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Selected Flatfish: factors that control distribution and abundance in Pacific Coast estuaries and a case study of Elkhorn Slough, California

Peter A. Nelson, Sharon Kramer, and Jennifer Brown

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ABOUT THIS DOCUMENT

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Jim Allen, Southern California Coastal Water Research Project
Larry Allen, California State University, Northridge
Jim Barry, Monterey Bay Aquarium Research Institute
Bob Emmett, National Oceanic and Atmospheric Administration Fisheries Service
Lara Ferry-Graham, Moss Landing Marine Labs
Steve Ralston, National Oceanic and Atmospheric Administration Fisheries Service

This document is part of a series of reports on key species that use estuarine habitats on the Pacific Coast. Coastal decision-makers are setting habitat and water quality goals for estuaries worldwide and exploring restoration projects to mitigate the major degradation estuarine ecosystems have undergone in the past century. These goals can be informed by an understanding of the needs of key species that use estuarine habitats. To inform on-going restoration planning as a part of ecosystem-based management at Elkhorn Slough, an estuary in central California, we have selected eight species / groups of organisms that are ecologically or economically important to estuaries on the Pacific coast of the United States. The first five sections of each review contain information that should be broadly relevant to coastal managers at Pacific coast estuaries. The final sections of each review focus on Elkhorn Slough.

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The mission of the Elkhorn Slough Foundation and the Elkhorn Slough National Estuarine Research Reserve is conservation of estuarine ecosystems and watersheds, with particular emphasis on Elkhorn Slough, a small estuary in central California. Both organizations practice science-based management, and strongly support applied conservation research as a tool for improving coastal decision-making and management. The Elkhorn Slough Technical Report Series is a means for archiving and disseminating data sets, curricula, research findings or other information that would be useful to coastal managers, educators, and researchers, yet are unlikely to be published in the primary literature.

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A. Background

This review focuses on the following species of flatfish found in estuaries along the Pacific coast of North America: California halibut (*Paralichthys californicus*), speckled sanddab (*Citharichthys stigmaeus*), diamond turbot (*Pleuronichthys guttulatus*), starry flounder (*Platichthys stellatus*), English sole (*Parophrys vetulus*), and California tonguefish (*Symphurus atricaudus*) (Figure 1). These were chosen as key species, relevant to the public and coastal decision-makers, for these principal reasons:

1. Estuaries may provide nursery habitat (sensu Beck et al. 2001) for California halibut, diamond turbot, starry flounder, speckled sanddab, and English sole as well as Essential Fish Habitat (EFH) for starry flounder and English sole. These fishes are common constituents of estuarine fish sampling efforts on the Pacific coast; their frequent presence is indicative of the habitat's importance to their ecology.
2. Some of these species are of importance to fisheries — commercial, recreational or both. California halibut supports an important recreational fishery, and the commercial fishery landed approximately 324.6 mt from California waters in 2006 (Pacific States Marine Fisheries Commission, PacFIN database). With the exception of California tonguefish and speckled sanddab, the remaining species also have a presence in Pacific coast commercial fisheries although their role has been declining for a variety of reasons.
3. These fishes play an important role in the community ecology of Pacific coast estuaries. They feed on a wide range of invertebrates (e.g., clams, brittle stars, polychaetes, crustaceans) and fishes, and larger fishes, birds and pinnipeds feed on them.
4. As benthic inhabitants of a coastal habitat heavily impacted by human activity, these fishes are affected by various pollutants. English sole, in particular, has been the subject of numerous toxicological studies. This research forms a basis for future work, possibly using this species as an indicator both of habitat degradation and restoration success.

General information, including coast-wide distribution, habitat association and trophic ecology, for each of the species has been summarized in Table 1.

B. Trends in distribution and abundance

Our understanding of nearshore fish populations for nearly all Pacific coast species prior to industrialized fishing is very poor. For most populations, fisheries statistics offer the best long-term data sets; however, not until 1950 are fisheries statistics available and then only for the most important commercial species. Landings data frequently lump several flatfish species into a single category, making a meaningful quantitative assessment of recent population trends difficult. Nonetheless, some pertinent information is available for select species. For California halibut and English sole there is no indication of on-going over-fishing, landings are fairly stable and, in the case of English sole, abundance appears to have increased over the last decade. In addition to fishing pressure, oceanographic fluctuations and habitat alteration are all likely to affect nearshore fish populations. Oceanographic fluctuations likely affect all six species; speckled sanddab and California halibut have been investigated in this regard, but only the former demonstrates a clear correlation. The interannual variability of west coast estuarine fishes appears to be particularly high (e.g., Matern et al. 2002), although few long-term studies have been conducted (Allen et al. 2006). Thus, the limited data available suggest that populations appear to be healthy, but there are many questions that remain unaddressed.

California halibut

California halibut range from northern Washington to southern Baja California, Mexico (Love et al. 2005), and are most common in depths <30 m (see Kramer 1990). They reach a maximum length of about 1300 mm SL (Miller and Lea 1976). Despite the wide geographic range of this flatfish, the population center is in southern California; fishery-independent data from the early 1990s suggested that the biomass off central California was about one third of that off southern California (Leet et al. 2001). Heavy estuarine habitat loss in southern California (Zedler et al. 2001) render the central California estuaries especially important.

Commercial fishing following World War I heavily impacted the California halibut population; a reduction in effort during World War II appears to have allowed stocks to recover (Leet et al. 2001). Since the late 1940s, landings have been low. Variability in landings are attributable in part to regulatory conditions (Leet et al. 2001) and, perhaps, to changing oceanographic conditions (Baxter 1999, Allen et al. 2003, Norton and Mason 2003, but see Hsieh et al. 2005). The reduced availability of estuarine nursery habitat (Ryan and Patyten 2004), a resource that has been heavily impacted by human activities (Allen et al. 2006), may also be a factor.

In San Francisco Bay, trawl surveys from 1980-1995 indicate increased local adult population during the last 20 years, attributed by Baxter et al. (1999) to a succession of warm water and El Niño years. Population increases are likely due to the northward movement of juveniles and adults along the coast as well as local recruitment (Baxter 1999). Along southern California beaches and in associated bays and estuaries, California halibut was the predominant flatfish by weight and numerically second only to the speckled sanddab (Kramer 1990). Larger fish (> 150 mm SL), however, were found at greater depths, while halibut less than 150 mm SL were found mainly in the bays (Kramer 1990, Fodrie and Mendoza 2006). The distribution of “newly settled” juvenile halibut (< 17 mm SL) suggests that a sizeable proportion of these fish migrate inshore after first settling on the open coast or near the mouths of bays (Kramer 1990). Although most potential nursery habitat in southern California occurs along the exposed open coast, 0-age halibut are found mainly in protected embayments (Fodrie and Mendoza 2006). Fodrie and Levin (2008) have demonstrated the importance of estuarine nursery habitat to the local abundance of subadult California halibut at least in southern California.

Speckled sanddab

Speckled sanddab are widely distributed (northern Gulf of Alaska to Bahia Magdalena, southern Baja California, Mexico, Leet et al. 2001), and most common at depths less than 40 m (see Kramer 1990). Due to its small maximum adult size (to 144 mm SL, Miller and Lea 1976), it is not a significant component of any commercial or recreational fishery, but is likely an important forage species for larger fishes, birds and marine mammals.

Population-level studies emphasize a relationship between oceanic conditions and population trends; we are not aware of any research linking anthropogenic factors and speckled sanddab populations. In the Southern California Bight, speckled sanddab populations are negatively correlated with the El Niño-Southern Oscillation (Allen et al. 2004). In San Francisco Bay, Baxter (1999) linked their increased abundance during the late 1980s and early 1990s to ocean conditions.

There is some indication that Elkhorn Slough functions as a nursery for speckled sanddab. Brown (2003) found that speckled sanddab grew faster within estuaries than did coastal fish, and that the largest size classes of sanddab were found only on the open coast, suggesting that smaller juveniles may enter the estuary, but leave for the open coast at a greater size. Prior studies that found speckled sanddab predominately in coastal versus estuarine sites (e.g., Kramer 1990, Yoklavich et al. 1991) may be a reflection of an ontogenetic shift in habitat association rather than an indication that estuaries are relatively unimportant for this species.

Diamond turbot

Diamond turbot are found from Cape Mendocino, northern California to Cabo San Lucas, southern Baja California, Mexico (Leet et al. 2001), most commonly in less than 20 m depth (see Kramer 1990). They are caught by commercial fishermen, but they have historically been lumped with roughly a dozen additional species for fisheries statistics, so there is no definitive information on long-term population fluctuations over the extent of their range. They are targeted by recreational fishermen, partially due to their availability in protected waters (bays, sloughs and estuaries, Leet et al. 2001), which diamond turbot use as nurseries (Kramer 1990).

In San Francisco Bay, adult diamond turbot populations increased in the late 1980s-1990s similarly to California halibut, suggesting that the same environmental factors positively affect both species (Baxter 1999). Also like California halibut, diamond turbot exhibit a positive correlation between size and depth of capture (Kramer 1990). However, Kramer (1990) also found that the location and timing of settlement differed between these two species: Halibut settled between March and September on the open coast or in the bays near the opening. Turbot settled between January and March in the inner-most portions of the bays.

Starry flounder

Starry flounder range from the Sea of Japan to the Arctic Ocean and south to Los Angeles Harbor, southern California, with a maximum size of 910 mm TL (Table 1; fishbase.org, 30 Oct 2007). They are considered “marine immigrants”, using estuarine sloughs (Yoklavich et al. 1991) and shoals (Baxter 1999) as nursery habitats. There is evidence from San Francisco Bay to suggest that the abundance of age-0 starry flounder is negatively correlated with salinity; freshwater inflow during the winter may provide a refuge from less tolerant predators (Baxter 1999). In San Francisco Bay, abundance of starry flounder was higher during years of comparatively high freshwater outflow in the 1980s than in the 1990s when salinities were generally higher. Juvenile starry flounder used habitats with lower salinity and higher temperatures than other flatfish species (Baxter 1999). In Elkhorn Slough, juvenile starry flounder dominated the catch in sloughs in winter (Yoklavich et al. 1991).

Starry flounder contribute a sizeable proportion of the commercial and recreational catch of flatfish, although this take is generally incidental to efforts directed at petrale sole (*Eopsetta jordani*) or California halibut (Leet et al. 2001). Landings have declined over the last two decades (Leet et al. 2001), largely due to changing commercial fishing regulations (Sampson et al. 2005, Ralston 2006, Stewart 2007). California ("Southern Area") stocks are estimated to be above the target population level, and take by fisheries is low (Sampson et al. 2005, Ralston 2006, Stewart 2007).

English sole

English sole are found from the (Bering Sea and Aleutian Islands to Bahia San Cristobal, central Baja California, Mexico, Leet et al. 2001), and are common in California estuaries north of Point Conception as juveniles (Allen et al. 2006). As adults, they are typically found between 35 and 280 m, to as much as 550 m (Gunderson et al. 1990, Leet et al. 2001). These fish were a mainstay of the commercial trawl fishery, particularly during its west coast origins in San Francisco Bay in the late 19th century (Leet et al. 2001). The proportion of English sole to the total quantity of flatfish landed, however, has declined gradually since the early 1980s (Figure 2). A major factor in this decline is likely the comparatively deeper habitat used by English sole, with 93% of reported commercial catches taken from water < 32 fathoms (Sampson et al. 2005). All available information suggests that the population, coast-wide, is strong, at or above unexploited levels (Sampson et al. 2005, Ralston 2006, Stewart 2007).

Estuarine habitats provide significant nursery habitat for English sole; in a sample of adult English sole collected in central California, 45% to 57% were recruits that used estuarine habitats even though estuaries comprise much less than 50% of the available juvenile habitat in central California (Brown 2006). English sole are known to use Elkhorn Slough as nursery habitat and may be limited in their use of shallow habitats in southern estuaries such as Elkhorn Slough and San Francisco Bay by thermal, depth and salinity tolerances (Yoklavich et al. 1991, Baxter 1999, Brown 2003, Brown 2006). Juveniles come inshore to estuarine habitat; adults (to 610 mm TL, Love et al. 2005) are found offshore (Gunderson et al. 1990).

California tonguefish

California tonguefish are found from Vancouver Island, Canada, south to the Gulf of California (Leet et al. 2001), and are most abundant between 20 and 60 m depth (see Kramer 1990). They are a small flatfish (to 210 mm SL Love et al. 2005) that lacks any fisheries significance but are part of a large suite of forage fishes and are ecologically important (Barry et al. 1996). Kramer (1990) found that the smallest (< 30 mm SL) and largest (>151 mm) size classes were most abundant in deeper, open coast sites; the intermediate size classes were generally shallow (< 7 m) and in bays.

