Futures for Delta Smelt

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The delta smelt is a small, endangered fish that lives mainly in the Delta, the epicenter of California's complex water distribution system. The Delta is the upper part of the San Francisco Estuary (SFE). The smelt was listed as a threatened species in 1993 and its protection has been controversial ever since, mainly because it competes with people for the water in which it prefers to live. In 2009, the US Fish and Wildlife Service issued a Biological Opinion (BiOp) in which the agency determined that operation of the massive pumps that export water from the Delta are jeopardizing the smelt's continued existence.

In 2019, however, the USFWS issued a new BiOp that concludes that increasing diversions from the pumps will *not* jeopardize continued existence of delta smelt. The smelt will survive, it implies, because various agencies plan to spend $1.5 billion on habitat restoration and other measures, most already planned in one document or another, albeit with sources of money uncertain. But habitat-based projects will take years or decades to implement and mature. And major manipulations of outflow to benefit smelt, especially increased flows, seem unlikely to happen (although possible). The 2019 BiOp relies on creating a production hatchery for Delta smelt as a short-term solution. Such a hatchery would release large numbers of fish into the wild to "supplement" the existing population. There is no guarantee this (or increased flows) will work. The smelt already in culture show some signs of becoming domesticated, likely reducing their ability to re-establish 'natural' self-sustaining populations.

Does this mean extinction in the wild is likely? One view of the US Fish and Wildlife Service BiOp is that the federal decision makers expect extinction to occur soon, making much of the BiOp moot, and making more water available for export from the Delta without expensive mitigation projects. This essay explores some issues affecting the future of delta smelt and possible alternative futures.

Delta smelt: a brief introduction

The delta smelt is a remarkable species that lives *only* in the San Francisco Estuary. Typical adult size is 60-70 mm. It is adapted to spending its one-year life span in open waters in loose groups, feeding on zooplankton, before spawning and dying. This estuary has always had wide fluctuations in environmental conditions, a challenging habitat for the survival of any fish. Historically, during extreme droughts, habitat conditions favoring smelt would have existed mainly in the Delta, while in wet years favorable conditions would have existed throughout the system, including San Francisco Bay. As a result, the smelt evolved multiple life history strategies, from being a resident species in freshwater sloughs or brackish open water, to being semi-anadromous (Hobbs et al. 2019). In recent decades, the semi-anadromous life history has been most dominant, with juveniles rearing in Suisun Bay and Marsh, from which adults migrated into the freshwater Delta for spawning; the larvae would then drift back into the brackish-water rearing habitat in Suisun Bay. We do not know if the alternative life-history strategies are genetically based, respond to specific environmental cues, or both.

The basic problem

The estuary to which delta smelt are adapted no longer exists. Much of the water that once flowed through the estuary is stored or diverted upstream or exported by the huge pumping plants in the south Delta (Hobbs et al. 2017; Moyle et al. 2016, 2018). Physical habitat was first modified by huge flows of sediment from placer mining in the Sierra Nevada, and later by the conversion of the huge expanse of tidal marsh into a system of artificial channels and levees to protect islands of agriculture from flooding. The transformation of flow and habitat, which began over a century ago, has resulted in an ecosystem that is novel and still changing in ways usually not favorable to smelt.

The transformed Delta was easily invaded by non-native organisms, some of which disrupt food webs and confound restoration. Salts, toxic chemicals, and nutrients created by the action of people flow and diffuse into and accumulate in the Delta. Blooms from harmful algae are a regular summer occurrence. The historically turbid waters have become clear and low on planktonic food. As climate change disrupts the timing of flows and increases summer temperatures, little historic habitat is left for sensitive species like smelt.

A tipping period

Smelt populations have probably been in gradual decline since at least the middle of the 20th century (Figure 1), a trend consistent with other native and introduced fishes. But a more precipitous decline has occurred since the 1980s, tracking the increase in State Water Project exports (Figure 2). The coincidence of smelt decline with increased water exports is compelling, but it exists in the context of other major systemic changes. By the end of the cycle of floods and drought during the latter half of the 1980s, an invasive clam that filtered the water clear of planktonic food had spread across the estuary. In addition, an invasive weed that had been present for decades spread widely across the Delta, blocking waterways and transforming former Delta smelt habitat into a clear, food limited, lake-like environment. The 1969-89 period seems to have been the tipping period that shifted the Delta away from habitat that supported delta smelt to habitat that supported a novel ecosystem unfavorable to them. This shift is irreversible.

