10

CHAPTER TEN

Fishes

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Fishes are among the most conspicuous and best-studied inhabitants of Elkhorn Slough. Long a source of food and recreation, they are of special interest to humans and—as both predator and prey—play a critical role in the slough ecosystem.

The fish fauna in Elkhorn Slough is abundant, diverse, and dominated by marine and estuarine species (Cailliet et al. 1977; Yoklavich et al. 1991; Yoklavich, Stevenson, and Cailliet 1992). The slough provides critical habitat not only for year-round residents, but also for marine species from nearshore waters that enter sloughs to feed, mate, and spawn. Many marine fishes, including a number of economically important species, inhabit the slough's relatively warm, calm waters as juveniles before moving to nearshore coastal waters.

Early studies on the slough's fish populations provided baseline information critical to long-term monitoring of Elkhorn Slough's fish *assemblages*, their response to potential environmental changes, and their contribution to the nearshore fishery resources of Monterey Bay. More recent studies reveal that human impacts on Elkhorn Slough have fundamentally changed available fish habitat, resulting in changes to fish assemblages and an overall decline in diversity of both fishes and their prey.

In this chapter we review the results of all studies of Elkhorn Slough's fish assemblages and prey items, with particular reflection on their response to significant habitat modifications (e.g., increased erosion and tidal scour) that have occurred during the last twenty years. We also offer recommendations for further research to monitor the continued impact of human and natural changes on the slough's fish populations, and to understand the contribution that the slough makes to fish resources in the Monterey Bay area.

Historical Perspective

The ichthyofauna of Elkhorn Slough was described first by George MacGinitie (1935), who documented the general natural history of the coastal end of the embayment in the 1930s. In the 1950s and 1960s, Earl S. Herald and colleagues from the California Academy of Sciences collected data on elasmobranch (shark and ray) populations by monitoring sportfishing derbies. Using data from Gary Kukowski (1972), a graduate student at Moss Landing Marine Laboratories (MLML), Bruce Browning (1972) produced the first checklist of the slough's fishes as part of a series on California's wetlands.

Detailed scientific studies of fish assemblages in Elkhorn Slough began in the mid-1970s and continue today. The faculty and students of MLML have conducted the majority of these studies. Investigations have focused on distribution, abundance, diversity, seasonality, and feeding habits and energetics of adult and juvenile fishes in various habitats throughout the slough system and adjacent marine coastal areas (Ambrose 1976; Ruagh 1976; Appiah 1977; Cailliet et al. 1977; Antrim 1981;

Barry and Cailliet 1981; Yoklavich 1982a, b; Barry 1983; ABA Consultants 1989; Oxman 1995; Lindquist 1998; Cailliet et al., unpublished data). Taxonomic and life history data, including seasonal and spatial patterns of abundance, also have been collected on egg and larval stages of slough fishes (Wang 1981; Yoklavich, Stevenson, and Cailliet 1992).

The elasmobranchs are especially well studied. Background information comes from angling derbies in the 1940s. More recently, researchers have studied feeding ecology (Talent 1976, 1982), reproduction (Martin 1982; Talent 1985; Martin and Cailliet 1988a; Kusher, Smith, and Cailliet 1992), and age and growth (Kusher 1987; Yudin 1987; Martin and Cailliet 1988b; Yudin and Cailliet 1990; Cailliet 1992) of slough elasmobranchs. Field and laboratory experiments on the feeding energetics of the leopard shark are among the most recent projects (San Filippo 1995; Kao 2000).

Interest in the fish fauna was stimulated further by the designation of Elkhorn Slough as a National Estuarine Research Reserve (ESNERR) in 1979 (U.S. Dept. of Commerce 1979; Elkhorn Slough Estuarine Sanctuary Advisory Committee 1985). The reserve's goals include:

- initiation of long-term monitoring of fish populations in Elkhorn Slough;
- assessment of fish responses to natural and human-induced environmental changes; and
- determination of the slough's contribution to the nearshore fishery resources of Monterey Bay.

With support from ESNERR, the results of several of the past studies on fish assemblages in the slough have received recent attention, especially in terms of slough dependence or opportunism, culminating in scientific publications with broad distribution (Yoklavich et al. 1991; Yoklavich, Stevenson, and Cailliet 1992; and Barry et al. 1996).

Distribution, Abundance, and Diversity

Overview

A minimum of 102 species of fishes from 43 families has been identified in Elkhorn Slough and adjacent waters (appendix 10.1). The vast majority (82 species) are marine fishes from Monterey Bay. Sixteen of these marine species use Elkhorn Slough as a spawning or nursery ground; known as immigrant marine fishes (or slough opportunists), this group includes the northern anchovy, Pacific herring, cabezon, and 6 species of flatfish (halibut, sole, sanddab, etc.). Eight fish species are permanent residents that spawn and complete their entire life cycle in Elkhorn Slough; residents include the Pacific staghorn sculpin, black surfperch, bay pipefish, and 5 species of gobies. Six other species are partial residents—they primarily live and reproduce in the slough but move to the ocean during some seasons or life stages. The partial residents are topsmelt, jacksmelt, shiner and white surfperches, leopard shark, and bat ray. Six species are primarily associated with freshwater; these are American and threadfin shad, mosquitofish, prickly sculpin, threespine stickleback, and striped bass. Notably, only 4 species of fish (yellowfin goby, mosquitofish, American shad, and striped bass) are considered to be nonnatives to the Elkhorn Slough system. There seems to have been little opportunity for the introduction of exotic fish species. The slough's narrow opening may isolate it from tanker traffic and mariculture, the activities usually implicated in the introduction of nonnative fish species.

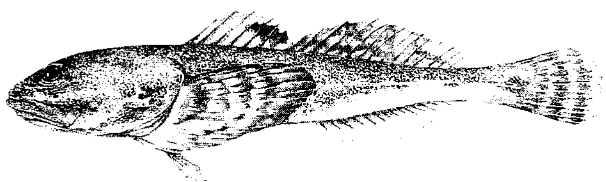
Common and Best Recognized Species

Among the many species collected in Elkhorn Slough, several have been consistently common as adults and juveniles in surveys over the past twenty-five years.

Shiner surfperch.
Photo credit: © Monterey Bay Aquarium Foundation.

Surfperches (Embiotocids) are the most diverse (14 species) and abundant group of fishes in the slough. Shiner surfperch seasonally are common in many slough habitats, including the main channel, tidal creeks, and Bennett Slough. Adult shiners are relatively small (maximum total length is 18 cm) and silvery, with three yellow vertical bars on the mid-body. This partial resident gives birth to live young (usually 7–10) in the shallow parts of the slough in summer months and leaves the slough for deeper water in winter. Shiners eat small crustacea living on the slough floor, and are important forage food for birds, pinnipeds, and fish. Shiners commonly are caught by anglers both at the mouth and upper reaches of the slough.

Able to tolerate a wide range of salinities, the **Pacific staghorn sculpin** is most abundant in upper slough areas and in Bennett Slough. This relatively large sculpin (total length to 46 cm) is the color of mud (green-brown to gray), has a flattened head, no scales, and large antlerlike spines forward on the gill cover.

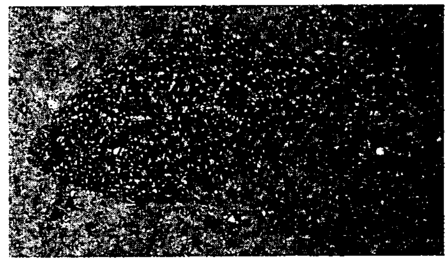


Pacific staghorn sculpin. Illustration credit: Ann Caudle, © Monterey Bay Aquarium Foundation.

Staghorns spawn in the slough in winter months. They eat small crustacea living on the slough floor, and are themselves preyed upon by birds (notably blue herons and cormorants) and harbor seals. Anglers commonly take staghorns throughout the slough.

Northern anchovy is a marine immigrant that visits the slough to spawn in summer and fall. Large numbers of young anchovies dominate the shallow inland areas of the slough in fall and winter. Anchovies feed on zooplankton and diatoms in the water column. They are an important forage fish for coastal marine birds, fish, and mammals. Rarely caught by anglers in the slough, anchovies have been the target of a significant bait and reduction commercial fishery within the Monterey Bay National Marine Sanctuary.

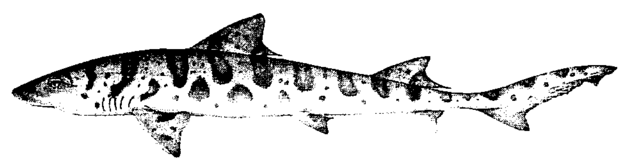
Northern anchovy. Photo credit: Bruce Stewart.



Speckled sanddab. Photo credit: © Monterey Bay Aquarium Foundation.