We lack sufficient data to draw any conclusions regarding range-wide and long-term trends in the population, although surveys ending in 1998 from San Francisco Bay by California Department of Fish and Game provide some insight regarding local abundance. In San Francisco Bay, California tonguefish abundance peaked in 1983, and 1993-1994, with a smaller peak in 1988 (Baxter 1999). Abundance appears to be linked to fall and winter water temperature, especially toward the northern part of the species' range (Baxter 1999). California tonguefish are relatively uncommon in Elkhorn Slough (Yoklavich et al. 1991).

C. Factors affecting estuarine abundance

From a restoration perspective, the estuarine abundance of these flatfish species appears to be determined by two sets of factors: Those driven by <u>local factors</u> within estuaries such as water quality, quantity of rearing habitat, prey availability, and fishing pressure and regional factors that include larval survival, and oceanographic conditions — marine ecological factors regulating populations (e.g., life stage-specific survival). In this section we address the factors unlikely to be directly addressed by restoration efforts, but important when considering estuarine restoration or alteration.

Biogenic habitat

Estuarine substrate characteristics are strongly influenced by resident fauna, both infauna such as bivalves and crustaceans (e.g., MacGinitie 1935, Wood and Widdows 2002) and epifauna such as rays, some flatfish and other benthic foragers. Woody debris (Maser and Sedell 1994) and detritus from the upland watershed and from marsh and estuarine plants (Kimmerer 2004) also contribute to the qualities of the habitat. Microbial activity also affects fish ecology; Powers et al. (2005) found that hypoxic conditions attributed to decreasing water quality in an estuary in the eastern U.S. had deleterious effects on the prey base for estuarine fishes.

Vegetation in the form of salt marsh plants, submerged flowering plants and algae also plays a role in the ecology of estuarine fishes. Eelgrass, for example, provides important habitat for a number of estuarine fishes (e.g., pipefishes, shiner perch, Allen et al. 2002). These resources also provide a significant component of the trophic basis for estuarine fishes (Kwak and Zedler 1997).

Prey

Estuaries are some of the most biologically productive natural systems in the world (Whittaker and Likens 1973). The availability of flatfish prey resources undoubtedly affects their estuarine abundance, especially for those species using estuaries as nursery habitat (Able 2005). Presumably, high productivity contributes to the role of estuaries as nursery habitat for select fish species. The role of prey availability and its influence on the community and trophic ecology of estuarine fishes in Elkhorn Slough has been documented by Barry et al. (1996).

Predation

Predation is often cited as a contributing factor to the importance of estuaries as nursery habitat, but the data to test this hypothesis is conspicuously lacking (Able 2005). While estuaries may offer some refuge from larger fishes, piscivorous fishes certainly are not absent; leopard sharks, sand sole and California halibut are perfectly capable predators (Barry et al. 1996). In addition, the reduced depth brings their inhabitants closer to the surface and in range of a wide array of avian predators (Kushlan 1976, Ehrlich et al. 1988); piscivorous marine mammals, especially harbor seals, also use estuaries (Oxman 1995). However, turbidity may be higher in estuaries, helping fish avoid visual predators. In addition, higher growth rates associated with abundant food resources and higher temperatures may also decrease vulnerability to predators.

Climate

Large-scale changes in the ocean environment have been correlated with fish population fluctuations (e.g., Lehodey et al. 1997, Pearcy 2002, Torres-Orozco et al. 2006), but the response—where investigated—by these flatfish species has been variable. Allen et al. (2003, Allen et al. 2004) documented evidence that the abundance of speckled sanddab was negatively correlated with El Niño-Southern Oscillation; California halibut population may respond to the Pacific Decadal Oscillation though the authors point out that the increase in halibut landings in the 1990s may be attributable to the closure of the set gillnet fishery. In short, oceanographic changes are likely to affect fish populations and may have positive or negative effects. In all instances, these may be complicated by factors such as evolving fishing regulations, habitat changes, introduced species and more.

Human harvest

Recreational and commercial fishermen both use estuaries. Perch, sharks, and Pacific herring (*Clupea pallasi*) are among the more important commercial species or species groups captured from these environments. Recreational fishermen target perch, sharks, bat rays, and flatfishes. Both user groups have the potential to impact local populations significantly.

While fishing activities are capable of impacting fish populations (e.g., Pauly et al. 1998, Coleman et al. 2004, Love 2006), in general, there is little evidence that fisheries at their current level of intensity are regulating populations of these flatfish species. As indicated in a previous section, commercial fishing activity during the 1920s was probably largely responsible for declines in the California halibut population (Leet et al. 2001) and Engel and Kvitek (1998) documented changes in the putative flatfish prey base attributable to the effects of bottom trawling, but we are aware of no evidence that these species are currently over-fished.

Offshore resources

Offshore habitat and prey availability could, in theory, affect flatfish populations and thus their estuarine abundance. To our knowledge, only Engel and Kvitek (1998) have addressed this possibility for California species, by comparing benthic fish and invertebrate fauna between a lightly trawled and a heavily trawled areas. Despite dramatic habitat changes and alterations to the benthic infauna, they found no significant differences in the local abundance of flatfishes although there did appear to be changes in prey composition based on gut content analyses (Engel and Kvitek 1998).

Recruitment limitation

There is little evidence to suggest that estuaries offer important habitat to larval or pre-settlement juvenile flatfishes, although they have been present in ichthyoplankton surveys, generally in those areas most directly affected by the ocean (Nybakken et al. 1977, Emmett et al. 1991). Post-settlement juvenile English sole, California halibut, speckled sanddab, and starry flounder migrate into estuarine areas from the open coast (Orcutt 1950, Gunderson et al. 1990, Haugen 1990, Kramer 1990, Baxter 1999, MacNair et al. 2001, Fodrie and Mendoza 2006). While post-settlement processes associated with estuarine conditions could affect recruitment strength, the relative importance of recruitment limitation in fish populations has been the subject of considerable debate (Mapstone and Fowler 1988, Sale 1990, Caley et al. 1996, Levin 1998, Planes et al. 1998, Mora and Sale 2002). English sole, California halibut and starry flounder recruitment levels appear to have a comparatively high probability of affecting population demographics.

D. Factors that determine estuarine distribution

In general, estuarine and embayment habitats with conditions comparable to nearshore coastal habitats are most important to flatfish species. Water depth, tidal influence, temperature, salinity, and water quality (including dissolved oxygen, turbidity, and pollution levels) can affect fish distributions (Table 2).

In particular, water quality and habitat complexity have important, albeit complicated, effects on fish ecology (e.g., Wooton 1991, Matern et al. 2002). Higher temperatures associated with shallow bays and estuaries can contribute to increased growth rates (Schmidt-Nielsen 1997) and the relevance of these habitats to the ecology of juvenile fishes (e.g., Barry et al. 1996, Walsh et al. 1999, Beck et al. 2003, Able 2005). Field studies, however, have been equivocal on this issue (Able 2005). Clearly, other factors are likely to be involved. Dissolved oxygen levels (Powers et al. 2005, Thomas et al. 2007), turbidity (Walsh et al. 1999, Islam and Tanaka 2006), ultraviolet radiation (Nelson et al. 2003, Zamzow 2004), flow or current (Emmett et al. 1991, Ritter et al. in press), and substrate composition (Cabral 2000) also have known or potential impacts on the distribution of estuarine fishes.

Along the California coast, the salinity of estuaries has a strong seasonal component (Allen et al. 2006). This is reflected by intra- and inter-annual changes in fish abundance (e.g., Matern et al. 2002, Allen et al. 2006). Matern et al. (2002) characterized the fishes of Suisun Marsh, in part, on the basis of those that exhibited seasonal abundance patterns. This association is not unique to the west coast of North America; Cabral (2000), for example, measured greater seasonal fluctuations in salinity and temperature in the inner portions of a Portuguese estuary; these patterns were positively correlated with the abundance of five local flatfish species.

‘Estuarine dependence’ is a term more easily employed than demonstrated (Able 2005). There are varying levels of dependency, geographic variations, and a broad array of environmental and life history factors at play. The best established relationships between fish distribution and environmental factors pertinent to this report are the use of estuarine nursery habitat by California halibut (Kramer 1991, Fodrie and Mendoza 2006), starry flounder (Orcutt 1950), speckled sanddab (Brown 2003) and English sole (Brown 2006) (Tables 3 and 4). For these species, the availability of shallow, tidally influenced habitat appears to be crucial.

Estuarine restoration efforts involving changes to the physical environment are likely to affect flatfish populations. Depth and the relative availability of channels, bay mouth habitat, and tidal flats are similarly important, both directly in terms of the quantity of suitable habitat and indirectly with their impact on predators and prey. Flatfishes generally are associated with soft bottom substrates, but individual species exhibit habitat preferences. Despite the relatively low number of marine fish species that rely directly on estuarine habitat, the combination of the low initial availability of estuarine habitat and its elimination and degradation on the west coast of the United States make it a conservation priority. In addition, indirect effects, such as changes to trophic level interactions that result in the altered availability of prey species or predation pressure, are more difficult to anticipate but are likely to be significant.

E. Predicted changes in estuary-wide abundance in response to estuarine restoration projects

Because these flatfishes use estuaries, an increase in subtidal habitat in any estuary is likely to benefit local populations. Those species most affected by changes to the deeper portions of an estuary, closer to the confluence with the ocean, would be the speckled sanddab and larger starry flounder. Juvenile starry flounder and juvenile California halibut would probably be more strongly affected by changes to shallower habitat (both) and those portions with greater freshwater influence (starry flounder). Based on the catch statistics reported by Barry et al. (1996), California tonguefish may benefit from increased availability of high salinity (i.e. minimal freshwater input) back channels. Brown (personal communication) captured large numbers of the smallest size classes of English sole and speckled sanddab on shallow mudflats; for these species, the loss of shallow mudflats could be detrimental.

In general, deeper habitat, close to the mouth of the slough, is of greater value than shallow habitat, but some species use shallow portions, tidal flats, and the more euryhaline sections as small juveniles, moving into deeper habitat as they grow larger. Restoration projects that improved water quality through vigorous tidal exchange and reduced non-point source pollution would offer similar benefits, generally.

F. Status and trends of Elkhorn Slough populations

Quantitative sampling of flatfish populations in Elkhorn Slough has occurred over the past thirty years. These data allow for detection of broad trends, but sampling frequency and consistency was not great enough to allow for robust characterization of fine-scale trends. Yoklavich et al. (2002) found that flatfish abundances at Dairy, Kirby Park and Long Canyon sites in 1995-1996 were less than those documented between 1974-1980 and 1991-1992 (Figure 3, Table 5). The abundance of speckled sanddab also declined at the Bridge site (Table 5). Starry flounder, common in Elkhorn and Bennett Sloughs during the 1970s and 1980s, are no longer abundant (Yoklavich et al. 2002). Grannis (2006) built on the Yoklavich data and found that variability in species distribution and abundance in ichthyoplankton in Elkhorn Slough was correlated to local variability in upwelling and large scale oceanographic events.

Studies of midden data offer a perspective on human uses of Elkhorn Slough resources and on changes in its fish comunity. Gobalet (1993) found the remains of starry flounder, English sole, California halibut and additional pleuronectid or paralichthyid flatfishes in sites adjacent to Elkhorn Slough that date to 7,500 years before present. In a later study, 33% of the fish remains from Elkhorn Slough middens were from flatfishes, mostly starry flounder (Gobalet and Jones 1995). These collections document a rather different Elkhorn Slough fish community: Prior to 1908 the Salinas River reached the ocean via Elkhorn Slough, and the fish assemblage sampled by Native Americans included a sizeable proportion of freshwater species (Gobalet and Jones 1995). The Slough, cut off from the Salinas River, is now dominated by marine fishes (Yoklavich et al. 1991).

Creel surveys of recreational anglers also indicate different trends in abundance than the trawl data. Sand sole, speckled sanddab, and, to a lesser extent, starry flounder have, apparently, increased in the western reaches of the Slough (Table 6). English sole, slender sole and diamond turbot, which were found in low numbers west of the Highway One bridge in the 1970s, were absent from surveys during the 1980s and 1990s (Table 6). Starry flounder had been caught in the eastern sites in the 1970s, but was not present during later surveys (Table 6). An early study (MacGinitie 1935) also mentioned that starry flounder were "quite plentiful" at the Slough in the 1920s, with fishermen catching "considerable numbers" of them.

