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The low-salinity zone in the San Francisco Estuary as a proxy for delta smelt habitat: A case study in the misuse of surrogates in conservation planning

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ABSTRACT

The use of surrogates in conservation planning for at-risk species is both a necessary and a fraught practice. Here we assess the use of the position of the low-salinity zone in California's Sacramento-San Joaquin Delta as a surrogate for the extent and quality of habitat available to the imperiled delta smelt. The U.S. Fish and Wildlife Service issued a biological opinion and incidental take statement under the Endangered Species Act analyzing the impacts of ongoing operation of two large water infrastructure projects on the delta smelt. The Service's analysis and the conservation actions it imposed are based on the assumption that the low-salinity zone can serve as a "surrogate indicator" for delta smelt habitat. We demonstrate that available scientific information on the species countermands use of the low-salinity zone to represent delta smelt habitat in conservation planning for the species, and that the U.S. Fish and Wildlife Service erred by assuming the existence of a surrogate relationship absent validation using the best available scientific information. Notably, large expanses within the low-salinity zone are unoccupied by delta smelt and the species consistently occurs outside of it. This case serves to remind scientists of the dysfunction between a consensus in the scientific literature that calls for analytical validation prior to the use of species surrogates and habitat proxies, and the commonplace practice of using surrogates and proxies based on surmise and assertion.

1. Introduction

The well-considered mandate in the Endangered Species Act (ESA) that requires the U.S. Fish and Wildlife Service (FWS or the Service) to inform its determinations and decisions using the best available scientific information seems straightforward on its face. However, many threatened or endangered species are rare or at least rarely encountered and of those many are elusive, cryptic, and notoriously challenging to study. Accurate and reliable data and analyses on the distributions, abundances, and population dynamics of imperiled species more often than not are limited or non-existent (Raphael and Molina, 2007). Unsurprisingly the best available scientific information on the scarcest of the imperiled species receiving federal protection often is not much scientific information at all.

Under such circumstances, the Service frequently draws inferences from more readily available data, including from potential surrogates for listed species or proxies for their habitats. But the use of information on more abundant and less imperiled species in regulatory determinations for species at risk of extinction is fraught (Cushman et al., 2010; Murphy et al., 2011; Evans et al., 2016). Niche theory proposes that the salient ecological attributes of and patterns of resource use by closely related, co-occurring species inevitably vary, allowing similar species to coexist and perforce limiting the value of one as potential surrogate for another (for example Magg et al., 2019). The multidimensional nature of habitats typically obviates the easy identification of one or just a few environmental attributes that might serve as proxy measures for purposes of directing resource management efforts. Concerns regarding the use and misuse of surrogates and proxies in conservation planning have stimulated a substantial area of research over the past quarter century (see Caro, 2010).

Here we document and assess the use by FWS of the position and extent of the dynamic low-salinity zone in the San Francisco Estuary as a proxy for habitat of the narrowly endemic and threatened delta smelt (*Hypomesus transpacificus*) to inform agency decision-making. Delta smelt are endemic to the Sacramento-San Joaquin Delta (Delta) in central California. The short-lived species spawns in winter, develops through its larval and juvenile stages in spring and summer, and then matures into adulthood during autumn. The species' life cycle is carried out in brackish water at the interface between San Francisco Bay (Bay) and the main-stem Sacramento and San Joaquin rivers and several

