FISH AND INVERTEBRATE ECOLOGY OF TILLAS AND ISLAS SLOUGHS, SMITH RIVER ESTUARY, DEL NORTE COUNTY, CALIFORNIA

by

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ABSTRACT

Fish and invertebrate ecology of Tillas and Islas Sloughs, Smith River estuary, Del Norte County, California

Debra J. Parthree

As wetland habitat continues to disappear along the Pacific coast of North America, more research is being conducted to examine the importance of this habitat for the survival of various fish species. Sloughs, marshes, and side channel type habitats have been shown to provide an important niche for estuarine fauna and flora. Before this study, fish and invertebrate fauna of Tillas and Islas Sloughs in the Smith River estuary, California, were not formally examined. During the study period, 26 fish species were found belonging to 14 families. The sloughs were found to be highly productive in terms of fish, invertebrate abundance, and grass and algae cover. However, they were low in diversity, as is typical of estuarine habitats. Abundances of the most dominant fish species, including Chinook salmon, *Oncorhynchus tshawytscha*, were variably correlated with temperature, salinity, dissolved oxygen, nutrient concentration, and grass and algal cover. The sloughs were shown to be used by permanent resident fishes as well as by spawning adults, juvenile fishes, and foraging visitors. Benthic fauna appeared to be controlled primarily by predation by fish and displayed no significant correlation with environmental parameters.

for Gianna Skye Parthree

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INTRODUCTION

The importance of estuarine systems to the productivity and biodiversity of fauna and flora is well established. Species successfully adapted to the highly dynamic estuarine environment are specialized and often exhibit high production. An organism's tolerance to fluctuations in temperature, salinity, and dissolved oxygen, due to tidal exchange, often dictates its distribution and abundance in the estuary. A dissolved oxygen level of 0 to 4 mg/l will create a hypoxic state and will drive a fish population away or cause mass mortality if escape is blocked (Kennish 1990). For benthic invertebrates, species richness will generally decrease away from the mouth of an estuary (Kennish 1990) and will reach a minimum at a critical salinity of approximately 5 to 8 ppt (Khlebovich 1968). Seasonal fluctuations in abundance of vascular plants and algae are also attributable to fluctuations in environmental conditions, namely temperature and salinity (Neushul 1967).

Estuarine fish are placed into six classes as described by McHugh (1967): freshwater fish that occasionally enter the estuary; true estuarine residents that reside in the estuary year-round; diadromous species such as salmon and eels that use the estuary as a migratory corridor; marine species such as topsmelt and surfsmelt that visit the estuary as adults, often for spawning purposes; marine juveniles that use the estuary as a nursery ground; and irregular visitors with no apparent necessity for the estuary. Typically eight to 15 species make up 90% of all the fish found in an estuary (Day et al. 1989). Most are seasonal migrants utilizing the estuary to spawn or rear (Kennish 1990), and very few are true estuarine residents (Day 1967, McHugh 1967, Miller and Dunn 1980).

The composition, abundance, and distribution of fish are influenced primarily by abiotic environmental factors and secondarily by biotic interactions (i.e. competition, predation) (Kennish 1990). Salinity, temperature, and dissolved oxygen are the abiotic factors that tend to impart the greatest influence, although dissolved oxygen is a function of salinity and temperature, and is also influenced by primary productivity and pollution. Spatial and temporal variations in temperature, salinity, and dissolved oxygen will force a fish to tolerate the change or relocate.

The bottom substrate of estuaries not only serves as a sink for organic matter and inorganic nutrients but also provides residence for rich infauna such as polychaetes and oligochaetes, epifauna such as gammarid amphipods, and motile organisms such as crabs and shrimp. The abundance of benthic fauna in any given area of an estuary is greater than that of adjoining freshwater and seawater habitats (Day et al. 1989), although less diverse (Day 1981, McLusky 1989). In fact, while zooplankton dominate the primary consumer constituent in the sea, most primary consumers in estuaries are benthic invertebrates (McLusky 1989). These consumers, in turn, provide energy to higher trophic levels.

Because estuarine food webs are detritus based, primary producers provide the principal energy source not as living plants but as decaying matter (Day et al. 1989, McLusky 1989). However, vascular plants such as seagrasses are highly productive in estuaries and provide essential habitat for estuarine fauna. Macroalgae, most commonly chlorophytes or green algae, are generally underrepresented in estuaries (Knox 1986) but serve as a source of organic matter regenerating nitrogen and phosphorus back into the water column (Wilkinson 1980, Day et al. 1989). Microalgae, such as diatoms, may colonize the surfaces of plants as well as the bottom substrate. Microalgae contribute a significant portion to primary productivity (Kennish 1990) thereby creating an oxygenated zone on the surface of sediments and providing an energy source for bacteria and herbivorous consumers (McLusky 1989).

Estuarine organisms are adapted not only to the physical and chemical parameters of estuarine water, but also to the unique habitat and niche opportunities available to them. Depending on the type of estuary, habitats such as salt marshes, mudflats, sandflats, tidal creeks, slough channels and seagrass beds are to some degree inundated and desiccated regularly by the tides. These specific habitat types have been examined extensively, especially recently, and have been proven to play a critical role in the overall function of an estuary with respect to fish (Yoklavich et al. 1991, Yoklavich et al. 1992, Barry et al. 1996, Desmond et al. 2000), benthic invertebrates (Robert and Matta 1984, Fritz 2001, Cai et al. 2001, Powers et al. 2002), and marsh flora (Fritz 2001). Furthermore, Healey (1982) hypothesizes that unique habitats such as marshes, tidal creeks, and weed beds play a role in the carrying capacity of the estuary as a whole to support juvenile salmon and stresses the need for conservation of these habitats. This hypothesis has been tested in Pacific Northwest estuaries where studies show these habitats are, in fact, beneficial to juvenile salmon survival and growth (Levy and Northcote 1981, Ryall and Levings 1987, Shreffler et al. 1992, Miller and Simenstad 1997, Miller and Sadro 2003).

Historically, the Pacific Northwest has been affected by the enactment by the United States Congress of the federal Swamp Lands Acts of 1849, 1859, and 1860, which encouraged construction of dikes and drainage ditches to create farmland. This resulted in the loss of tidal marshes and swamps, and greatly contributed to a 90% loss of estuarine habitat (Boulé and Bierly 1987). From 1986 to 1997, the major reason for marine and estuarine wetland losses was the filling or draining of wetlands for urban and rural development (Dahl 2000). Further, pollution such as fertilizers and livestock wastes, generated from agriculture, compromised the water quality of estuaries (Boulé and Bierly 1987) creating an excessively enriched environment susceptible to eutrophication (Parker and Wright 1999, United States Geological Survey 1999).

Eutrophication, an undisputed environmental concern worldwide, can occur when the nutrients nitrogen and phosphorus, most commonly in the form of nitrate (NO_3^-) and phosphate (PO_4^{-3}), enrich a water body resulting in an overwhelming increase in primary production. The United States Environmental Protection Agency (1986) has established a total phosphorus concentration of greater than 0.1 mg/l as the level at which eutrophication will occur in freshwater. In bays and estuaries, however, excessive nitrate is the primary cause of eutrophication and no established national criteria for this nutrient exists. Because estuarine consumers derive most of their energy from detritus and not living plants, consumer grazing does not directly serve to control the excess plant biomass. The subsequent increase in primary production has immediate effects on higher trophic levels. As microbial respiration increases, due to the decomposition of plants and algae biomass, oxygen is depleted in the benthic zone. The result is anoxia, a foul-smelling oxygen-starved system, with elevated ammonia (NH_3) and hydrogen sulfide (H_2S) concentrations

(McComb and Lukatelich 1995). This is a potentially lethal environment for benthic invertebrates and bottom dwelling fishes (McLusky 1989, Horne and Goldman 1994, United States Geological Survey 1999). The United States Environmental Protection Agency (1986) has established a chronic criteria range for ammonia concentration of 0.07-2.1 mg/l with regard to toxicity to fish.

Land-use management of riparian zones surrounding estuaries is constantly improving as our knowledge of estuaries and their role in biodiversity becomes more extensive. As previously stated, organisms that use estuaries do so because the physical and chemical characteristics meet their physiological needs. Human-induced alterations to the estuary make the environment less than optimal for, and in some cases, detrimental to the aquatic community as essential habitat slowly disappears or degrades. McCabe et al. (1997) stated that shallow littoral areas, side channels, and backwaters often support higher standing crops of benthic invertebrates than main channel areas due to the diminished river flow velocity, and that these habitats are generally more impacted by human activity. Consequently, wetland restoration activities such as removing dikes and creating estuarine sloughs have been initiated to recover this critical habitat (Ryall and Levings 1987, Miller and Simenstad 1997, Fritz 2001). In addition, benthic invertebrates, especially polychaetes, crustaceans, and mollusks, are frequently examined as indicators of organic enrichment in estuaries. Large fluctuations in the density of opportunistic species such as the polychaete *Capitella capitata* are now being closely monitored (McLusky 1989, Kennish 1990, Holte and Oug 1996, Cardell et al. 1999, Méndez 2002).

The Smith River and Smith River estuary have been the subjects of research both in the present and past (Iwatsubo 1982, Mitchell 1988, Reedy 1995, Mizuno 1998, Quiñones 2003, Zajanc 2003). However, limited examination of estuarine sloughs leaves a gap in our knowledge of the Smith River system as a whole. To our knowledge, questions of water quality and faunal and floral productivity in these sloughs have never been addressed. The goals of this study were to describe and quantify environmental parameters, water quality, and the fauna and flora communities of Tillas and Islas Sloughs; and to illustrate the productivity inherent in wetland habitats. Because the restoration of the Smith River estuary has been identified as a primary objective in northern California watershed enhancement, this project provides important baseline information for future restoration goals and monitoring practices.

STUDY SITE

Tillas and Islas Sloughs are part of the Smith River estuary system in Del Norte County, California, 3.5 mi. south of the Oregon border (Figures 1-3). Both Tillas and Islas Sloughs project southeast from the east bank of the main estuary channel. The mouth of Tillas Slough lies approximately 1.5 km upstream from the mouth of the estuary, while the mouth of Islas Slough lies approximately 1 km uptream of Tillas Slough. During the spring, summer, and fall months, the depth of Tillas Slough, at the deepest part of the channel, ranged from only 0.1 m at low tide to 2.5 m at high tide. The depth of Islas Slough ranged from 0 to 2.0 m. Islas Slough is longer and narrower than Tillas Slough and is lagoon-like in that it receives regular tidal influx with no freshwater input other than precipitation. A road crosses Tillas Slough via a dike near the entrance into the main estuary channel. Two 1.5 m culverts accommodate the exchange of water through the dike road. Upslough of the dike road, Ritmer Creek and Delilah Creek together flow into Tillas Slough near the middle of its range, however significant freshwater input from these creeks was not detected in the study area, which was restricted to the portion downslough of the dike road. The common substrate in both sloughs is mud in the backwaters and sand in the middle reaches and mouth. In addition, cobble and gravel-sized particles are found in both sloughs, and a prominent patch of cobble lies midway between the mouth and backwaters of Islas Slough. Emergent vegetation (*Carex lyngbyei*) is present along the banks of both sloughs. A variety of birds and waterfowl frequent the sloughs and include pelicans, ducks, geese, great blue herons, night herons, gulls, and other shorebirds. Harbor seals,

Figure 1. Tillas and Islas Sloughs within the Smith River estuary, Del Norte County, California. The mouth of Tillas Slough is located at N41°56'17.20", W124°11'46.09". The mouth of Islas Slough is located at N41°55'46.06", W124°11'47.67" (United States Geological Survey 1993).

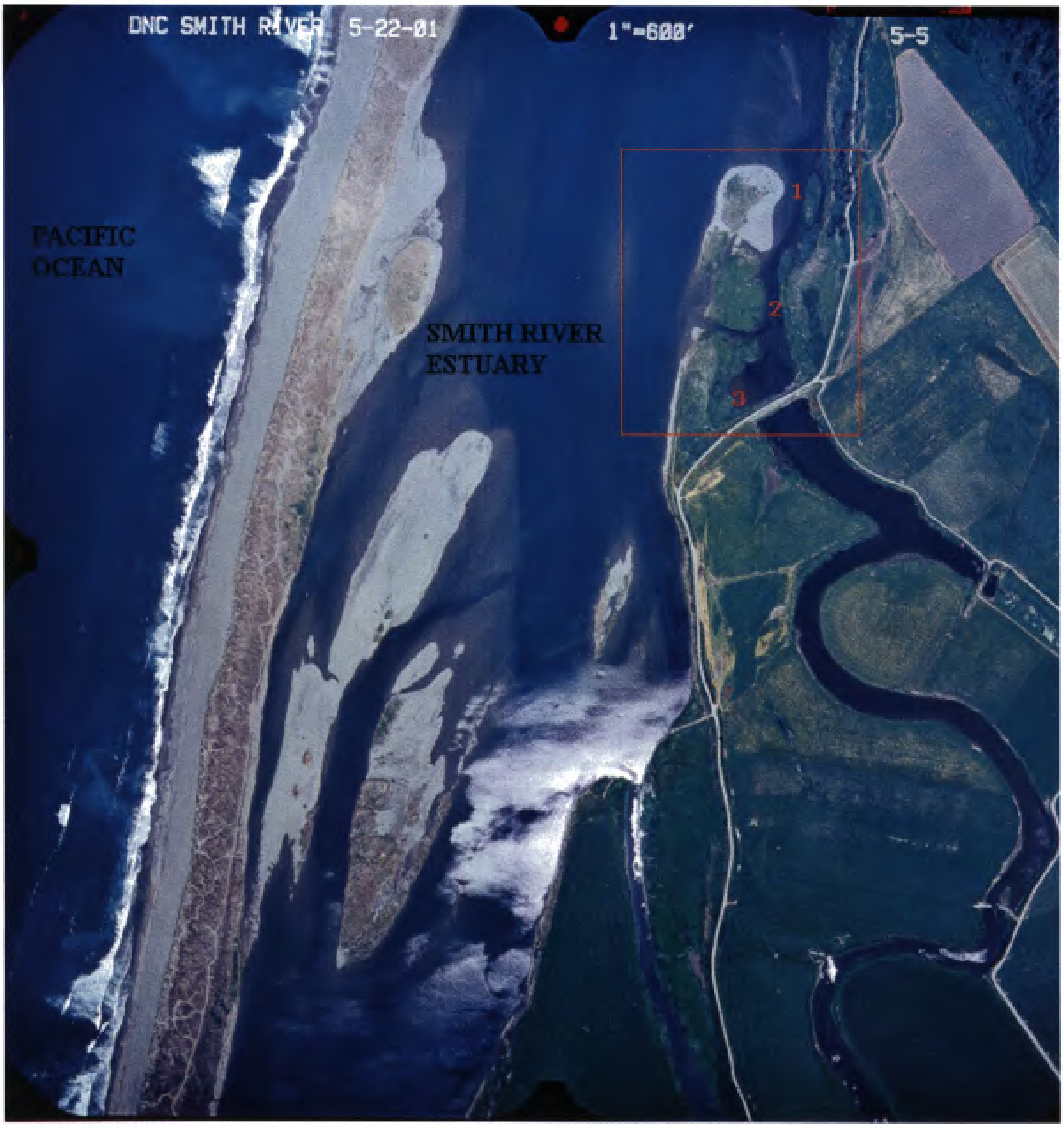


Figure 2. Stations 1, 2, and 3 sampled in Tillas Slough, Smith River estuary, Del Norte, County, California (Del Norte County Planning Department 2001a).

Figure 3. Stations 1, 2, and 3 sampled in Islas Slough, Smith River estuary, Del Norte County, California (Del Norte County Planning Department 2001b).

otters, raccoons, and deer visit the sloughs as well. Recreationally, the sloughs are used by duck hunters in the fall.

The Smith River estuary is a drowned-river estuary and is consistent with Day et al.'s (1989) description of a boreal estuary dominated by the fish families Cottidae, Gasterosteidae, Osmeridae, and Salmonidae. It provides habitat for four species of anadromous salmonids, Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead trout (*O. mykiss*), and cutthroat trout (*O. clarki*), which utilize the estuary as a migratory corridor (Quiñones 2003, Zajanc 2003).