Of the fishes considered here, English sole abundance was most seasonal; during spring, juveniles were abundant at all stations in the main channel (Yoklavich et al. 1991). Their abundance increased at the ocean station during the fall; the greater size of the latter samples supports the hypothesis that these juveniles were emigrating to marine habitats during this period (Yoklavich et al. 1991). Speckled sanddab, California halibut, and starry flounder occurred as juveniles in larger numbers at the stations closest to the entrance of Elkhorn Slough and during the spring and summer months (Yoklavich et al. 1991).

We are unaware of any on-going, systematic effort to quantitatively monitor changes in flatfish abundance in the Slough at this time, although Brown (2002) has proposed a monitoring plan that would address this need.

One of the major challenges in assessing anthropogenic effects on marine populations is distinguishing between changes due to human activity and those due to environmental variables. Allen et al. (2004) point out that cyclical climate change (e.g., the Pacific Decadal Oscillation) has been shown to have demonstrable effects on fish populations, principally through their effect on larval ecology or on planktonic prey availability (Chavez et al. 2003). The status of these cyclical climatic/oceanographic processes should be considered when evaluating anthropogenic effects, including restoration efforts, on estuarine systems.

Factors affecting distribution and abundance at Elkhorn Slough

Major factors that may have influenced the distribution and abundance of these flatfish at Elkhorn Slough over the past 150 years are reviewed below.

Restriction of tidal exchange

More than 50% of Elkhorn Slough's estuarine habitats were diked and removed from natural tidal influence to support human land uses over the past 150 years (van Dyke and Wasson 2005). While tidal exchange has been restored to some of these areas, about a third of historic estuarine habitat still remains behind water control structures. A recent study (Ritter et al. in press) found that flatfish are more common in Elkhorn Slough at sites with full tidal exchange than ones behind water control structures; they are absent entirely from tidally restricted sites with minimal tidal exchange, and less common in sites with moderate exchange through water control structures. One extensive wetland area, the Parsons Slough complex, was diked and drained for decades, but returned to tidal exchange in the 1980s (van Dyke and Wasson 2005). Therefore, in this area, there has been a net gain of potential mudflat habitat for flatfish. Overall, however, the restriction of tidal exchange has likely decreased the abundance of flatfishes in Elkhorn Slough.

Harbor mouth

In 1946, the Army Corps of Engineers created a new, larger mouth to the Elkhorn Slough to accommodate Moss Landing Harbor. The effects of harbor construction and mouth maintenance on flatfish populations are unclear. On the one hand, this may have increased the net amount of suitable habitat for these species near the mouth of the estuary, deepening the entrance channel and increasing the rate of tidal exchange. The increased tidal range also dramatically increased the area of intertidal mudflats along the main Elkhorn Slough channel (Wasson, personal communication), although most of the extensive new areas of mudflat are far from the mouth and at a high intertidal elevation, and thus may not represent appropriate mudflat habitat for flatfish.

Conversely, the altered harbor may also have led to a decrease in suitable habitat for flatfish. The harbor was constructed in areas that formerly hosted abundant populations of invertebrates in intertidal mudflats and shallow subtidal mudflats and eelgrass beds (MacGinitie 1935). There was a substantial loss of habitat as harbor structures replaced these natural habitats. In portions of the main channel of Elkhorn Slough, rapid tidal velocities related to the artificially large estuarine mouth have scoured unconsolidated soft substrate (J. Oliver, personal communication), which may have decreased flatfish invertebrate prey resources. The timing of dredging also could interrupt the migration of juvenile flatfish entering or leaving estuarine habitat.

In summary, it is unknown whether there has been a net gain or loss of suitable habitat in Elkhorn Slough, and thus estuary-wide abundance of flatfish resulting from the construction and maintenance of the harbor mouth.

Water quality

Freshwater inputs to Elkhorn Slough have decreased over the past century, with diversion of rivers and decrease in groundwater due to heavy agricultural usage (Caffrey et al. 2002). During the rainy season, salinity has likely increased significantly in the estuary compared to historical levels. The shift to more marine salinities year-round may have increased the distribution of flatfish species that cannot tolerate extended periods of low salinity (e.g., speckled sanddab, sand sole (*Psettichthys melanostictus*).

Water quality in Elkhorn Slough has decreased over time as a result of changes in land use. In particular, high concentrations of pesticides and nutrients occur during the rainy season, especially in southwestern portion of the estuary and near the mouth (Caffrey et al. 2002). This is important because flatfishes may be uniquely sensitive to the presence of contaminants, and represent a possible means for monitoring estuarine pollutants (LeBlanc and Bain 1997, Allen et al. 1999, Allen 2006).

Power plant entrainment

A large power plant operates near the mouth the estuary, with intake pipes in the harbor taking in a volume of water equivalent to about a third of the volume of Elkhorn Slough per day when operating at maximum capacity. Plankton tows and population modeling suggest that impacts on most fish populations in the Slough are minor (TENERA 2005), but power plant effects on flatfish abundance cannot be ruled out.

G. Predictions for Elkhorn Slough

Overview

Four large-scale management alternatives for Elkhorn Slough were developed with the goal of decreasing rapid rates of subtidal channel scour and salt marsh conversion to mudflat habitat that have been documented over the past decades (Largay and McCarthy, 2009; Williams et al., 2008). Changes to physical processes and water quality in response to these management alternatives vs. a "no action" alternative have been modeled and summarized (Williams et al. 2008, Largay and McCarthy 2009). To determine which management alternative best optimizes estuarine ecosystem health, the coastal decision-makers involved in this process of wetland restoration planning require at minimum some basic information about how species that play major ecological or economic roles are likely to respond to the different management alternatives. In the absence of detailed demographic data and rigorous quantitative modeling, it is impossible to obtain robust quantitative predictions about response of these key species. Instead, the goal of the preceding review of factors affecting density and distribution of the species across their range and the evaluation of trends at Elkhorn Slough is to provide sufficient information to support qualitative predictions based on professional judgment of experts. These predictions represent informed guesses and involve a high degree of uncertainty. Nevertheless, for these species the consensus of an expert panel constitutes the best information available for decision-making.

Biological predictions based on habitat extent

Our assessment of the management alternatives has multiple components. First, we predict how population sizes will respond to alternatives based only on extent of habitat of the appropriate tidal elevation. This assessment was based on the predictions of habitat extent at Year 0, 10, and 50 under the five alternatives (as summarized in Largay and McCarthy 2009 and shown in Table 7). Note that all alternatives involve major loss of salt marsh and concurrent gain of other habitat types at year 50; this is due to an assumption of 30 cm of sea level rise after 50 years, which largely overshadows effects of the alternatives. A significant change in habitat area was defined as an increase or decrease of 20% or greater over year 0, No Action (Alternative 1) acreages. Likewise, a significant change in population size of the species was defined as an increase or decrease of 20% or greater over the average population size of the past decade (1999-2008). For the habitat and species predictions, the geographic boundaries are all the fully tidal estuarine habitats of Elkhorn Slough excluding the Parsons complex (predictions do not include tidally restricted areas). For this first component, we made a very simplified assumption that estuary-wide population size is a linear function of area of habitat of appropriate tidal elevation. Thus for example a significant increase in habitat extent translates directly into a significant increase in local population size. For some species this may be true (if the habitat converted is high quality) while for others it will not be true. There is some level of uncertainty in the actual habitat conversions and the quality of the converted habitat for different species.

The flatfish considered here are found in intertidal and subtidal mudflats (and both shallow and deep subtidal areas), so we used habitat predictions for "total mud" (part E of Table 7). The shallower areas may be especially important as nursery habitat, but deeper areas are also used for foraging. The predictions based on habitat extent alone are indicated with "H" and shown in blue in Figure 4. At the scale of a whole estuary, there is probably a weak correlation between areal extent of available habitat and estuary-wide population size. For instance, a tiny estuary is likely to host fewer flatfish than a large one. For two estuaries of equal size, one dominated by salt marsh with only a few areas of mud in narrow tidal creeks is likely to host fewer flatfish than one with extensive intertidal mudflats or subtidal channels. So habitat-based predictions are a reasonable starting point for considering management effects on flatfish.

Factors other than habitat extent that may be altered by management alternatives

Clearly the assumption of a strictly linear correlation between population size and extent of habitat of appropriate tidal elevation is overly simplistic and unlikely to accurately describe population response to the alternatives. Habitat quality (changes in bank slope or sediment type) or environmental conditions other than habitat extent are also important drivers of estuary-wide population size. Unfortunately, at this time, we lack quantitative predictions for most parameters relevant to habitat quality for these species. In order to address this shortcoming, we attempted to identify key aspects of each management alternative that might affect habitat quality or critical environmental conditions. Consideration of these aspects led to characterization of “best case” and “worst case” scenarios for each alternative, indicated by arrows in Figure 4. These arrows represent qualitative assessments; the exact length or location of the arrow has no quantitative significance. Each arrow is marked with a letter; abbreviations are described below. The description of the range of possible outcomes may be as important for decision-makers as the rough predictions of changes to population sizes based on habitat extent. Moreover, we indicate what sort of measures might be taken to avoid or mitigate the worst-case scenario. This information will provide important guidance on future design or refinement of management alternatives. Identification of important parameters other than habitat extent which may be altered by the management alternatives may also lead to future physical modeling (such as geomorphic changes) and predictions of these parameters, funding permitting, which would enable more robust biological predictions to be made in future iterations of this process, as management alternatives are refined. Here we review the factors invoked in the development of worst and best case scenarios for each of the alternatives.

Marine influence will increase over time under Alternatives 1 and 4, likely with associated habitat quality changes, such as increased extent of sandy (vs. silty or muddy) habitat, increased tidal prism and decreased residence time. Conversely, marine influence will decrease under Alternatives 2-3, which shrink the estuarine mouth size to various degrees. Dissolved oxygen concentrations in Elkhorn Slough show much stronger diurnal fluctuations in the upper vs. lower estuary, and hypoxia is more prevalent in the upper estuary (Figure 5). Increased marine influence under Alternatives 1 and 4 should dampen dissolved oxygen fluctuation, while decreased marine influence under Alternative 2 and 3 may increase diurnal cycling and hypoxia. Salinity in the estuary is not anticipated to change significantly under the management alternatives, since freshwater inputs to the head of the estuary are very limited relative to tidal flushing. Currently there are few differences between the lower and upper estuary in salinity, although during rainstorms temporary decreases in salinity are more pronounced in the upper estuary (Figure 6).

As a group, these selected flatfish are likely to respond favorably to increased marine influence and unfavorably to decreased marine influence. In particular, the stronger diurnal cycling of dissolved oxygen associated with reduced tidal flushing may have negative effects on flatfish and decrease population sizes in the estuary. Starry flounders have a tolerance for low salinity, even fresh water (Love 1996), but the potential benefit from a slight reduction in salinity in rainy periods is likely to be minor compared to the potential harm from greater oxygen cycling and increased hypoxia. Greater marine influence also involves better connectivity between Monterey Bay and Elkhorn Slough, through a larger mouth opening and shorter residence time of estuarine waters, which might increase population sizes of all the species. These potential increases in estuary-wide population size associated with increased marine influence are illustrated with arrows marked “+m” in Alternatives 1 and 4 in Figure 4; conversely, the potential decreases in estuary-wide population size associated with decreased marine influence are illustrated with arrows marked “-m” in Alternatives 2-3 in Figure 4. No doubt the magnitude of the effects of these changes in habitat quality would differ between alternatives (e.g., weaker in 3a than 3b) and between individual flatfish species (e.g., tonguefish favor marine conditions more than starry flounder), but for the purposes of these predictions, our intent was to identify broadly the likely direction of change in habitat quality for these flatfish as a group.

The three alternatives which decrease the estuarine mouth size (Alternatives 2, 3a, 3b) might lead to decreased estuarine population sizes due to navigational issues. However, the mouth size still should be ample for passage under Alternative 2 (new mouth) and Alternative 3a (low sill), since it would be no smaller than mouths of many estuaries along this coast which harbor flatfish populations. Alternative 3b (high sill) might pose significant navigational barriers, such as high turbulence or unusual currents, or increased predation risk in the shallow waters of the sill. Potential decreases in estuarine population sizes resulting from such navigational barriers are indicated with “+b” for Alternative 3b in Figure 4.

Biological predictions under different management alternatives

Each alternative is evaluated below. The assessment for each includes a) predictions based on extent of habitat of appropriate tidal elevation alone (Table 7), summarized by the “H” and blue font in Figure 4, and b) consideration of other factors (habitat quality, environmental conditions) related to the management alternatives that might alter these predictions. For each management alternative, the “best” and “worst” case scenarios (indicated by arrows in Figure 4), are presented, including suggestions for mitigation or avoidance of worst case scenarios.