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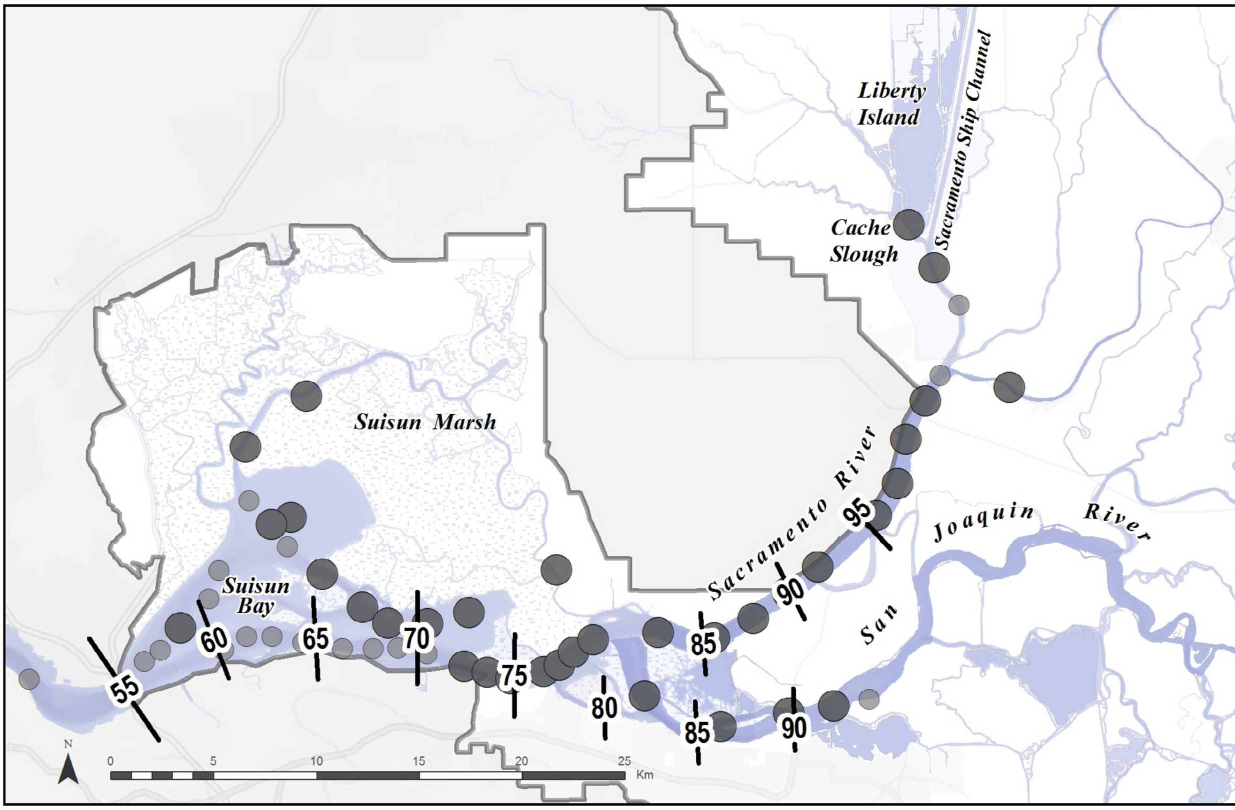

Fig. 1. The eastern portion of the San Francisco Estuary and the Sacramento-San Joaquin Delta. The numbers represent the distance in kilometers from the Golden Gate and Pacific Ocean. At flood tide the salt field from San Francisco Bay (just beyond the left-side map limit) pushes east into the Delta; at ebb tide freshwater moves westward toward the Bay. The average annual location of the X2 isohaline in the autumn has ranged from below 65 km (from the Golden Gate) in years with high through-Delta outflow to nearly 95 km in years with low outflow. The geographic distribution of delta smelt is illustrated from annual survey samples from 1987 to 2012. The dark larger circles represent survey stations that collectively accounted for 90% of the delta smelt catch in the autumns during that period. The lighter, smaller circles represent survey stations that accounted for 9% of the catch.

tributaries (Bennett, 2005).

The FWS assumes that the monthly average location of the low-salinity zone is an accurate proxy for delta smelt habitat and predictor of its population dynamics (USFWS, 2008). This assumption is a foundational element of both the FWS's analysis of the effects of water-export operations on the delta smelt and the resulting conservation measures imposed on the federal and state agencies that operate water-export projects that service agriculture and urban users in central and southern California (USFWS, 2008). As presented here, prevailing practices in the scientific community and the best scientific information available indicate that the position of the low-salinity zone is not a valid proxy for delta smelt habitat. As a result, society has invested resources in a management action that has been both costly and ineffective.

We begin by assessing the literature on the relation between the low-salinity zone and habitat of delta smelt and other fishes that occupy the Delta. Next, we describe how the Service uses changes in the average location of the low-salinity zone to evaluate the status of delta smelt and proposes to manipulate the location of low-salinity zone to conserve delta smelt. We suggest criteria for establishing whether a potential ecological indicator is a valid proxy for the habitat of a protected species. We evaluate whether the location of the low-salinity zone in the estuary – described as the location of X2, the distance from the Golden Gate, where San Francisco Bay meets the Pacific Ocean, to the location of the two parts per thousand isohaline (see Jassby et al., 1995) – is a robust measure of the extent of delta smelt habitat. As part of our evaluation, we examine the implications of the Service's efforts to manage the average location of X2 in the estuary for both delta smelt and the regulated community in California.