The Smith River system is federally designated as a Wild and Scenic River, and includes more than three hundred miles of free-flowing water, more than any other river in the country (California Resources Agency 2002). Despite this, the estuary has been severely altered by anthropogenic influences. Based on an analysis of historical and recent aerial photographs, it has been estimated that more than 40% of the original estuarine rearing habitat has been lost due to diking, draining, and gravel extraction (Quiñones; 2003). Furthermore, before these modifications took place, a complex system of sloughs was present in the Smith River estuary branching out on both sides (Bledsoe 1881). The riparian zone surrounding Tillas and Islas Sloughs is extensively diked and has been private rangeland since the mid-1800s, and land-use practices today have converted previous tidal flat habitat into lily bulb fields and cattle grazing pastures. Pesticide use was extensive in Del Norte County during the study period with a total of 275,096 pounds of pesticides applied in the year 2000 and 350,262 pounds in 2001. Pesticides applied to lily bulb fields in the Smith River floodplain accounted for 90% of the total use in the county (California Department of Pesticide Regulation 2000, 2001). Cattle frequent the banks of Islas Slough and have been observed crossing the slough. Diking of the estuary channels has disturbed the morphology of both sloughs by redirecting flows at Islas Slough and by reducing tidal exchange in Tillas Slough. Although cattle are prevented from entering the study site where Tillas Slough is diked, the area upslough of the dike road is a relatively stagnant pool where cattle are unconfined and free to move into the water. Because of this, the water quality of Tillas Slough is expected to be inferior to that of Islas Slough.

MATERIALS AND METHODS

Three sampling stations within each slough were established at non-random points in the upper (Station 3), middle (Station 2), and lower (Station 1) regions. The upper regions included the backwaters, and the lower regions included the mouth of each slough. Stations were chosen based on ease of obtaining samples with respect to bank access, velocity of flow, and deepness of channel.

The sampling season extended from 22 May to 18 November 2000 and 14 March to 19 November 2001. Drifting fauna, water quality, slough fishes, and grass and algal cover were sampled twice a month. Benthic fauna was sampled monthly. Specific sampling dates and times were dictated by the tides. Temperature (°C), salinity (ppt), and dissolved oxygen concentration (mg/l) were measured using a YSI model 85 field meter in concurrence with all biological sampling.

Water Quality

Water samples were taken at the same time as drifting fauna samples from each station at the deepest part of the channel and analyzed colorimetrically for nitrate (NO_3^-) (mg/l), phosphate (PO_4^{-3}) (mg/l), and ammonia (NH_3) (mg/l) concentrations using a HACH DR850 portable colorimeter. The estimated detection limit (EDL) for this machine is 0.8 mg/l for NO_3^-, 0.05 mg/l for PO_4^{-3}, and 0.08 mg/l for NH_3. The tests detected NO_3^- in the range of 0.0 to 30.0 mg/l, and both PO_4^{-3} and NH_3 ranging from 0.00 to 2.50 mg/l. In some cases, water samples were collected and kept under refrigeration for up to six hours or frozen for up to 10 days and analyzed off-site.

Vegetataion

Submerged aquatic vegetation cover was estimated using a 1 m^2 quadrat at three random replications at each station. Grass and algae were identified as % cover grass and % cover algae.

Fishes

Fishes were sampled using 4.6 m long fyke nets, with 4.8 mm mesh, 0.9 m x 1.2 m mouth openings, and 4.6 m wings. Two nets were deployed side by side at the mouth of each slough (Station 1) and fished at night during an outgoing tide. Night tides were used because gear avoidance by fish causes low daytime catch totals (Horn 1980). Fyke netting was standardized by sampling tides that produced a six to eight ft. difference between the high and low tide. Up to 50 individuals of a particular species were measured to the nearest 1 mm total length. Additional fish were counted only. The fyke netting operations represented a total of 348 effort hours. Monthly abundance was plotted for the nine most numerically dominant species for each slough to determine variations in species composition between seasons, years, and sloughs. Length-frequency diagrams were created for the nine most numerically dominant species to determine the life history stage of the fish utilizing the slough channels. This project involves the humane care and use of live vertebrate animals, and was approved by Humboldt State University's Institutional Animal Care and Use Committee (IACUC) under permit #99/00.F.118.A.

Benthic Fauna

At each station, benthic cores were taken from the slough substrate to sample for macrofauna at two of the same three random locations used to sample grass and algae cover. A 15.5 cm diameter PVC pipe was used to obtain a core by driving the pipe 5 cm into the substrate and extracting it with a straight-edged shovel, generating a 943 cm^3 (943 ml) sample. For the months of August through November of 2001, a smaller coring device was used that generated a 192 cm^3 sample. The core was washed, using slough water, through a 500 µm mesh sieve, as recommended by McLusky (1989). The retained sample was kept cold for up to six hours, fixed in 10% formalin off-site, and stored in 40% isopropanol. A total of 288 core samples were obtained and processed. Specimens were sorted, identified to the lowest possible taxon, and enumerated using a dissecting microscope and identification manuals by Arnett 1973, White 1983, Kathman et al. 1986, Blake and Hilbig 1993a, b, Goulet and Huber 1993, Kozloff 1996, Merritt and Cummins 1996, Arnett Jr. 2000, and Shanks 2001.

Samples with a sieved volume of 192 ml or greater were subsampled to produce a 192 ml subsample volume. A unique correction factor (CF) was applied to each of these samples to produce the proportion of the original sample to be processed as:

$$CF = \frac{192}{V}.$$

Abundance (A) of each taxon was estimated as:

$$A = \frac{S}{CF},$$

where V is the volume of the original sample after sieving and S is number of individuals counted in the subsample. Due to the change in size of the sample taken beginning in August 2001, it is important to analyze the density of benthic fauna rather than the actual number found. Density was calculated as:

$$D = \frac{A}{CoreVolume \times 2},$$

where "CoreVolume" is the original volume of the coring device.

Faunal Diversity

In order to fully describe the diversity and community structure of the fauna in each of the sloughs, monthly diversity indices were computed for fish and benthic populations. Two diversity indices were calculated for the fish assemblages. The Shannon-Wiener Diversity Index (Pielou 1966) and the Simpson's Index (Simpson 1949). The Shannon-Wiener Index is estimated as:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i, \text{ where } p_i = \frac{n_i}{N},$$

where n_i is the number of individuals in species i, N is the total number of individuals collected of all species, and s is the species richness, or the number of species collected that month. The Shannon-Wiener diversity index increases as species richness increases (Levinton 1982), but is also influenced by rarely collected species (Peet 1974). The Simpson's Index (SI') was used to describe species evenness. The Simpson's Index is:

$$SI' = \sum_{i=1}^{s} \frac{n_i(n_i - 1)}{N(N-1)}.$$

It reflects species evenness by detecting species dominance (Kennish 1990) and allows for interpretation of the population based on the spread of individuals among the different species. This index gives the probability that two individuals selected from the same population will be the same species (Levinton 1982).

The benthic community structure within each station of each slough was described in terms of species richness using the Shannon-Wiener diversity index and species evenness (Pearson and Rosenberg 1978, Robert and Matta 1984). Species evenness (J') is:

$$J' = \frac{H'}{\ln s}.$$

Species evenness ranges from 0 to 1 and approaches 1 as the number of individuals in each species approaches equality (Levinton 1982).

Multiple Regression

Correlation matrices and stepwise multiple regression procedures were performed using NCSS (Hintze 2001). In order to determine interrelationships between environmental parameters that may affect regression analyses, Spearman's correlation matrices were created. The Spearman's correlations, which are unaffected by nonnormality, are determined using the rank value of the data instead of the actual data value (Hintze 2001). Thus, any variable that was correlated with other variables was either eliminated from further analysis or analyzed with caution.

Separate stepwise multiple regression procedures were performed for each of the most numerically dominant fish and invertebrate species. The environmental parameters (temperature, salinity, dissolved oxygen, nitrate, phosphate, grass cover, and algal cover) were considered the independent variables (x), and natural log-normalized abundance data for the nine most abundant fish species and the nine most abundant benthic taxa were the dependent (y) variables. An additional regression analysis was performed using *Capitella capitata* abundance with environmental parameters. Only those variables that significantly changed the r^2 value upon entering into the regression equation were considered to be relevant and included in the regression model. The model was standardized with the intercept=0 to show the relative importance of each variable based on the absolute value of the standardized coefficient (Bigg 2003, personal communication).

Drift Fauna

Drift fauna was sampled at each station, avoiding low tides, using a Miller plankton net (15 cm diameter, 353 μm mesh). The net was attached to a 1.2 m wooden pole and pulled through the water column. Three repetitions were carried out for 2 minutes each, one at each bank and one at midchannel. The length of the tow was ca. 30 m. Samples were kept cold for up to six hours, fixed in 10% formalin off-site, and stored in 40% isopropanol. A total of 174 drift samples (6 stations, twice per month, 14.5 months) were obtained and processed. Specimens were sorted, identified to the lowest possible taxon, and enumerated using a dissecting microscope. For drift fauna, relative abundance values for each slough were calculated. Because tidal influence was excessive and is an important factor in controlling the distribution of estuarine plankton (Grindley 1981), further quantitative analyses were not conducted.

RESULTS

Tillas and Islas Sloughs in the Smith River estuary experienced significant ranges of environmental parameters during the study period. Seasonal changes, specifically, created the greatest range of parameters within both sloughs and both years. Only minor differences were evident when comparing the environmental parameters between sloughs and those between years. Overall, within Tillas and Islas Sloughs and during 2000 and 2001, monthly mean water temperatures ranged from 9.8-20.7°C, salinity ranged from 0.3-23.9 parts per thousand (ppt), and dissolved oxygen ranged from 4.93-11.45 mg/l (Figure 4). The mean water temperatures for each year and for each slough were nearly equal to the overall mean of 16.5 °C.

In both sloughs during both years, the range of monthly mean nitrate concentrations was 2.1-8.8 mg/l. Phosphate concentrations ranged 0.24->2.5 mg/l, and of ammonia concentrations ranged 0.01-0.38 mg/l (Figure 5). The maximum detectable phosphate concentration of the colorimeter was 2.5 mg/l, so the actual maximum level was not established. Monthly mean grass cover ranged from 0-68%, and algal cover ranged from 0%-70% (Table 1, Figure 6). The sloughs riparian zones, which are regularly inundated by tidal influx, were dominated by the sedge *Carex lyngbyei* during the entire sampling period, and only about 15% of the western bank of Tillas Slough was devoid of the sedge.

Tillas Slough

Although the mean water temperature and phosphate and ammonia concentrations throughout the 2000 to 2001 study period were nearly equal between the sloughs, Tillas

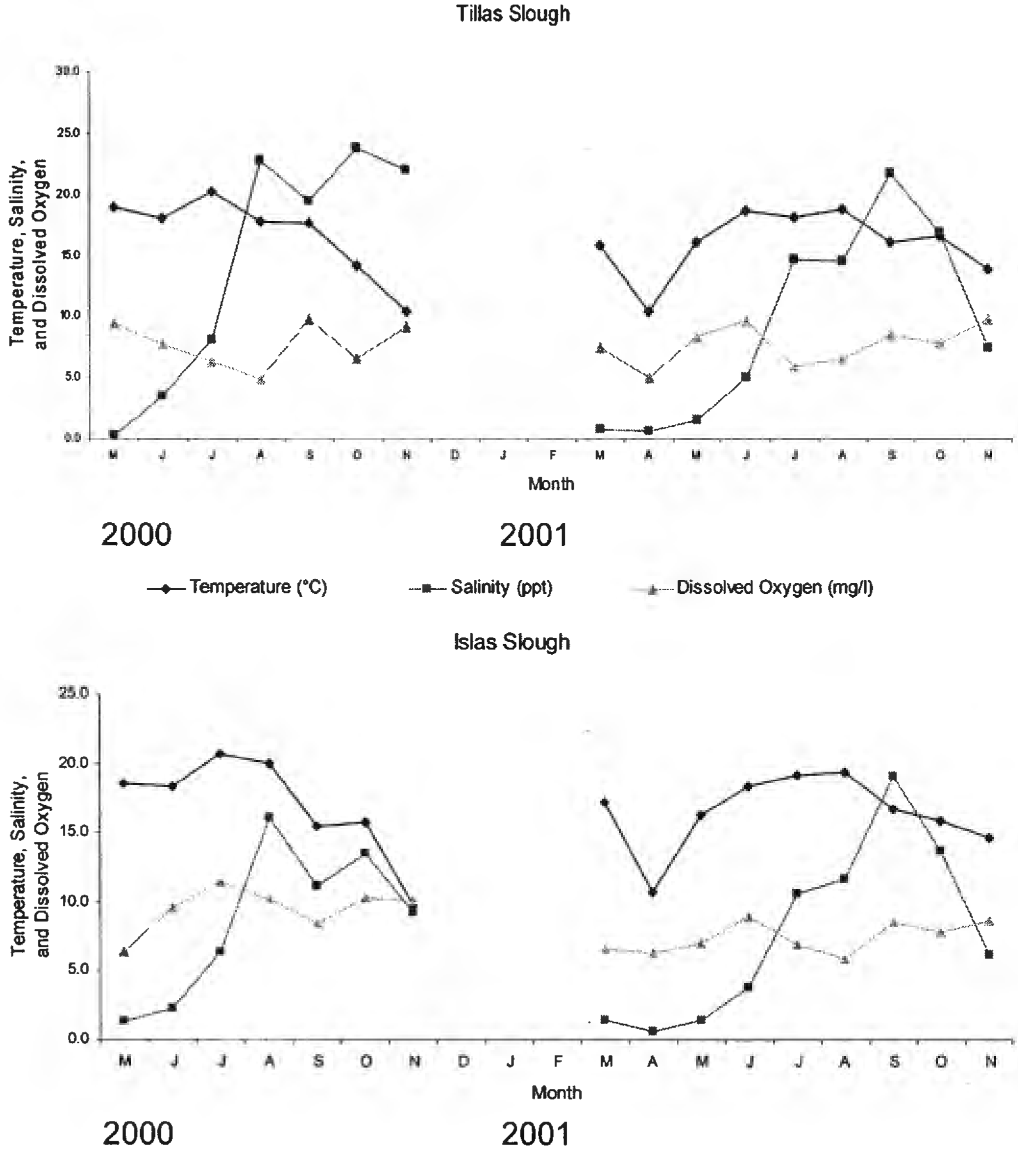


Figure 4. Mean temperature, salinity, and dissolved oxygen levels in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001.