Alternative 1 – No action

By definition, there will be no significant change in Year 0. Based on habitat extent changes alone, we also predict no change at Year 10. By Year 50, rising sea level is expected to increase significantly the extent of mud habitats, such that from habitat availability alone, we predict an estuary-wide increase in the population sizes of flatfish under consideration.

At Year 10 and 50, marine influence will have increased due to further tidal scour, greater channel cross-section, and larger tidal prism. Increased marine influence may improve habitat quality for flatfish in the estuary, leading to increased estuary-wide population sizes beyond what is predicted based on habitat extent alone; these potential increases are shown with the arrows marked “+m” for this alternative for Years 10 and 50 in Figure 4.

Alternative 2 – Re-route of estuary mouth to create new inlet and decrease tidal prism

Based on habitat extent changes alone, we predict no changes in estuary-wide population sizes of flatfish in any year, since no significant change in total mud habitat is predicted.

Decreased marine influence resulting from this alternative may however decrease habitat quality for flatfish species, in particular by resulting in increased frequency or duration of hypoxia. Connectivity between Monterey Bay and Elkhorn Slough may also be reduced due to the decreased mouth size and tidal currents and flushing. Potential decreases in estuary-wide flatfish population sizes resulting from decreased marine influence are shown with arrows marked "-m" for this alternative for all years.

Potential decreases in flatfish populations from this alternative might be mitigated by designing the estuarine mouth to both reduce the likelihood of water column stratification and subsequent hypoxia and to improve connectivity and fish movement between Monterey Bay and Elkhorn Slough. To mitigate a worst case scenario associated with extended hypoxia, implementation of this alternative could occur concurrently with changes in land use practices to decrease nutrient loading to the estuary.

Alternative 3a – Low sill under Highway 1 bridge to slightly decrease tidal prism

The habitat-based predictions are the same as those for Alternative 1: based on habitat extent alone, estuary-wide population sizes are not expected to change significantly in Years 0 and 10, but are expected to increase significantly in Year 50.

The habitat quality predictions are the same as those for Alternative 2: in all years, there could be potential decreases in estuary-wide flatfish populations resulting from factors associated with decreased marine influence. The mechanisms for mitigating these decreases are also the same as described above for Alternative 2.

Alternative 3b – High sill under Highway 1 bridge to strongly decrease tidal prism

The habitat-based predictions and potential decreases resulting from reduced marine influence are identical to those provided for Alternative 2, and the mechanisms for mitigating for the potential reductions are the same. In addition, the high sill may provide a significant barrier to fish passage, resulting in further decreases in fish population sizes as indicated by the "+b" in Figure 4.

Alternative 4 – Decreased tidal prism in Parsons complex

The predictions for this alternative are identical as those for Alternative 1.

Synthesis: ranking management alternatives for this taxon

Overall, it appears that Alternatives 1 and 4 are the ones most likely to optimize flatfish abundance in the estuary. Habitat extent (intertidal and subtidal mudflats and channels) increases under Alternatives 1, 3a, and 4. But while habitat quality has the potential to increase as well under Alternatives 1 and 4 due to increasing marine influence, it has the potential to decrease under Alternative 3a as well as 3b and 2. Of these latter Alternatives, Alternative 3b is of greatest concern due to the potential barrier to navigation. In general, then "no action" or conditions and trends similar to the present are better for flatfish than marine engineering

projects which decrease the size of the estuarine mouth and/or tidal prism. The ranking of alternatives from the perspective of flatfish is:
Alternative 1 > 4 > 3a > 2 > 3b.

External factors affecting population trends and importance relative to management alternatives

In addition to changes induced by the above management alternatives, populations of these flatfish species may be significantly affected by other factors over the next decades. Further constraints on recreational fishing would likely result in local abundance increases. In addition, significant changes in the abundance of predators unrelated to the management alternatives could translate into changes in the abundance of Elkhorn Slough flatfish species. For instant, declines in the population abundance of pinnipeds, leopard sharks, or other predators of larval, juvenile, or adult flatfishes could lead to increased flatfish numbers. Demographic trends for these predators are too uncertain to predict whether this will be an important factor relative to habitat changes. Other potential factors include changes in the entrainment of larvae in the cooling waters of the Moss Landing Power Plant or global climate change, including ocean acidification, alterations in the seasonal patterns or intensity of coastal upwelling or water temperature. These could have direct as well as indirect effects, but uncertainty about the timing and local intensity of these phenomena is still very high. Thus there are no factors that are clearly likely to overshadow the habitat changes resulting from the management alternatives, though this possibility cannot be ruled out.

Targeted restoration actions for these species at Elkhorn Slough

There are no species-specific, targeted restoration methods that would have a high likelihood of enhancing the numbers of Elkhorn Slough flatfish species. Improvements to water quality, including reductions in nutrient loading which would decrease frequency and duration of low oxygen conditions, would probably benefit flatfish populations as well as many other indicators of ecosystem health.

Importance of Elkhorn Slough population sizes

Estuarine habitats have been declining along the California coast for over a century, and with them nursery habitat for California halibut, Pacific sanddab, diamond turbot and English sole. Estuarine habitat is utilized heavily by starry flounder, but there are no apparent indications that the reduction in estuarine habitat is affecting the stock abundance of starry flounder. Changes in Elkhorn Slough are unlikely to have measurable impacts on range-wide population sizes of these flatfish species. Nevertheless, Elkhorn Slough likely plays a significant regional role for flatfish populations on the central California coast – these flatfish populations have important ecological roles and support significant sport and commercial fisheries. Based on all of the above, significant declines in these species are a cause for concern and should be avoided.

H. References

Able KW (2005) A re-examination of fish estuarine dependence: Evidence for connectivity between estuarine and ocean habitats. Estuar Coast Shelf Sci 64:5-17

Allen LG, Findlay AM, Phalen CM (2002) Structure and standing stock of the fish assemblages of San Diego Bay, California from 1994 to 1999. Bulletin of the Southern California Academy of Sciences 101:49-85

Allen LG, Yoklavich MM, Cailliet GM, Horn MH (2006) Bays and Estuaries. In: Allen LG, Pondella DJ, Horn MH (eds) The Ecology of Marine Fishes: California and Adjacent Waters. University of California Press, Berkeley, p 119-148

Allen MJ (2006) Pollution. In: Allen LG, Pondella DJ, Horn MH (eds) The Ecology of Marine Fishes: California and Adjacent Waters. University of California Press, Berkeley, p 595-610

Allen MJ, Smith RW, Jarvis ET, Raco-Rands V, Bernstein BB, Herbinson KT (2003) Temporal trends in southern California nearshore fish populations relative to environmental influences, DRAFT REPORT Prepared for California State Coastal Conservancy and Santa Monica Bay Restoration Commission, Southern California Coastal Water Research Project, Westminster, CA

Allen MJ, Smith RW, Jarvis ET, Raco-Rands V, Bernstein BB, Herbinson KT (2004) Temporal trends in southern California coastal fish populations relative to 30-year trends in oceanic conditions. In: Weisberg SB, Elmore D (eds) Southern California Coastal Water Research Project Biennial Report 2003-2004. Southern California Coastal Water Research Project, Westminster, CA, p 264-285

Allen Y, Scott AP, Matthiessen P, Haworth S, Thain JE, Feist S (1999) Survey of estrogenic activity in United Kingdom estuarine and coastal waters and its effects on gonadal development of the flounder *Platichthys flesus*. Environmental Toxicology and Chemistry 18:1791-1800

Appiah JC, Jr. (1977) Species composition and abundance of fish populations in Bennett Slough, Monterey Bay, California. California State University

Barry JP (1983) Utilization of shallow marsh habitats by fishes in Elkhorn Slough, California. California State University, San Jose

Barry JP, Yoklavich MM, Cailliet GM, Ambrose DA, Antrim BS (1996) Trophic ecology of the dominant fishes in Elkhorn Slough, California, 1974-1980. Estuaries 19:115-138

Baxter R (1999) Pleuronectiformes. In: Orsi JJ (ed) Report on the 1980-1995 Fish, Shrimp, and Crab Sampling in the San Francisco Estuary, California Technical Report 63. The Interagency Ecological Program for the Sacramento-San Joaquin Estuary, Sacramento, California, p 74

Beck MW, Heck Jr. KL, Able KW, Childers DL, Eggleston DB, Gillanders BM, Halpern BS, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MP (2001) The identification, conservation and management of estuarine and marine nurseries for fish and invertebrates. Bioscience 51:633-641

Beck MW, Heck Jr. KL, Able KW, Childers DL, Eggleston DB, Gillanders BM, Halpern BS, Hays CG, Hoshino K, Minello TJ, Orth TJ, Sheridan PF, Weinstein MP (2003) The role of near shore ecosystems as fish and shellfish nurseries. Issues in Ecology 11:1-12

Brown JA (2002) A plan for monitoring the fish assemblage in Elkhorn Slough, Elkhorn Slough National Estuarine Research Reserve

Brown JA (2003) An evaluation of the nursery role of estuaries for flatfish populations in central California. Dissertation, University of California

Brown JA (2006) Using the chemical composition of otoliths to evaluate the nursery role of estuaries for English sole (*Pleuronectes vetulus*) populations. Marine Ecology Progress Series 306:269-281

Cabral HN (2000) Distribution and abundance patterns of flatfishes in the Sado Estuary, Portugal. Estuaries 23:351-358

Caffrey J, Brown M, Tyler WB, Silberstein M (2002) Changes in a California estuary: a profile of Elkhorn Slough, Vol. Elkhorn Slough Foundation, Moss Landing, California

Cailliet GM, Burton EJ, Cope JM, Kerr LM (2000) Biological characteristics of nearshore fishes of California: A review of existing knowledge and proposed additional studies for the Pacific Ocean interjurisdictional fisheries management plan coordination and development, California Department of Fish and Game

Caley MJ, Carr MH, Hixon MA, Hughes TP, Jones GP, Menge BA (1996) Recruitment and the local dynamics of open marine populations. Ann Rev Ecol Syst 27:477-500

Chavez FP, Ryan J, Lluch-Cota SE, Niquen C M (2003) From Anchovies to Sardines and Back: Multidecadal Change in the Pacific Ocean. Science 299:217-221

Coleman FC, Figueira WF, Ueland JS, Crowder LB (2004) The Impact of United States Recreational Fisheries on Marine Fish Populations. Science 305:1958-1960

Ehrlich PR, Dobkin DS, Wheye D (1988) The Birder's Handbook: A Field Guide to the Natural History of North American Birds, Vol. Fireside

Emmett RL, Hinton SA, Stone SL, Monaco ME (1991) Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume II: Species life history summaries. Report No. ELMR Rep. No. 8, NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD

Engel J, Kvitek R (1998) Effects of Otter Trawling on a Benthic Community in Monterey Bay National Marine Sanctuary. Conservation Biology 12:1204-1214

Fodrie FJ, Levin LA (2008) Linking juvenile habitat utiilization to population dynamics of California halibut. Limnology and Oceanography 53:799-812

Fodrie FJ, Mendoza G (2006) Availability, usage and expected contribution of potential nursery habitats for the California halibut. Estuar Coast Shelf Sci 68:149-164

Fritzsche RA, Cavanagh JW (1995) A Guide to the Fishes of Humboldt Bay, Vol. Humboldt State University Press, Arcata, California

Gobalet KW (1993) Additional archaeological evidence for endemic fishes of California's Central Valley in the coastal Pajaro-Salinas Basin. The Southwestern Naturalist 38:218-223

Gobalet KW, Jones TL (1995) Prehistoric Native American fisheries of the central California coast. Transactions of the American Fisheries Society 124:813-823

Grannis EP (2006) Long-term variability in the distribution, abundance, and taxonomic composition of larval fishes in Elkhorn Slough, California . M.S. Thesis, California State University, Monterey Bay and Moss Landing Marine Laboratories

Gunderson DR, Armstrong DA, Shi Y-B, McConnaughey RA (1990) Patterns of estuarine use by juvenile English sole (*Parophrys vetulus*) and Dungeness crab (*Cancer magister*). Estuaries 13:59-71

Haugen CW (1990) The California Halibut, *Paralichthys californicus*, resource and fisheries. In: Haugen CW (ed), p 475

Hsieh C-h, Reiss C, Watson W, Allen MJ, Hunter JR, Lea RN, Rosenblatt RH, Smith PE, Sugihara G (2005) A comparison of long-term trends and variability in populations of larvae of exploited and unexploited fishes in the Southern California region: A community approach. Progress in Oceanography 67:160-185

Islam MS, Tanaka M (2006) Spatial variability in nursery functions along a temperate estuarine gradient: role of detrital versus algal trophic pathways. Can J Fish Aquat Sci 63:1848-1864

King JM, Mayer M, Oliver J, Ramer B, Small D, al. e (1986) Monitoring ecological changes in the New South Marsh on Elkhorn Slough National Estuarine Sanctuary, Office of Ocean and Coastal Resource Management, Sanctuary Programs Division, National Oceanic and Atmospheric Administration, Washington, D.C.