The speckled sanddab is a relatively small flatfish (maximum total length to 17 cm) that commonly occurs in summer and fall during the egg, larval, and juvenile stages, primarily in areas closest to the slough entrance. Juvenile sanddabs feed on small crustacea near the slough floor, and are prey for marine birds, fish, and mammals, including harbor seals and otters. They also are taken by anglers fishing off the jetty at the slough entrance.

Part-time slough residents, adult **leopard sharks** are abundant in spring and summer, when they give birth to live young in the warm tidal creeks. These sharks are about 20 to 25 centimeters long at birth and grow to a maximum of 2 meters. Leopard sharks feed along the slough's floor on mobile prey such as small fishes, crabs, and fat innkeeper worms. They are taken occasionally by recreational anglers in the slough.



Leopard shark. Illustration credit: Ann Caudle, © Monterey Bay Aquarium Foundation.

Starry flounder are easy to recognize by their diamond shape and alternating black and yellow bands on their dorsal and anal fins. This marine immigrant commonly was found in both Elkhorn and Bennett Sloughs during surveys conducted in the 1970s and 1980s, but currently is not abundant. Although

Starry flounder. Photo credit: © Monterey Bay Aquarium Foundation.

most of the starry flounders taken in slough surveys have been juveniles (<30 cm long), they can reach up to 90 centimeters in length. They mostly prey on molluscs (e.g., bivalve siphons) and infaunal worms. Starry flounders have been caught by sportfishers throughout the slough.

Distribution by Habitat

The Elkhorn Slough system traditionally has been divided into several distinct fish habitats; these are the Moss Landing Harbor and adjacent nearshore sandflats of Monterey Bay, the lower and upper main channel, tidal creeks, Bennett Slough, pickleweed marshes, and salt evaporation ponds. All are connected by the exchange of tidal water, but differ in water depth, tidal influence (primarily salinity and current flow), and biological components such as plants that provide refuge for prey and spawning. As a result, each habitat supports a different assemblage of fish species.

Overall, fish distribution patterns vary with distance from the mouth of the slough. For example, marine species typically reside in the lower slough and harbor, where waters are strongly influenced by ocean and bay hydrographic properties such as higher salinity, lower water temperature, and variable turbulence compared with upper reaches of the slough. Resident fishes are distributed widely but are most abundant in the upper slough. Freshwater species occupy the middle and upper slough including tidal creeks, ponds, and salt marshes. Dominant species of the upper slough and tidal creeks are best characterized as *euryhaline*, with affinities toward higher temperature. In the following sections, we detail assemblages found in the slough's various habitats and discuss changes in these assemblages over time.

Moss Landing Harbor and Adjacent Coastal Waters Assemblages of fishes in the harbor have not been thoroughly surveyed, but sporadic sampling indicates that the species composition resembles a combination of fishes found in the lower channel of the slough and in coastal nearshore waters. Much of this information was gathered from fishes collected by impingement in the Pacific Gas and Electric (now Duke Energy North America) cooling water intake structures (PGE Co. 1983).

Nearshore juvenile and adult fishes were surveyed systematically at least monthly from August 1974 to June 1976 with a small otter trawl fished along 1 kilometer of the sandy shelf (water depth = 5–10 m) to the north and south of the harbor entrance. Abundance consistently was low throughout all seasons, with an average of 13 fish per 10-minute tow. Species diversity (expressed as the number of species) was high (34 species) compared to upper areas of the slough. The four most abundant species in nearshore waters have not been collected anywhere in the slough and yet represented nearly 50% of all fishes taken in the nearshore ocean habitat. These were sand sole, barred and spotfin surfperch, and curlfin turbot. Two abundant nearshore species (speckled sanddab and white surfperch) are marine immigrants into lower slough habitats.

Elkhorn Slough: Main Channel and Tidal Creeks The main channel covers approximately 1.4 square kilometers and extends inland about 10 kilometers from the bay. Depth and width vary considerably with tidal height, but range from nearly 200 meters wide and 7.5 meters deep at the mouth to 15 meters across and 1.5 meters deep at the head of the slough near Hudson's Landing (Crampton 1994). Extensive mudflats fringe the main channel. Lying about 1.3 meters above mean low low water (MLLW), the mudflats are flooded during higher *semidiurnal tides*, at which time several fish species move into this habitat from the main channel. A network of tidal creeks meanders through the salt marshes and, together with the main channel, covers nearly 10 square kilometers. Key features that could affect fish distribution include water depth, turbulence and turbidity, salinity, temperature, food, and predation.

Species composition, abundance, and distribution of fishes in different areas of the main channel and selected tidal creeks are best known from detailed surveys conducted monthly from the mid-1970s to 1980, and repeated twice in the 1990s (Yoklavich et al. 1991; Oxman 1995; Cailliet and Oxman, unpubl. data). Small otter trawls were used to collect adult and juvenile fishes at six sites (fig. 10.1): the Bridge and Dairy stations in the deeper main channel of the lower slough; Rubis and Long Canyon, tidal creeks midway up the slough (beach seine and channel nets also were used at these sites); and Kirby Park and Hudson's Landing, in the shallower waters of the upper slough.

In the 1970s, mean fish abundance was consistently higher in the main slough than in the tidal creeks (table 10.1). Abundance (209 fish per tow) and diversity (37 species) were highest at the Bridge, with shiner surfperch (43%), white surfperch (17%), black surfperch (15%), and speckled sanddab (10%) accounting for almost 85% of the catch

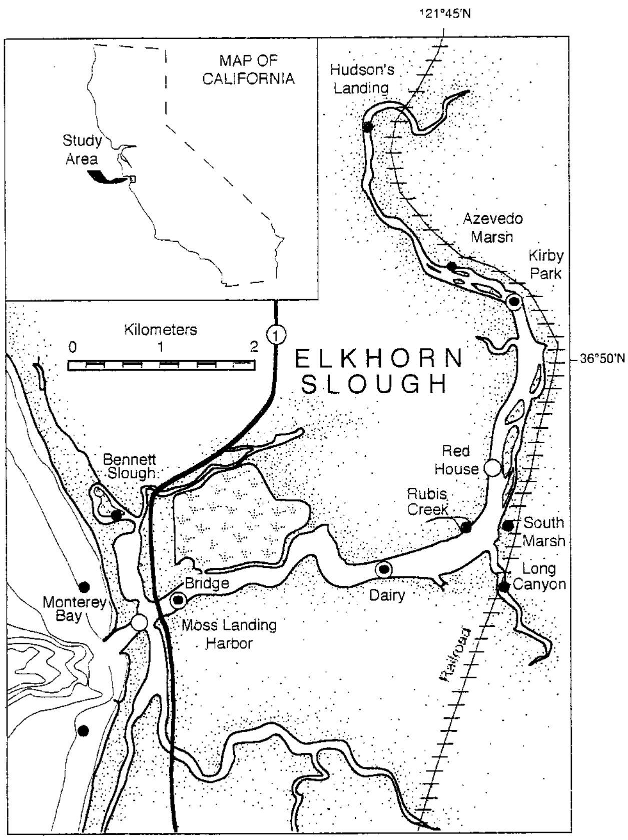


Figure 10.1. Juvenile and adult (●) and larval (O) fish sampling locations in Elkhorn and Bennett Sloughs and the adjacent nearshore ocean.

(table 10.2). The Dairy featured the same diversity but much lower abundance (66 fish per tow); the three surfperches also were predominant here. Fish assemblages at Kirby Park and Hudson's Landing featured intermediate levels of diversity and abundance. Shiner surfperch (54%), Pacific staghorn sculpin (13%), and English sole (11%) were the three most abundant species at Kirby Park. The sculpin (58%), northern anchovy (18%), and Pacific herring (15%) predominated at Hudson's Landing. The tidal creeks (Long Canyon and Rubis Creek stations) had comparable diversity but the lowest mean abundance (12 and 39 fish per tow). The Pacific staghorn sculpin predominated (>40%) at both sites.

Three stations (Bridge, Dairy, and Kirby Park) were resurveyed in the early 1990s. Abundance was significantly lower (table 10.1), but surfperches, flatfishes, and the Pacific staghorn sculpin remained the predominant species at all sites (table 10.2). Cabezon (17%) was the second most abundant fish at the Bridge. California tonguefish (12%) were common at Kirby Park.

Surveys in the mid-1990s again found low abundance (>70% lower than 1970s levels) at the deep channel sites (Bridge and Dairy). Surfperches remained predominant at both sites, but northern anchovy and Pacific herring were common at the Dairy. Conversely, abundance was two to four times higher (than 1970s levels) at three of the four sites farther up the slough. This largely was due to seasonally high numbers of northern anchovy, Pacific herring, and shiner surfperch.