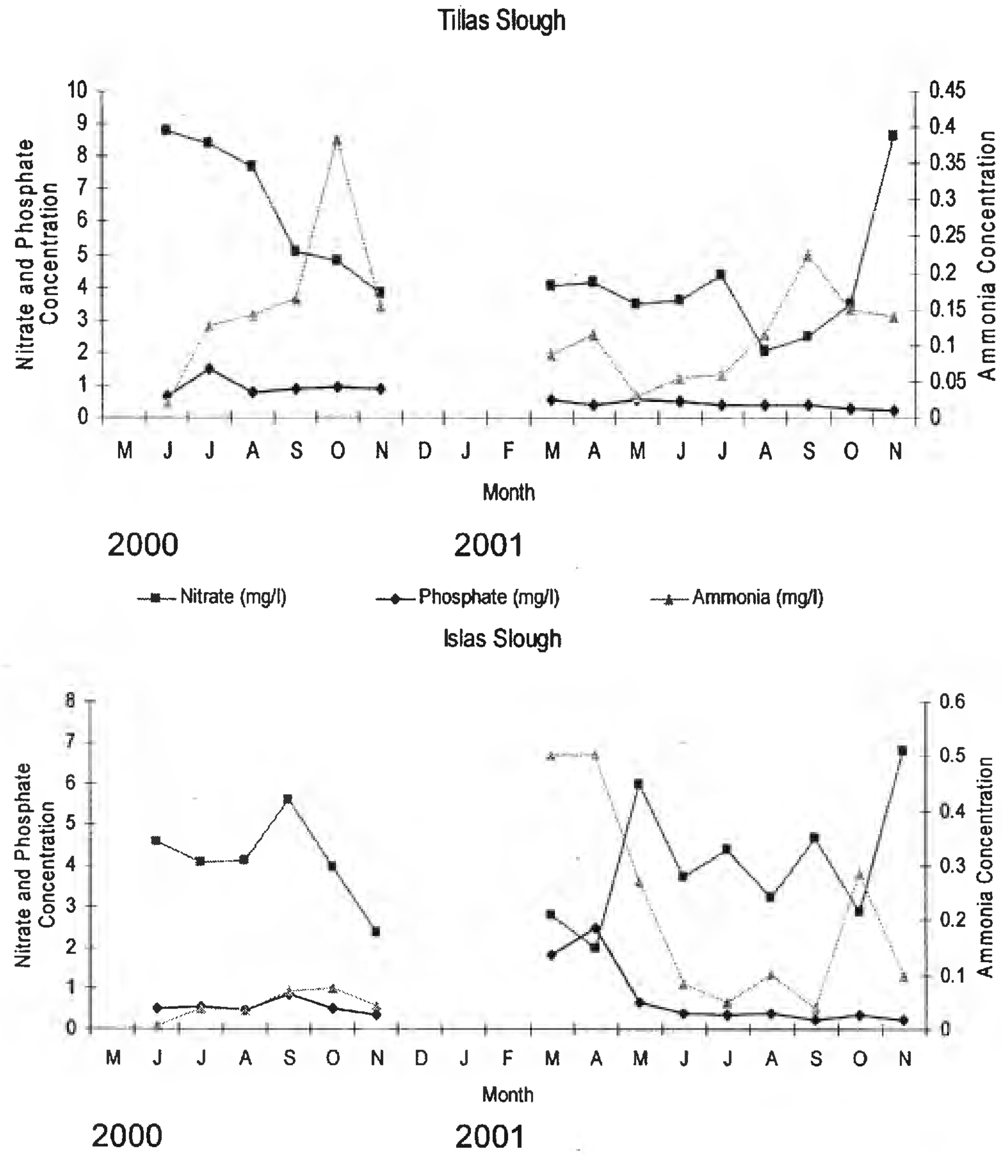
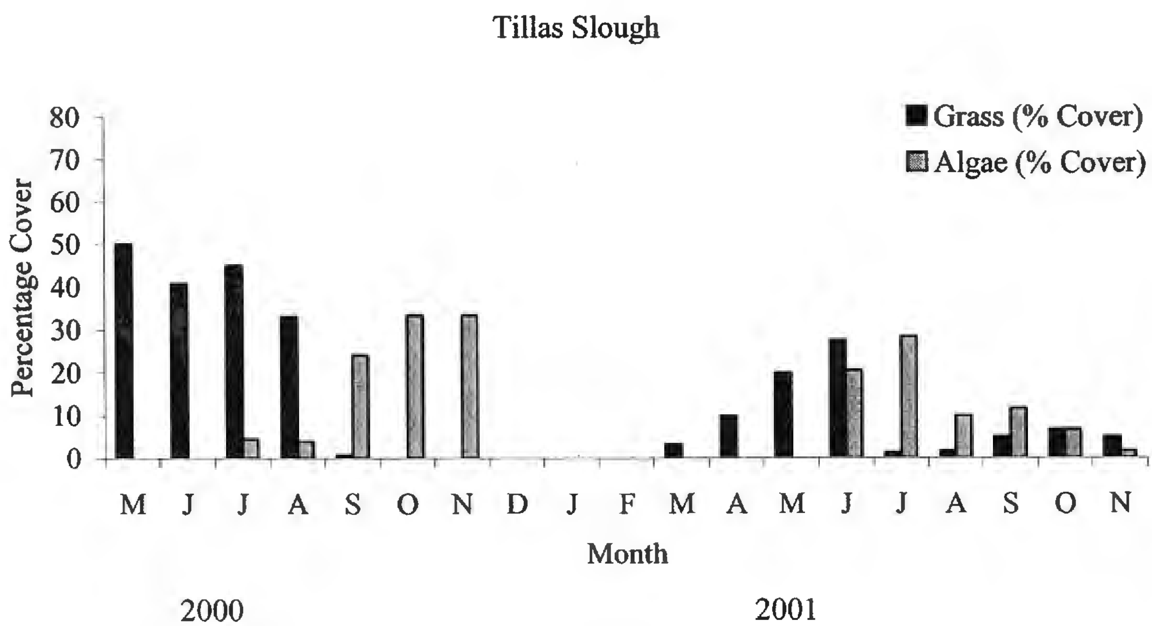


Figure 5. Mean nitrate, phosphate, and ammonia concentrations in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001.

Table 1. Flora found in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001.

	Tillas Slough			Islas Slough		
	Station 1	Station 2	Station 3	Station 1	Station 2	Station 3
Carex lyngbyei (Lyngby's sedge)	X	X	X	X	X	X
Ruppia maritime (Widgeongrass)	X	X	X	X	X	X
Enteromorpha linza[a]	X					
Enteromorpha intestinalis[a]		X		X	X	X
Ulva fenestrata[a]	X	X				
Ulva californica[a]			X			
Cladophora microcladioides[a]				X		
Cladophora seriecea[a]					X	
Melosira sp. (chain-forming diatom)	X	X	X	X	X	X

[a] Green alga (=chlorophyta)



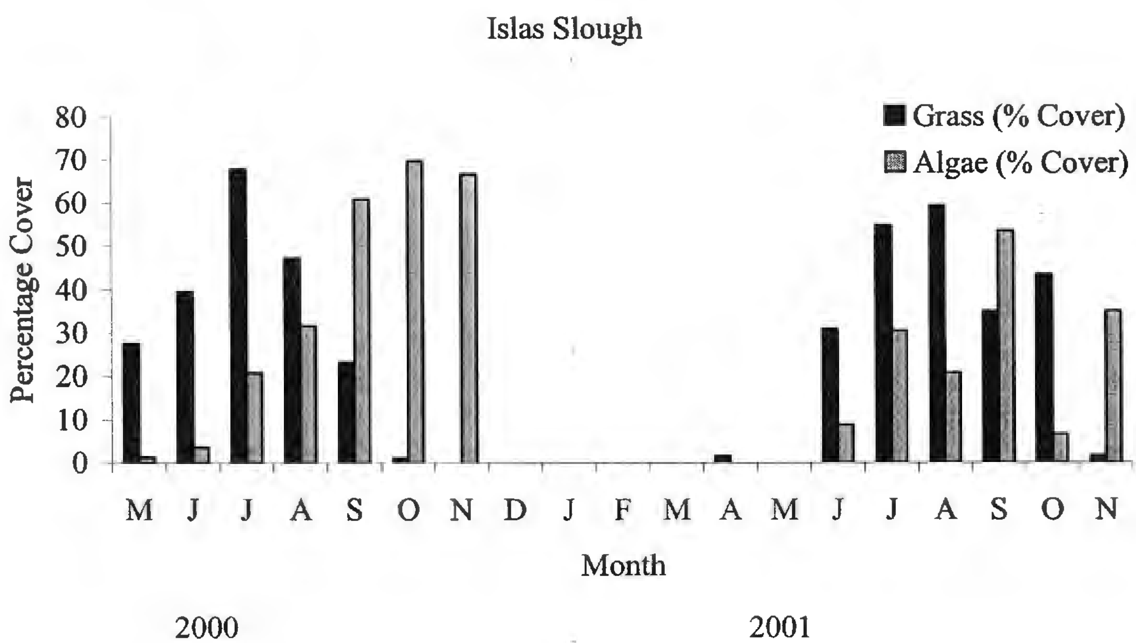


Figure 6. Widgeongrass and algae cover in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001.

Slough experienced a higher mean salinity and higher mean nitrate concentration than Islas Slough. The highest monthly mean water temperatures observed in Tillas Slough generally occurred during the summer and peaked in July of 2000 at 20.2°C. The lowest temperatures typically occurred at the beginning and end of the sampling season with the lowest mean temperature of 10.4°C recorded in November of 2000 and April of 2001. The range of monthly mean salinity in Tillas Slough increased from a low of 0.3 ppt in May of 2000 to a peak of 23.9 ppt in October of 2000, reflecting an increasing trend in salinity from spring to fall. Dissolved oxygen concentration in Tillas Slough did not reflect any seasonal trends as the lowest monthly mean dissolved oxygen level was 4.93 mg/l, occurring in August of 2000, and in the following month, September of 2000, the mean monthly dissolved oxygen levels achieved a peak at 9.75 mg/l. Likewise, any clear trends in mean nutrient concentrations were not evident. Tillas Slough experienced a peak in monthly mean nitrate concentration at 8.8 mg/l in June of 2000, and the lowest mean concentration was 2.1 mg/l occurring the following year in August of 2001. Mean phosphate concentration peaked at 1.48 mg/l in July of 2000 and was lowest in November of 2001 with a value of 0.24 mg/l. Ammonia concentration, however, tended to increase over the seasons; the monthly mean values achieved a maximum of 0.38 mg/l in October of 2000, increasing from a springtime low of 0.02 mg/l in June of 2000. Grass cover was clearly most elevated in spring, with 50% cover in May of 2000 decreasing to 0% cover by October of 2000. Algal cover was not evident at all in the spring. May and June of 2000 and March, April, and May of 2001 had no algae growth while the mean algae cover reached a maximum of 33% in October and November 2000.

Islas Slough

In comparison, Islas Slough experienced a higher mean dissolved oxygen level as well as greater mean grass and algae cover than Tillas Slough during the study period. The highest and lowest mean water temperatures in Islas Slough occurred in the same months as those in Tillas Slough. The peak mean temperature was 20.7°C in July of 2000. The lowest were 9.8°C and 10.7°C in November of 2000 and April of 2001, respectively. Reflecting a similar increasing trend from spring to fall, seen in Tillas Slough, the mean salinity minimum in Islas Slough occurred in April of 2001 with a value of 0.6 ppt. The maximum salinity of 19.0°C occurred in September of 2001. Islas Slough, although more oxygen-rich than Tillas Slough, experienced similar patterns of dissolved oxygen levels attaining a peak in July of 2000 at 11.45 mg/l and the lowest level of 5.87 mg/l in August of 2001. The peak in mean nitrate concentration was 6.8 mg/l and occurred in November of 2001. The lowest mean concentration was 2.0 mg/l, occurring in April of 2001. Mean phosphate concentration attained a peak in April of 2001 above the maximum detectable limit of 2.50 mg/l on the colorimeter used. The lowest mean value was 0.24 mg/l, occurring in both September and November of 2001. Unlike Tillas Slough, Islas Slough did not experience a pattern of fall enrichment of ammonia. The maximum mean level was attained in both March and April of 2001 at 0.50 mg/l.The lowest mean was 0.01 mg/l, attained in June of 2000. The maximum mean grass cover was 68%, occurring in July of 2000, but by November of 2000 grasses had died off to 0% cover. Mean grass cover was also at 0% in May of 2001. Algae peaked at 67% cover as the mean in October of 2000 and the lowest algal productivity occurred from March to May of 2001 during which the cover remained at 0%.

Differences in environmental parameters between years were also evident. Prior to sampling in 2000, the rainfall in Crescent City, CA during the rainy season (October to May) totaled 169 cm, whereas the rainy season prior to the 2001 sampling produced only 93 cm. of rainfall, nearly 64 cm less than normal for those months (National Oceanic and Atmospheric Adminstration 1999, 2000, and 2001). Smith River discharge, accordingly, was higher during the 1999/2000 rainy season (Figure 7). The means of salinity, dissolved oxygen, nitrate, and phosphate were higher in 2000 than in 2001. Mean ammonia concentration and grass and algae cover were higher in 2001. Mean water temperatures were not significantly different between years.

Some environmental parameters, when compared between years, revealed differences between Tillas and Islas Sloughs that were not apparent in the overall mean results. Tillas Slough, when averaged over the entire study period, experienced a higher mean salinity and nitrate concentration. Although the mean salinity was higher in Tillas Slough for both years, the mean nitrate concentration in Tillas Slough was higher only in 2000 and nearly equal to that in Islas Slough in 2001. Likewise, mean dissolved oxygen concentration was higher in Islas Slough only in 2000 and was nearly equal to that in Tillas

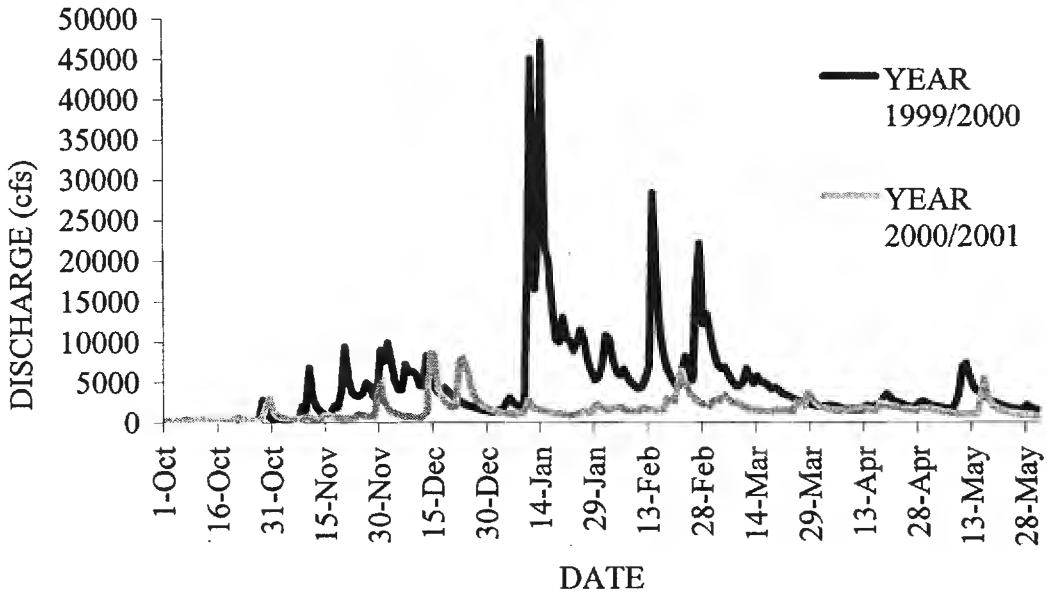


Figure 7. Daily streamflow values for the 1999/2000 and 2000/2001 rainy seasons, Smith River at Crescent City, California USGS Gage Station (United States Geological Survey 2001).

Slough in 2001. Mean phosphate and ammonia concentrations were both higher in Tillas Slough in 2000 as well as in Islas Slough in 2001. Nutrient concentrations commonly showed a reversal of results between years; often a peak in concentration one year corresponded to a low around the same time the following year. Grass and algae were more prolific in 2000 than in 2001.

Fishes

A total of 110,725 fish were captured in fyke nets in Tillas (40,146 fish) and Islas (70,579 fish) Sloughs during the sampling periods of 2000 and 2001 (Tables 2-6). The fish community was represented by a total of 26 species (24 in Tillas Slough and 20 in Islas Slough) representing 14 families. Overall, two species, threespine stickleback (*Gasterosteus aculeatus*) and staghorn sculpin (*Leptocottus armatus*), made up 82% of the total individuals captured. Five species, *G. aculeatus*, *L. armatus,* shiner surfperch (*Cymatogaster aggregata*), surfsmelt (*Hypomesus pretiosus*), and prickly sculpin (*Cottus asper*) accounted for 95.5% of the total. In Tillas Slough, *L. armatus* (56.6%), *G. aculeatus* (12.7%), and *H. pretiosus* (12.2%) made up 81.5% of the slough's total; and in Islas Slough, *G. aculeatus* (74.7%) and *L. armatus* (14.3%) accounted for 89% of the slough's total. Larval fish (<50 mm) from the families Osmeridae and Atherinidae were not identified, but were probably surfsmelt (*H. pretiosus*) and topsmelt (*Atherinops affinis*). Osmerid larvae comprised 1.4 percent of the overall fish catch, 3.7 percent of the total catch from Tillas Slough, and less than 0.01 percent of the catch in Islas Slough. In

Table 2. Fish species and incidental fauna captured in fyke nets in Tillas Slough, Smith River estuary, California, May to November 2000.

		M	J	J	A	S	O	N[a]	TOTALS
FISH	*Leptocottus armatus* (staghorn sculpin)	350	2767	4838	910	32	6	32	8935
	Hypomesus pretiosus (surfsmelt)	18	1	178	115	357	1269	640	2578
	Gasterosteus aculeatus (threespine stickleback))	94	101	72	190	330	1448	337	2572
	Cottus asper (prickly sculpin)	3	127	474	257	645	509	161	2176
	Clupea pallasii (pacific herring)	0	97	15	33	77	296	30	548
	Pholis ornata (saddleback gunnel)	0	88	35	102	91	116	18	450
	Cymatogaster aggregata (shiner surfperch)	133	71	46	78	82	2	1	413
	Oncorhynchus tshawytscha (chinook salmon)	9	29	0	9	0	0	1	48
	Osmerid juveniles (smelts)	0	0	0	0	51	8	15	74
	Atherinops affinis (topsmelt)	0	9	0	0	3	21	2	35
	Platichthys stellatus (starry flounder)	0	2	0	3	0	0	0	5

Table 2. Fish species and incidental fauna captured in fyke nets in Tillas Slough, Smith River estuary, California, May to November 2000 (continued).