Kramer SH (1990) Habitat specificity and ontogenetic movements of juvenile California halibut, *Paralichthys californicus*, and other flatfishes in shallow waters of southern California. Report No. LJ-90-22, National Marine Fisheries Service

Kramer SH (1991) Growth, mortality, and movements of juvenile California Halibut, *Paralichthys californicus* in shallow coastal and bay habitats of San Diego County, California. Fishery Bulletin 89:195-207

Kushlan JA (1976) Wading bird predation in a seasonally fluctuating pond. The Auk 94:464-476

Kwak TJ, Zedler JB (1997) Food web analysis of southern California coastal wetlands using multiple stable isotopes. Oecologia 110:262-277

Largay B, McCarthy E (2009) Management of tidal scour and wetland conversion in Elkhorn Slough: Synthesis of technical reports on large-scale alternatives. Elkhorn Slough Foundation, p 34

LeBlanc GA, Bain LJ (1997) Chronic toxicity of environmental contaminants: Sentinels and biomarks. Environmental Health Perspectives 105:65-80

Leet WS, Dewees CM, Klingbeil R, Larson EJ (2001) California's Living Marine Resources: A Status Report, California Department of Fish and Game

Lehodey P, Bertignac M, Hampton J, Lewis A, Picaut J (1997) El Niño southern oscillation and tuna in the western Pacific. Nature 389:715-718

Levin PS (1998) The significance of variable and density-independent post-recruitment mortality in local populations of reef fishes. Austr J Ecol 23:246-251

Love MS (1996) Probably more than you want to know about the fishes of the Pacific coast. Really big press, Santa Barbara, California, 381 pp.

Love MS (2006) Subsistence, commercial, and recreational fisheries. In: Allen LG, Pondella DJ, Horn MH (eds) The Ecology of Marine Fishes: California and Adjacent Waters. University of California Press, Berkeley, p 567-594

Love MS, Mecklenburg CW, Thorsteinson LK (2005) Resource inventory of marine and estuarine fishes of the west coast and Alaska: A checklist of North Pacific and Arctic Ocean species from Baja California to the Alaska-Yukon border. Report No. OCS Study MMS 2005-030 and USGS/NBII 2005-001, U. S. Department of the Interior, U. S. Geological Survey, Biological Resources Division, Seattle, Washington

MacGinitie GE (1935) Ecological aspects of a California marine estuary. American Midland Naturalist 16:629-765

MacNair LS, Domeier ML, Chun CSY (2001) Age, growth, and mortality of California halibut, Paralichthys californicus, along southern and central California. Fish Bull 99:588-600

Mapstone BD, Fowler AJ (1988) Recruitment and the structure of assemblages of fish on coral reefs. Trends Ecol Evol 3:72-77

Maser C, Sedell JR (1994) From the Forest to the Sea: The Ecology of Wood in Streams, Rivers, Estuaries, and Oceans, Vol. St. Lucie Press

Matern SA, Moyle PB, Pierce LC (2002) Native and alien fishes in a California estuarine marsh: Twenty-one years of a changing assemblages. Transactions of the American Fisheries Society 131:797-816

Miller DJ, Lea RN (1976) Guide to the coastal marine fishes of California, Vol. California Department of Fish and Game

Monaco ME, Nelson DM, Emmett RL, Hinton SA (1990) Distribution and abundance of fishes and invertebrates in west coast estuaries, Volume 1: Data summaries. Report No. ELMR Rep. No. 4, NOAA/NOS Strategic Environmental Assessments Division, Silver Spring, MD

Mora C, Sale PF (2002) Are populations of coral reef fish open or closed? Trends Ecol Evol 17:422-428

Nelson PA, Kajiura SM, Losey GS (2003) Exposure to solar radiation may increase ocular UV-filtering in the juvenile scalloped hammerhead shark, *Sphyrna lewini*. Marine Biology 142:53-56

Nernev L, Lindquist D, Leopold B (1993) A temporal comparison of fish abundances and composition in the restoration site of the Elkhorn Slough National Estuarine Research Reserve, Moss Landing Marine Laboratories

Norton JG, Mason JE (2003) Environmental influences on species composition of the commercial harvest of finfish and invertebrates off California. CalCOFI Report 44:123-133

Nybakken JW, Cailliet GM, Broenkow W (1977) Ecologic and hydrographic studies of Elkhorn Slough, Moss Landing Harbor and nearshore coastal waters. Moss Landing Marine Laboratories, Moss Landing, California, p 465

Orcutt HG (1950) The life history of the Starry Flounder *Platichthys stellatus* (Pallas). Fish Bulletin 78:64

Oxman DS (1995) Seasonal abundance, movements, and food habits of harbor seals (*Phoca vitulina richardsi*) in Elkhorn Slough, California. M.S. Thesis, California State University, Stanislaus and Moss Landing Marine Laboratories

Pauly D, Christensen V, Dalsgaard J, Froese R, Torres Jr. F (1998) Fishing down marine food webs. Science 279:860-863

Pearcy WG (2002) Marine nekton off Oregon and the 1997-98 El Nino. Progress in Oceanography 54:399-403

Philip Williams & Associates L (2008) Hydrodynamic modeling and morphologic projections of large-scale restoration actions, Elkhorn Slough Tidal Wetland Project

Planes S, Jouvenel J-Y, Lenfant P (1998) Density dependence in post-recruitment processes of juvenile sparids in the littoral of the Mediterranean Sea. Oikos 83:293-300

Powers SP, Peterson CH, Christian RR, Sullivan E, Powers MJ, Bishop MJ, Buzzelli CP (2005) Effects of eutrophication on bottom habitat and prey resources of demersal fishes. Marine Ecology Progress Series 302:233-243

Radtke LD (1966) Distribution of smelt, juvenile sturgeon, and starry flounder in the Sacramento-San Joaquin delta with observations on food of sturgeon. In: Turner JL, Kelley DW (eds) Ecological studies of the Sacramento-San Joaquin estuary Part 2, Vol Fish Bulletin 136. Department of Fish and Game, Sacramento, p 115-129

Ralston SV (2006) An assessment of starry flounder off California, Oregon, and Washington. In: Volume 2, Status of the Pacific Coast Groundfish Fishery Through 2005, Stock Assessment and Fishery Evaluation. Pacific Fishery Management Council, Portland, Oregon, p 74

Ritter AF, Wasson K, Lonhart SI, Preisler RK, Woolfolk A, Griffith KA, Connors S, Heiman KW (in press) Ecological signatures of anthropogenic alteration of tidal exchange in estuarine ecosystems. Estuaries and Coasts:49

Rooper C, Gunderson D, Armstrong D (2003) Patterns in use of estuarine habitat by juvenile English sole (*Pleuronectes vetulus*) in four Eastern North Pacific estuaries. Estuaries and Coasts 26:1142-1154

Ryan C, Patyten M (2004) Annual Status of the Fisheries Report Through 2003, California Department of Fish and Game

Sale PF (1990) Recruitment of marine species: Is the bandwagon rolling in the right direction? Trends Ecol Evol 5:25-27

Sampson D, Mohn R, Volstad J, Ianelli J (2005) Starry Flounder, Pacific Marine Fisheries Council, Northwest Fisheries Science Center

Schmidt-Nielsen K (1997) Animal Physiology: Adaptation and Environment, Vol. Cambridge University Press

Schoenherr JR (1984) Fish species composition in Elkhorn Slough National Estuarine Sanctuary and in two other shallow tidal creeks in Elkhorn Slough, Moss Landing Marine Laboratories

Small D (1984) Diel and tidal variation in catch composition of small otter trawls in a shallow tidal creek in Elkhorn Slough National Estuarine Sanctuary, Moss Landing Marine Laboratories, Moss Landing, California

Stewart IJ (2007) Updated U.S. English sole stock assessment: Status of the resource in 2007. In: Volume 2, Status of the Pacific Coast Groundfish Fishery Through 2007, Stock and Assessment and Fishery Evaluation. Pacific Fishery Management Council, Portland, Oregon, p 213

TENERA (2005) Intake effects assessment, TENERA Environmental

Thomas P, Rahman MS, Khan IA, Kummer JA (2007) Widespread endocrine disruption and reproductive impairment in an estuarine fish population exposed to seasonal hypoxia. Proceedings of the Royal Society B: Biological Sciences 274:2693-2701

Toole CL (1980) Intertidal recruitment and feeding in relation to optimal utilization of nursery areas by juvenile English sole (*Parophrys vetulus*: Pleuronectidae). Environ Biol Fish 5:383-390

Torres-Orozco E, Muhlia-Melo A, Trasviña A, Ortega-Garcia S (2006) Variation in yellowfin tuna (*Thunnus albacares*) catches related to El Niño-Southern Oscillation events at the entrance to the Gulf of California. Fishery Bulletin 104:197-203

van Dyke E, Wasson K (2005) Historical ecology of a central California estuary: 150 years of habitat change. Estuaries 28:173-189

Walsh HJ, Peters DS, Cyrus DP (1999) Habitat utilization by small flatfishes in a North Carolina estuary. Estuaries 22:803-813

Whittaker RH, Likens GE (1973) Carbon in the biota. In: Woodwell GM, Pecan EV (eds) Carbon and the biosphere Conference 72501. National Techn. Information Services, Springfield, VA, p 281-300

Wood R, Widdows J (2002) A model of sediment transport over an intertidal transect, comparing the influences of biological and physical factors. Limnology and Oceanography 47:848-855

Wooton RJ (1991) Ecology of Teleost Fishes, Vol. London, Chapman & Hall

Yoklavich MM, Cailliet GM, Barry JP, Ambrose DA, Antrim BS (1991) Temporal and spatial patterns in abundance and diversity of fish assemblages in Elkhorn Slough, California. Estuaries 14:465-480

Yoklavich MM, Cailliet GM, Oxman S, Barry JP, Lindquist D (2002) Fishes. In: Caffrey JM, Brown M, Tyler B, Silberstein M (eds) Changes in a California Estuary: A Profile of Elkhorn Slough. Elkhorn Slough Foundation, Moss Landing, California, p 163-185

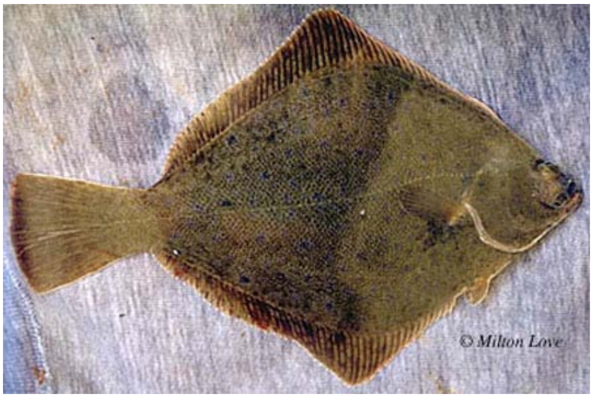
Zamzow JP (2004) Effects of diet, ultraviolet exposure, and gender on the ultraviolet absorbance of fish mucus and ocular structures. Marine Biology 144:1057-1064

Zedler JB, Callaway JC, Sullivan G (2001) Declining biodiversity: Why species matter and how their functions might be restored in Californian tidal marshes. Bioscience 51:1005-1017

California halibut
(Photo by Shane Anderson*)

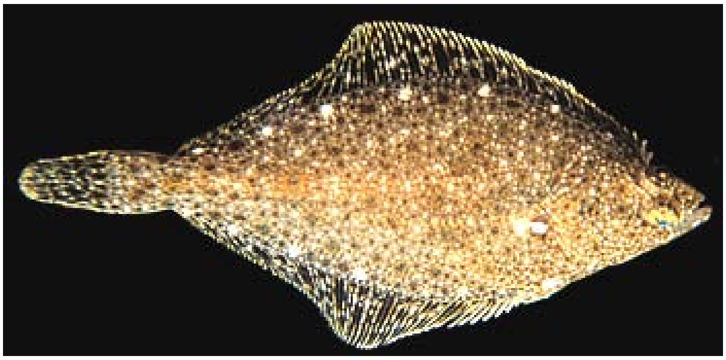
Speckled sandab
(Photo by Shane Anderson*)

Diamond turbot
(Photo by Milton Love*)



Starry flounder
(Photo by Bill Barss)

English sole
(Photo by Jennifer Brown*)



California tonguefish
(Photo by P. J. Bryant*)

Figure 1. Selected flatfish for which Pacific coast estuaries play an important role.
[*Permission received to use photos.]