Species diversity seems to have decreased throughout the slough in these twenty years of studies (table 10.1). While the deep main channel stations once had higher numbers of species than the shallow upper slough stations, diversity is now similar and relatively low at all sites. The Bridge station has maintained the highest diversity (24 species in 1995–1996), probably due to the site's diverse habitats (including submerged rocks and pier pilings) and its proximity to the ocean. Marine fishes typical of rocky coastal habitats have been collected in low numbers at the Bridge, but rarely at other stations; these include the scalyhead sculpin, blackeye goby, kelp greenling, rainbow surfperch, onespot fringehead, lingcod, cabezon, and 11 species of juvenile rockfishes. The decline in species richness and change in species composition with increasing distance inland has been noted in other estuarine systems as well. For example, the number of fish species in estuaries of temperate southwestern and tropical northern Australia was highest in the mouth and mid-estuary, largely reflecting the occurrence of marine species that rarely were found in the upper areas (Loneragan et al. 1986) and greater diversity of habitats in lower areas (Blaber, Brewer, and Salini 1989).

Graduate students from Moss Landing Marine Laboratories retrieve a small otter trawl in the main channel during the 1974–1976 Elkhorn Slough fish survey. Left to right: Doug Vaughan, Ed Osada, Dave Ambrose, and Brooke Antrim. Photo credit: Gregor Cailliet.

Table 10.1. Summary of diversity, abundance, and dominance of fishes captured with otter trawls at six locations in Elkhorn Slough during 1974–1980 (from Yoklavich et al. 1991), 1991–1992 (from Oxman 1995) and 1995–1996 (Cailliet and Oxman unpubl. data). Five-minute tows conducted at Rubis Creek and Long Canyon were adjusted to 10-minute tows.

1974–1980	**Bridge**	**Dairy**	**Kirby Park**	**Hudson's Landing**	**Rubis Creek**	**Long Canyon**
# of species	37	37	26	24	32	20
# of tows	35	49	49	44	50	52
Total # of fish	7,326	3,244	3,807	4,479	1,933	596
Mean # / tow (SE)	209.3 (82.4)	66.2 (2.0)	77.7 (15.3)	101.8 (21.8)	38.7 (9.6)	11.5 (1.7)
Dominance index	0.26	0.19	0.32	0.37	0.22	0.29

1991–1992	**Bridge**	**Dairy**	**Kirby Park**	**Hudson's Landing**	**Rubis Creek**	**Long Canyon**
# of species	25	22	30	–	–	–
# of tows	27	28	28	–	–	–
Total # of fish	452	312	1,191	–	–	–
Mean # / tow (SE)	16.7 (5.1)	11.1 (2.9)	42.5 (10.7)	–	–	–
Dominance index	0.12	0.14	0.26	–	–	–

1995–1996	**Bridge**	**Dairy**	**Kirby Park**	**Hudson's Landing**	**Rubis Creek**	**Long Canyon**
# of species	24	15	21	19	17	16
# of tows	33	32	30	22	28	31
Total # of fish	1,801	626	7,973	2,285	2,258	924
Mean # / tow (SE)	54.6 (10.7)	19.6 (5.6)	265.8 (96.8)	103.9 (34.1)	80.6 (39.4)	29.8 (8.2)
Dominance index	0.15	0.22	0.70 *	0.32	0.29	0.30

* = Elevated dominance index was due to the great numbers of northern anchovy caught between April and September at Kirby Park.

Overall similarity of fish assemblages at different sites can be compared by means of a percent similarity index (PSI), which is the sum of the smallest percentage by number of each pair of species. This index ranges from zero (no similarity) to one (identical species arrays). PSI values greater than 0.60 were interpreted as significant. In the 1970s, the fish assemblages near the mouth of the slough (e.g., Bridge and Dairy stations) were very different from those of the tidal creeks (table 10.3; Barry 1983; Yoklavich et al. 1991). The assemblage at the eastern end of the slough (e.g., Hudson's Landing) was more similar in composition to the tidal creek fauna, while the assemblage at Kirby Park was more like those from the main channel to the west.

Twenty years later, however, these geographical differences have disappeared (table 10.3). Fish assemblages in the lower main channel are mostly unchanged, but assemblages in the tidal creeks now resemble those of the lower slough. In fact, assemblages from the Dairy and Long Canyon stations have the highest PSI (0.76) of all 1990s comparisons, due to three dominant species (shiner surfperch, northern anchovy, and Pacific herring). These changes in fish assemblages coincide with the continued erosion and scouring of the slough during the last twenty-five years, which has resulted in a geomorphology of the tidal creeks that is now more similar to that of the main channel (Malzone and Kvitek 1994).

Bennett Slough Bennett Slough is a shallow (0.3–2.5 m) tidally influenced embayment (figure 10.1), with a soft mud bottom often covered by sea lettuce. It originally was connected to Elkhorn Slough via a single small culvert (0.6 m diameter) at the north end of Moss Landing Harbor. This culvert was destroyed by the 1989 earthquake and subsequently replaced with six larger culverts (each 1.2 m diameter). This likely has increased tidal current velocities and water depth adjacent to the culverts.

The fish assemblage in Bennett Slough generally is similar to those surveyed at the tidal creek and Hudson's Landing stations of Elkhorn Slough (Yoklavich et al. 1991). Species composition is least similar to that of the Moss Landing Harbor and adjacent

Table 10.2. Relative abundance (%) of dominant species totaling 80% or greater of fishes collected by small otter trawl during the day in Elkhorn Slough, 1974–1980 (from Yoklavich et al. 1991), 1991-1992 (from Oxman 1995), and 1995–1996 (from Cailliet and Oxman, unpubl. data). See legend of appendix 10.1 for life-style categories (in parentheses).

	1974–1980						1991–1992			1995–1996					
Species	Bridge	Dairy	Kirby Park	Hudson Landing	Rubis Creek	Long Canyon	Bridge	Dairy	Kirby Park	Bridge	Dairy	Kirby Park	Hudson Landing	Rubis Creek	Long Canyon
speckled sanddab (MI)	10.3	4.4					18.4	14.4		7.0					
white surfperch (PR)	16.6	28.4					7.1	14.1		15.1	12.1				
English sole (MI)		4.0	10.7				9.1	23.4	21.2						
starry flounder (MI)		3.9	5.9			5.9									
shiner surfperch (PR)	43.4	28.8	53.7		15.5		10.6	16.3	42.9	26.9	35.5		9.8	31.4	48.1
black surfperch (R)	14.6	13.4			7.7	3.7	15.3			18.0					
Pacific staghorn sculpin (R)			13.1	57.6	41.1	51.2	4.4	9.9	13.4				44.1	9.1	
northern anchovy (MI)				18.3	9.2					9.2	16.1	83.1	32.3	41.5	17.3
Pacific herring (MI)				15.0	3.8						21.2				16.2
queenfish (MI)						9.5									
topsmelt (PR)						4.9									
arrow goby (R)						3.7									
leopard shark (PR)						3.7									
lingcod (M)								5.8							
cabezon (MI)							17.3								
bay pipefish (R)										6.3					
California tonguefish (MI)									12.0						
Total (%)	84.9	82.9	83.4	90.9	81.3	82.6	82.2	83.9	89.5	82.5	84.9	83.1	86.2	82.0	81.6
No. of dominant species	4	6	4	3	6	7	7	6	4	6	4	1	3	3	3

coastal waters. From 86 samples collected with beach seines in the mid-1970s, Appiah (1977) described a relatively low-diversity fish assemblage (20 species) that had a high average abundance (59.1 fish per sample) dominated by 3 euryhaline species (Pacific staghorn sculpin, starry flounder, and arrow goby). Jacksmelt, topsmelt, and three-spined stickleback also were numerous. Most of these species are slough residents or partial residents.

The fishes in Bennett Slough were resurveyed with beach seines in April 1996 (J. Field and S. Sundberg, MLML unpubl. report), well after the earthquake and culvert modifications. This survey of more than 1,300 fishes (about 25% of the total number of fishes from the earlier survey) was dominated by jacksmelt, staghorn sculpin, topsmelt, arrow goby, and bay goby. Most of these fishes were young-of-the-year, suggesting the likely role of Bennett Slough as a nursery. Although limited in scope, this study indicates that the fish assemblage in Bennett Slough has not changed significantly, despite the physiographic changes resulting from post-earthquake construction.

South Marsh The South Marsh (fig.10.1) restoration site, located within the ESNERR, represents approximately 20% of the wetted area and 30% of the total volume of Elkhorn Slough (Malzone and Kvitek 1994). Once an active salt marsh, this area was almost completely cut off from the main slough with the construction of the Southern Pacific Railway in the late 1800s, resulting in a brackish-water habitat. Tidal flow was restored in 1983.

Small (1986) surveyed the fish and macroinvertebrate fauna of South Marsh before and after the restoration. Prerestoration surveys in April and August 1983 resulted in fairly high abundances (677 to 1,240 fish per tow) of 9 small species. The euryhaline three-spined stickleback was predominant, but species of greater marine affinity, such as topsmelt, Pacific staghorn sculpin, Pacific herring, California tonguefish, arrow goby, northern anchovy, shiner surfperch, and jacksmelt, also were present.