	M	J	J	A	S	O	N[a]	TOTALS
Atherinopsis californiensis (jacksmelt)	0	0	0	3	0	0	0	3
Allosmerus elongatus (whitebait smelt)	0	2	0	0	0	0	0	2
Oncorhynchus mykiss (steelhead trout)	0	0	0	1	0	1	0	2
Engraulis mordax (northern anchovy)	0	0	0	0	1	1	0	2
Lampetra tridentata (pacific lamprey)	1	0	0	0	0	0	0	1
Catostomus rimiculus (smallscale sucker)	1	0	0	0	0	0	0	1
Oncorhynchus clarki (cutthroat trout)	0	1	0	0	0	0	0	1
Scorpaenichthys marmoratus (cabezon)	0	1	0	0	0	0	0	1
Clinocottus acuticeps (sharpnose sculpin)	0	0	0	0	1	0	0	1
INVERTEBRATES (incidental)								
Crangon sp. (shrimp)	0	0	0	0	930	7180	1125	9235

Table 2. Fish species and incidental fauna captured in fyke nets in Tillas Slough, Smith River estuary, California, May to November 2000 (continued).

	M	J	J	A	S	O	N[a]	TOTALS
Cnidaria (jellyfish)	0	0	0	0	9	9	0	18
Ctenophora (comb jelly)	0	0	0	0	0	12	0	12
Cancer magister (dungeness crab)	0	0	0	0	0	1	0	1

[a] Due to seasonal weather constraints, fish were sampled only once rather than twice in these months.

Table 3. Fish species and incidental fauna captured in fyke nets in Tillas Slough, Smith River estuary, California, March to November 2001.

		M	A[a]	M	J	J	A	S	O[a]	N[a]	TOTALS
FISH	*Leptocottus armatus* (staghorn sculpin)	157	651	999	7697	3954	137	170	3	20	13788
	Gasterosteus aculeatus (threespine stickleback)	299	183	188	123	148	140	81	108	1267	2537
	Hypomesus pretiosus (surfsmelt)	73	84	180	1401	265	340	90	8	2	2443
	Osmerid juveniles (smelts)	198	1091	65	0	0	0	0	0	0	1354
	Cymatogaster aggregata (shiner surfperch)	4	16	6	42	291	42	537	1	0	939
	Cottus asper (prickly sculpin)	194	41	62	7	10	84	17	5	9	429
	Pholis ornata (saddleback gunnel)	3	4	9	38	28	175	100	14	51	422
	Clupea pallasii (pacific herring)	1	1	12	34	75	50	9	3	3	188
	Oncorhynchus tshawytscha (chinook salmon)	0	0	8	26	66	25	6	3	2	136
	Engraulis mordax (northern anchovy)	0	0	0	46	8	0	0	0	0	54
	Atherinops affinis (topsmelt)	0	0	1	1	6	0	2	0	2	12

Table 3. Fish species and incidental fauna captured in fyke nets in Tillas Slough, Smith River estuary, California, March to November 2001 (continued).

	M	A[a]	M	J	J	A	S	O[a]	N[a]	TOTALS
Spirinchus starksi (nightsmelt)	0	0	4	3	2	1	1	0	0	11
Oncorhynchus mykiss (steelhead trout)	6	0	0	0	1	0	0	0	0	7
Syngnathus leptorhynchus (bay pipefish)	0	0	0	1	0	1	1	1	2	6
Clinocottus acuticeps (sharpnose sculpin)	0	0	0	0	0	0	1	0	3	4
Platichthys stellatus (starry flounder)	0	1	0	0	1	1	1	0	0	4
Lampetra tridentata (pacific lamprey)	2	0	0	1	0	0	0	0	0	3
Catostomus rimiculus (smallscale sucker)	1	1	0	0	0	0	0	0	0	2
Sardinops sagax (pacific sardine)	0	0	0	0	2	0	0	0	0	2
Embiotoca lateralis (striped surfperch)	0	0	0	0	1	0	1	0	0	2
Oncorhynchus kisutch (coho salmon)	1	0	0	0	0	0	0	0	0	1
Psettichthys melanostictus (sand sole)	0	0	0	0	0	0	1	0	0	1

Table 3. Fish species and incidental fauna captured in fyke nets in Tillas Slough, Smith River estuary, California, March to November 2001 (continued).

	M	A[a]	M	J	J	A	S	O[a]	N[a]	TOTALS
Atherinid juveniles (silversides)	0	0	0	0	0	0	1	0	0	1
INVERTEBRATES (incidental)										
Crangon sp. (shrimp)	6	81	3	14	15	74	606	245	2308	3352
Cancer magister (dungeness crab)	0	0	0	0	0	0	27	3	41	71
Cnidaria (jellyfish)	0	0	0	0	15	20	29	5	0	69
Ctenophora (comb jelly)	0	0	0	0	3	0	8	0	0	11
Acrididae (grasshopper)	0	0	0	0	0	1	0	0	0	1
Gastropoda (snail)	0	0	0	0	0	1	0	0	0	1
Anisoptera (dragonfly larva)	0	0	0	0	0	0	0	0	1	1

[a] Due to seasonal weather constraints, fish were sampled only once rather than twice in these months.

Table 4. Fish species and incidental fauna captured in fyke nets in Islas Slough, Smith River estuary, California, May to November 2000.

		M	J	J	A	S	O	N[a]	TOTALS
FISH	*Gasterosteus aculeatus* (threespine stickleback)	390	1046	172	201	336	11404	165	13714
	Leptocottus armatus (staghorn sculpin)	210	603	1746	1439	138	3	5	4144
	Cottus asper (prickly sculpin)	0	331	126	164	459	64	50	1194
	Cymatogaster aggregata (shiner surfperch)	33	82	358	587	89	14	0	1163
	Pholis ornata (saddleback gunnel)	0	16	24	72	15	8	4	139
	Oncorhynchus tshawytscha (chinook salmon)	92	10	2	1	0	0	0	105
	Hypomesus pretiosus (surfsmelt)	0	1	76	4	3	9	6	99
	Atherinops affinis (topsmelt)	0	0	3	0	3	45	7	58
	Platichthys stellatus (starry flounder)	12	11	13	1	0	0	0	37
	Clupea pallasii (pacific herring)	0	12	8	1	0	1	0	22
	Allosmerus elongatus (whitebait smelt)	0	5	0	0	0	0	0	5

Table 4. Fish species and incidental fauna captured in fyke nets in Islas Slough, Smith River estuary, California, May to November 2000 (continued).

	M	J	J	A	S	O	N[a]	TOTALS
Oncorhynchus clarki (cutthroat trout)	1	1	0	0	0	0	0	2
Lampetra tridentata (pacific lamprey)	0	0	1	1	0	0	0	2
Oncorhynchus mykiss (steelhead trout)	0	0	0	1	0	1	0	2
Citharichthys stigmaeus (speckled sanddab)	1	0	0	0	0	0	0	1
INVERTEBRATES (incidental)								
Crangon sp. (shrimp)	0	0	0	0	800	365	320	1485
Ctenophora (comb jelly)	0	0	0	0	0	4	0	4

[a] Due to seasonal weather constraints, fish were sampled only once rather than twice in these months.

Table 5. Fish species and incidental fauna captured in fyke nets in Islas Slough, Smith River estuary, California, March to November 2001.

		M[a]	A	M	J	J	A	S	O[a]	N[a]	TOTALS
FISH	*Gasterosteus aculeatus* (threespine stickleback)	253	726	1175	1712	2416	365	138	197	32050	39032
	Leptocottus armatus (staghorn sculpin)	738	2743	748	782	798	72	75	5	13	5974
	Cymatogaster aggregata (shiner surfperch)	2	0	41	27	2316	199	459	0	0	3044
	Oncorhynchus tshawytscha (chinook salmon)	0	11	173	635	68	25	1	2	1	916
	Hypomesus pretiosus (surfsmelt)	0	4	3	112	16	252	39	0	1	427
	Cottus asper (prickly sculpin)	30	9	44	30	25	14	68	9	3	232
	Pholis ornata (saddleback gunnel)	0	0	2	2	3	2	98	2	3	112
	Atherinops affinis (topsmelt)	0	0	0	0	24	8	11	28	33	104
	Oncorhynchus mykiss (steelhead trout)	4	16	3	1	7	2	2	0	0	35
	Platichthys stellatus (starry flounder)	0	0	0	2	1	0	0	0	0	3
	Catostomus rimiculus (smallscale sucker)	1	0	1	0	0	0	0	0	0	2

Table 5. Fish species and incidental fauna captured in fyke nets in Islas Slough, Smith River estuary, California, March to November 2001 (continued).

	M[a]	A	M	J	J	A	S	O[a]	N[a]	TOTALS
Clupea pallasii (pacific herring)	0	0	0	1	1	0	0	0	0	2
Oncorhynchus kisutch (coho salmon)	2	0	0	0	0	0	0	0	0	2
Lampetra tridentata (pacific lamprey)	0	0	2	0	0	0	0	0	0	2
Sardinops sagax (pacific sardine)	0	0	0	0	2	0	0	0	0	2
Oncorhynchus clarki (cutthroat trout)	0	1	0	0	0	0	0	0	0	1
Scorpaenichthys marmoratus (cabezon)	0	0	0	0	0	0	1	0	0	1
Engraulis mordax (northern anchovy)	0	0	0	1	0	0	0	0	0	1
INVERTEBRATES (incidental)										
Crangon sp. (shrimp)	0	0	0	1	14	43	150	9	1	218
Cnidaria (jellyfish)	0	0	0	0	0	3	12	1	1	17
Cancer magister (dungeness crab)	0	0	0	0	0	0	2	0	0	2

Table 5. Fish species and incidental fauna captured in fyke nets in Islas Slough, Smith River estuary, California, March to November 2001 (continued).

	M[a]	A	M	J	J	A	S	O[a]	N[a]	TOTALS
Belostomatidae (giant water bug)	0	0	0	1	0	0	0	0	0	1
AMPHIBIANS (incidental)										
Rana aurora draytonii (redlegged frog)	0	0	1	1	0	0	0	0	0	2

[a] Due to seasonal weather constraints, fish were sampled only once rather than twice in these months.

Table 6. Overall relative abundance of fish species and incidental fauna captured in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001.

Fish	Tillas Slough (%)	Islas Slough (%)	Overall (%)
Gasterosteus aculeatus (3-spine stickleback)	12.7	74.7	52.3
Leptocottus armatus (staghorn sculpin)	56.6	14.3	29.7
Cymatogaster aggregata (shiner surfperch)	3.4	6.0	5.0
Hypomesus pretiosus (surfsmelt)	12.2	0.7	4.9
Cottus asper (prickly sculpin)	6.5	2.0	3.6
*Osmeridae (smelt*s)	3.7	0.0	1.4
*Oncorhynchus tshawytscha (chinook salmo*n)	0.5	1.4	1.1
Pholis ornata (saddleback gunnel)	2.2	0.4	1.0
Clupea pallasii (pacific herring)	1.8	<0.1	0.7
Atherinops affinis (topsmelt)	0.1	0.2	0.2
Engraulis mordax (northern anchovy)	0.1	<0.1	0.1
Platichthys stellatus (starry flounder)	<0.1	0.1	<0.1
Oncorhynchus mykiss (steelhead trout)	<0.1	0.1	<0.1
Spirinchus starksi (nightsmelt)	<0.1	0.0	<0.1

Table 6. Overall relative abundance of fish species and incidental fauna captured in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Fish	Tillas Slough (%)	Islas Slough (%)	Overall (%)
Lampetra tridentata (pacific lamprey)	<0.1	<0.1	<0.1
Allosmerus elongatus (whitebait smelt)	<0.1	<0.1	<0.1
Syngnathus leptorhynchus (bay pipefish)	<0.1	0.0	<0.1
Catostomus rimiculus (smallscale sucker)	<0.1	<0.1	<0.1
Clinocottus acuticeps (sharpnose sculpin)	<0.1	0.0	<0.1
Oncorhynchus clarkii clarkii (cutthroat trout)	<0.1	<0.1	<0.1
Sardinops sagax (pacific sardine)	<0.1	<0.1	<0.1
Atherinopsis californiensis (jacksmelt)	<0.1	0.0	<0.1
Embiotoca lateralis (striped surfperch)	<0.1	0.0	<0.1
Oncorhynchus kisutch (coho salmon)	0.0	<0.1	<0.1
Scorpaenichthys marmoratus (cabezon)	<0.1	<0.1	<0.1
Atherinidae (silversides)	<0.1	0.0	<0.1
Citharichthys stigmaeus (speckled sanddab)	0.0	<0.1	<0.1

Table 6. Overall relative abundance of fish species and incidental fauna captured in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Fish	Tillas Slough (%)	Islas Slough (%)	Overall (%)
Psettichthys melanostictus (sand sole)	<0.1	0.0	<0.1
Crangon sp. (shrimp)	98.8	98.5	98.7
Cnidarian (jellyfish)	0.5	1.0	0.6
Cancer magister (dungeness crab)	0.6	0.1	0.5
Ctenophore (comb jelly)	0.1	0.2	0.1
Rana aurora draytonii (redlegged frog)	0.0	0.1	<0.1
Acrididae (grasshopper)	<0.1	0.0	<0.1
Belostomatidae (giant water bug)	0.0	<0.1	<0.1
Gastropoda (snail)	<0.1	0.0	<0.1
Anisoptera (dragonfly larva)	<0.1	0.0	<0.1

Tillas Slough, peak abundance was observed in July and June in 2000 and 2001, respectively, mostly due to the great abundance of *L. armatus*. In Islas Slough, peak abundance occurred in October and November in years 2000 and 2001, respectively, mostly due to the high numbers of *G. aculeatus*. Monthly abundance is plotted for the nine most numerically dominant species in Figure 8. The populations of *Gasterosteus aculeatus*, saddleback gunnel (*Pholis ornata*), *C. asper*, and *A. affinis* peaked in fall and *L. armatus* populations peaked in summer in both sloughs over both years. The abundance of *C. aggregata* was greatest in late summer in 2000 and in fall in 2001. Conversely, *H. pretiosus* and *C. pallasii* populations peaked in the fall in 2000 and in the summer of 2001. The brief appearance of Chinook salmon (*Oncorhynchus tshawytscha*) occurred in summer of both years. Six of the nine top species were clearly more abundant in 2001 than 2000. Exceptions were *C. asper* whose capture was 80% higher in 2000 than in 2001, *C. pallasii* whose capture was 67% higher in 2000, and *H. pretiosus* where the catch between years was nearly equal. Five species, *L. armatus*, *H. pretiosus*, *C. asper*, *P. ornata*, and *C. pallasii* were more abundant in Tillas Slough; and four species, *G. aculeatus, C. aggregata*, and *O. tshawytscha*, and *A. affinis* were more abundant in Islas Slough.

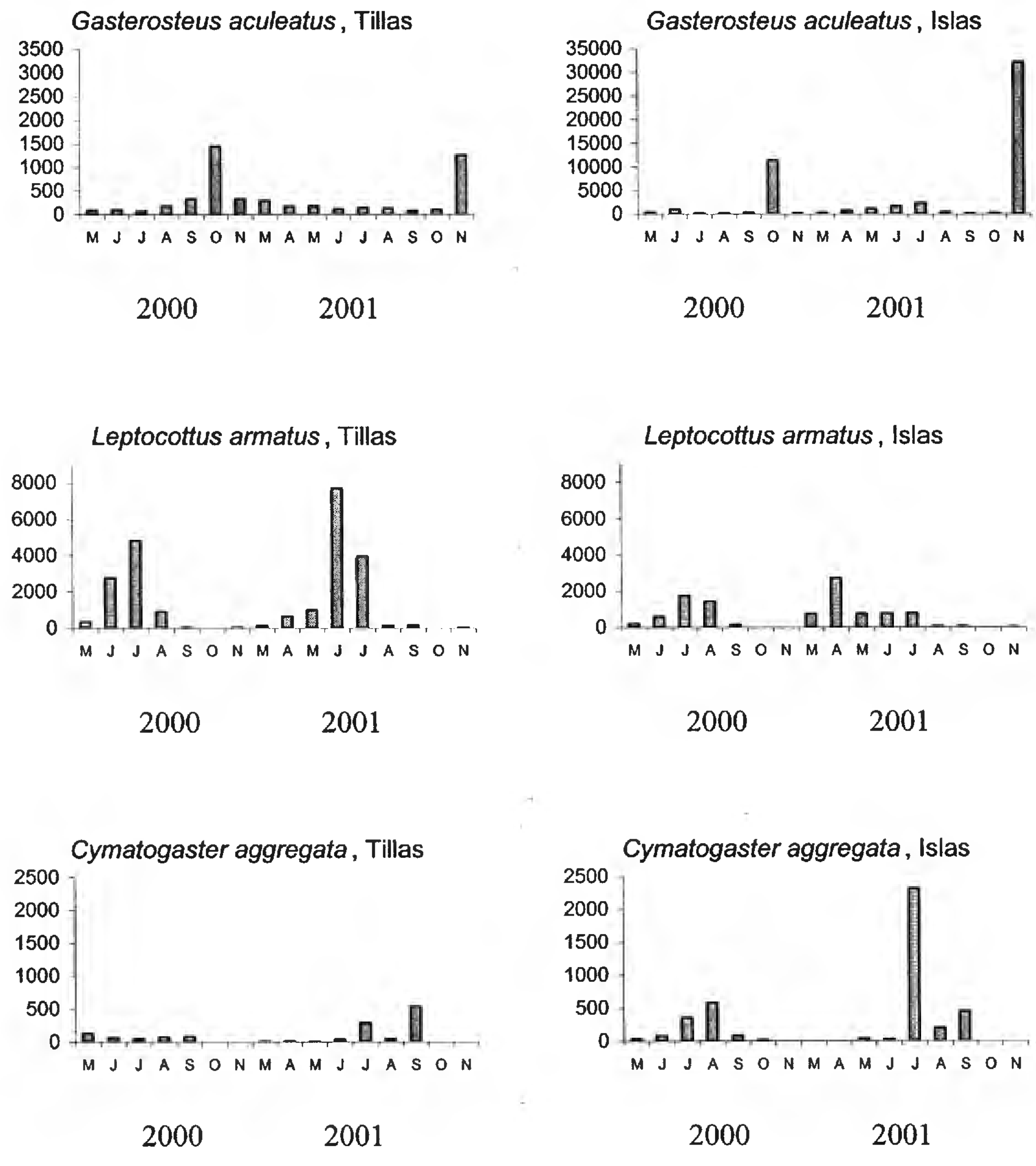


Figure 8. Abundance of the nine most numerically dominant fish species captured in fyke nets in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001. Note that for *Gasterosteus aculeatus*, *Oncorhynchus tschawytscha*, and *Clupea pallasii* the y-axis scale differs between sloughs because the difference in abundance was greater than an order of magnitude.