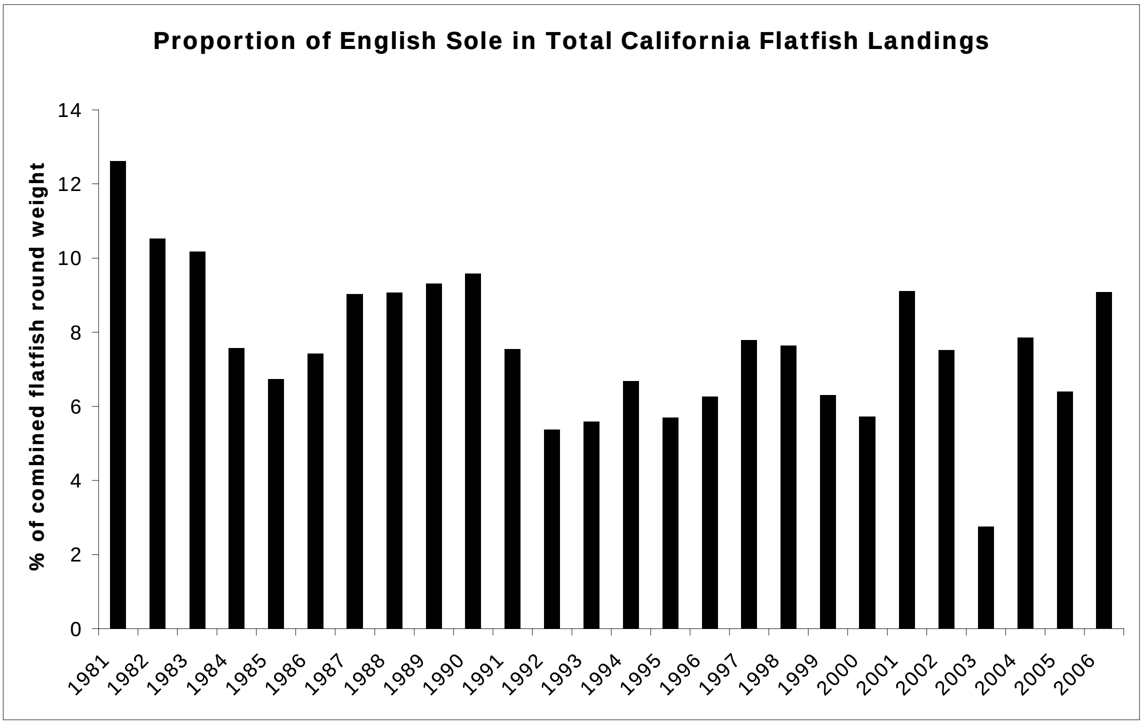


Figure 2. English sole contributed a small and slowly declining proportion of the total quantity of flatfish landed in California ports (commercial fisheries only).

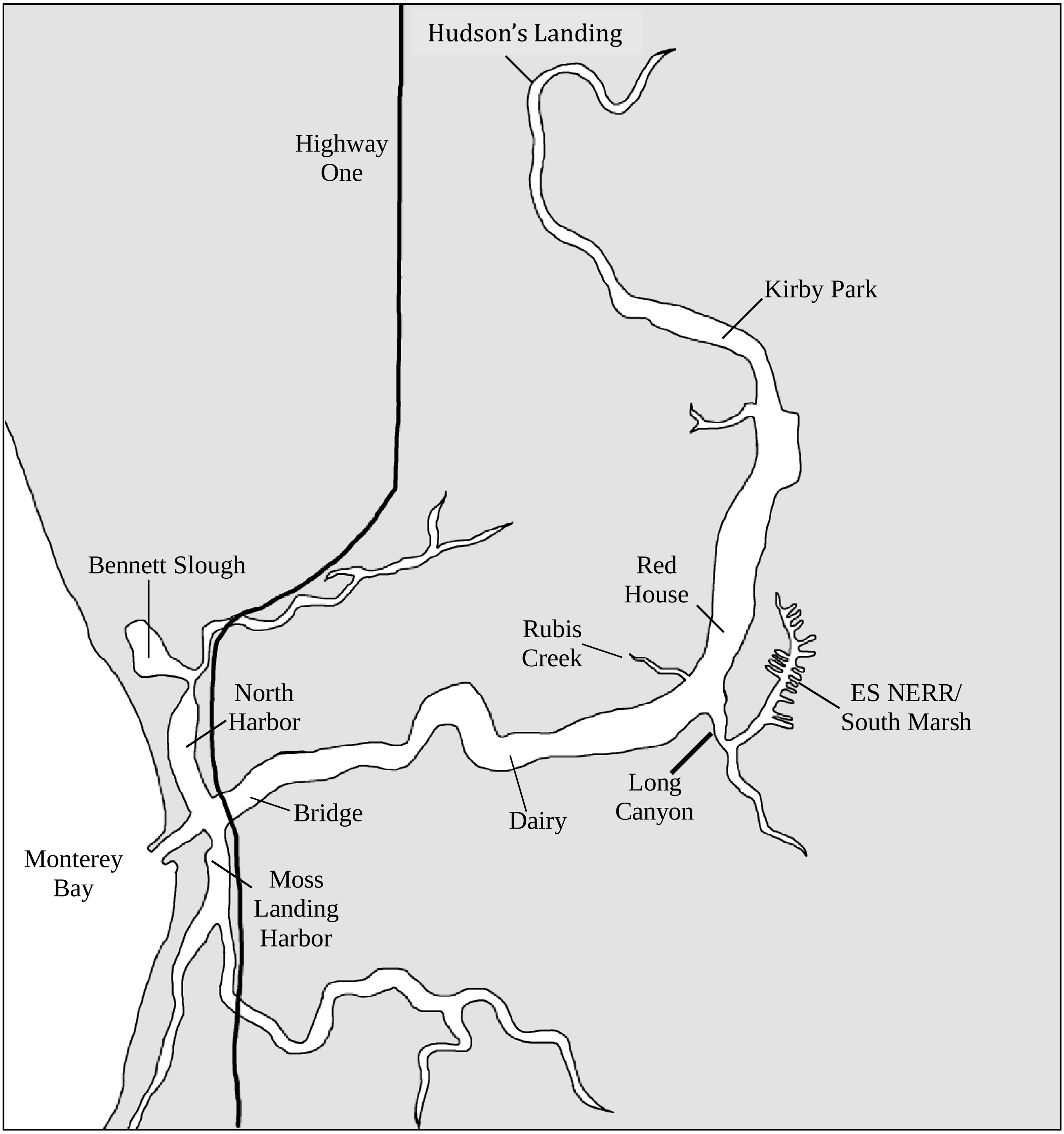


Figure 3. Sampling sites in the greater Elkhorn Slough area. Elkhorn Slough is adjacent to the Monterey Bay on the central California coast.

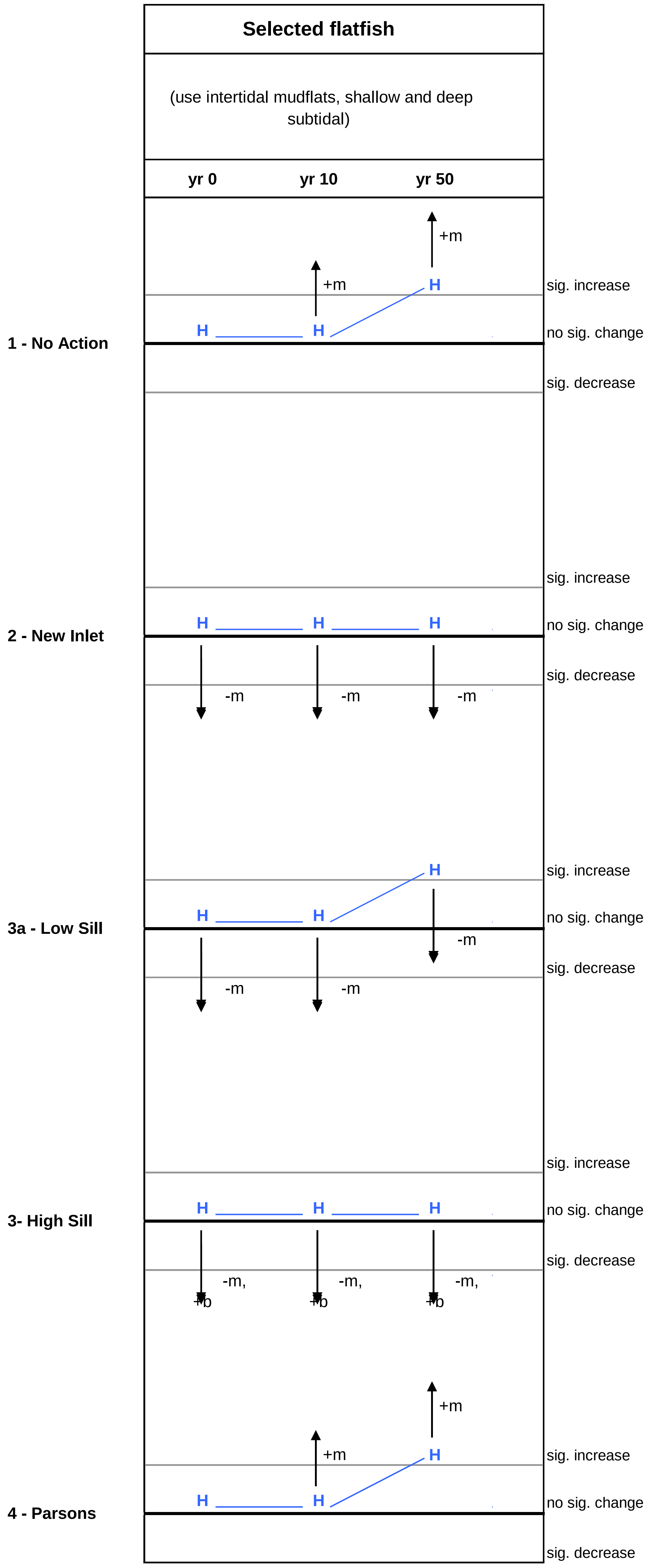


Figure 4. Predicted response of selected flatfish to management alternatives.

Legend for Figure 4

For each group of species, predictions made solely based on habitat extent are shown with a blue "H". These predictions make the simplified assumption of a linear relationship between estuary-wide population size and aerial extent of habitat of the appropriate tidal elevation. Thus a significant increase or decrease in habitat area translates to a significant change in population size.

The habitat predictions summarized in Largay & McCarthy 2009 were used for these projections. For these selected flatfish species, total mud area (intertidal mudflat, shallow subtidal, and deep subtidal) was used as the basis for predictions.

A significant change in habitat area was defined as an increase or decrease of 20% or greater over year 0, No Action (Alternative 1) acreages. Likewise, a significant change in population size of the species was defined as an increase or decrease of 20% or greater over the average population size over the past decade (1999-2008).

For the habitat and species predictions, the geographic boundaries are all the fully tidal estuarine habitats of Elkhorn Slough excluding the Parsons complex (predictions do not include tidally restricted areas).

In addition to the habitat-based predictions, we illustrate a range of worst case and best case scenarios using arrows. These represent qualitative assessments of potential factors related to the management alternatives that might increase or decrease populations in ways other than predicted based on habitat extent alone; the exact length or location of the arrow has no quantitative significance. Each arrow is marked with a letter; legend for letters below. See text for more detail.