The delta smelt now appears to be on a trajectory to extinction. It is largely absent from standard surveys that once easily tracked its abundance, and is found rarely in special surveys that focus on a few key areas where smelt are known to concentrate. So, how will we know when the delta smelt is extinct, and once extinct, will that event release water exporters from environmental restrictions on pumping?

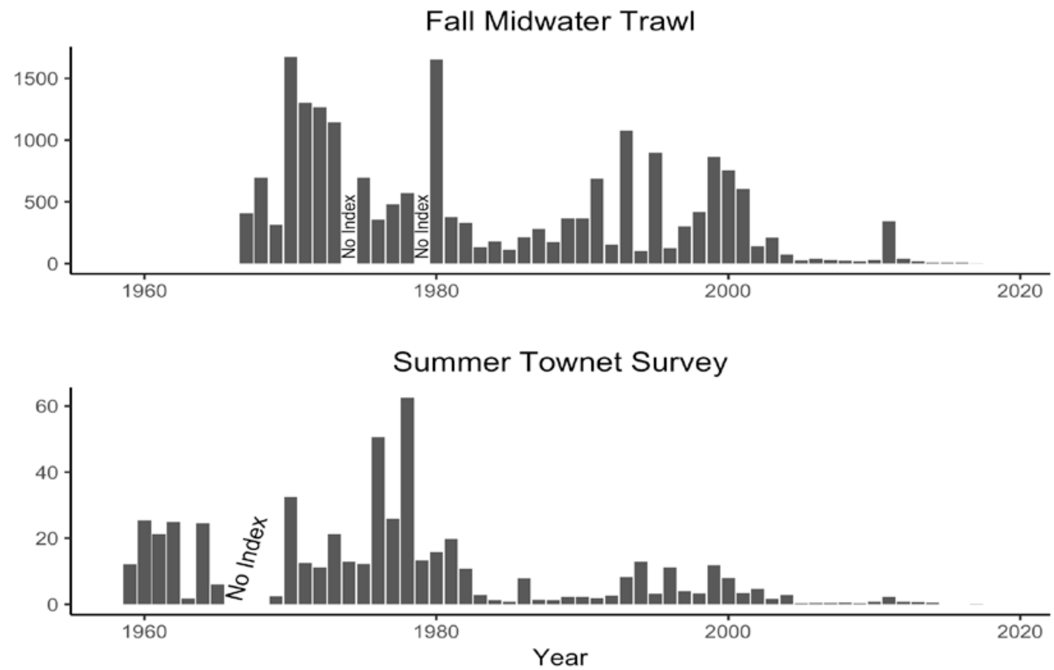

Figure 1. Indices of Delta Smelt abundance in the two longest-running fish sampling programs in the delta. The Summer Townet Survey samples juvenile smelt while the Fall Midwater Trawl Survey samples subadult smelt, mostly pre-spawning individuals. Figure by Dylan Stompe.