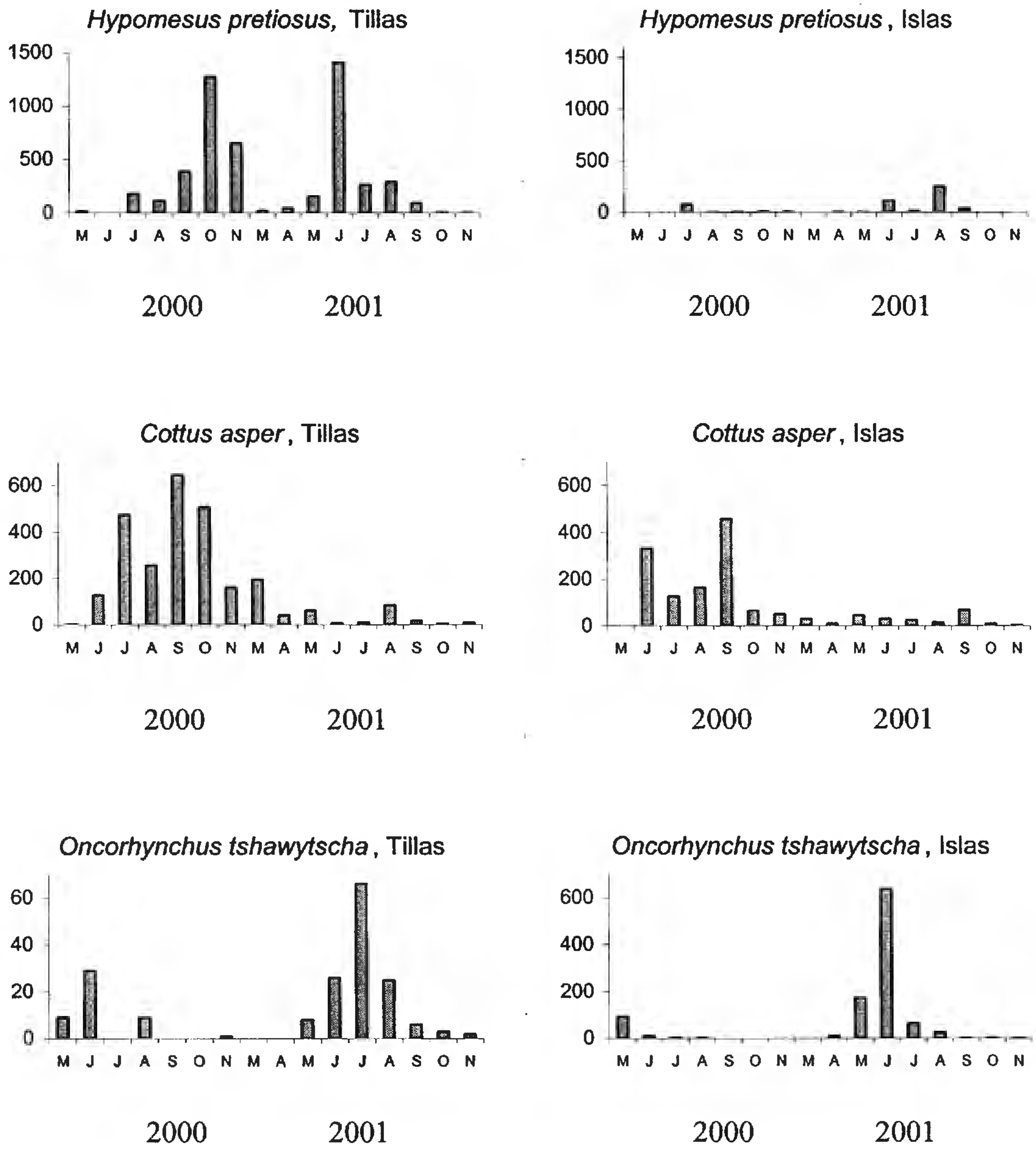


Figure 8. Abundance of the nine most numerically dominant fish species captured in fyke nets in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001. Note that for *Gasterosteus aculeatus*, *Oncorhynchus tschawytscha*, and *Clupea pallasii* the y-axis scale differs between sloughs because the difference in abundance was greater than an order of magnitude (continued).

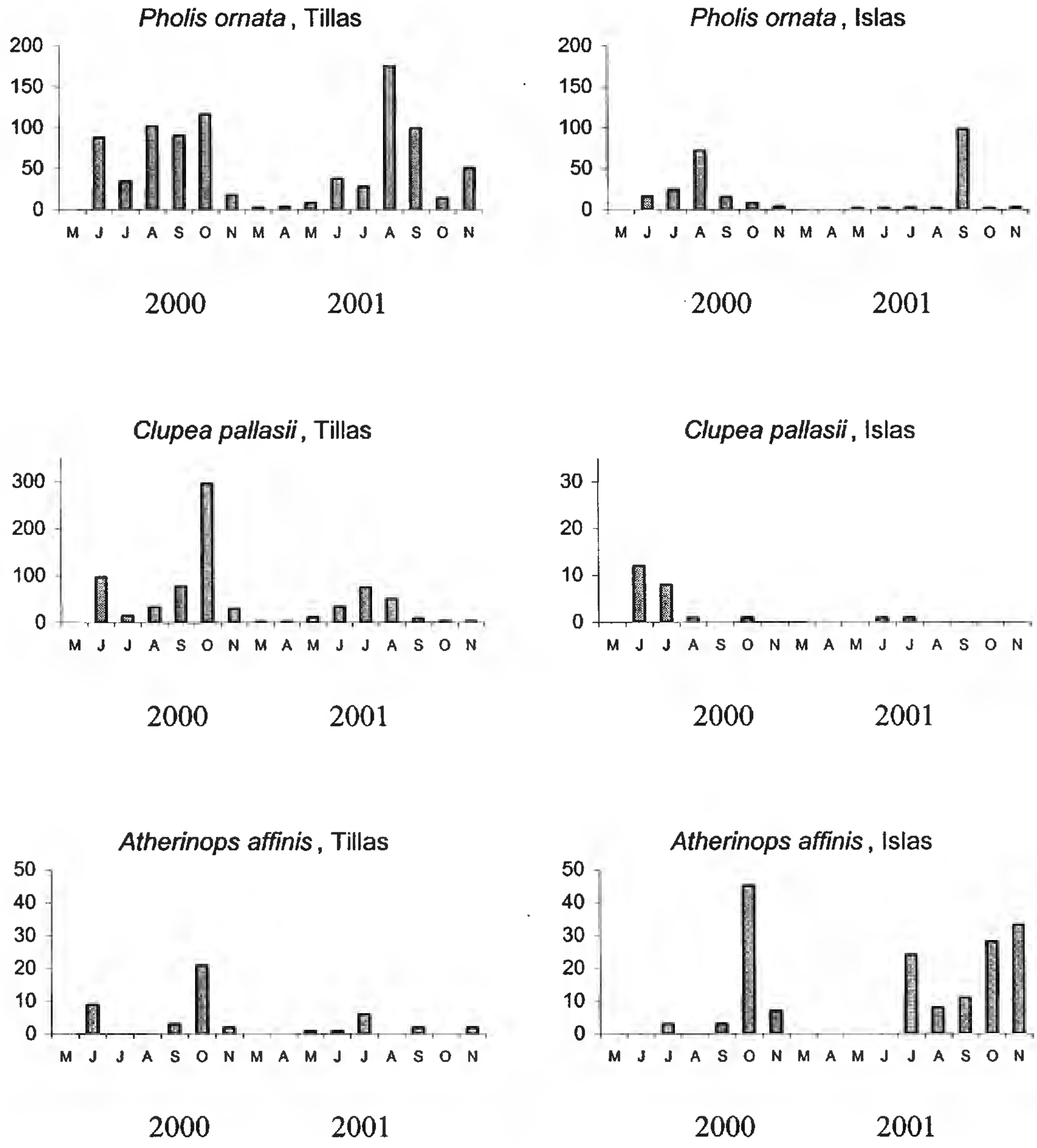


Figure 8. Abundance of the nine most numerically dominant fish species captured in fyke nets in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001. Note that for *Gasterosteus aculeatus*, *Oncorhynchus tschawytscha*, and *Clupea pallasii* the y-axis scale differs between sloughs because the difference in abundance was greater than an order of magnitude (continued).

Species richness (S) for each month among Tillas and Islas Sloughs ranged from six to 16 (Tables 7, 8, Figure 9) and was only slightly higher in 2001 (10.3) than in 2000 (9.5). Tillas Slough had a higher species richness than Islas Slough in 14 out of the 16 total months sampled and an equal species richness in one month. Only seven species of fish were captured in Tillas Slough in July 2000 whereas 16 species were captured in September 2001. The mean species richness for all months in Tillas Slough was 11.1, with a mean of 10.1 in 2000 and a mean of 11.9 in 2001. Islas Slough had a higher species richness than Tillas Slough in only 1 out of the 16 months. Only six species of fish were captured in each of the months of November 2000 and October 2001, fewer than any other month sampled. The most speciose month was July 2001 when 12 species were captured. The mean species richness for all months in Islas Slough was 8.8 with a mean of 8.9 in 2000 and 8.8 in 2001.

Shannon-Wiener diversity (Tables 7, 8, Figure 9) was generally higher in Tillas Slough than in Islas Slough. Within Tillas Slough, the monthly Shannon-Wiener Diversity Index (H') was higher in 10 out of the 16 months sampled. The highest diversity occurred in July 2001. The lowest diversity in Tillas Slough occurred in October 2001. In Islas Slough, diversity peaked in September 2001 and was lowest in November 2001. The average Shannon-Wiener diversity for both sloughs during the study period was 1.05. The monthly Simpson's Index (SI'), describing the degree of species dominance expressed within the community, was higher in Islas Slough in 9 out of the total 16 months sampled. *Gasterosteus aculeatus* displayed nearly 100%

Table 7. Indices of diversity of fishes in Tillas Slough, Smith River estuary, California, May to November 2000 and March to November 2001.

Year	Month	N	Species Richness (S)	Shannon-Wiener Diversity Index (H')	Simpson's Diversity Index (SI')
2000	M	609	8	1.15	0.40
	J	3296	13	0.74	0.71
	J	5658	7	0.59	0.74
	A	1701	11	1.49	0.33
	S	1670	11	1.63	0.24
	O	3677	11	1.38	0.30
	N	1237	10	1.24	0.36
2001	M	939	12	1.52	0.22
	A	2073	10	1.13	0.39
	M	1534	11	1.20	0.46
	J	9420	13	0.63	0.69
	J	4853	15	0.80	0.67
	A	949	11	1.86	0.18
	S	1019	16	1.48	0.33
	O	146	9	1.03	0.56
	N	1361	10	0.35	0.87

Table 8. Indices of diversity of fishes in Islas Slough, Smith River estuary, California, May to November 2000 and March to November 2001.

Year	Month	N	Species Richness (S)	Shannon-Wiener Diversity Index (H')	Simpson's Diversity Index (SI')
2000	M	739	7	1.18	0.38
	J	2118	11	1.26	0.35
	J	2529	11	1.08	0.50
	A	2472	11	1.17	0.41
	S	1043	7	1.30	0.32
	O	11549	9	0.09	0.98
	N	237	6	0.93	0.53
2001	M	1030	7	0.74	0.57
	A	3510	7	0.59	0.65
	M	2192	10	1.09	0.41
	J	3305	11	1.21	0.36
	J	5677	12	1.14	0.37
	A	939	9	1.47	0.27
	S	892	10	1.50	0.31
	O	243	6	0.70	0.67
	N	32104	7	0.01	1.00

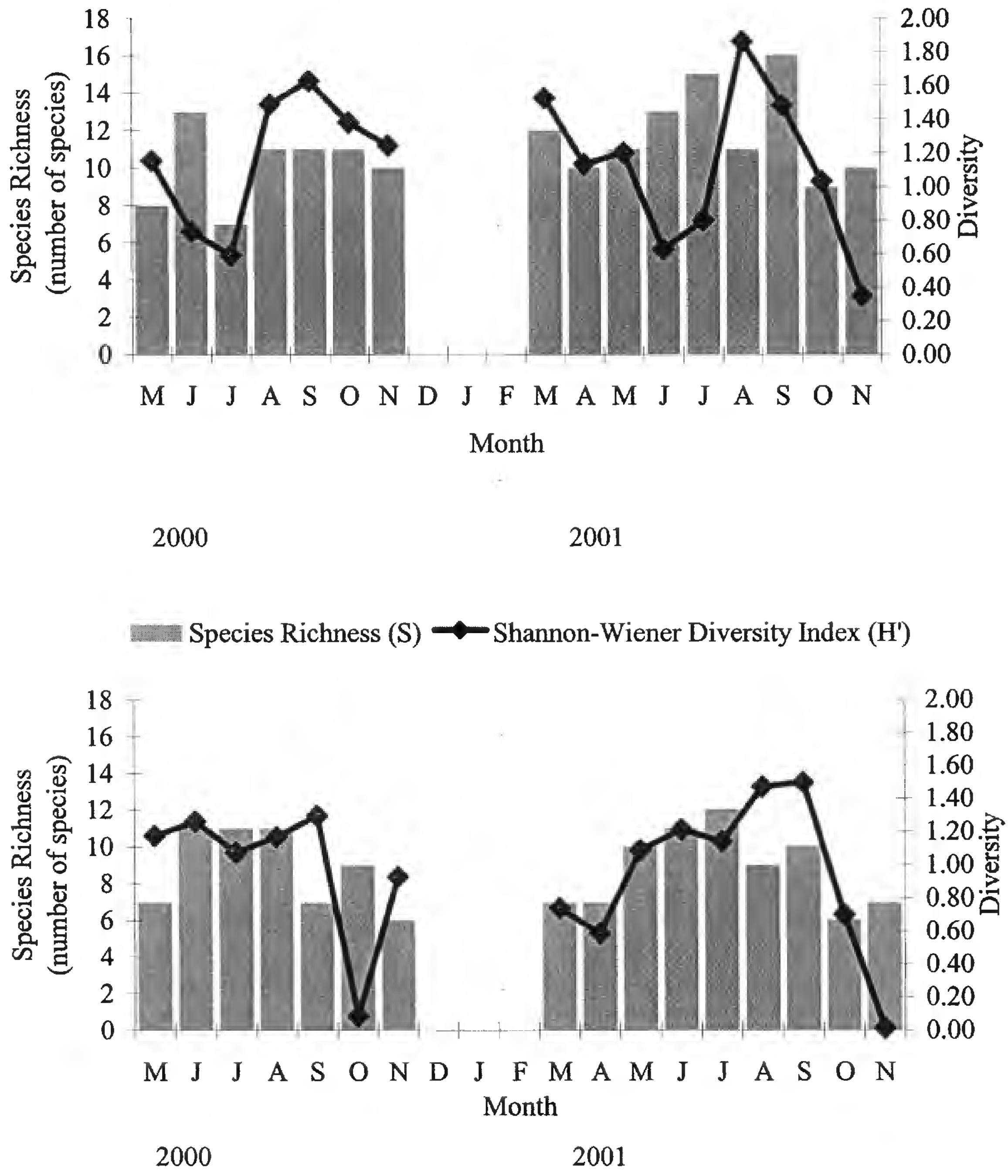


Figure 9. Shannon-Wiener diversity and species richness of fishes in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001.

dominance in Islas Slough in October 2001 and total dominance in November 2001. In both sloughs, the Simpson's Index was highest in November 2001 and lowest in August 2001.