The consequences of well-meaning but ill-informed regulations have the potential to be dire. "Reclamation" of the Delta by the forbearers of its present-day residents (including the destruction and conversion of more than 95 percent of the vast wetlands once inhabited by delta smelt and channelization of the Delta's watercourses) in combination with upstream and within-Delta consumption of water by California's growing population has greatly disrupted and fragmented the estuarine context within which the species persists (Mount et al., 2016). As a result the delta smelt has experienced a dramatic decline in numbers (Hamilton and Murphy, 2018). In response, investment in efforts to conserve delta smelt has been significant. Against that backdrop it is understandable that stakeholders expect government policies to be informed by the best available scientific information.

2. Relations between the low-salinity zone and habitat for fishes

The position of the low-salinity zone as a focal environmental target for conservation planning in the San Francisco Estuary has definite appeal. Flows and tidal influences in an estuary functionally define estuarine ecosystems and influence their structure and composition. A salinity gradient limits the distributions of many species and directly and indirectly affects their abundances. At the same time, no attribute of an estuary is quite so dynamic. Survival of estuarine species reflects their adaptation to fine-resolution spatial and temporal variation in salinity that is driven by variation in landforms, bathymetry, fresh groundwater inputs, and other physical factors (Day, 1981; McLusky and Elliott, 2004; Wolanski, 2007). Seasonal variation in estuary through-flows can lead to dramatic differences in the position and extent of the low-salinity zone over the longer term. One might expect the strongest constraints on the extent and quality of habitat for an estuarine fish to be less dynamic physical (abiotic) factors, rather than highly dynamic salinity conditions.

Nonetheless, the extent of the low-salinity zone long has been used as a measure of the health of the Delta's aquatic ecosystem. In 1994, a number of federal and state agencies and other stakeholders agreed to salinity standards for then-identified ecologically sensitive geographic areas of the Delta (National Research Council, 2012:240-241). The positioning of the low-salinity zone in westerly portions of the Delta, where tributary waters empty into the Bay, reduces salinity at myriad delta water intakes, thereby lessening water treatment requirements prior to agricultural and urban uses. The location of the X2 in the estuary can be used to mark the landward limit of the salt field, and functionally represents salinity stratification in the water body (see Fig. 1). Importantly, the location of X2 is determined by water outflows to the Bay through the Delta and ebb and flood tides. The quantity of outflows reflects precipitation in the watershed and withdrawal of water by users within and upstream of the Delta (Lund et al., 2007). Outflow quality is influenced by contaminant inputs from urban, industrial, and agricultural sources.

Jassby et al. (1995) described the location of X2 in the estuary as an ecosystem-level "indicator" of conditions that affect diverse aquatic species. But the effects of the location of X2 on specific native fishes, including fishes listed under the California and U.S. Endangered Species Acts, and the ecological communities that support those species, are not well understood (although see Hieb and Fleming, 1999). As the position of X2 in the Delta moves towards the Bay and salinity in the Delta decreases, the abundances of some aquatic species appear to increase. Other species that inhabit the low-salinity zone tolerate a range of salinities and their abundances do not appear to respond similarly. Kimmerer (2002) examined the relationships between the location of X2 in the spring and abundance indices for seven fish and aquatic invertebrates. Correlations between the position of X2 and abundances of five species were negative – higher abundances were associated with higher through-Delta outflow – but the correlations for two other species, one of them the delta smelt, were not statistically significant. Given that other organisms at lower trophic levels did not respond positively to the position of X2 in the estuary, Kimmerer concluded that the proximate mechanisms of a positive relation between the location of X2 and abundances of certain fishes may not be related to salinity, but to geographically constrained physical phenomena, such as access to floodplains or marshes that provide food, refugia from predators, or spawning substrates.

Feyrer et al. (2007) analyzed the relationship between three physical environmental factors that vary across the estuary in the autumn – water temperature, Secchi depth (a measure of turbidity), and conductivity (a measure of salinity) – and the distribution of three fishes. The authors examined time-series survey data on striped bass (*Morone saxatilis*), threadfin shad (*Dorosoma petenense*), and delta smelt derived from the Fall Midwater Trawl (FMWT), a seasonal survey of fishes in the open waters of the Bay and Delta, and data on environmental factors from the survey stations. They found that salinity and turbidity explained slightly more than a quarter of the variance in delta smelt presences and absences across the Delta. The authors acknowledged that physical and biological factors that were not included in the analysis, including competition, predation, and food availability, could have major effects on the distributions of the three fishes.