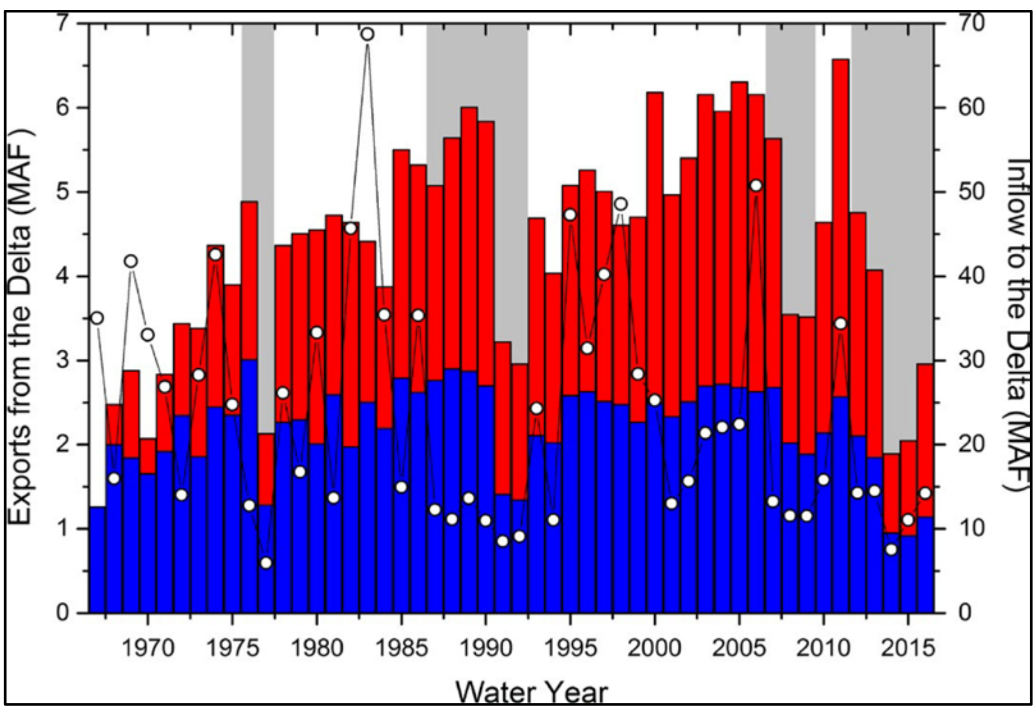

Figure 2. Annual export (left axis) of water from the south delta by the State Water Project (red) and federal Central Valley Project (blue) in million acre-feet. Gray bars show periods of drought, when pumping was reduced primarily because of low inflows. Annual water inflows to the delta in million acre-feet (right axis) are the open circles. Data: www.water.ca.gov/dayflow. Figure: Moyle et al. 2018 https://afspubs.onlinelibrary.wiley.com/doi/full/10.1002/fsh.10014

Defining extinction

Baumsteiger and Moyle (2017) recommend a formal process to declaring extinction in fishes that involves intensive sampling for several years once standard surveys no longer detect them. If no smelt are caught, the sampling is followed by a waiting period based on generation time (e.g., 10 generations, which is only 10 years for delta smelt) during which routine sampling continues. Baumsteiger and Moyle note that determination of extinction is not easy because extinction comes in different forms, such as extinction in the wild versus global extinction. If the delta smelt continues to exist in the wild but only if assisted by artificial propagation, is it extinct? If the only populations are those artificially maintained in giant public aquaria, is the smelt extinct? If a form nearly identical to delta smelt continues in the wild as a hybrid with the introduced wakasagi, is the delta smelt extinct? If the delta smelt exists only as a population in a reservoir, where it's existence depends on reservoir management, is it effectively extinct? These questions are typical when species approach extinction, but in this case the answers have outsized economic and political influence on managing water that flows through the Delta.

The Federal Endangered Species Act (FESA) offers a legal approach, without answering the underlying scientific questions. When the Fish and Wildlife Service or National Marine Fisheries Service undertake their mandated 5-year review of the status of listed species, they are empowered to delist species that they determine are extinct using the best available science. They also may delist species due to extinction in response to a petition from the public. The agencies have delisted species as extinct at least 11 times since passage of the FESA. Similarly, under the California Endangered Species Act (CESA), the California Department of Fish and Wildlife can delist species when they determine the species is extinct. CDFW has done so twice since passage of CESA, for the Tecopa pupfish and the thicktail chub.

Is habitat restoration the answer?

But let's suppose that the decision is made to pull out all the stops to try to keep a self-sustaining population of smelt going. What is the potential of habitat restoration to support the flagging smelt population? Under EcoRestore, some 9000 acres of tidal and subtidal habitat are expected to be restored. While these improved habitats will benefit multiple species, including native fishes, birds, reptiles and mammals, there is little guarantee that this restored habitat will be enough to restore Delta smelt. This is true for several reasons.