Several commercially important species, including four salmonids, were found in the sloughs. These included *C. pallasii*, northern anchovy (*Engraulis mordax*), nightsmelt (*Spirinchus starksi*), Pacific lamprey (*Lampetra tridentata*), Pacific sardine (*Sardinops sagax*), cabezon (*Scorpaenichthys marmoratus*), and dungeness crab (*Cancer magister*). Chinook salmon comprised 96% of the total salmonid catch, and low numbers of steelhead trout (*O. mykiss*), cutthroat trout (*O. clarki*), and coho salmon (*O. kisutch*) made up the remaining salmonid abundance. Of the 1,258 salmonids captured during the entire sampling period, 84% were found in Islas Slough (n=1063) and 16% were found in Tillas Slough (n=195). Thirteen percent were found in 2000 (n=160) and 87% were found in 2001 (n=1098). Salmonids were most abundant in May 2000 and June 2001. Although salmonids were more abundant in Islas Slough, peak abundances for Tillas Slough salmonids occurred, for both years, in the month following the peak of total fish abundance (June 2000 and July 2001).

Stepwise multiple regression analyses of the nine most numerically dominant fish species, which related abundance to the measured environmental parameters, is shown in Table 9. Environmental parameters explained the most variability in *C. pallasi* (r^2=0.50), *C. aggregata* (r^2=0.49), *O. tshawytscha* (r^2=0.45), *L. armatus* (r^2=0.44), *A. affinis* (r^2=0.31) and *P. ornata* (r^2=0.30). It explained very little variability in *H. pretiosus* (r^2=0.25), *C.*

Table 9. Standarized regression equations (intercept=0) and r^2 values relating the abundance of dominant fish species to environmental parameters in Tillas and Islas Sloughs, Smith River estuary, California, May through November 2000 and March through November 2001.

	Standarized Coefficient							
Species	Temperature	Salinity	Dissolved Oxygen	Nitrate	Phosphate	Grass	Algae	r^2
Gastosteus aculeatus	-0.2163	-0.2189					0.3336	0.1694
Leptocottus armatus	0.4692	-0.3856	-0.1864		0.2122			0.4441
Hypomesus pretiosus		0.4188	-0.1879	-0.2137			-0.2772	0.2485
Cymatogaster aggregata	0.2704		-0.2754		-0.2377	0.4017	0.3083	0.4864
Cottus asper		0.2625			0.3632	0.2270		0.2082
Clupea pallasii	0.2844	0.4260		-0.5072	0.6518			0.5028
Oncorhynchus tshawytscha		-0.4629	-0.5301		-0.4360	-0.2095		0.4459
Pholis ornata	0.3214	0.4505						0.2991
Atherinops affinis			-0.2511		-0.2225	-0.2552	0.4477	0.3080

asper (r^2=0.21), and *G. aculeatus* (r^2=0.17). Salinity explained the most variability in abundance of *H. pretiosus*, and *P. ornata*. Algae cover explained the most variability in *G. aculeatus* and *A. affinis*. Phosphate explained most variability in *C. asper*, and *C. pallasii*. Grass cover explained most variability in *C. aggregata*, temperature explained the most variability in *L. armatus*, while dissolved oxygen concentration explained the most variability in *O. tshawytscha*. Spearman correlations (r) revealed only slight correlations between ammonia and phosphate (0.38), ammonia and dissolved oxygen (-0.32), ammonia and grass cover (-0.37), and temperature and grass cover (0.35). Because of these correlations, ammonia was eliminated as a variable from regression analyses, and regression results including temperature and grass cover together were interpreted with caution.

Length frequency histograms of the nine most numerically dominant fish species reveal the population size distributions (Figure 10). Bimodal distributions were displayed in 3 taxa: *G. aculeatus*, *C. aggregata*, and osmerid smelts. The most frequent lengths for *G. aculeatus* were 43 mm and 64 mm. The most frequent lengths for *C. aggregata* were 70 mm, 96 mm, and 105 mm; and for Osmeridae were 54 mm and 167 mm. Trimodal distributions were displayed in two species: *C. pallasii* and *A. affinis*. The mode lengths for *C. pallasii* were 86 mm, 144 mm, and 191 mm; and for *A. affinis* were 85 mm, 148 mm, and 237 mm. Non-normal distributions were displayed in 4 species: *L. armatus* (mode=[66,76] mm), *P. ornata* (mode=95 mm), *C. asper* (mode=63 mm), and *O. tshawytscha* (mode=59).

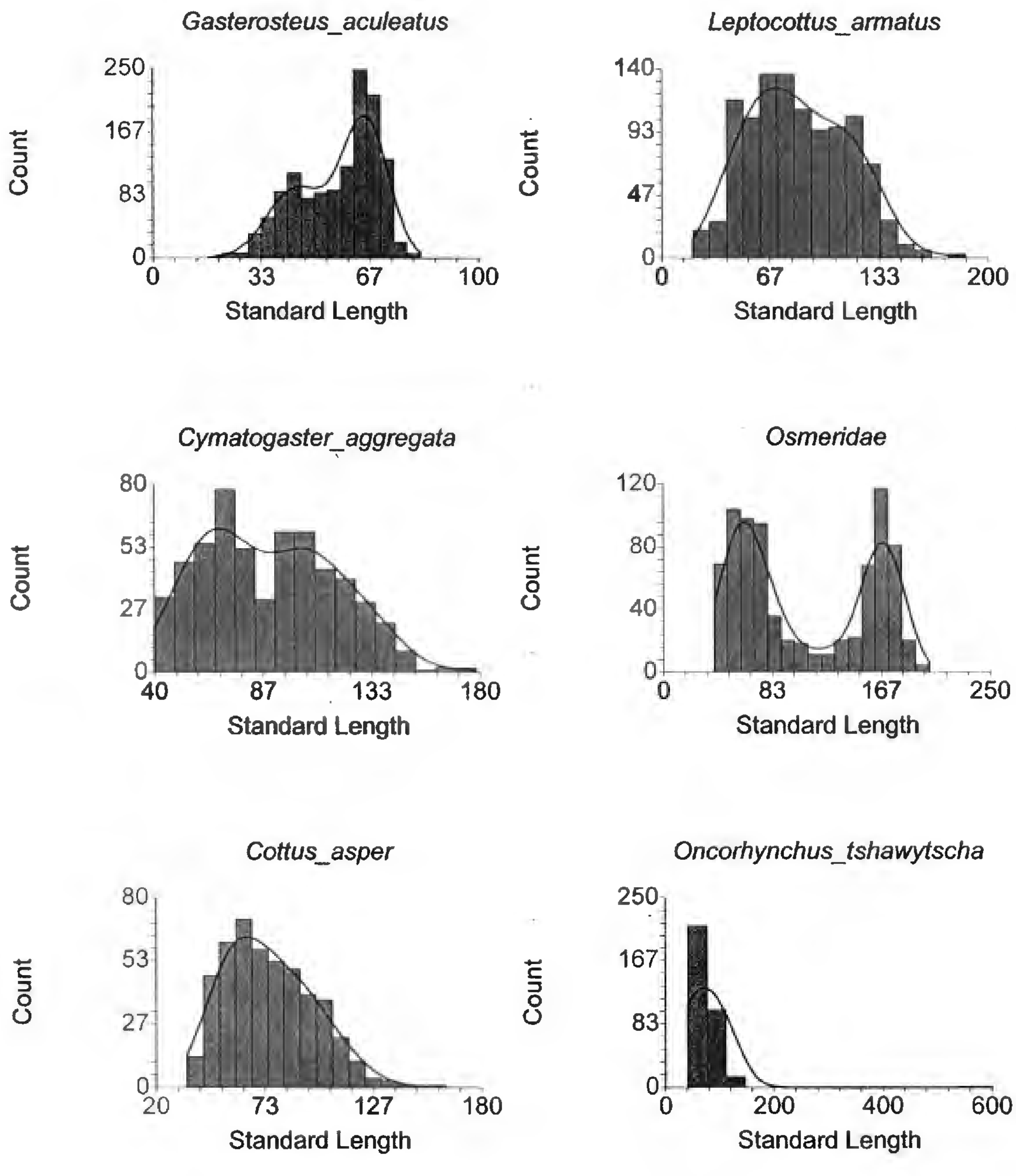


Figure 10. Length-frequency histograms of the nine most numerically dominant fish species in Tillas and Islas Sloughs, Smith River estuary, May to November 2000 and March to November 2001.

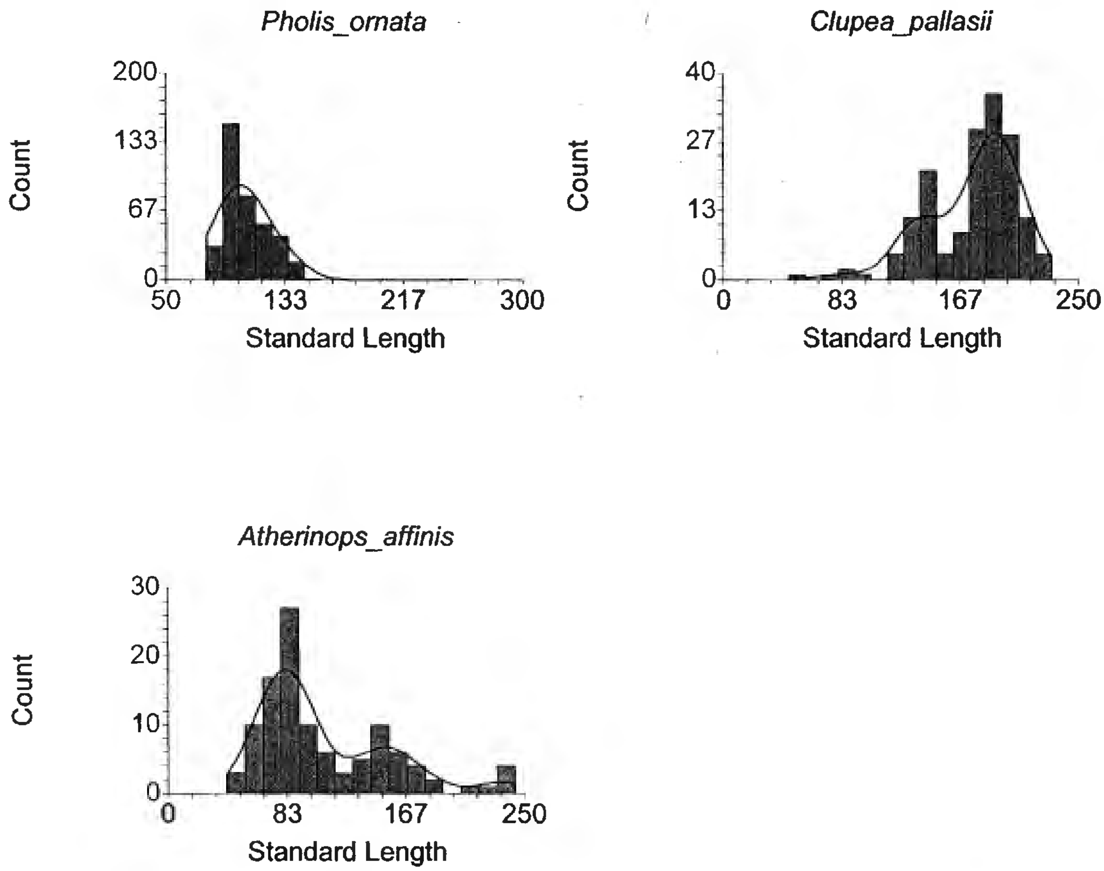


Figure 10. Length-frequency histograms of the nine most numerically dominant fish species in Tillas and Islas Sloughs, Smith River estuary, May to November 2000 and March to November 2001 (continued).

Benthic Fauna

A total of 343,407 benthic individuals (209,246 in Tillas Slough and 134,161 in Islas Slough; 217,494 in the year 2000 and 125,913 in the year 2001) were identified belonging to 10 phyla (Table 10). Phylum Arthropoda was represented by 11 crustacean taxa, six orders of Insecta, and two orders of Arachnida. Four polychaete species and oligochaetes represented Phylum Annelida. Benthic fishes and fish eggs represented Phylum Chordata. Less abundantly represented phyla included Platyhelminthes (Order: Rhabdocoela), Nematoda, Cnidaria (Order: Hydroida), Mollusca (Classes: Bivalvia and Gastropoda), Bryozoa, Nemertea, and Granuloreticulosa (Class: Foraminifera). Overall, the diversity of taxa found at each station increased with distance from the mouth of each slough. Although Tillas and Islas Sloughs were dominated by different taxa, the two sloughs were nearly identical with regard to diversity of taxa. Four taxa made up 82% of the total abundance of benthic fauna: unidentified *Corophium sp.* (27%), Class: Oligochaeta (24%), *Corophium spinicorne* (19%), and *Gnorimosphaeroma insulare* (12%). An additional five taxa, Subclass: Ostracoda (6%); *Eogammarus confervicolus* (4%); *Corophium salmonis* (3%); Family: Chironomidae (2%); and *Neanthes limnicola* (1%), increased the relative abundance to 98%. Another six taxa represented nearly 2% of the total, and an additional 37 taxa were found only rarely.

Tillas Slough was dominated by the amphipod *C. spinicorne* (Table 11). At station 1, *C. spinicorne* accounted for 33% of the total individuals counted. *Corophium spinicorne* with an additional five taxa made up 98% of the total. Fall 2001 reflected the

Table 10. Benthic taxa found in core samples in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001.

Taxon	Individuals (N)	Relative Abundance (%)
Arthropoda		
Crustacea		
Amphipoda		
Corophium sp.	91,751	26.7
Corophium spinicorne	64,849	18.9
Corophium salmonis	10,369	3.0
Eogammarus confervicolus	12,019	3.5
Isopoda		
Gnorimosphaeroma insulare	39,477	11.5
Ostracoda	21,843	6.4
Copepoda		
Harpacticoida	189	0.1
Calanoida	168	<0.1
Cyclopoida	15	<0.1
Other Crustaceans		
Balanus crenatus	3	<0.1
Neomysis mercedis	3	<0.1
Crangon franciscorum	1	<0.1

Table 10. Benthic taxa found in core samples in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Unidentified Decapoda larva	1	<0.1
Insecta		
Diptera		
Chironomidae larva	6,437	1.9
Chironomidae pupa	160	<0.1
Chironomidae adult	1	<0.1
Ephydridae larva	10	<0.1
Ceratopogonidae	7	<0.1
Empididae larva	6	<0.1
Dolichopodidae larva	3	<0.1
Cecidomyiidae	1	<0.1
Unidentified Diptera larva	1	<0.1
Homoptera		
Aphididae	14	<0.1
Cercopidae	1	<0.1
Cicadellidae	1	<0.1
Odonata		
Zygoptera	7	<0.1

Table 10. Benthic taxa found in core samples in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Collembola		
Collembola	3	<0.1
Coleoptera		
Dytiscidae	2	<0.1
Nitulidae	1	<0.1
Ptiliidae	1	<0.1
Other Insects		
Corixidae	1	<0.1
Formicidae	1	<0.1
Arachnida		
Acarina	27	<0.1
Araneae egg case	21	<0.1
Annelida		
Clitellata		
Oligochaeta	81,252	23.7
Oligochaete egg case	2,571	0.7

Table 10. Benthic taxa found in core samples in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Polychaeta		
Neanthes limnicola	4,428	1.3
Capitella capitata	1,255	0.4
Armandia brevis	3	<0.1
Nereis vexillosa	2	<0.1
Nematoda	2,470	0.7
Rhabdocoela	2,172	0.6
Chordata		
Cottidae		
Cottid eggs	547	0.2
Leptocottus armatus	10	<0.1
Cottidae	6	<0.1
Cottus asper	1	<0.1
Gasterosteidae		
Gasterosteus aculeatus	8	<0.1

Table 10. Benthic taxa found in core samples in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Pholidae		
Pholis ornata	8	<0.1
Atherinidae		
Atherinid eggs	3	<0.1
Cordylophora caspia	541	0.2
Bryozoa zoeids	391	0.1
Mollusca		
Mytilus sp.	332	0.1
Gastropoda	1	<0.1
Nemertea	2	<0.1
Granuloreticulosa		
Foramenifera	1	<0.1

Table 10. Benthic taxa found in core samples in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Unidentified Phylum		
Eggs	8	<0.1
TOTAL	343,407	100

Table 11. Benthic taxa dominant in Tillas Slough, Smith River estuary, California, May to November 2000 and March to November 2001.