Samples taken in April and August 1984, after South Marsh was opened to tidal influence, had higher diversity (16 species) but much lower abundances (42 to 73 fish per tow). Marine and brackish-water fishes were more prevalent, with Pacific staghorn sculpin and northern anchovy the dominant species. Other common species included the arrow goby, California tonguefish, Pacific herring, longjaw mudsucker, plainfin

Table 10.3. Comparison of fish species composition in otter trawl collections from six stations in Elkhorn Slough during 1974–1980 (top half of matrix and bold) and 1995–1996 (bottom half of matrix and not bold) based on percent similarity index (PSI).

	Bridge	Dairy	Kirby Park	Hudson's Landing	Rubis Creek	Long Canyon
Bridge	---	**0.77**	**0.60**	**0.07**	**0.32**	**0.16**
Dairy	0.59	---	**0.48**	**0.11**	**0.36**	**0.18**
Kirby Park	0.19	0.29	---	**0.27**	**0.45**	**0.32**
Hudson's Landing	0.26	0.41	0.47	---	**0.61**	**0.62**
Rubis Creek	0.52	0.66	0.56	0.56	---	**0.66**
Long Canyon	0.44	0.76	0.31	0.66	0.63	---

midshipman, English sole, shiner surfperch, yellowfin goby, and bay goby (Small 1986). Small numbers of California halibut, bay pipefish, Pacific sardine, starry flounder, diamond turbot, and bat ray also were collected. The restoration process apparently increased saltwater mixing and allowed a higher diversity of marine and estuarine fishes to occupy this formerly brackish-water marsh.

In subsequent monthly surveys of South Marsh through 1985 (Small 1986), 10 species were consistently abundant (Pacific staghorn sculpin, shiner surfperch, northern anchovy, arrow goby, Pacific herring, California tonguefish, English sole, California halibut, starry flounder, and bat ray). Strong peaks in abundance were detected in late spring and early summer, primarily due to the influx of juveniles. Thus, the fish assemblage in this newly developed area of the South Slough is now quite similar to that of the adjacent slough waters.

Salt Evaporation Ponds: Azevedo Marsh The Azevedo Marsh system comprises several salt evaporation ponds, covering about 4.7 square kilometers that were separated from the main slough by Southern Pacific Railway dikes in the late 1800s (see ABA Consultants 1989). Commonly called pocket marshes, these ponds are connected to the slough by culverts under the railroad dikes. They often are filled by freshwater discharge, but there is significant tidal exchange (especially since 1982, when the dikes were partially breached by erosion), so the ponds sometimes become brackish or even marine. These ponds probably represent one of the most extreme habitats occupied by fishes in the slough system. They are characterized by highly variable water quality and are dominated by seasonally changing plant assemblages, including pickleweed and drift algae. They are shallow, very muddy, offer restricted access and egress, and they receive heavy runoff of nutrients and pesticides from adjacent agricultural fields.

The fishes in the saltponds of Azevedo Marsh were surveyed by beach seine during spring 1998 (A. Spotswood and A. Devitt, MLML unpubl. report). In general, the species composition was quite similar to that of Bennett Slough, dominated by Pacific staghorn sculpin, arrow goby, and topsmelt; large numbers of northern anchovy were collected at high tide in the largest pond. Other fishes included shiner surfperch, mosquitofish, three-spined stickleback, and yellowfin goby.

Overall, this is an interesting mixture of freshwater, brackish-water, and saltwater fishes. However, much higher than normal rainfall in 1998 (an El Niño year) might have influenced these results. Species composition in these ponds might differ considerably in other years or seasons. The longjaw mudsucker was common in North Azevedo Pond during summer 1998 (S. Ross, North Carolina NERR, unpubl. data). This goby seems particularly well adapted to the pond's harsh environment, which includes extreme variations in temperature and dissolved oxygen (ESNERR unpubl. data). Small leopard sharks also have been observed in the Azevedo ponds (M. Silberstein, pers. comm.).

Seasonality and Spawning

The abundance and distribution of several fish species in Elkhorn Slough vary significantly from season to season, primarily as a function of the fishes' reproductive habits. Like other estuarine systems, Elkhorn Slough serves as a spawning and nursery ground for many fishes, including some commercially and recreationally important species (Barry 1983; Yoklavich et al. 1991; Yoklavich, Stevenson, and Cailliet 1992). Its protected waters (relative to the open ocean) provide abundant food resources, perhaps lower predation pressure, and a variety of shallow habitats with elevated water temperature for juveniles and spawning adults.

The overall abundance and diversity of fishes in Elkhorn Slough peak during summer (Cailliet et al. 1977; Barry 1983; Small 1986; Yoklavich et al. 1991). Many marine species enter the slough as young juveniles or reproductively active adults during this season. Also, locally spawned juveniles grow large enough by summer to be collected in the survey nets.

Abundance and diversity decline during fall, when many of the partial-resident and marine-immigrant juveniles leave the slough and return to the ocean. Fishes overwintering in the slough are mainly resident species capable of coping with the wide range in salinity that is typical of the rainy season (see chapter 4, "Hydrography").

Seasonal variations in abundance and distribution of adult and juvenile fishes in the Elkhorn Slough system are similar to patterns described for other estuarine systems. Higher abundance and species richness during the summer invasion of young-of-the-year marine species also have been documented for fish assemblages in other temperate bays and estuaries, and were positively correlated with temperature (Allen and Horn 1975; Hoff and Ibara 1977; Allen 1982; Onuf and Quammen 1983).

Seasonal distribution and abundance of adults, juveniles, and larvae vary significantly from species to species, depending on their spawning cycles. For example, increased springtime abundance of juvenile Pacific herring in the upper slough follows winter spawning in eelgrass beds of central California bays and estuaries. The high abundance of the three dominant species of surfperches (shiner, black, and white) in summer and early fall reflects their summer spawning (Antrim 1981). Shiner surfperch enter upper areas of the slough to spawn (Barry 1983), while white surfperch spawn at the lower stations (Antrim 1981).

The English sole, a commercially important marine immigrant, relies heavily on large northern estuaries as nursery grounds (Myers 1974; Krygier and Pearcy 1986; Pearcy and Toole 1980; Gunderson et al. 1990). Young benthic (bottom-dwelling) juveniles that are newly settled from the plankton enter Elkhorn Slough in early spring, increase in abundance in the main channel, and reach peak numbers at Kirby Park in summer. Elkhorn Slough is thought to be the southernmost major nursery for juvenile English sole, which are conspicuously absent from fish surveys of southern California bays (Horn and Allen 1985). Their occurrence in shallow inshore areas may be limited by specific thermal tolerances during various stages in development.

Although categorized as partial residents, two species of elasmobranchs, the leopard shark and bat ray, occur nearly year-round and spawn in Elkhorn Slough (Talent 1985). Other elasmobranch species appear to be more seasonal in occurrence. Patterns in occurrence may be related to food abundance, breeding areas, and nursery grounds (Barry and Cailliet 1981; Barry 1983; Martin and Cailliet 1988a; Talent 1976, 1982, 1985).

Fish Eggs and Larvae

Some fishes lay eggs that are free floating; others attach their eggs to plants or other substrates. Floating fish eggs and newly hatched larvae are part of the ichthyoplankton that is moved about by wind and water currents. The distribution of young fishes at these developmental stages provides evidence for the occurrence, timing, and location of spawning within the slough.

Patterns of seasonal and spatial abundance of free-floating fish eggs and larvae in Elkhorn Slough are known from ichthyoplankton samples collected monthly from 1974 to 1976 at five stations (Harbor, Bridge, Dairy, Red House, and Kirby Park) along the main channel (fig. 10.1; Yoklavich, Stevenson, and Cailliet 1992). Twenty-nine taxa of fishes were collected in this study (appendix 10.1). Gobiid (gobies) and clupeoid (herrings and anchovies) larvae were numerically predominant. Seven species accounted for 94% of the total larval fish catch: in order of abundance, longjaw mudsucker, northern anchovy, arrow goby, unidentified osmerid (probably surf smelt), Pacific staghorn sculpin, white croaker, and Pacific herring. Among the eggs, northern anchovy, unidentified sanddab, and white croaker accounted for 83% of the catch.

Larval fish assemblages varied seasonally in Elkhorn Slough. Northern anchovy and two gobies (longjaw mudsucker and arrow goby) were most abundant during summer and fall.

California halibut. Left: Three larval stages of development, ranging from 7.3 mm long (top) to 14.0 mm long (bottom). Photo credit: Bruce Stewart. Right: Adult about 1.2 meters long, held by former Moss Landing Marine Laboratories graduate student Brooke Antrim. Photo credit: Gregor Cailliet.