Feyrer et al. (2011) drew from that earlier work in developing a delta smelt habitat index that "accounted for both the quantity and quality of abiotic habitat" for delta smelt and used it "to model the index as a function of estuarine outflow." The index used "general additive modeling to identify habitat suitability based on combinations of water temperature, clarity, and salinity from surveys conducted during fall," applying it "using outflow predictions under future development and climate change scenarios." The authors reasoned that the extent of "abiotic habitat" would decrease over time as flows through the Delta decreased and the low-salinity zone extended further east into the Delta where the areal extent of waterways is limited.

The inferences of Feyrer et al. (2007, 2011) have high uncertainty. Feyrer et al. (2007) limited the environmental correlates of delta smelt presence in the estuary to only three physical variables. Additionally, Feyrer et al. (2007) analyzed data from a subset of the areas included in the trawl survey and occupied by delta smelt. Among the areas not included in the analysis (some because time-series data were not then available) were several near-freshwater stations proximate to Cache Slough in the northeast Delta, where as much as a third of the delta smelt detected in recent years were recorded (Sommer and Mejia, 2013). Furthermore, most of the FMWT survey stations are in relatively deep, open waters of the Delta's larger channels and bays; therefore, the FMTW does not sample the full range of delta smelt or the extent and diversity of its habitat, which is associated with shoals, shallows, and the complex bathymetry of the estuary's sub-littoral zone. Some areas with high concentrations of delta smelt were discovered after publication of Feyrer et al. (2007) (see Polansky et al., 2018). Moreover, the habitat index developed by Feyrer et al. (2011) did not include an independent estimate of delta smelt abundance, is not spatially explicit, and has low predictive ability (Manly et al., 2015).

3. Use of X2 as a surrogate for delta smelt habitat by the Fish and Wildlife Service

In 2008, the Service issued a biological opinion and incidental take statement that analyzed the effects of operation of the Central Valley Project (CVP) and State Water Project (SWP), which export water from the Delta to urban and agricultural uses across California, on delta smelt. The documents authorized the continued operation of the two projects subject to certain measures intended to protect delta smelt, referred to as reasonable and prudent alternatives.

The Service determined that ongoing CVP and SWP operations, as proposed by the U.S. Bureau of Reclamation (Reclamation), were likely to jeopardize the continued existence of delta smelt and destroy or adverse modify designated critical habitat for delta smelt. The reasonable and prudent alternatives included five components, one of which, the Fall X2 Action, is intended to improve the habitat of delta smelt during the autumn by increasing outflow through the Delta during that period (USFWS, 2008:282,369).

In analyzing the effects of ongoing CVP and SWP operations on delta smelt, the Service noted that habitat for the species in the autumn can be defined as the abiotic and biotic environmental factors that allow delta smelt to survive, persist, and recover (USFWS, 2008:233). But in analyzing the effects of operations on delta smelt habitat, the Service narrowed its assessment, first to "suitable abiotic habitat" and then to X2. The agency explained that its examination of habitat suitability in the autumn was drawn from Feyrer et al. (2007) and an unpublished manuscript that included the analysis subsequently published in Feyrer et al. (2011) (USFWS, 2008:234). The Service concluded that over time water export operations have led to an upstream shift in X2, thereby decreasing the amount of habitat for delta smelt and reducing the species' abundance (USFWS, 2008:235-238). This conclusion contributed to the Service's supposition that proposed CVP and SWP operations were likely to jeopardize the continued existence of delta smelt.

The Fall X2 Action requires Reclamation and the California Department of Water Resources (DWR) to manage upstream releases of water from reservoirs, and water-export operations in the south Delta, such that the monthly average location of X2 meets specified targets in water years characterized as wet or above normal. The water-year classification is based on indices of the volume of runoff into major tributaries to the Delta. In September and October of wet and above-normal years, Reclamation and DWR must maintain the monthly average location of X2 at 74 km and 81 km, respectively (USFWS, 2008:369). In November (and, in some cases, extending into December), the Fall X2 Action requires Reclamation and DWR to release an amount of water equivalent to all inflow into Sacramento Valley basin reservoirs; these releases will increase outflow through the Delta and maintain the mandated monthly average location of X2 (USFWS, 2008:369).