"+m" MARINE-INFLUENCED, SANDY HABITAT EXTENT WITH LOW RESIDENCE TIME increases as a result of increased tidal prism
"-m" MARINE-INFLUENCED, SANDY HABITAT EXTENT WITH LOW RESIDENCE TIME decreases as a result of decreased tidal prism
"+b" BARRIER TO PASSAGE FROM OCEAN OR HARBOR TO SLOUGH might decrease movement of marine mammals or fish

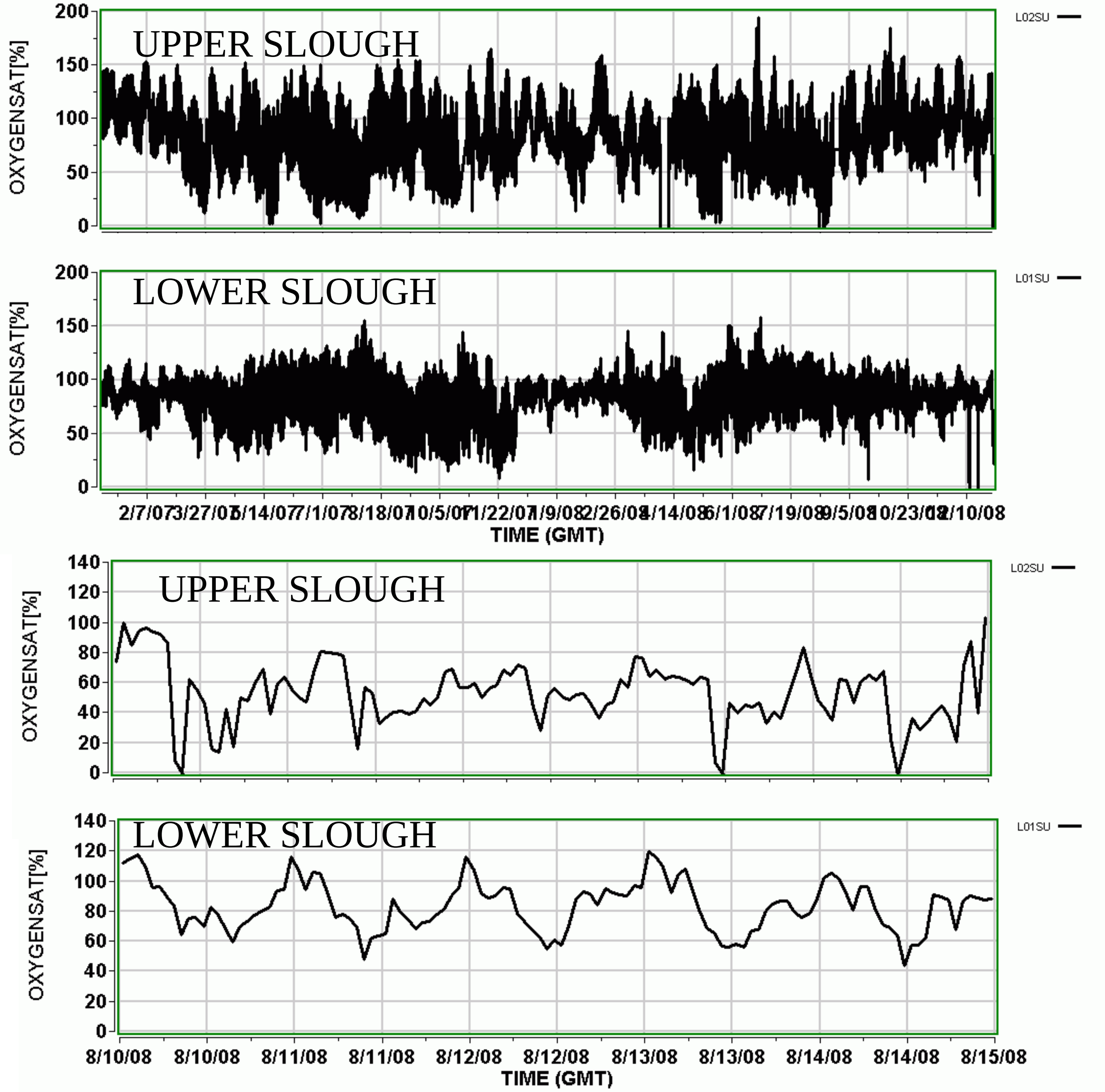


Figure 5. Dissolved oxygen saturation in the upper Slough (Kirby Park) and lower Slough (station between Hwy 1 and Seal Bend), courtesy of Ken Johnson (www.mbari.org/lobo). Top panels: 2 years of data, showing that low oxygen occurs more frequently in upper Slough. Bottom panels: 5 days of summer data where upper Slough shows occasional hypoxia and frequent low oxygen conditions. Oxygen dynamics in the lower Slough might shift somewhat towards conditions in the current upper Slough under management alternatives 2-3.

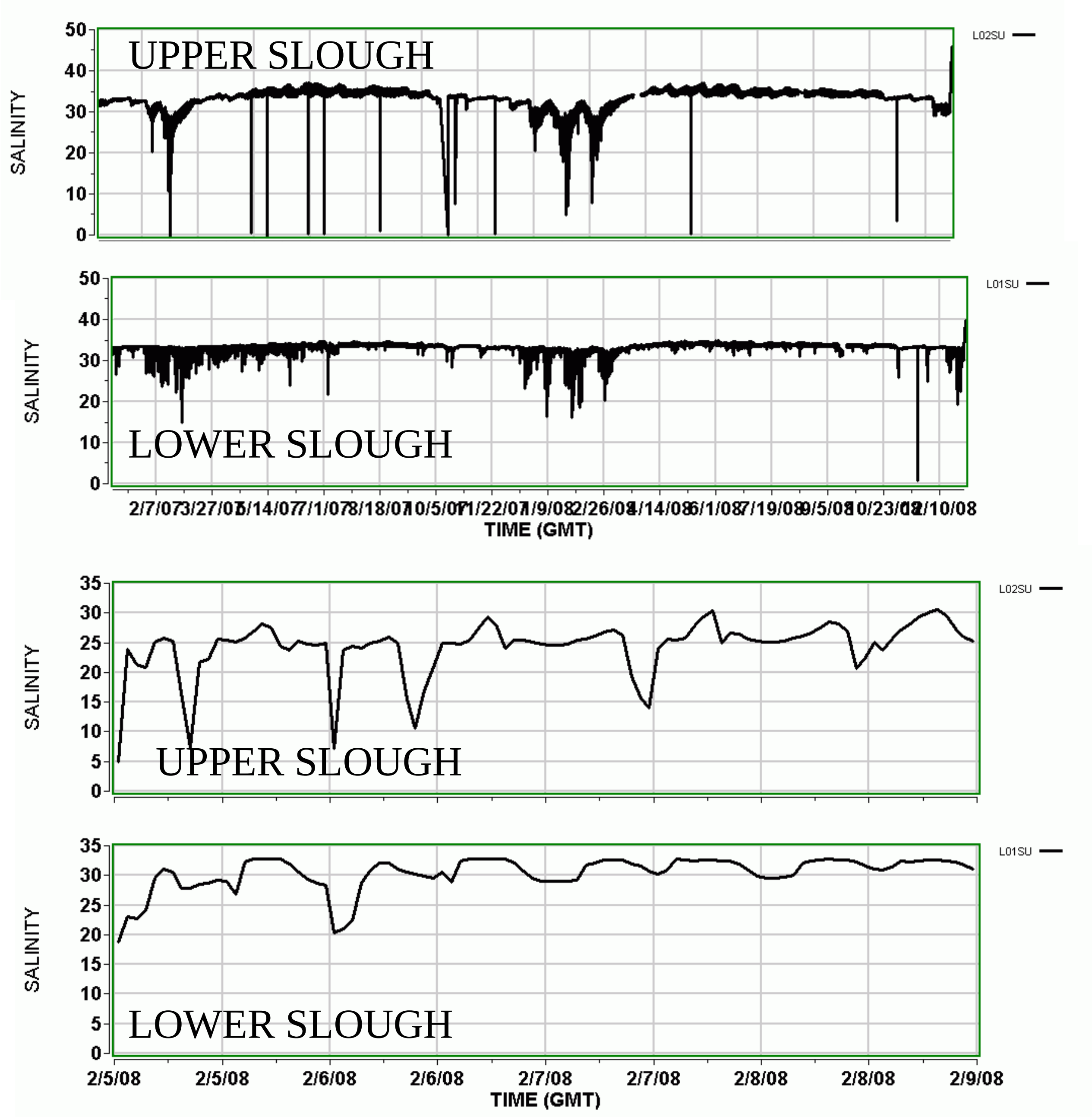


Figure 6. Salinity in the upper Slough (Kirby Park) and lower Slough (station between Hwy 1 and Seal Bend), courtesy of Ken Johnson (www.mbari.org/lobo). Top panels: 2 years of data; lower panels; 5 winter days. Under Alternatives 2 and 3b, salinity conditions might shift somewhat towards the profile currently found in the upper Slough.

Table 1. General flatfish information

Common Name	**California halibut**	**speckled sanddab**	**starry flounder**	**English sole**	**diamond turbot**	**California tonguefish**
Scientific Name	*Paralichthys californicus*	*Citharichthys stigmaeus*	*Platichthys stellatus*	*Parophrys vetulus*	*Pleuronichthys guttulatus*	*Symphurus atricaudus*
Taxonomy	Bothidae, Paralichthyidae[1]	Bothidae, Paralichthyidae[1]	Pleuronectidae[1]	Pleuronectidae[1]	Pleuronectidae[2]	Cynoglossidae[1]
Geographic Range	Quillayute River, northern Washington to Cabo Falsa (22° 50'N), Baja California[2]	Prince William Sound, Alaska to Bahia Magdelena, southern Baja California[1]	Sea of Japan off Korea, Beaufort Sea, Canadian Arctic, Bering Sea and Aleutian Islands to Los Angeles Harbor, southern California[2]	Bering Sea and Aleutian Islands to Bahia San Cristobal, central Baja[1]	Cape Mendocino, northern California to Cabo San Lucas, southern Baja; Gulf of California[2]	Barkley Sound, Vancouver Island to Gulf of California; also reported from Peru[2]
Observed Depth Range	nearshore to 281 m, majority <30 m[3]	intertidal-366 m; majority of pop <50 m[1, 2]	intertidal-600 m[3], majority of adults <150 m[4]	intertidal to 550 m[3], majority of adults <100 m[4]	1.5-82 m[1]	surf zone to 305 m[2]
Coastal Habitat Distribution, Juveniles	Coastal embayments and estuaries, also in shallow open coastal waters[1]	Estuaries used as nursery and rearing areas before migrating to the open coast to spawn[1]	Nearshore in estuaries and sandy intertidal, and lower reaches of major coastal rivers[1]	Common in shallow waters along the coast as well as in bays and estuaries[1]	Benthic in bays, estuaries and sloughs and nearshore coastal waters[1]	Sand and mud of bays and open coast[1]
Coastal Habitat Distribution, Adults	Benthic, sandy substrate often aggregate near structures; occurs nearshore, with larger individuals occurring deeper[1]	Nearshore sandy substrate[1]	Gravel, sand, and mud; most adults found in less than 150 m[1]	Soft sand or mud, located offshore[1]	Benthic in bays, estuaries and sloughs and nearshore coastal waters[1]	Sand and mud bottom[1]

Common Name	**California halibut**	**speckled sanddab**	**starry flounder**	**English sole**	**diamond turbot**	**California tonguefish**
Ecological Highlights of Estuarine Habitat Use	Juveniles remain in bays approx. 2 yrs, then emigrate to coast[1]	Estuaries used as nursery and rearing areas before migrating to the open coast to spawn[1]	Juveniles move to areas of higher salinity, but remain in estuaries through their 2nd year[1] This species appears to be estuarine dependant[5]	Estuaries are used and nursery grounds, before immigrating to the open coast (6-18 months)[1]	This species appears to be dependent on bays and estuaries, thus population sizes and fish health may reflect the condition of these systems[5]	Estuaries used as nursery and feeding areas, most leave after 1st year[1]
Timing of estuarine residence	Primary settlement period February – August; reside in bays for 1-2 years until approximately 20-25 cm[6]	Primary settlement periods October – January and April-June in San Francisco Bay; all life stages found in the bay however, spawning occurs on the coast[7]	Primary settlement period March – May inhabiting low salinity/warm waters; reside in estuaries for 1-2 years[7]	Primary settlement period December – May; reside in estuaries for 1-2 years[7]	Primary settlement period April – September, all life stages found in bays[7]	Primary settlement period May – October, reside in estuaries 1-2 years[7].
Primary Predators	Juv: shore birds, water fowl, and fishes in bays[1] Adult: angel shark, electric ray, California sea lion, bottlenose dolphin, and other larger predators[1]	Juv: larger demersal fish particularly California halibut[1] Adult: larger demersal piscivores, including California halibut, pigeon guillemots, Caspian terns, cormorants, seals, sea lions, other fish and crabs[1]	Juv: larger fishes, sharks, herons, cormorants, seabirds, pinnipeds[1] Adult: larger fishes, sharks, herons, cormorants, seabirds, pinnipeds[1]	Juv: large fishes (lingcod, greenlings, rockfish, sharks, croakers), piscivorous birds and mammals[1] Adult: arrowtooth flounder, sharks, skates, lingcod, and rockfish, cormorants, California sea lions, harbor seals[1]	Juv: electric ray, angel shark, and other piscivorous fishes[1] Adult: electric ray, angel shark, and other; piscivorous fishes; birds[1]	Juv: unknown? Adult: leopard shark, rockfish, California halibut, angel sharks, and electric rays, loons, cormorants[1]