Both gobies have protracted spawning seasons from February to September (Weisel 1947; Prasad 1948) that peak during late summer when water is warm (18–23°C). Northern anchovies spawn primarily in the lower slough in summer and early fall, in water temperatures of 14–18°C. Newly hatched northern anchovies are distributed progressively eastward from the harbor to at least Kirby Park. The shallow upper slough waters provide a nursery for these larvae during fall and winter.

A different assemblage of young larvae is found during winter and early spring. This group is more diverse but less abundant than the summer-fall assemblage. Pacific staghorn sculpin, surf smelt, two species of Atherinids (topsmelt and jacksmelt), and Pacific sand lance are the dominant larvae in this season. This group also is more variable in occurrence, with pulses of high numbers of young surf smelt and Pacific sand lance collected in single samples.

There are at least two spatially distinct larval assemblages in the slough, one located in the most inland areas and another at the near-ocean stations. These distributions are attributed to reproductive specialization (egg type and spawning origin of adults) and hydrographic conditions.

Upper slough waters featured fewer taxa but greater numbers of individual larvae. Resident gobies produced the most abundant larvae in the slough, and their numbers increased with distance from the harbor. Adults and juveniles of longjaw mudsucker and arrow goby were collected almost entirely in tidal creeks and inland slough waters (Barry 1983; Yoklavich et al. 1991). The extensive pickleweed beds bordering these regions provide suitable habitat for spawning gobies.

Pacific herring larvae were abundant in spring in the upper slough where pickleweed beds occupy the intertidal marsh zone. Submerged aquatic vegetation is relatively sparse elsewhere in Elkhorn Slough. The lack of adequate spawning substrate, such as seagrass beds, potentially limits use of the lower slough as nursery habitat. Restoration of seagrass beds in Elkhorn Slough could modify distribution and enhance recruitment for species with adhesive, *demersal* eggs, such as Pacific herring.

Along with localized spawning habits of adults, significant differences between larval assemblages in the lower and upper slough suggest that the tidal prism (a wedge of marine water flowing along the bottom of the main channel on a rising tide to about 4.8 km from the harbor entrance) assists in retaining young fishes within the slough. Mid-slough species composition represents a transition between lower and upper groups. Water is exchanged daily by tidal currents, and seasonal variations in temperature and visibility are similar at harbor entrance, Bridge, and Dairy stations. The most abundant larvae at these stations were very small northern anchovy and surf smelt, species that are classified as slough immigrants.

The water mass to the east of the tidal prism fluctuates widely in temperature and salinity, and has lower visibility. The high water *residence time* and increased summer water temperatures and available substrate for adhesive demersal eggs in shallow inland marsh habitats of the slough could enhance reproductive success, larval retention, and survival.

There are similarities in species composition among Elkhorn Slough larval fish assemblages and those described in the few comparable studies of other West Coast estuaries. Gobiid and clupeoid larvae dominate most systems, including almost all southern California bays and estuaries (McGowen 1977; Leithiser 1981; Nordby 1982; Horn and Allen 1985), northern California's Humboldt Bay (Eldridge and Bryan 1972), and Yaquina Bay, Oregon (Pearcy and Myers 1974). Seasonal and spatial patterns of larval fish abundance also were similar in many of the West Coast studies of inshore larval fish assemblages.

Feeding Habits

The diets of the dominant fishes in Elkhorn Slough are known from analysis of the stomach contents of juvenile and adult fishes collected at eight stations in 1974–1980 (Ambrose 1976; Cailliet et al. 1977; Antrim 1981; Barry and Cailliet 1981; Barry 1983; Barry et al. 1996). Diets at four of these stations were reexamined in 1996–1997 to assess potential effects of slough erosion and scour on the fishes' trophic ecology (Lindquist 1998).

Based on these studies, four *trophic guilds* have been described for the slough (fig. 10.2). The most distinct guild, which includes Pacific staghorn sculpin, arrow goby, shiner surfperch, and speckled sanddab, feeds principally on *epifaunal* crustacea (especially gammarid amphipods and harpacticoid copepods). A second guild, including English sole, starry flounder, white surfperch, and bat ray, eats mostly molluscs and *infaunal* worms (especially during the 1970s). A third guild consists of fishes that primarily prey on mobile crustaceans (such as mysids, *Crangon* shrimp, and grapsid crabs); these are sand sole (at near ocean stations), leopard shark (in the 1970s), and white surfperch (in the 1990s). The fourth guild comprises fishes that feed primarily on zooplankton and diatoms in the water column; topsmelt, Pacific herring, and northern anchovy are among the species in this group.

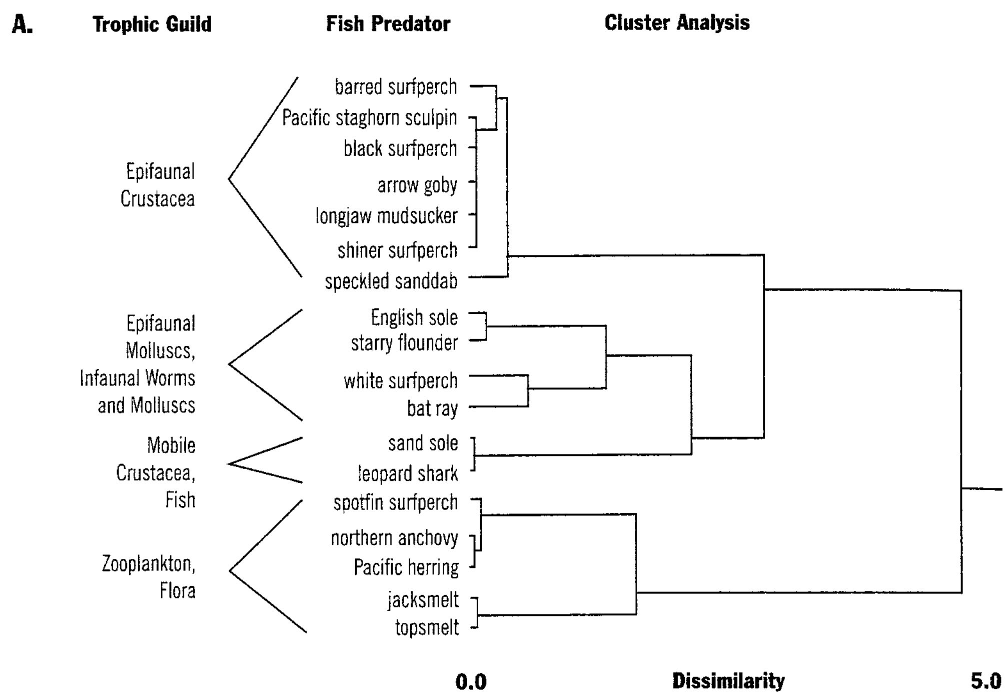
Prey diversity was noticeably lower in the 1990s than in the 1970s. This trend was evident at all four stations and for all of the nine fish species found in both studies. The main difference was the reduced use of infaunal worms and molluscs (Lindquist 1998). For example, the English sole had the most diverse diet (44 prey taxa, including many infaunal worms) in the 1970s, but ate only 14 prey items in the 1990s. Infaunal prey were largely replaced with epifaunal crustacea in the English sole's diet, and with mobile crustacea (specifically *Hemigrapsus* crabs) in the diet of the white surfperch.

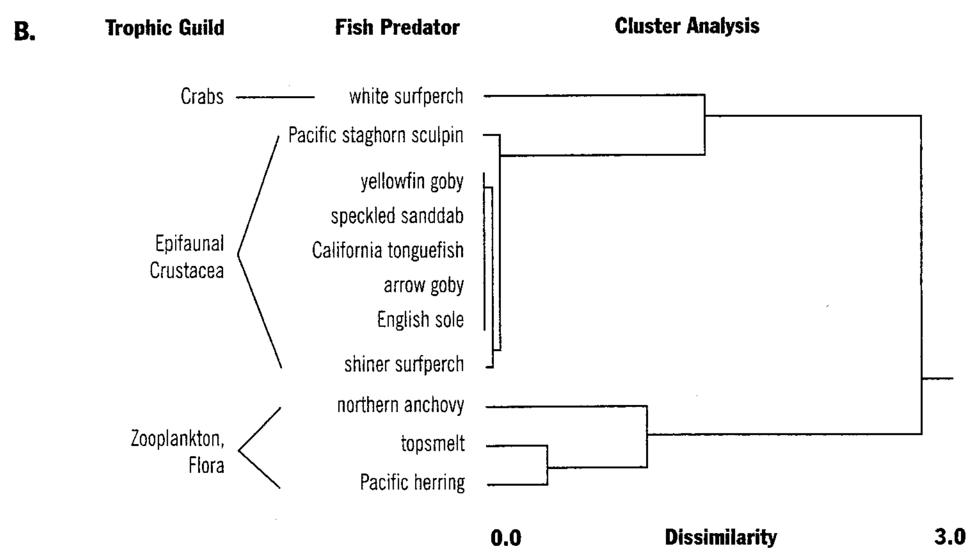
Fishes of estuaries and shallow marsh habitats often are categorized as trophic generalists that use abundant, but highly variable, prey resources. Diets of the benthic foraging fishes (such as sanddab, starry flounder, and shiner surfperch) in Elkhorn Slough reflected prey availability in core samples of bottom sediments (Barry et al. 1996; Lindquist 1998). Prey availability in the main channel, however, changed during the twenty years of studies. Overall densities of benthic invertebrates have decreased (Lindquist 1998). Notable were the increased relative abundance of epifaunal crustacea (amphipods and tanaids) and the dramatic decrease in infaunal worms.