Station 1	Percent
Corophium spinicorne	33
Corophium sp.	26
Oligochaetes	18
Gnorimosphaeroma insulare	18
Eogammarus confericolus	2
Rhabdocoela	1
Total	98

Station 2	Percent
Corophium sp.	37
Class: Oligochaeta	27
Corophium spinicorne	23
Gnorimosphaeroma insulare	5
Eogammarus confericolus	3
Ostracods	2
Nematodes	1
Total	98

Station 3	Percent
Corophium sp.	21
Ostracods	19
Oligochaetes	15
Corophium salmonis	15
Corophium spinicorne	8
Gnorimosphaeroma insulare	5
Eogammarus confericolus	4
Neanthes limnicola	3
Capitella capitata	3
Oligochaete egg capsules	3
Cottid eggs	2
Chironomids	1
Total	99

highest diversity at this station, and the lowest diversity was found in the fall of 2000 (Table 12). Species evenness was highest in fall 2000 and lowest in fall 2001. At station 2, *Corophium sp.* accounted for 37% of the total individuals and with an additional six taxa accounted for 98% of the total. The highest diversity was, again, found during the fall of 2001, but the lowest diversity was found in the spring of 2001. Evenness was highest in fall 2001, during the time of highest diversity at this station, and lowest in spring 2000. At station 3, *Corophium sp.* accounted for 21% of the total individuals and with an additional 11 taxa accounted for 99% of the total. This total includes individual fish eggs from the family Cottidae, whose numbers accounted for 2%. The highest diversity occurred in the summer of 2000, and species evenness was highest in the spring of 2001. The lowest diversity and evenness occurred together in the fall of 2001, when the other stations were experiencing high diversity.

Islas Slough is dominated by oligochaetes, ostracods, and the isopod *G. insulare* (Table 13). At station 1, oligochaetes accounted for 30% of the total individuals enumerated and with an additional seven taxa accounted for 99%. The highest diversity and evenness occurred together in the fall 2001 (Table 14), when much of Tillas Slough experienced high diversity. The lowest diversity and evenness were found in spring 2001. At station 2, *G. insulare, Corophium sp.*, and oligochaetes each accounted for 24% of the total individuals with an additional seven taxa increasing this to 98% relative abundance. Again, the fall of 2001 reflected the highest diversity and evenness, while the lowest diversity and evenness occurred together in spring and early summer of 2001. At station 3, ostracods accounted for 27% of the total individuals and with an additional 8

Table 12. Abundance (N), density, and indices of diversity of benthic fauna in Tillas Slough, Smith River estuary, California, May to November 2000 and March to November 2001.

Station	Year	Month	N	Density (individuals/cm^3)	Species Richness (S)	Shannon-Wiener Diversity Index (H')	Species Evenness (J)
1	2000	M	1690	0.90	11	1.34	0.56
		J	1596	0.85	8	1.50	0.72
		J	7138	3.78	9	1.44	0.65
		A	7792	4.13	11	1.44	0.60
		S	7482	3.97	7	1.47	0.76
		O	540	0.29	6	0.79	0.44
		N	8969	4.76	8	1.31	0.63
	2001	M	2901	1.54	8	1.41	0.68
		A	1125	0.60	9	1.41	0.64
		M	2146	1.14	7	1.15	0.59
		J	2472	1.31	9	1.50	0.68
		J	4042	2.14	7	1.38	0.71
		A	1196	3.11	9	1.54	0.70
		S	1016	2.65	9	1.34	0.61
		O	1243	3.24	11	1.02	0.42
		N	1559	4.06	13	1.01	0.39

Table 12. Abundance (N), density, and indices of diversity of benthic fauna in Tillas Slough, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Station	Year	Month	N	Density (individuals/cm^3)	Species Richness (S)	Shannon-Wiener Diversity Index (H')	Species Evenness (J)
2	2000	M	6655	3.53	15	1.66	0.61
		J	5118	2.71	15	1.44	0.53
		J	27953	14.82	13	1.16	0.45
		A	13136	6.97	12	1.46	0.59
		S	13477	7.15	12	1.39	0.56
		O	5752	3.05	10	1.63	0.71
		N	11716	6.21	11	1.53	0.64
	2001	M	4628	2.45	9	1.34	0.61
		A	3866	2.05	10	1.31	0.57
		M	6896	3.66	11	1.15	0.48
		J	8342	4.42	11	1.27	0.53
		J	6661	3.53	10	1.27	0.55
		A	1848	4.81	10	1.80	0.78
		S	1208	3.15	11	1.97	0.82
		O	1301	3.39	10	1.58	0.69
		N	1625	4.23	11	1.42	0.59

Table 12. Abundance (N), density, and indices of diversity of benthic fauna in Tillas Slough, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Station	Year	Month	N	Density (individuals/cm^3)	Species Richness (S)	Shannon-Wiener Diversity Index (H')	Species Evenness (J)
3	2000	M	1988	1.05	14	1.73	0.65
		J	1244	0.66	10	1.78	0.77
		J	2656	1.41	17	2.10	0.74
		A	1236	0.66	11	1.62	0.67
		S	1649	0.87	14	1.99	0.75
		O	5747	3.05	14	1.87	0.71
		N	4093	2.17	11	1.98	0.82
	2001	M	2462	1.31	11	1.79	0.75
		A	2445	1.30	11	1.95	0.81
		M	2859	1.52	11	2.02	0.84
		J	2604	1.38	13	1.92	0.75
		J	1929	1.02	10	1.30	0.56
		A	1057	2.75	11	1.79	0.75
		S	1930	5.03	9	1.20	0.54
		O	1028	2.68	9	1.68	0.76
		N	1230	3.20	11	1.36	0.57

Table 13. Benthic taxa dominant in Islas Slough, Smith River estuary, California, May to November 2000 and March to November 2001.

Station 1	Percent
Oligochaetes	30
Gnorimosphaeroma insulare	22
Corophium sp.	18
Corophium spinicorne	15
Eogammarus confericolus	7
Neanthes limnicola	3
Ostracods	2
Corophium salmonis	2
Total	99

Station 2	Percent
Gnorimosphaeroma insulare	24
Corophium sp.	24
Oligochaetes	24
Corophium spinicorne	13
Eogammarus confericolus	4
Chironomids	4
Ostracods	2
Corophium salmonis	1
Cordylophora caspia	1
Neanthes limnicola	1
Total	98

Station 3	Percent
Ostracods	27
Oligochaetes	21
Corophium sp.	18
Corophium spinicorne	8
Chironomids	8
Corophium salmonis	7
Gnorimosphaeroma insulare	3
Eogammarus confericolus	3
Oligochaete egg capsule	2
Neanthes limnicola	1
Total	98

Table 14. Abundance (N), density, and indices of diversity of benthic fauna in Islas Slough, Smith River estuary, California, May to November 2000 and March to November 2001.

Station	Year	Month	N	Density (individuals/cm^3)	Species Richness (S)	Shannon-Wiener Diversity Index (H')	Species Evenness (J)
1	2000	M	1625	0.86	14	1.86	0.70
		J	6747	3.58	13	1.64	0.64
		J	3734	1.98	12	1.59	0.64
		A	11437	6.06	12	1.31	0.53
		S	6345	3.36	12	1.74	0.70
		O	1916	1.02	13	1.84	0.72
		N	6761	3.58	14	1.64	0.62
	2001	M	2247	1.19	10	1.21	0.53
		A	2405	1.28	10	1.04	0.45
		M	3668	1.94	12	1.32	0.53
		J	2907	1.54	9	1.43	0.65
		J	2796	1.48	9	1.18	0.54
		A	1130	2.94	8	1.43	0.69
		S	923	2.40	11	1.77	0.74
		O	1050	2.73	14	1.63	0.62
		N	834	2.17	11	1.90	0.79

Table 14. Abundance (N), density, and indices of diversity of benthic fauna in Islas Slough, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Station	Year	Month	N	Density (individuals/cm^3)	Species Richness (S)	Shannon-Wiener Diversity Index (H')	Species Evenness (J)
2	2000	M	827	0.44	9	1.32	0.60
		J	4900	2.60	13	1.56	0.61
		J	2569	1.36	9	1.56	0.71
		A	3009	1.60	12	1.49	0.60
		S	3087	1.64	11	1.49	0.62
		O	1897	1.01	7	1.57	0.81
		N	2714	1.44	11	1.23	0.51
	2001	M	1333	0.71	10	1.27	0.55
		A	1786	0.95	8	0.58	0.28
		M	1109	0.59	10	1.29	0.56
		J	6267	3.32	15	1.35	0.50
		J	4205	2.23	12	1.56	0.63
		A	982	2.56	11	1.57	0.66
		S	479	1.25	9	1.89	0.86
		O	596	1.55	13	1.85	0.72
		N	1283	3.34	11	1.67	0.70

Table 14. Abundance (N), density, and indices of diversity of benthic fauna in Islas Slough, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Station	Year	Month	N	Density (individuals/cm^3)	Species Richness (S)	Shannon-Wiener Diversity Index (H')	Species Evenness (J)
3	2000	M	3004	1.59	12	1.64	0.66
		J	3642	1.93	10	1.75	0.76
		J	8202	4.35	19	1.89	0.64
		A	2098	1.11	12	2.03	0.82
		S	1915	1.02	15	2.16	0.80
		O	1219	0.65	13	1.73	0.68
		N	2219	1.18	12	1.87	0.75
	2001	M	2730	1.45	10	1.32	0.57
		A	1493	0.79	9	1.40	0.64
		M	1401	0.74	5	0.94	0.59
		J	3039	1.61	9	1.41	0.64
		J	4037	2.14	10	1.98	0.86
		A	385	1.00	10	1.80	0.78
		S	3225	8.40	9	0.71	0.32
		O	900	2.34	11	1.49	0.62
		N	1085	2.83	9	1.41	0.64

taxa accounted for 98% relative abundance. This total includes individual oligochaete egg capsules, whose numbers accounted for 2%. Diversity was highest in the summer of 2000 and lowest in fall 2001, corresponding to the lowest diversity in the backwaters of Tillas Slough. Evenness was highest in the summer of 2001 and lowest in the spring of 2000.

Drift Fauna

Overall, plankton samples produced a much wider diversity of taxa than did benthic core samples (Table 15). A total of 95,011 individuals of drifting fauna were identified belonging to nine phyla. Phylum Arthropoda was represented by 15 Crustacean taxa, 14 orders of Insecta, and two orders of Arachnida. Four polychaete species and oligochaetes represented Phylum Annelida. Coleoptera was the most abundant insect order found with 18 families identified, Hymenoptera included 17 families, and Diptera included 7 families. Larval fishes and fish eggs represented Phylum Chordata. Phyla with low abundances included Mollusca (Classes: Bivalvia and Gastropoda and Order:

Sacoglossa), Cnidaria (Class: Hydrozoa), Platyhelminthes (Order: Rhabdocoela), Nematoda, Granuloreticulosa (Class: Foraminifera), and Ctenophora. In both sloughs, the abundance of individuals found at each station increased with distance from the mouth.

Eight taxa made up 93% of the total abundance: Subclass: Ostracoda (26%), *G. insulare* (23%), *Corophium sp.* (17%), Class: Oligochaeta (6%), Order: Calanoida (copepod) (5%), *E. confervicolus* (5%), Family: Chironomidae (5%), *C. spinicorne*

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001.

Taxon	Individuals (N)	Relative Abundance (%)
Arthropoda		
Crustacea		
Ostracoda	24,876	26.2
Isopoda		
Gnorimosphaeroma insulare	21,852	23.0
Amphipoda		
Corophium sp.	16,160	17.0
Eogammarus confervicolus	5,072	5.3
Corophium spinicorne	4,578	4.8
Corophium salmonis	457	0.5
Hyperiidea	1	<0.1
Copepoda		
Calanoida	5,776	6.1
Cyclopoida	266	0.3
Harpacticoida	156	0.2
Cladocera		
Cladocera	170	0.2
Decapoda		

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Crangon sp.	66	0.1
Crangon franciscorum	3	<0.1
Cancridae zoea stage	2	<0.1
Unidentified Decapod zoea	2	<0.1
Unidentified shrimp	1	<0.1
Unidentified Decapod megalopa	1	<0.1
Cirripedia		
Balanus sp. cyprid	60	0.1
Balanus sp. nauplii	20	<0.1
Balanus crenatus	1	<0.1
Other Crustaceans		
Neomysis mercedis	122	0.1
Unidentified Cumacean	1	<0.1
Insecta		
Diptera		
Chironomidae larva	5,004	5.3
Chironomidae pupa	312	0.3
Chironomidae adult	233	0.2

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Ephydridae larva	134	0.1
Ephydridae adult	55	0.1
Ephydridae pupa	7	<0.1
Ceratopogonidae pupa	11	<0.1
Ceratopogonidae adult	4	<0.1
Unidentified Diptera adult	6	<0.1
Simulidae	1	<0.1
Phoridae	1	<0.1
Tipulidae	1	<0.1
Dryomyzidae	1	<0.1
Unidentified Diptera pupa	1	<0.1
Hemiptera		
Corixidae	484	0.5
Hemiptera	3	<0.1
Gerridae	3	<0.1
Saldidae	2	<0.1
Ephemeroptera		

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Baetidae	203	0.2
Unidentified Ephemeroptera	1	<0.1
Homoptera		
Aphididae	180	0.2
Cicadellidae	6	<0.1
Homoptera	5	<0.1
Delphacidae	1	<0.1
Cercopidae	1	<0.1
Odonata		
Unidentified Zygoptera	97	0.1
Gomphidae	9	<0.1
Collembola		
Unidentified Collembola	44	<0.1
Sminthuridae	5	<0.1
Hymenoptera		
Eucoilidae	29	<0.1
Braconidae	28	<0.1

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Scelionidae	21	<0.1
Ichneumonidae	15	<0.1
Megaspilidae	9	<0.1
Mymaridae	8	<0.1
Cynipidae	5	<0.1
Ceraphronidae	4	<0.1
Encyrtidae	3	<0.1
Torymidae	3	<0.1
Tetracampidae	3	<0.1
Cimbicidae	2	<0.1
Pteromalidae	1	<0.1
Eurytomidae	1	<0.1
Eulophidae	1	<0.1
Diapriidae	1	<0.1
Formicidae	1	<0.1
Unidentified Hymenoptera	16	<0.1
Coleoptera		
Staphylinidae	29	<0.1

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Hydrophilidae	24	<0.1
Lathridiidae	7	<0.1
Elmidae	7	<0.1
Dytiscidae	4	<0.1
Ptiliidae	3	<0.1
Salpingidae	2	<0.1
Histeridae	2	<0.1
Pselaphidae	1	<0.1
Helophoridae	1	<0.1
Curculionidae	1	<0.1
Hydroscaphidae	1	<0.1
Elateridae	1	<0.1
Coccinellidae	1	<0.1
Scarabaeidae	1	<0.1
Carabidae	1	<0.1
Monotomidae (=Rhizophagidae)	1	<0.1
Other Insects		
Thysanoptera-Thripidae	18	<0.1

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Psocoptera	6	<0.1
Anoplura	3	<0.1
Mallophaga	2	<0.1
Lepidoptera larva	1	<0.1
Orthoptera	1	<0.1
Unidentified insects	12	<0.1
Arachnida		
Acarina	294	0.3
Araneae eggs	198	0.2
Araneae	55	0.1
Annelida		
Clitellata		
Oligochaeta	5,834	6.1
Oligochaete egg case	29	<0.1
Polychaeta		
Neanthes limnicola	220	0.2
Syllidae	2	<0.1

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Capitella capitata	1	<0.1
Chordata		
Gasterosteidae		
Gasterosteus aculeatus	409	0.4
Cottidae		
Unidentified Cottids	8	<0.1
Cottus asper	4	<0.1
Leptocottus armatus	2	<0.1
Cottid eggs	1	<0.1
Atherinidae		
Atherinidae eggs	1	<0.1
Unidentified fish		
Fish eggs	30	<0.1
Fish	5	<0.1
Cnidaria		
Hydrozoa		

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Cordylophora caspia	726	0.8
Hydrozoa medusa	10	<0.1
Other Cnidarians	3	<0.1
Platyhelminthes		
Turbellaria		
Rhabdocoela	335	0.4
Mollusca		
Gastrpoda		
Unidentified Gastropods	44	<0.1
Hermaeidae	1	<0.1
Bivalvia		
Mytilus sp.	6	<0.1
Ctenophora	13	<0.1
Granuloreticulosa		

Table 15. Drift fauna captured using a plankton net in Tillas and Islas Sloughs, Smith River estuary, California, May to November 2000 and March to November 2001 (continued).