First, even 9,000 acres is insufficient habitat. Delta smelt originally inhabited a vast area, about the size of Rhode Island, that included bay and river water, marsh sloughs, and productive wetlands across both brackish and freshwater gradients. Because smelt tend to surf currents to move about, their principal physical locations shifted seasonally, and in response to droughts and floods. Additionally, their habitat included spawning sites on substrates that remain poorly known, making them difficult to target. To be successful, habitat restoration must include multiple sites adjacent to the open water corridors (especially the Sacramento River). It must include both spawning and rearing sites, as well as abundant food and thermal refuges.

Second, the general approach to restoration has thus far been more opportunistic than strategic, with restoration locations often focusing on wetlands with willing sellers. Some restoration sites are far from habitat corridors; other sites are subsided or highly altered by previous use. We have little working knowledge about how to build, connect, and manage these sites as an integrated system. Some sites will be worked over to provide some semblance of natural tidal drainage patterns and planted with native plants,

Third, there is often an expectation that breaching levees to open wetlands to tidal action will be sufficient. It will not. Most Delta restoration sites, as in the rest of the estuary, are vulnerable to invasion by non-native species which can subvert the best-laid restoration plans. These invaders can disrupt or destroy restoration sites for native fishes. Successful restoration sites will thus require intensive management and, although California was built on actively managing the flow of water, there appears to be little incentive to manage “natural” restoration sites actively. It is reasonable to assume that nearly every site will need intensive, continuous management to meet even minimum expectations of a restored habitat.

Fourth, tidal aquatic habitats also require flow to function. The limited extent and function of habitat restoration could be better supported by more reliable outflows, which would improve function, and give better control of where delta smelt end up during the spring, summer and fall--but this would require spending water, which is resisted by many water users, as reflected in the BiOp. An additional problem is that smelt populations are too small to be able to see an immediate (annual) response to a large increase in outflows.

Can increased outflows favor smelt?

Restoration of aquatic habitats can only succeed if water is flowing across the landscape. Moving water promotes the exchange of nutrients, controls introduced species, distributes food production, and creates habitat structure. It helps restoration sites mimic natural environments and improves their effectiveness. While water users seem to hope that habitat restoration provides an alternative to water use, this is not realistic. Estuarine habitat requires substantial outflows from the rivers.

If we are serious in providing the outflow required for habitat for smelt and other fishes, a substantial environmental water right is needed to provide reliable water to interact with physical habitat to produce food and shelter. An actual sufficient environmental water right is difficult to envision, given the current conflicts in the Delta. But realistic proposals generally propose providing significant water for Delta fish, often as a percentage of the natural flow regime. If the water required could be guaranteed one way or another, delta smelt might have a fighting chance.

Can hatcheries restore smelt?

A genetically managed delta smelt population has been maintained at the UC Davis Fish Conservation and Culture Laboratory (FCCL), in collaboration with the UC Davis Genomic Variation Laboratory, since 2008 (Lindberg et al. 2013). As a conservation hatchery, the FCCL is permitted to collect and incorporate 100 wild delta smelt into the population annually to increase diversity and reduce inbreeding. With the decline of the wild population, the FCCL has been unable to capture the 100 individuals needed, at least for the 2018-19 season. Inbreeding has been kept low ($F<0.002$) for the past 9 generations (Finger et al. 2018), but will rapidly increase without input from the wild population. Developing new methods in addition to the current hatchery strategy will be needed. Would maintaining some families in captivity with “rare” genes and allowing them to spawn a second year help? Should we cryo-preserve wild smelt milt or even cryo-preserve milt from less-inbred smelts for the future population?

Although delta smelt can survive in captivity with natural food only (Hung et al. 2019), genetic adaptation to captivity has been observed in the FCCL population (Finger et al. 2018). Because domestication is unavoidable, what critical information should we obtain before greatly expanding the rearing facility and reintroducing fish into the wild?