A principal assumption of the biological opinion that CVP and SWP operations were likely to jeopardize delta smelt is that the location of X2 is a proxy for the extent of delta smelt habitat, and that as the value of X2 increases, the amount and quality of delta smelt habitat decreases (USFWS, 2008:373). The Service opined that reduction in the amount and quality of delta smelt habitat, driven by the location of X2, limits the distribution of delta smelt in the autumn "mainly to a core region in the vicinity of the Sacramento and San Joaquin Rivers (Feyrer et al., 2007)" (USFWS, 2008:179). Therefore, the Service assumed that the Fall X2 Action would increase the extent of delta smelt habitat and, accordingly, expand the distribution of delta smelt. The Service further indicated that the loss of delta smelt habitat is reflected in a statistical association between the location of X2 in autumn and the abundance of young delta smelt the following year (USFWS, 2008:373), positing that implementation of the Fall X2 Action would lead to an increase in the abundance of delta smelt the following year.

4. Salinity and habitat quality for delta smelt

The conservation actions prescribed for delta smelt by the Service were sufficiently controversial that a committee of the National Research Council was convened at the request of Congress to review the agency's determinations, including the Fall X2 Action. The NRC committee report (NRC, 2010:53) observed, "the X2 action is conceptually sound in that to the degree that the amount of habitat available for delta smelt limits their abundance, the provision of more or better habitat would be helpful." But the committee could find no scientific justification for the assertion that the position of X2 determines either the amount or quality of delta smelt habitat or the abundance of the fish. They pointed to the "weak statistical relationship between the location of X2 and the size of smelt populations" observing that "the distribution of salinity and turbidity regimes and smelt abundance indices is unclear." The committee further described the derivation of the Fall X2 Action as lacking "rigor," noting that the action is "based on a series of statistical analyses" linking "the relationship of presence/absence data to environmental variables, the relationship of habitat to X2, [and] the relationship of X2 to smelt abundance," and that "each step of this logical train of relationships is uncertain." The NRC committee was not availed of spatial data on the distribution of delta smelt habitat, the distribution of delta smelt in the autumn of years with different outflow regimes, nor the distribution and abundance of food for delta smelt in the same years. That the Feyrer et al. (2007) analysis used a subset of the FMWT data, as described above, also was problematic.

The premise in the 2008 biological opinion is that delta smelt habitat can be characterized for purposes of management planning as an "area of suitable abiotic habitat," or, more specifically, the low-salinity zone as represented by the location of the X2 isohaline. But habitat is not the surface area or volume of water that exhibits physical variables in a particular range. Rather, the habitat of a species consists of the biological and physical resources and ecological processes present in a geographic area that support the survival and reproduction of that species (see Murphy and Noon, 1991; Morrison et al., 1992; Hall et al., 1997). The extent and quality of habitat for delta smelt is a function of the availability and types of the zooplankton on which they feed, refuge from predators, substrates for spawning, and values of numerous physical variables, including salinity, turbidity and temperature. Furthermore, the habitat used by delta smelt varies with its life stages. Those essential resources and resource conditions are met in bays and channels with complex bathymetry, in areas close to shoals and shallows, and in springtime in areas near shorelines with little submerged vegetation and minimal densities of the toxic cyanophyte *Microcystis* and in proximity to tidal or freshwater marshlands and other wetlands.

5. The position of the low-salinity zone as a "surrogate indicator" of delta smelt habitat

The Service's determination is based on the supposition that the position of X2 in the estuary is a direct measure of the location, extent, and quality of delta smelt habitat or, according to the Service, X2 can serve as "a surrogate indicator of habitat suitability and availability for delta smelt in all years" (USFWS, 2008). In other words, all elements of delta smelt habitat are represented by X2. The reference to a "surrogate indicator" combines two concepts – surrogates and ecological indicators, or as we reference them here, proxies – that individually have valuable applications in conservation planning. But a growing body of literature warns against use of surrogates or proxies unless the relationship between the conservation target and the surrogate or proxy has been validated (Murphy and Weiland, 2014; Murphy et al., 2011; Wenger, 2008; Caro et al., 2005).