Increased rates of erosion, water current velocity, and scour of the slough (Williams et al. 1992; Crampton 1994; see chapter 4), which were initially caused by the construction of the entrance to Moss Landing Harbor in 1947, have resulted in significant changes to the vegetated salt marshes, mudflats, main channel, and tidal creeks. In the late 1970s, Long Canyon was 1–1.5 kilometers long, 5–10 meters wide, and 2 meters deep at its intersection with the main channel (about 4 km east of Moss Landing Harbor entrance) and received freshwater runoff from the adjacent watershed. Rubis Creek, which intersects the main channel across from Long Canyon, was about the same width and depth as Long Canyon in the late 1970s, but received little freshwater runoff. Long Canyon increased 62% in width from 1980 to 1987, and is continuing to erode. Rubis Creek increased 8% in width during this time. The main channel also has broadened and deepened (J. Oliver et al., MLML unpubl. report; Malzone and Kvitek 1994). Mudflat habitat that fringes the main channel and harbors dense assemblages of infaunal and epifaunal invertebrates likely is diminishing (ABA Consultants 1989).

As the main channel and tidal creeks of the slough continue to broaden and deepen, the species composition of fish predators and invertebrate prey apparently is being altered. The trophic patterns of fishes in the tidal creeks are now more similar to those of fishes in the main channel than was indicated from surveys in the 1970s (Lindquist 1998). Interestingly, prey richness in the 1970s was greatest at stations in the main channel and lowest in the tidal creeks (Barry et al. 1996). In the 1990s study, prey richness was similar between main channel and tidal creek sites (Lindquist 1998).

Figure 10.2. Cluster analysis of fishes in Elkhorn Slough, based on dietary information summed to trophic guilds. A. Fishes collected from 3 main channel, 2 tidal creek, and 2 nearshore ocean stations 1974-1980 (Barry et al. 1996). B. Fishes collected from 2 main channel and 2 tidal creek stations 1996-1997 (Lindquist 1998).





Sportfisheries

Sportfishing has been popular in Elkhorn Slough for many decades, but there is little historical information on the level of effort or impact on the fish populations. Two long-term studies of sportfish catches have provided some information about those species popular with anglers. These are shark derbies and creel surveys.

Shark Derbies

In the 1940s, the Pajaro Valley Rod and Gun Club (PVRGC) and the Castroville Rod and Gun Club (CRGC) initiated late spring–early summer angling derbies for elasmobranchs in Elkhorn Slough. In addition to their recreational value, these derbies were meant to control shark and ray populations that were believed to be reducing populations of more desirable finfish and shellfish in the slough. The last derbies (by either angling or archery) for elasmobranchs in Elkhorn Slough occurred in 1996.

Ichthyologists, most notably Earl S. Herald from the California Academy of Sciences, took an early interest in these derbies as a means of collecting data on estuarine elasmobranch populations. From 1951 to 1962, these researchers monitored the Elkhorn Slough derby catches each year, recording species composition, total length, weight, sex, gut content, stage of sexual maturity, and fishing effort (Herald and Dempster 1952; Herald 1953; and Herald et al. 1960). In 1963 and 1964, the sponsoring clubs collected similar data from their own derbies. Collection of data from the elasmobranch derbies was resumed in 1971 by ichthyologists at MLML, California Department of Fish and Game, California Academy of Sciences, and San Francisco State University. Between 1980 and 1996, this was an annual event conducted by MLML personnel (King and Cailliet 1992). In 1988, MLML, the PVRGC, Monterey Bay Aquarium, and the Elkhorn Slough Foundation cooperatively initiated a tag-and-release program during the angling derbies, which continued until 1996.

Based on data collected from shark derbies (King and Cailliet 1992), and some presented by Talent (1985), we know that 7 species of large elasmobranchs are relatively common in Elkhorn Slough: bat ray, shovelnose guitarfish, leopard shark, gray smoothhound, brown smoothhound, thornback, and round stingray. Two others, the spiny dogfish and Pacific electric ray, also have been caught in the slough.

Species composition and catch-per-unit-effort (CPUE) were evaluated from forty-eight elasmobranch derbies held in Elkhorn Slough during May, June, and July 1951–1990. The most noticeable change in species composition over these forty years was the nearly complete disappearance of the shovelnose guitarfish after 1972. From 1951 through 1960, catch ranged from 60 to 240 elasmobranchs per derby, with an average of about 100 fish per derby. Catch was lower in the more recent years, ranging from 60 to 170 fish, with an average of about 85. Although data were not available for all years, CPUE peaked in the mid to late 1950s (0.3–1.8 fish per fisherman), and declined since 1960 (0.3–0.4 fish per fisherman).

These researchers also presented trends in size structure and sex ratios for the most abundant species (bat ray, shovelnose

A young visitor to the Elkhorn Slough National Estuarine Research Reserve holds a small gray smoothhound. Photo credit: ESNERR.

guitarfish, and leopard shark) and noted that neither varied significantly over the years. One exception was that the smaller size classes of shovelnose guitarfish disappeared from the catch earlier (before the 1970s) than the larger fishes. Also, female bat rays and shovelnose guitarfish were larger than their male counterparts, and outnumbered males nearly 2:1, whereas female and male leopard sharks were nearly equal in size and sex ratio.

Recreational Creel Surveys

From July 1974 to June 1976, Cailliet et al. (1977) conducted monthly creel censuses at popular sportfishing sites along the shores of Elkhorn Slough. Sampling sites were combined into those west of the Highway One bridge (including the Jetties, Skippers, and Bennett Slough) and those to the east (mainly Kirby Park; see fig. 10.1). The number of censuses at each of these two general locations ranged from 6 to 66 per month, and averaged 35.

At least 46 species of fishes were caught by sportfishermen in the marine waters west of the bridge; more than half of these were rare (less than 1% of the total; table 10.4). The ten most frequently reported species were Pacific staghorn sculpin, sand sole, walleye surfperch, white surfperch, shiner perch, white croaker, starry flounder, black surfperch, jacksmelt, and pile perch. Farther up the slough, catches were lower in abundance (only 37 specimens were surveyed), and only 8 species were reported. White surfperch, shiner perch, and rubberlip perch were reported to be the most abundant species.

In the 1980s and 1990s, creel censuses of similar seasonal coverage but much lower sample sizes were conducted by the National Marine Fisheries Service (NMFS), through the Marine Recreational Fishing Statistics Survey (MRFSS). NMFS used somewhat different survey techniques, but changes in sportfishery catches can be evaluated by comparing relative abundance (rank). The trends west of the bridge basically were similar. Only 25 species were caught, but eight of the top ten species were the same. The notable differences were lower rankings for sand sole (8th) and shiner perch (tied 14th) and higher rankings for silver surfperch (7th), barred surfperch (2nd), calico surfperch (tied 10th), and señorita (12th). The latter three species are more commonly found in southern California; increased numbers in the vicinity of Elkhorn Slough could reflect the coastwide warming trend in nearshore waters that has occurred since the late 1970s (Barry et al. 1995; Roemmich and McGowan 1995).

Based on small samples, 7 species were reported from upper slough sites. Five of these were the same as the 1970s. Pile perch (in 2nd rank) and brown rockfish (tied 6th) were new to the survey; shiner perch, starry flounder, and striped bass were absent.

During both time periods, catches east of the Highway One bridge were lower in abundance and diversity than catches in the west end of the slough. In the 1970s, the dominant species taken in the upper reaches of the slough were white surfperch, shiner surfperch, rubberlip perch, Pacific staghorn sculpin, striped surfperch, starry flounder, striped bass, and cabezon. Pacific staghorn sculpin dominated the catches in the 1980–1990s, followed by pile surfperch, striped surfperch, rubberlip perch, white surfperch, cabezon, and brown rockfish, the latter probably being primarily juveniles.

Management Issues and Research Recommendations

Elkhorn Slough provides habitat for many fishes, and serves as spawning and nursery grounds for a variety of ecologically, commercially, and recreationally important species. Juveniles of some commercially important fish species found in the slough include Pacific herring, English sole, and northern anchovy.

