jassby et al. 2003). Although we will draw upon this work, this review will provide a unique set of insights and knowledge by stressing the importance of determining interactions that exist at upper trophic levels (i.e. fishes), and by working toward the development of an empirical model that can be adaptively built and used to predict future changes to the Delta ecosystem.

Expected Products and Outcomes

This review will produce a report assessing the current knowledge of the species interactions – food web dynamics – in the Delta. It will explore how understanding food web interactions can improve predictions of how environmental drivers and management actions affect aquatic community abundances. This review aims to consolidate current knowledge of food web interactions, encourage the development of a common database to contain this information, and to build connections across investigators and organizations who are conducting related or complementary research. Additionally, the report will summarize the tools currently used to evaluate single-species management, and explore emerging tools and techniques, such as the development of quantitative food web modeling, that would improve multi-species and ecosystem-scale management. Recommendations will support the development and implementation of multi-trophic level food web modeling in the Delta. Additional products may include official ISB recommendations to DPIIC about food web modeling, and a scientific publication.

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