A proxy for habitat must meet three criteria to be reliable for conservation planning (consistent with Dale and Beyeler, 2001; Hunsaker and Carpenter, 1990; Niemi and McDonald, 2004). First, the proxy must spatially and temporally co-occur with the organism and its habitat. Second, there must be a plausible ecological mechanism by which the proxy affects the distribution or abundance of the species, or the extent or condition of its habitat. Third, changes in the location, extent, or condition of the proxy must coincide with changes in the status of the species or its habitat. That is, a measurable change in the position or status of the proxy should be correlated with changes in the abundance of the species or the extent or condition of its habitat that can be affected by management actions.

The location of X2 in the estuary in autumn does not meet the criteria for serving as a proxy for delta smelt habitat. Delta smelt frequently and consistently occur outside of the X0.5 to X6 range that was used to define the fish's abiotic habitat (Feyrer et al., 2007, 2011; also Brown et al., 2013) and, in most years, large areas of the estuary experiencing X0.5 to X6 in autumn are unoccupied by delta smelt (Merz et al., 2011; Murphy and Hamilton, 2013). The location and extent of the low-salinity zone therefore does not adequately represent delta smelt habitat. Delta smelt occur along a salinity gradient from freshwater (near 0 parts per thousand, or X0) to 16 or more parts per thousand (X16) (see Hieb and Fleming, 1999; Moyle et al., 2010). No data indicate that survival and reproduction of delta smelt significantly differ along that salinity gradient.

Although delta smelt almost certainly were historically more widespread in the Delta, the fish now is largely restricted to the more northern sub-areas of the estuary, from Suisun Bay and Suisun Marsh in the west into the main-stem Sacramento River in the east, with highest densities around Liberty Island, Cache Slough, and the Sacramento River deep-water ship channel (Fig. 1). The low-salinity zone lies across much of that area, with seasonal, longitudinal shifts of up to 24 km, in east and west directions, and across southern and eastern areas of the Delta that are sparsely occupied or unoccupied by delta smelt. In areas in which the relative abundance of delta smelt in the autumn appears to be high, salinity often is low consistent with the biological opinion's description of habitat. However, some occupied areas intermittently become freshwater. Delta smelt have been recorded in the western portions of their range in years in which autumn outflow is low (X2 near 90 km and above, as in autumn 2007; Fig. 2) and the low-salinity zone is positioned in the eastern Delta. Delta smelt also occur in near-freshwater, well east of the X2 isohaline, in years in which autumn outflow is comparatively high (X2 below 80 km, as in 1995; Fig. 2). Moreover, delta smelt frequently and consistently are detected outside of the core occupied areas in the Delta, and large portions of the lens of low salinity in the Delta are unoccupied by delta smelt in autumn. On the basis of raw occurrence data, X2 neither uniquely defines delta smelt habitat nor is a valid indicator of areas in which the species occurs. An interagency synthesis on the ecology of delta smelt (IEP MAST, 2015) states "data generally supported the idea that lower X2 and