From the studies on fishes of Elkhorn Slough from the 1970s to the present, it is obvious that changes in habitat significantly influence the distribution, abundance, and trophic patterns of the slough's ichthyofauna. There are distinct relationships between the physical characteristics of these habitats, such as water depth, distance from the ocean, magnitude of tidal currents, temperature, and salinity, and the fish fauna that occupy them. As habitats are modified (e.g., broadening and deepening of tidal creeks due to tidal scour and erosion), the fish assemblages and their use of these habitats also change.

The contribution that estuaries and bays such as Elkhorn Slough make to the survival of coastal marine fishes is difficult to assess. The high relative abundance of marine-related (i.e., marine, marine-immigrant, and partial-resident life style categories) individuals and species entering Elkhorn Slough early in life or as spawning adults demonstrates the importance of this habitat to nearshore fish communities. Relatively large numbers of marine immigrants, especially in the highly productive shallow tidal creeks and upper areas of the slough, potentially can transport energy from nursery habitats to offshore waters. The scarcity of habitats like Elkhorn Slough along the central California coast implies that remaining areas are important to the success of nearshore marine fishes.

Here we suggest additional research topics that could help us to better understand the role of Elkhorn Slough and other estuaries in the life cycles of nearshore marine fishes; to measure the ongoing impacts of natural and human-induced changes on fish populations, their predators, and prey; and to interpret change in the fish assemblages through time.

Long-Term Monitoring of Fish and Ichthyoplankton

Surveys of the fishes occupying Elkhorn Slough and its habitats have been conducted over the past few decades. However, these were mostly opportunistic and related to environmental surveys required of industry or for land-use practices. It is now

Adult leopard shark collected for tag-and-release in the slough. Photo credit: ESNERR.

recognized that regular surveys of the fish fauna and associated environmental conditions could help us interpret fluctuations in these populations over time. With such data, a better assessment of fish responses to natural and human-induced environmental changes would be possible.

Ichthyoplankton surveys recently completed in association with the Moss Landing Power Plant modernization project (Tenera Environmental Services 2000) provide a third decade of information on the fish larvae dispersed throughout Elkhorn Slough over the seasons. Such longterm information will be useful in predicting the effects that entrainment of fish larvae into the power plant may have on the adult populations in the slough.

Use of Habitats by Fishes

Continued monitoring of the habitats in Elkhorn Slough, especially as it relates to erosional processes, is essential to predict change in fish assemblages. As we evaluate ways to control erosion, it will be important to document the types of available habitats and their distribution and relative proportion within the slough ecosystem.

Defining the patterns in habitat use by fishes will help us understand the functional relationships among habitats and the fish assemblages in the slough. Tag-recapture and tracking studies of various slough fishes could help us identify important feeding and nursery habitats. Indeed, it is known that several species of elasmobranchs pup in Elkhorn Slough in the spring, and the young sharks typically occupy tidal creeks for feeding and shelter (Barry and Cailliet 1981; Barry 1983; Barry et al. 1996). However, the physiographic and ecologic nature of these tidal creeks has been changing with continued erosion; the impact of such changes on the function of these habitats and associated fishes remains unknown.

Long-Term Predator and Prey Surveys

Because of the pronounced change in the prey assemblages consumed by fishes following two decades of increased tidal scour of Elkhorn Slough, it is important to monitor the ecological factors that could influence fish survival. Continued surveys of benthic infaunal and epifaunal organisms would enhance our ability to evaluate the importance of the slough as fish feeding grounds. Likewise, continued surveys of birds and mammals in the slough can help us determine potential effects that these predators may have on fishes and shared prey resources.

Contribution to Nearshore Fisheries in Monterey Bay and the Central California Coast

The prevalence of estuarine dependence by nearshore fishes, especially during their early life history, has often been suggested as one reason for the ecological importance of estuaries. However, few studies have adequately tested the hypothesis that some species of fishes are, indeed, estuarine dependent, or have identified the extent to which specific estuaries are used by coastal fishes during their early life history. Recently, scientists at the University of California, Santa Cruz (Pete Raimondi and Jennifer Brown, pers. comm.) have analyzed trace chemical elements in the *otoliths* of flatfishes to differentiate juveniles living in estuaries from those found

Table 10.4. Fish 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 from the 1970s (taken from Cailliet et al. 1977)) and the 1980s–1990s (summarized from the NMFS Marine Recreational Fishing Statistics Surveys [MRFSS] data base). Data are grouped into those sites west of the Highway One bridge (Jetties, Skippers, Bennett Slough) and those to the east (mainly Kirby Park).

		1970s		1980s–1990s	
Scientific Name	**Common Name**	**West**	**East**	**West**	**East**
Leptocottus armatus	Pacific staghorn sculpin	1	4.5	1	1
Psettichthys melanostictus	sand sole	2.5	-	8	-
Hyperprosopon argenteum	walleye surfperch	2.5	-	5	-
Phanerodon furcatus	white surfperch	4	1	9	5
Cymatogaster aggregata	shiner surfperch	5	2	14.5	-
Genyonemus lineatus	white croaker	6	-	6	-
Platichthys stellatus	starry flounder	7	6	9	-
Embiotoca jacksoni	black surfperch	8	4.5	10.5	3
Atherinopsis californiensis	jacksmelt	9	-	3	-
Rhacochilus vacca	pile surfperch	10	-	13	2
Sebastes paucispinis	bocaccio	11	-	-	-
Rhacochilus toxotes	rubberlip surfperch	12	3	17	4
Ophiodon elongatus	lingcod	13	-	24	-
Hexagrammos decagrammus	kelp greenling	14	-	-	-
Scorpaenichthys marmoratus	cabezon	15	8	17	6.5
Citharichthys stigmaeus	speckled sanddab	16	-	22.5	-
Embiotoca lateralis	striped surfperch	17	-	22.5	-
Sebastes mystinus	blue rockfish	18	-	24	-
Morone saxatilis	striped bass	19	7	-	-
Hyperprosopon ellipticum	silver surfperch	20	-	7	-
Amphistichus rhodoterus	redtail surfperch	21	-	-	-
Amphistichus argenteus	barred surfperch	22	-	2	-
Sebastes auriculatus	brown rockfish	tr	-	14.5	6.5
Sebastes chrysomelas	black-and-yellow rockfish	tr	-	-	-
Amphistichus koelzi	calico surfperch	tr	-	10.5	-
Squalus acanthias	spiny dogfish	tr	-	-	-
Oxylebius pictus	painted greenling	tr	-	-	-
Porichthys notatus	plainfin midshipman	tr	-	-	-
Atherinops affinis	topsmelt	tr	-	-	-
Parophrys vetulus	English sole	tr	-	-	-
Neoclinus uninotatus	onespot fringehead	tr	-	-	-
Hypsurus caryi	rainbow surfperch	tr	-	-	-
Oncorhynchus tsawytscha	chinook salmon	tr	-	-	-
Hyperprosopon anale	spotfin surfperch	tr	-	-	-
Lyopsetta exilis	slender sole	tr	-	-	-
Ammodytes hexapterus	Pacific sand lance	tr	-	-	-
Trachurus symmetricus	jack mackerel	tr	-	-	-
Gibbonsia sp.	kelpfish	tr	-	-	-
Cebidichthys violaceus	monkeyface prickleback	tr	-	-	-
Engraulis mordax	northern anchovy	tr	-	-	-
Hypsopsetta guttulata	diamond turbot	tr	-	-	-
Oxyjulis californica	señorita	tr	-	12	-
Microgadus proximus	Pacific tomcod	tr	-	-	-
Myliobatis californica	bat ray	tr	-	-	-
Sebastes spp.	misc. rockfishes	tr	-	tr	-
Peprilus simillimus	Pacific pompano	tr	-	-	-
Triakis semifasciata	leopard shark	-	-	17	-
Anarrhichthys ocellatus	wolf-eel	-	-	22.5	-
TOTAL NUMBER OF SPECIMENS SURVEYED		**5,832**	**37**	**1,033**	**32**
TOTAL NUMBER OF SPECIES		**46**	**8**	**25**	**7**

offshore, and to potentially identify the actual estuary in which the young fishes grew up. Additional studies of this nature would identify and quantify essential estuarine habitats for fish species in central California.

Identification and Enumeration of Fishes from Archaeological Surveys

A great deal of information about the historical status of fishes can be obtained from archaeological samples. Several Native American archaeological sites around the Elkhorn Slough area have been sampled for fishes (Gordon 1985; Dietz, Hildebrandt, and Jones 1988; see chapter 6, "Archaeology and Prehistory"). Evidence to date indicates that these Native Americans harvested both freshwater and marine fishes, presumably at a time when the Salinas and Pajaro Rivers connected near the site where the Salinas River and Elkhorn Slough now converge (Gobalet 1990, 1993).