An ultimate goal of maintaining a captive population is supplementation of the existing wild population. So we need to prepare this delicate fish for reintroduction. The preparation should be based on the environment where the fish will live. The fact that wild delta smelt have/had several life-history phenotypes (Hobbs et al. 2019) makes reintroduction more complicated because we cannot be sure which life history strategy will be adopted by reintroduced smelt. In addition, the current setup and operation strategy at the FCCL is to maintain high genetic diversity through multiple generations. Considerable effort and additional research will be needed to convert current hatchery methods into a mass production facility as proposed in the BiOp, especially the expectation that fish will be produced with minimal inbreeding and domestication. Some basic questions include: How many fish would need to be released for a detectable response in the wild? What life stage should be released to contribute the most successful completion of the life history? How would a large-scale reintroduction program be managed genetically? Would introducing large numbers of hatchery smelt into the best habitat available drive the remaining wild smelt to extinction, through competition and other interactions? Some preliminary considerations and risk assessments for using the captive delta smelt have been discussed by Lessard et al. (2018). Answering these questions will take a team of experts from different fields working together for reintroduction to be successful.

Can smelt inhabit reservoirs and other non-traditional habitats?

Sometimes potential conservation tools for species can emerge from “out-of-the-box” places. A well-known fish example in California is the “Nigiri Project” where researchers are testing benefits of rearing juvenile Chinook salmon on flooded rice fields in the Central Valley. Can smelt be reared under similar conditions or in other novel habitats, such as reservoirs? One place to look for insights into alternatives is research on other smelt species.

Delta smelt is a member of the fish family Osmeridae, which includes similar species from the Atlantic and Pacific seaboards. Rainbow smelt are particularly relevant because, like delta smelt, they are anadromous (live in saltwater but spawn in freshwater). Rainbow smelt have successfully invaded the Laurentian Great Lakes, and are now pushing into deep, cold inland lakes throughout midwestern USA states (Mercado-Silva et al. 2006, Roth et al. 2010). Much is known about rainbow smelt in these areas because of their negative impacts on native coldwater coregonids (ciscoes and whitefish) which occupy a similar plankton-feeding niche in lakes with extensive cold and well-oxygenated deepwater habitats. If, deep cold reservoirs offer habitat to other smelt species, could deep cold reservoirs in California support delta smelt?

California has many major reservoirs; many of these ecosystems contain suitable thermal and oxygen habitats for coldwater fishes, including smelts. Some reservoirs in California already support inland runs of native Chinook salmon and steelhead termed “adfluvial” runs (live in reservoirs, spawn in the inflowing rivers). For example, Almanor, Folsom, New Don Pedro, and Pine Flat reservoirs all support adfluvial populations of Chinook salmon (Perales et al. 2015). Several California reservoirs already have self-sustaining populations of wakasagi - a non-native Japanese smelt related to delta smelt. These smelt were introduced deliberately, using embryos imported from Japan. Combined, these patterns raise the possibility that delta smelt could survive in some California reservoirs (Teejay O’Rear, personal communication).

It is possible that there are already reservoir delta smelt populations, established by fish being carried down the California aqueduct, although this may be just wishful thinking. However, if it looks as if delta smelt can live in reservoirs, it could be worth considering establishment of reservoir populations to enhance genetic diversity and as another fail-safe habitat to prevent extinction, at least in the short-term.

Assisted movement to novel habitats is widely discussed as a strategy to counter effects of climate change, so the idea of moving delta smelt to potentially suitable habitat outside their native range is not novel. Successful movement to reservoirs could provide a temporary refuge for smelt, but would not address the larger, more systemic issues facing the Delta that will inevitably lead to problems for other aquatic species (and human health and safety). Presumably a strategy involving movement to reservoirs would be part of a grander experimental rescue strategy, involving habitat restoration, use of hatchery smelt, and use of existing artificial habitats such as floodplains (Yolo Bypass) and the Sacramento Deepwater Ship Channel.

Because the Delta smelt are listed as threatened under the Federal Endangered Species Act (FESA) and endangered under CESA, any assisted migration of Delta smelt would require permitting or other authorization under both FESA and CESA, which would likely be a complicated process.