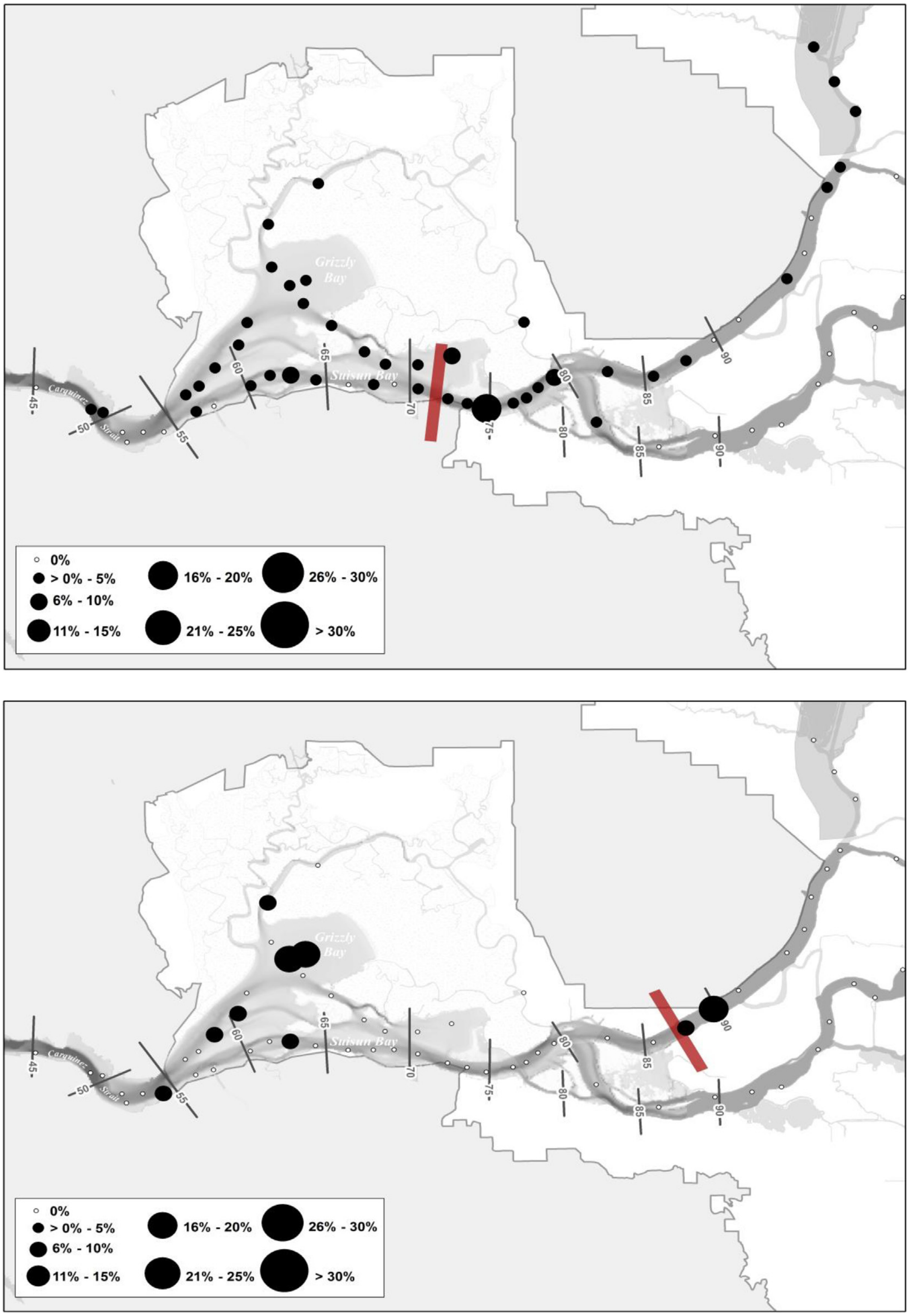

Fig. 2. a and b – Maps of the distribution and proportional catch in surveys of delta smelt (filled circles) in September and October of years with relatively higher through-Delta outflow (1995 with averaged X2 at 72 km – note the bar) and lower outflow (2007 with X2, the bar, at 88 km). Delta smelt were sampled from both the eastern and western ends of the species' distribution in the autumns of those years that exhibited higher and lower outflow.

greater area of the LSZ would support more sub-adult Delta Smelt" and the "position and area of the LSZ is a key factor determining the quantity and quality of low salinity rearing habitat available to Delta Smelt." But few empirical data support these statements. Although Sommer et al. (2011) report that the "centroid" of the distribution of delta smelt appears to shift with the location of the low-salinity zone, the position of X2 in the estuary does not define or reflect the location, extent, and quality of delta smelt habitat. Furthermore, the centroid of the population has no ecological meaning, that is, it does not explain patterns of the distribution of the species or its habitat. The continuous presence of delta smelt in habitats in western portions of its range in the Delta and in adjacent Suisun Bay and Suisun Marsh, in even dry years in which X2 moves east, is contrary to the assertion that X2 is a proxy measure for the location and extent of delta smelt habitat.

6. Further considerations regarding surrogates and proxies

Surrogates or proxies are used to infer salient ecological attributes of protected animals and plants and their habitats, which are poorly known or difficult to study, and to inform regulatory determinations and decisions under the ESA (see Caro 2010; Cushman et al., 2010). Inferences from co-occurring, more readily observed, and better-studied species, or from biological or physical features of a species' habitat, may provide useful information to resource managers. However, no surrogate species for delta smelt has been proposed, and considering the points above, it is unlikely that a readily measurable surrogate or proxy measure that co-occurs with and varies predictably across the spatial extent of delta smelt habitat exists. In any case, should a surrogate for delta smelt or an ecological indicator of its habitat be proposed, it must be put through a validation procedure before being institutionalized in management planning (see Murphy and Weiland, 2014; Wenger, 2008).