While data on species composition are readily available from bones, scales, and otoliths of fishes, less information about seasonal occupation of these sites both by Native Americans and by fishes, or about the reproductive status, size ranges, age composition, or mortality rates of the fish, is available. Modern techniques used to analyze growth zones and stable isotopes in such calcified structures as fish otoliths from these archaeological surveys could uncover details about the ecology of the fishes that occurred in this estuarine system thousands of years ago.

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Appendix 10.1. Species of finfish (alphabetically ordered by Family) collected from Elkhorn Slough, California and adjacent areas (Moss Landing Harbor, Jetties and Bennett Slough).

Life style (M = marine, MI = marine immigrant, R = resident, PR = partial resident, and F = freshwater)
Life stage (A = adult, J = juvenile, L = larva, E = egg) '?' indicates that species or life stage were not verified.
NN indicates non-native species.
Common and scientific names follow Robins et al. (1991) and Robert N. Lea (pers. comm.).

Family	Species	Common Name	Life style	Life stage
Acipenseridae	*Acipenser medirostris*	green sturgeon	MI	A
Ammodytidae	*Ammodytes hexapterus*	Pacific sand lance	M	L, A
Anarhichadidae	*Anarrhichthys ocellatus*	wolf-eel	M	A
Atherinopsidae	*Atherinops affinis*	topsmelt	PR	L, J, A
	Atherinopsis californiensis	jacksmelt	PR	L, J. A
	Leuresthes tenuis	California grunion	M	A
Aulorhynchidae	*Aulorhynchus flavidus*	tubesnout	M	J, A
Bathylagidae	*Leuroglossus stilbius*	California smoothtongue	M	L
Batrachoididae	*Porichthys notatus*	plainfin midshipman	MI	J, A
Blenniidae	*Hypsoblennius gentilis*	bay blenny	M	J
Bothidae	*Citharichthys stigmaeus*	speckled sanddab	MI	E, L, J
	Paralichthys californicus	California halibut	MI	L, J, A
Carangidae	*Trachurus symmetricus*	jack mackerel	M	J, A
Carcharhinidae	*Mustelus californicus*	gray smoothhound	M	J, A

Family	Species	Common Name	Life style	Life stage
	Mustelus henlei	brown smoothhound	M	J, A
	Triakis semifasciata	leopard shark	PR	J, A
Clinidae	*Gibbonsia metzi*	striped kelpfish	M	L, A
	Heterostichus rostratus	giant kelpfish	M	J, A
	Neoclinus uninotatus	onespot fringehead	M	L, J, A
Clupeidae	*Alosa sapidissima* (NN)	American shad	F	J, A
	Clupea pallasi	Pacific herring	MI	L, J, A
	Dorosoma petenense	threadfin shad	F	A, ?
	Sardinops sagax	Pacific sardine	M	J, A
Cottidae	*Artedius harringtoni*	scalyhead sculpin	M	A, ?
	Clinocottus sp.	sculpin	M	L
	Cottus asper	prickly sculpin	F	?
	Leptocottus armatus	Pacific staghorn sculpin	R	L, J, A
	Scorpaenichthys marmoratus	cabezon	MI	J, A
Cyclopteridae	*Liparis* sp.[1]	snailfish	M	?
Embiotocidae	*Amphistichus argenteus*	barred surfperch	M	A
	Amphistichus koelzi	calico surfperch	M	A
	Amphistichus rhodoterus	redtail surfperch	M	A
	Cymatogaster aggregata	shiner surfperch	PR	J, A
	Embiotoca jacksoni	black surfperch	R	J, A
	Embiotoca lateralis	striped surfperch	M	A
	Hyperprosopon anale	spotfin surfperch	M	A
	Hyperprosopon argenteum	walleye surfperch	MI	J, A
	Hyperprosopon ellipticum	silver surfperch	M	A
	Hypsurus caryi	rainbow surfperch	M	A
	Micrometrus minimus	dwarf surfperch	MI	J, A
	Phanerodon furcatus	white surfperch	PR	J, A
	Rhacochilus toxotes	rubberlip surfperch	M	J, A
	Rhacochilus vacca	pile surfperch	MI	A
Engraulidae	*Engraulis mordax*	northern anchovy	MI	E, L, J, A
Gadidae	*Microgadus proximus*	Pacific tomcod	M	J, ?
Gasterosteidae	*Gasterosteus aculeatus*	threespine stickleback	F	J, A
Gobiidae	*Acanthogobius flavimanus* (NN)	yellowfin goby	R	J, A
	Clevelandia ios	arrow goby	R	L, J, A
	Eucyclogobius newberryi	tidewater goby	R	L, J, A
	Gillichthys mirabilis	longjaw mudsucker	R	L, J, A
	Lepidogobius lepidus	bay goby	R	L?, J?, A
	Rhinogobiops nicholsii	blackeye goby	M	L, J
	Tridentiger trigonocephalus ? (NN)	chameleon goby	M	?
Hexagrammidae	*Hexagrammos decagrammus*	kelp greenling	M	J, A
	Hexagrammos lagocephalus ?	rock greenling	M	?
	Ophiodon elongatus	lingcod	M	J, A
	Oxylebius pictus	painted greenling	M	J, A
Kyphosidae	*Girella nigricans*	opaleye	M	A
Labridae	*Oxyjulis californica*	señorita	M	L, A
Mugilidae	*Mugil cephalus*	striped mullet	MI	A
Myctophidae	*Stenobrachius leucopsarus*	northern lampfish	M	L
Myliobatidae	*Myliobatis californica*	bat ray	PR	J, A
Ophichthidae	*Ophichthus triserialis*	Pacific snake eel	M	A
Ophidiidae	*Chilara taylori*	spotted cusk-eel	M	J, A
Osmeridae	*Hypomesus pretiosus*	surf smelt	M	L, A
	Spirinchus starksi	night smelt	M	A

[1] *Liparis florae* would be expected.

Family	Species	Common Name	Life style	Life stage
Percichthyidae	*Morone saxatilis* (NN)	striped bass	F	J, A
Pleuronectidae	*Eopsetta exilis*	slender sole	M	L, A
	Hypsopsetta guttulata	diamond turbot	MI	J, A
	Platichthys stellatus	starry flounder	MI	L, J, A
	Parophrys vetulus	English sole	MI	J
	Pleuronichthys coenosus	C-O sole	M	E
	Pleuronichthys decurrens	curlfin turbot	M	E, J, A
	Pleuronichthys ritteri ?	spotted turbot	M	J, A
	Pleuronichthys verticalis	hornyhead turbot	M	E, L
	Psettichthys melanostictus	sand sole	M	L, J, A
Poeciliidae	*Gambusia affinis* (NN)	western mosquitofish	F	L, J, A
Rhinobatidae	*Platyrhinoidis triseriata*	thornback	M	A
	Rhinobatos productus	shovelnose guitarfish	M	A
Salmonidae	*Oncorhynchus mykiss*	rainbow trout (steelhead)	M	A
	Oncorhynchus tshawytscha	chinook salmon	M	A
Sciaenidae	*Seriphus politus*	queenfish	MI	J, A
	Genyonemus lineatus	white croaker	M	E, L, A
Scorpaenidae	*Sebastes atrovirens*	kelp rockfish	M	J
	Sebastes auriculatus	brown rockfish	M	J, A ?
	Sebastes carnatus	gopher rockfish	M	J
	Sebastes caurinus	copper rockfish	M	J
	Sebastes chrysomelas	black-and-yellow rockfish	M	J
	Sebastes dallii	calico rockfish	M	J
	Sebastes flavidus [2]	yellowtail rockfish	M	J
	Sebastes melanops	black rockfish	M	J
	Sebastes mystinus	blue rockfish	M	J
	Sebastes paucispinis	bocaccio	M	L, J
	Sebastes rastrelliger	grass rockfish	M	J, A
	Sebastes saxicola	stripetail rockfish	M	J
Soleidae	*Symphurus atricauda*	California tonguefish	MI	E, J, A
Squalidae	*Squalus acanthias*	spiny dogfish	M	A
Stichaeidae	*Cebidichthys violaceus*	monkeyface prickleback	M	L, A
Stromateidae	*Peprilus simillimus*	Pacific pompano	M	A
Syngnathidae	*Syngnathus californiensis*	kelp pipefish	M	A
	Syngnathus exilis	barcheek pipefish	M	A
	Syngnathus leptorhynchus	bay pipefish	R	L, J, A
Synodontidae	*Synodus lucioceps*	California lizardfish	M	J, A
Torpedinidae	*Torpedo californica*	Pacific electric ray	M	A
Urolophidae	*Urolophus halleri*	round stingray	M	J, A

[2] Difficult to distinguish from *Sebastes serranoides*.

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