FESA provides more flexibility than CESA, due both to its less stringent protections and to the smelt’s lower threatened classification at the federal level. Because it is ‘only’ threatened, the U.S. Fish and Wildlife Service (FWS) has power under FESA Section 4(d) to write regulations protecting the smelt in whatever way FWS “deems necessary or advisable to provide for the [protection and recovery] of such species.’’ Thus, if FWS determined that allowing reintroductions of smelt to the Delta or allowing reintroductions of the smelt outside of their historic range were advisable for the protection and recovery of the species, they could use the

4(d) process to allow such actions without requiring permits. Even without changing the 4(d) regulations, FWS could permit such reintroductions under FESA Section 10(a)(1)(A), which allows the FWS to permit actions "to enhance the propagation or survival of the affected species." This is the permitting basis for the current hatchery effort, and the permits could be expanded to include reintroduction. Finally, under FESA Section 10(j), the FWS can permit experimental reintroductions of a species in populations isolated from the rest of the species, including outside of the species historical range, and then use the 4(d) regulations to reduce protection for only the reintroduced population. This has traditionally been done to alleviate political opposition to reintroductions, but could be used as a general permitting mechanism.

CESA, unlike FESA, does not permit anything akin to the 4(d) regulations and does not allow for reduced protection for reintroduced populations, as found in FESA Section 10(j). Approaches relying on these authorities at the federal level would likely require legislative changes to CESA at the state level, as was done during the reintroduction of an experimental population of spring run Chinook salmon on the San Joaquin River several years ago. CESA does allow for a permit equivalent to the FESA Section 10(a)(1)(A) permits; under Fish and Game Code Section 2081(a), DFW can permit take of listed species for scientific, educational, or management purposes, which would allow for reintroductions.

Overcoming the rarity of smelt

The delta smelt population has become so low that individuals may have a difficult time finding either each other (the Allee Effect) or finding suitable spawning habitat. Captive populations can be used to support spawning and recruitment failures, with the expectation that increased smelt populations will increase opportunities for natural spawning. This experimental approach has high risk of failure, however. Supplementation programs for other species, especially salmon, have not been particularly successful at re-establishing wild, self-sustaining populations, but instead create a reliance on hatchery support.

It is thus a major, perhaps insurmountable, challenge to reverse the extinction spiral of delta smelt. But other native species are likely to follow a similar path if we cannot figure out how to reverse the smelt decline to rarity and extinction. Loss of our native fishes will continue without a change in our current approach to water, habitat and species management.

Environmental water right for smelt?

While we have focused on the endangered species act here because it is most conspicuously in play, there are a host of other legal approaches to protecting smelt and their habitats (e.g., Public Trust Doctrine). Given the failure of the ESAs to do much except slow the extinction spiral of smelt, other approaches may be needed in the future. One such approach is providing a water right for smelt, giving them a 'seat' at the negotiating table over water.

In terms of outflow required for smelt habitat, an environmental water right of perhaps 1- 2 million acre feet per year could increase the probability of success for habitat restoration, because flowing water interacts with physical habitat to produce food and shelter. This is difficult to envision, given the current conflicts in the Delta over future pump operations, the ongoing lawsuits over the revised Bay Delta Plan revision for the Lower San Joaquin River, and the forthcoming Bay Delta Plan revision for the Sacramento River. But the Bay Delta Plans do set aside significant water for Delta fish, albeit as a percentage of the natural flow, not as an environmental water right. If the water required by these plans could be managed as an environmental flow right, not just a year-round fixed flow based on estimated natural flows, these plans might give delta smelt a chance to be restored as a viable species.

Conclusions

The delta smelt has become so rare that we cannot really tell if the new BiOp will affect the species positively, negatively, or not at all. The Delta, along with the entire San Francisco estuary, has changed so much in past decades that suitable habitat for delta smelt is largely lacking. Large-scale restoration projects that provide habitat and food for smelt are required to counter past changes and prevent extinction of what self-sustaining populations remain. Such large-scale projects will require increases in outflows at times to work well. Desperation measures such as a production smelt hatchery and establishment of smelt in reservoirs may provide a veneer of 'saving' smelt for a while but they seem unlikely to prevent extinction in the long run.

The following seem the most likely alternative futures for delta smelt:

1. Extinction of the wild population in 1-5 years, with a population of increasingly domesticated hatchery smelt kept for display and research purposes.

2. Persistence of a small wild population in a few limited intensively managed habitats, until these habitats cease being livable (e.g., from global warming, other changes).

3. Global extinction after wild populations disappear and hatchery supplementation or replacement fails.

4. Replacement of the wild population with one of hatchery origin, continuously supplemented.

5. Persistence of wild populations through supplementation and through establishment of reservoir populations.

Further reading

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