For purposes of conservation planning, the best habitat for delta smelt is defined not by X2 as a surrogate indicator; rather, the best habitat is defined by its comparative capacity to support and sustain the fish. That habitat can be found east in the Delta, in the lower Sacramento River near continuous freshwater conditions, and west in the Delta and in and around Suisun Bay and Suisun Marsh, where salinity conditions typically are highest in the delta smelt's geographic range. While San Francisco Bay's saline waters to the west and the freshwater Sacramento River to the east bound the range of delta smelt, the location of X2 in the Bay-Delta tidal zone by and large neither predicts nor determines the location of other resources – food, predators, water temperature and turbidity, and channel depth, proximity to shoreline, and bathymetric features – that affect the survival and successful reproduction of delta smelt or the extent or quality of its habitat.

The case of the delta smelt is not unique; government regulators frequently rely on surrogates and proxies when they lack species- and habitat-specific information. Default to information drawn from abiotic surrogates and proxies for aquatic species and their habitats in marine or estuarine environments is de rigueur reflecting the challenges of surveys, monitoring, and assessment of fishes in those environments (see MacArthur et al., 2010). Noting that the effectiveness of abiotic factors to serve as surrogates in the design of marine reserves is constrained by "statistical and sampling constraints," Mellin (2015) found the use of abiotic factors in conservation planning to be highly sensitive to survey data and sampling design, observing that because species-specific ecological processes link target species and candidate surrogates, planners should focus consideration of surrogates on environmental gradients that exert influence on the target species, gradients of resources used by the species, and indirect gradients to evaluate prospective surrogates or proxies. Wenger (2008) proposed that the responses of one or more surrogate species (which could readily be extended to habitat proxies) to environmental stressors be used to develop a working hypothesis or model of the stressor response of the target species. The process identifies one or more candidate surrogates, models the relationship between the stressor and the response variable (s) of interest, adapts the stressor-response relationship from the surrogate to a model for the target species, and incorporates additional data as they become available, adjusting the response model of the target species.

When surrogates and proxies are not validated there is substantial risk that regulators will expend limited societal resources on ineffective conservation actions. Acknowledging that reality, Murphy and Weiland (2014) offered a step-down validation procedure that can be adapted and employed when a habitat proxy is considered. We suggested that the use of the proxy be justified, first, by describing the ecological attributes of the target species' habitat, and any logistical or practical challenges that impede its direct measurement. Second, we recommend application of a structured, deductive process to evaluate the correspondence between a prospective proxy and the species' habitat. That process can draw on information on the distribution and ecology of the target species, on related species and their habitats, and from other conservation planning efforts that have successfully or unsuccessfully used habitat proxies. Third, similarities and differences between the likely responses of the habitat proxy and the actual habitat of the target species to salient environmental phenomena should be described, and any uncertainties that may lead to different responses should be identified. It may be necessary to describe how data on the proxy must be updated to enable its successful application in management planning for the species and its habitat.

The validation of species surrogates and habitat proxies is best facilitated prior to them being incorporated into the risk assessment phase of conservation planning – alternatively referred to as impact assessment or effects analysis – which is carried out in support of the selection of resource management actions from among alternatives. Surrogate or proxy validation procedures are data hungry. Available quantitative information that describes the functional relationships between the performance of imperiled species and relevant habitat metrics frequently is lacking or unreliable. More often than not, salient knowledge is actually anecdotal, based on surmise rather than drawn from direct measures. Accordingly validation of surrogates and proxies should be undertaken as a step in a structured decision-making procedure that differentiates between the best available scientific information and that of lesser quality, and uses it to evaluate the effects of activities that impact at-risk species or to identify targeted management actions that can contribute to protecting such species (Murphy and Weiland, 2016; Lowell and Kelly, 2016; Esch et al., 2018). In the context of risk assessment, the validation procedure should include evaluation of management-relevant hypotheses that inform the development of quantitative models relating species performance to habitat conditions and predicted management outcomes (Gemeinhardt et al., 2016; Fischenich et al., 2016). We suggest that a validation procedure so approached should become standard professional practice before surrogates and proxies are used in conservation planning applications. This suggestion is consistent with the Endangered Species Act's mandate to use the best scientific information available, and to ensure both responsible stewardship of at-risk species and the public fisc.

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