Common Name	**California halibut**	**speckled sanddab**	**starry flounder**	**English sole**	**diamond turbot**	**California tonguefish**
Primary Prey	Juv: larval and small fish, small crustaceans (e.g., gammarid amphipods, mysids, harpacticoid copepods)[1] Adult: primarily schooling fishes (e.g., sardine, croaker, anchovy), squid, crustaceans (mysids, caridean shrimp)[1]	Juv: specializes on epifaunal crustacea, esp. gammarid amphipods and harpacticoid copepods (Barry et al. 1996); cumaceans, mysids[1] Adult: small crustaceans (e.g., amphipods, mysids, crabs), polychaetes, mollusks, fishes [1]	Juv: small crustaceans (copepods, mysids, amphipods), annelid worms, nemerteans, priapulids, tanaids[1] Adult: small bivalves, clam siphons, crustaceans (e.g., amphipods, isopods, shrimp, copepods, crabs), polychaetes, sand dollar, brittle star, fishes[1]	Juv: small crustaceans (e.g., harpacticoid copepods, gammarid amphipods, mysids) cumaceans, small polychaetes, small bivalves and bivalve siphons, and other benthic invertebrates[1] Adult: primarily polychaetes, small crustaceans (e.g, amphipods, crabs, shrimp, cumaceans, mysids), small bivalves, gasteropods, brittle stars, sand dollars, small fish[1]	Juv: polychaetes, clams and clam siphons, gastropods, ghost shrimp, amphipods, crustaceans, small fish[1] Adult: primarily molluscs, clam siphons, small crustaceans (e.g., isopods, young sand barnacles, crabs, worms, and fishes[1]	Juv: unknown Adult: gammarid amphipods, crabs, worms, microcrustaceans, polychaetes, and mollusks[1]
Key References	[1] (Cailliet et al. 2000); [2] (Love et al. 2005); [3] (Emmett et al. 1991) [4] (Pacific Fishery Management Council 2005); [5] (Emmett et al. 1991); [6] (Kramer 1990); [7] (Baxter et al. 1999)					

Table 2. List of flatfish species and their preferred estuarine habitats types; E = eggs; L = Larvae; J = Juvenile; A = Adult; X = present, life stage not known; ? = Potential for occurrence.

	Geographic range of estuarine use along U.S. continental west coast		**Estuarine Habitat Type**				
Species	**Abundant (at least one life stage)**	**Present**	**Open Bay**	**Tidal Channels/ Sloughs**	**Tidal Mudflat**	**Tidal Marsh**	**Ponds**
English sole	Puget Sound – Elkhorn Slough[1, 6]	Morro Bay – San Pedro Bay[1]	L,J, A	L, J	J		?
Starry flounder	Puget Sound – Elkhorn Slough[1. 6]	Morro Bay[1]	L, J, A	L, J, A	J	J	J
Speckled sanddab	Humboldt Bay – Morro Bay[2, 6]	Puget Sound – Tijuana Estuary[2]	J, A	J			
California halibut	Santa Monica Bay – Tijuana Estuary[1]	Tomales Bay – Morro Bay[1, 6]	J, A	J	J		
Diamond turbot	Alamitos Bay – San Diego Bay[1]	San Francisco Bay – San Diego Bay[1, 4, 6]	J, A				
California tonguefish		Humboldt Bay – San Diego Bay[3, 4, 6]	X	X			

We define ‘open bay’ as those subtidal areas with regular tidal exchange and most closely allied with conditions on the open coast ; ‘tidal channels/sloughs’ as those with reduced tidal exchange, a low width to length ratio and reduced water depth—bank characteristics may be important ; ‘tidal mudflats’ are intertidal areas characterized by broad expanses of fine, unconsolidated sediment ; ‘tidal marshes’ are similarly intertidal but structured principally by the dominant vegetation ; and ‘ponds’ are tidally-influenced areas with limited tidal exchange, not connected to sloughs or bays by any well defined channel.

[1] (Emmett et al. 1991); [2] (Allen et al. 2006); [3] (Fritzsche & Cavanagh 1995); [4] (Kramer 1990); [5] (Yoklavich et al. 1991) ; 6 (Allen et al. 2006)

Table 3. Spatial distribution of fish in the greater Elkhorn Slough area. The fraction in each cell represents the "frequency of occurrence" of a species at a given site: the denominator is the number of studies that collected fish at a site; the numerator is the number of those studies in which at least one individual of a given species was collected (reproduced from Table 3, Page 17 in Brown 2002).

Common Name	Bennett Slough	North Harbor/ Skipper's	Bridge	Dairy	Kirby Park	Hudson's Landing	Long Canyon	Rubis Creek	NERR/ South Slough	References
California halibut	0/2	0/1	4/4	2/4	6/6	2/2	2/2	4/4	4/4	(Nybakken et al. 1977, Barry 1983, Schoenherr 1984, Small 1984, King et al. 1986, Yoklavich et al. 1991, Nernev et al. 1993, Oxman 1995), Brown (unpublished data)
speckled sanddab	0/2	0/1	4/4	4/4	5/5	2/2	2/2	3/3	3/3	(Nybakken et al. 1977, Barry 1983, Small 1984, King et al. 1986, Yoklavich et al. 1991, Nernev et al. 1993, Oxman 1995), Brown (unpublished data)
starry flounder	3/3	0/1	4/4	3/4	6/6	2/2	2/2	4/4	4/4	(Appiah 1977, Nybakken et al. 1977, Barry 1983, Schoenherr 1984, Small 1984, King et al. 1986, Yoklavich et al. 1991, Nernev et al. 1993, Oxman 1995), Brown (unpublished data)
English sole	0/2	0/1	4/4	4/4	5/5	2/2	0/2	3/3	2/2	(Nybakken et al. 1977, Barry 1983, Small 1984, King et al. 1986, Yoklavich et al. 1991, Oxman 1995), Brown (unpublished data)
diamond turbot	0/2	0/1	1/4	2/4	5/6	2/2	2/2	4/4	2/2	(Nybakken et al. 1977, Barry 1983, Schoenherr 1984, King et al. 1986, Yoklavich et al. 1991, Oxman 1995), Brown (unpublished data)
California tonguefish	0/2	0/1	3/4	1/4	3/5	2/2	2/2	3/3	2/2	(Nybakken et al. 1977, Barry 1983, Small 1984, King et al. 1986, Yoklavich et al. 1991, Oxman 1995), Brown (unpublished data)

Table 4. Temporal Occurrence of Fish in the Greater Elkhorn Slough Area. The fraction in each cell represents the "'frequency of occurrence" of a species in a given month: the denominator is the number of sampling events that were examined; the numerator is the number of those sampling events in which at least one individual of a given species was collected. These data includes all methods of collection and all locations in the greater Elkhorn Slough area (Reproduced from Table 4, page 20 in Brown 2003).

Common Name	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	References
California halibut	4/12	4/16	4/15	5/14	6/16	5/14	5/10	9/18	9/18	3/12	6/18	2/12	(Nybakken et al. 1977, Barry 1983, King et al. 1986, Monaco et al. 1990), Brown (unpublished data)
speckled sanddab	4/8	6/10	5/11	5/10	5/10	5/10	4/7	7/12	5/15	4/8	4/9	5/8	(Nybakken et al. 1977), Brown (unpublished data)
diamond turbot	2/10	4/14	1/13	4/12	4/14	1/12	1/9	5/17	2/17	3/10	8/16	1/10	(Nybakken et al. 1977, King et al. 1986, Monaco et al. 1990), Brown (unpublished data)
starry flounder	12/13	14/17	12/16	12/15	12/17	9/15	8/11	11/19	13/19	10/13	17/19	12/13	(Appiah 1977, Nybakken et al. 1977, Monaco et al. 1990), Brown (unpublished data)
English sole	0/10	1/14	6/13	8/12	12/14	9/12	6/9	5/16	6/17	3/10	3/16	0/10	(Nybakken et al. 1977, King et al. 1986, Monaco et al. 1990), Brown (unpublished data)
California tonguefish	0/8	0/10	0/11	0/10	0/10	1/10	0/7	1/12	1/15	0/8	0/9	0/8	(Nybakken et al. 1977), Brown (unpublished data)

Table 5. (Reproduced from Table 10.2 page 169, Yoklavich et al. 2002): Relative abundance (%) of dominant species totaling 80% or greater of fishes collected by small otter trawl during the day in Elkhorn Slough, 1974-1980 (Yoklavich et al. 1991), 1991-1992 (Oxman 1995), and 1995-1996 (from Cailliet and Oxman, unpubl. data).

Species	**1974-1980**				**1991-1992**			**1995-1996**			
	Bridge	Dairy	Kirby Park	Long Canyon	Bridge	Dairy	Kirby Park	Bridge	Dairy	Kirby Park	Long Canyon
Speckled sanddab	10.3	4.4			18.4	14.4		7			
English sole		4.0	10.7		9.1	23.4	21.2				
Starry flounder		3.9	5.9	5.9							
California tonguefish							12.0				

Table 6. (Reproduced from Table 10.4 page 178, Yoklavich et al. 2002): Flatfish species taken in creel censuses from two general locations in Elkhorn Slough during the 1970s and the 1980s-1990s. Data are summarized as ranks (1 most abundant; tr = trace numbers) due to differences in techniques between the two surveys. Data are grouped into sites west (Jetties, Skippers, Bennett Slough) and east (mainly Kirby Park) of the Hwy 1 bridge. Data from the 1970s was published in Cailliet et al. 1977 and data from the 1980s-1990s was summarized from the NMFS Marine Recreational Fishing Statistics Surveys database.

Species	**1970s**		**1980s-1990s**	
	West	East	West	East
Sand sole	2.5	-	8	-
Starry flounder	7	6	9	-
Speckled sanddab	16	-	22.5	-
English sole	tr	-	-	-
Slender sole	tr	-	-	-
Diamond turbot	tr	-	-	-

Table 7. Predicted habitat extent under management alternatives.

The numbers represent percent change from baseline conditions (Year 0, No Action alternative) as predicted by H.T. Harvey and Associates and summarized in Largay & McCarthy 2009. Habitats were defined based tidal elevation zones. The area of habitat considered excludes the Parsons Slough complex and all wetlands behind water control structures.

To facilitate perusal of trends, significant increases are coded with warm colors (20% or greater = orange, 50% or greater = red). Significant decreases are coded with cool colors (20% or greater = light blue, 50% or greater = dark blue).

HABITAT PREDICTIONS FOR SINGLE HABITAT TYPES

	A. Deep (>2 m) subtidal			B. Shallow subtidal			C. Intertidal mudflat			D. Salt marsh		
ALTERNATIVE	**yr 0**	**yr 10**	**yr 50**	**yr 0**	**yr 10**	**yr 50**	**yr 0**	**yr 10**	**yr 50**	**yr 0**	**yr 10**	**yr 50**
1 - No Action	0%	9%	42%	0%	8%	15%	0%	3%	22%	0%	-7%	-65%
2 - New Inlet	54%	65%	105%	53%	70%	108%	-39%	-36%	-32%	18%	6%	-40%
3a - Low Sill	9%	12%	20%	8%	22%	72%	-10%	-3%	14%	9%	0%	-55%
3b - High Sill	39%	28%	6%	39%	75%	182%	-34%	-28%	-16%	22%	18%	-36%
4 - Parsons	1%	6%	38%	0%	5%	10%	0%	3%	19%	-1%	-6%	-61%

HABITAT PREDICTIONS FOR COMBINED HABITAT TYPES

	E. Total mud (A+B+C)			F. Shallow mud (B+C)			G. Subtidal (A+B)			H. Intertidal (C+D)		
ALTERNATIVE	**yr 0**	**yr 10**	**yr 50**	**yr 0**	**yr 10**	**yr 50**	**yr 0**	**yr 10**	**yr 50**	**yr 0**	**yr 10**	**yr 50**
1 - No Action	0%	5%	25%	0%	4%	21%	0%	8%	32%	0%	-1%	-12%
2 - New Inlet	-8%	-1%	15%	-24%	-19%	-9%	53%	67%	106%	-17%	-20%	-35%
3a - Low Sill	-4%	3%	23%	-7%	1%	23%	8%	16%	40%	-2%	-2%	-13%
3b - High Sill	-9%	-3%	14%	-22%	-11%	16%	39%	45%	72%	-12%	-10%	-24%
4 - Parsons	0%	4%	22%	0%	4%	18%	1%	6%	27%	0%	0%	-12%