Taxon	Individuals (N)	Relative Abundance (%)
Foramenifera	15	<0.1
Nematoda	23	<0.1
Unidentified Phylum		
Unidentified eggs	3	<0.1
TOTAL INDIVIDUALS	95,011	100

(5%), and *Cordylophora caspia* (hydroid) (1%). Seventeen taxa represented 4% of the total, and an additional 96 taxa were found only rarely.

In Tillas Slough, the dominant taxa varied between stations (Table 16). *Gnorimosphaeroma insulare* and *Corophium sp.* dominated station 1 (34% and 32%, respectively), *Corophium sp*. dominated station 2 (35%), and larva and pupa stages of the insect family Chironomidae dominated station 3 (29%). In Islas Slough, *G. insulare* very strongly dominated stations 1 and 2 (76% and 55%), and ostracods were dominant in station 3 (50%) (Table 17).

Table 16. Drift taxa dominant in Tillas Slough, Smith River estuary, California, May to November 2000 and March to November 2001.

Station 1	Percent
Gnorimosphaeroma insulare	34
Corophium sp.	32
Corophium spinicorne	9
Eogammarus confericolus	9
Cordylophora caspia	3
Oligochaetes	2
Spider egg sacs	2
Ostracods	1
Rhabdocoela	1
Total	93

Station 2	Percent
Corophium sp.	35
Eogammarus confericolus	18
Gnorimosphaeroma insulare	17
Corophium spinicorne	13
Oligochaetes	5
Ostracods	4
Rhabdocoela	2
Chironomids	1
Total	95

Station 3	Percent
Chironomids	29
Corophium sp.	15
Ostracods	12
Oligochaetes	9
Calanoid copepods	8
Gnorimosphaeroma insulare	5
Corophium spinicorne	4
Eogammarus confericolus	3
Corixids	2
Cyclopoid copepods	2
Baetid mayflies	1
Cordylophora caspia	1
Gasterosteus aculeatus	1
Neomysis mercedis	1
Total	93

Table 17. Drift taxa dominant in Islas Slough, Smith River estuary, California, May to November 2000 and March to November 2001.

Station 1	Percent
Gnorimosphaeroma insulare	76
Ostracods	10
Corophium sp.	4
Eogammarus confericolus	2
Corophium spinicorne	1
Oligochaetes	1
Calanoid copepods	1
Total	95

Station 2	Percent
Gnorimosphaeroma insulare	55
Calanoid copepods	19
Ostracods	8
Corophium sp.	5
Eogammarus confericolus	4
Oligochaetes	2
Corophium spinicorne	2
Total	95

Station 3	Percent
Ostracods	50
Corophium sp.	21
Oligochaetes	8
Corophium spinicorne	5
Eogammarus confericolus	4
Gnorimosphaeroma insulare	4
Calanoid copepods	2
Chironomids	2
Total	96

DISCUSSION

Tillas and Islas Sloughs experience regular tidal influx and are productive, dynamic systems distinct from the main channel of the Smith River estuary. They provide permanent habitat for several resident fish species, and provide feeding, spawning, and migratory grounds for temporary residents.

A comparison of water temperatures between sloughs and between years revealed very little difference. However, a wide range of both temperatures and salinities occurred throughout our sampling periods (Figure 4). Spring snowmelt from inland mountain areas contributed to high river runoff resulting in low temperatures and salinities during this season. A second temperature minimum occurred in the fall in the absence of a corresponding salinity minimum. At this time, the water was cooled as sunlight decreased during the shorter days and air temperature became colder with the changing season. The salinity maximum during fall can be attributed to low river flows typical of this time of year. From March to November, mean monthly temperatures for Crescent City, California are lowest in March and highest in August and mean monthly precipitation in Smith River, California is lowest in July and highest in November (National Oceanographic and Atmospheric Administration 1995). Salinity, unlike temperature, was slightly variable between sloughs and between years. The higher salinity of Tillas Slough reflects its closer proximity to the mouth of the estuary itself. Seasonal changes in salinity in correspondence to river discharge were also noted in Deas Slough, similar to the Smith River Sloughs, in the Fraser River estuary (Birtwell et al. 1987).

The amount of dissolved oxygen in water is inversely proportional to temperature and salinity (Landau 1992). Although temperature and dissolved oxygen minima and maxima did not always correspond perfectly, a general increasing trend in dissolved oxygen was observed in both sloughs, and both years, in conjunction with a decreasing trend in temperature (Figure 4). The backwater areas of both sloughs (Station 3) yielded the lowest dissolved oxygen levels, most likely due to a deeper, more stagnant habitat not susceptible to flushing. This is consistent with the upper Deas Slough area, which displayed low dissolved oxygen levels reportedly for these reasons (Birtwell et al. 1987). Furthermore, the backwater areas of the sloughs were unique in that the bottom substrate consisted of mud and organic material, likely producing a greater biological oxygen demand.

The sloughs were found to have nutrient concentrations higher than historical levels and comparable to those in other studies reporting poor water quality. The range of nitrate concentration in the sloughs (Figure 5) was higher than the range reported by the USGS in the Smith River at Crescent City from 1952 to 1960, 0.0-1.5 mg/l (n=18) (United States Geological Survey 2001). In this study, peak nitrate levels were observed early in the sampling season or closer to the end of the sampling season. Because increased freshwater runoff enhances nitrate levels in estuaries (Day et al. 1989), peaks occurring early in the season can be attributed to late rain from the previous winter, and peaks occurring at the end of the season can be attributed to early fall rains. Similarly, the sloughs experienced a higher range of phosphate concentration (Figure 5) compared to the range reported at Crescent City from 1974 to 1982, 0.0-0.09 mg/l (n=6) (United

States Geological Survey 2001). An unusual peak in phosphate was observed in Islas Slough in April 2001. Normally, phosphates are adsorbed to estuarine silt (Day et al. 1989), and therefore will reflect a low concentration in water sample analyses. Elevated phosphate levels the month prior to the peak level may have lessened the affinity of the slough substrate to act as a sink for phosphate ions, although this would require silt to be limiting in the environment. Ammonia concentration in the sloughs (Figure 5) as well, displayed a range higher than that reported at Crescent City from 1979 to 1980, 0.0-0.11 mg/l (n=19) (United States Geological Survey, 2001). Measured nutrient values were compared to those in the nutrient-enriched Sta. Rita River estuary in the Philippines impacted by fishpond effluents (Galope-Bacaltos et al. 1999). The average nutrient levels reported for the Sta. Rita River estuary were 0.19 mg/l for nitrate, 0.12 mg/l for phosphate, and 0.24 mg/l for ammonia. Another nutrient-enriched estuary, Kyeonggi Bay of the Yellow Sea in Korea has experienced water quality deterioration due to wetlands loss by reclamation and sewage discharge (Park and Park 2000). The reported mean nutrient concentrations in Kyeonggi Bay were 1.20-1.95 mg/l for nitrate, 0.07-0.10 mg/l for phosphate, and 0.24-0.58 mg/l for ammonia. The mean nitrate and phosphate levels in Tillas and Islas Sloughs exceeded those values in all months and the ammonia concentration fell within the range for Kyeonggi Bay in 5 of the 26 months sampled. Furthermore, nitrate and phosphate levels in the sloughs exceeded the mean levels of nitrate (0.97 mg/l) and phosphate (0.06 mg/l) from three selected sites in the San Joaquin Valley, California impacted by agriculture with the application of fertilizer and production of manure (Kratzer and Shelton 1998). Elevated nutrient levels were probably a result of fertilizer and cattle waste runoff from adjacent fields and pastures. The loss of habitat and cattle ranching in Tillas Slough upslough of the dike road may be the cause for the higher enrichment as compared to Islas Slough. Evidence of this could be observed in spring and early summer 2000 when nitrates and phosphates peaked in Tillas Slough, but were not elevated in Islas Slough. Higher nutrient levels in Tillas Slough corresponded to a peak in grass cover that was not seen in Islas Slough. In addition, a minimum in diversity of benthic fauna at Station 2 in Tillas Slough corresponded to the elevated nutrient levels in 2000. Ammonia levels in Tillas Slough showed a slight increasing trend during periods of decreasing or low grass cover possibly as a result of mass decomposition of plant biomass generating the ammonia byproduct.

A comparison of grass cover with that of algal cover reveals a clear inverse relationship between the two (Figure 6). In both sloughs and both years, it appears that maximum algal cover occurred following peak grass cover. Algae appeared to emerge quickly only when the grass died off. Thus, vascular plants may have had a competitive advantage over algae in this habitat. The weaker relationship observed in Islas Slough in 2001 is probably due to filamentous diatoms growing excessively on the substrate and as epiphytes on the grasses that year. The vast abundance of diatoms may also explain the abundant population of *Atherinops affinis* noted during the peak algal period in Islas Slough in 2001, as their diet consists primarily of *Melosira sp.* diatoms (Moyle 1976).

Fish and invertebrate populations of Tillas and Islas Sloughs were dominated by only a few species found in great abundance (Tables 7, 8, 12, and 14). This is typical, as the sloughs, like estuaries in general, are physically controlled habitats where environmental parameters fluctuate and organisms are exposed to physiological stress. Diversity is low because few species are adapted to the harsh nature of this environment, but those species gain an advantage and are highly productive. As juvenile fish tend to have a greater degree of tolerance for salinity fluctuations, are more vulnerable to predation, and require a rich prey base for high growth rates, the role of estuaries as spawning and nursery grounds leads to higher productivity. In particular, sheltered sloughs, marsh habitats, and side channels with vegetated shorelines serve as ideal nursery areas (Deegan et al. 2000).

Of the 26 fish species found in the sloughs, only about one-third (approximately the top nine most abundant species) depend on this habitat during some stage of their life either as permanent residents, marine transients, or anadromous migrators. Based on length-frequency histograms of these species (Figure 10), information regarding the life history stage of slough dependency can be inferred. Permanent residents of the sloughs include staghorn and prickly sculpins and the saddleback gunnel. The threespine stickleback may be a permanent resident of the sloughs as well; however, this conclusion should be considered tentative as this species is usually classified as anadromous (Miller and Lea 1972, Moyle 1976, Eschmeyer et al. 1983). In this study, few males in spawning color were observed, and larval fish were not found in significant numbers in plankton tows. It should also be noted that the choice of sampling gear might bias residency conclusions as the fyke nets captured fish as they were moving out of the channel. Any fish that typically would not migrate with the tide, such as pipefish and gobies, were observed only rarely or not at all. Marine transients are the most common fishes in Tillas and Islas Sloughs, and are estuarine dependent only part of the year (Deegan et al. 2000). Those transient species that display a bimodal distribution (threespine stickleback, shiner surfperch and osmerid smelts) apparently first use the sloughs as a nursery area, inhabit the ocean as they mature, and then return to the sloughs to spawn as adults. Species that display a trimodal distribution (Pacific herring and topsmelt) are apparently doing the same, however, these two species grow to larger standard length and probably spawn at two different age classes. Fronk (1969) observed three age classes of topsmelt in Newport Bay, California. Horn (1980) observed trimodal size distributions in topsmelt and shiner surfperch and in Morro Bay, California. These were attributed to the temporary presence of spawning adults and the subsequent appearance juvenile fish as the spawning grounds became nursery grounds. Thus, the shiner surfperch population in Morro Bay displayed stronger reproductive success as adults as two age classes were observed, while only one adult age class was observed in Smith River sloughs. The anadromous Chinook salmon displayed a narrow range of lengths at a high frequency because they are simply migrating through the estuary at a very specific life history stage. The remaining two-thirds of the fish species found in the sloughs probably utilize the estuary main channel, and occasionally use the sloughs as refuge from high flows when they are small. Rare marine transients were captured probably due to the proximities of the sloughs to the mouth of the estuary.

Of the nine most numerous fish species found in the sloughs, only two species, the prickly sculpin and the Pacific herring were more abundant in 2000 than in 2001, and one species, the surfsmelt, was nearly equally abundant in both years (Figure 8). The other six species were more abundant in 2001. Rainfall and river discharge was greater in 2000 than 2001. This is not consistent with a wet/dry year comparison of fish abundance in the San Francisco Bay estuary where many of the same species were more abundant in the wet year (Armor and Herrgesell 1985). It may be that the lower river discharge in 2001 resulted in bay water reaching further up the channel. This provided an opportunity for more marine transients to enter the estuary. This theory is reasonable given that the species that showed the greatest success in the sloughs in the year with higher river discharge was a freshwater-tolerant species, the prickly sculpin.

The Shannon-Wiener index describes species diversity while taking into account rarely collected species, and the Simpson's Index detects dominance among species. A comparison between the Shannon-Wiener diversity and species richness illustrates aspects of the fish community structure (Figure 9). Generally, high diversity corresponds to a high number of species (species richness). However, the Shannon-Wiener index will reveal a low diversity even though species richness may be elevated by a number of rarely collected species. Thus, a significant disparity between species richness and the Shannon-Wiener diversity will reflect a high degree of dominance, as illustrated by the Simpson's Index. In Tillas and Islas Sloughs, these indices are powerful tools for describing fish community structure given that the majority of the species collected were found at 0.1% or less relative abundance and that the threespine stickleback and staghorn sculpin together made up 82% relative abundance (Table 6). Species richness and diversity was greater in Tillas Slough than in Islas Slough (Tables 7 and 8). The average diversity of the fish community of the Smith River estuary sloughs ranged from 0.01 to 1.86. This was greater than that of Colorado Lagoon, California, an urban-impacted system with no riparian vegetation, having a Shannon-Wiener diversity range of 0.03 to 1.11 (Allen and Horn 1975). Tillas Slough is 1 km downstream of Islas Slough, so it received more marine transients. Therefore, it is reasonable to conclude that proximity to the mouth of an estuary reflects species diversity. This was found to be the case in Elkhorn Slough, California, where species richness was highest near the mouth of the slough (Yoklavich et al. 1991). In fact, those species found in Tillas Slough but not in Islas Slough, including larval osmerids, larval atherinids, bay pipefish (*Syngnathus leptorhynchus*), sharpnose sculpin (*Clinocottus acuticeps*), jacksmelt (*Atherinopsis californiensis*), striped surfperch (*Embiotoca lateralis*), and sand sole (*Psettichthys melanostictus*) indicate that Tillas Slough is more accessible to the ocean for rearing of larval smelts and for non-dependent marine species. Of the two species found in Islas Slough but not in Tillas Slough, coho salmon (*O. kisutch*) and speckled sanddab (*Citharichthys stigmeus*), only the sanddab originated from the marine environment. The low diversity in the fall suggests that occasional transients are least likely to be present in the sloughs during this season.

Conversely, the Simpson's Index revealed that Islas Slough displayed a greater degree of species dominance. It is reasonable that a community with lower diversity would be more strongly dominated by a single species. In 10 of the 16 months sampled, threespine stickleback dominated, displaying overwhelming dominance in October 2000 (SI'=0.98) and November 2001 (SI'=1.00). Of note is that the great abundance of threespine stickleback in Islas Slough explains why the total fish catch abundance for Islas Slough was 75% higher than that for Tillas Slough. In four months, staghorn sculpin dominated, and the month of September displayed dominance by prickly sculpin in 2000 and by shiner surfperch in 2001.

Multiple regressions of environmental parameters with fish abundance revealed varying degrees of dependence of the different species upon the physical and chemical environment. The standardized coefficients in Table 9 can be examined to determine the relative importance of each parameter in explaining the variability in abundance. Of the nine fish species analyzed, six were shown to have significant correlations with environmental parameters while three had low correlations. Temperature and salinity describe much of the variation in estuarine fish abundance (Kennish 1990). However, temperature and salinity appeared to be of primary importance to only two species, staghorn sculpin and saddleback gunnel. Phosphate and nitrate are correlated with the abundance of Pacific herring, and appeared to have a negative affect; fish abundance was low when nutrient levels were high. The direct effects of nutrients on Clupeid fishes remain in question. Grass and algae cover appear to have the greatest effect on shiner surfperch and topsmelt. The shiner surfperch is known to aggregate in shallow backwaters around seagrass beds and other structure (Eschmeyer et al. 1983). The topsmelt's diet is made up of algae, namely the diatom *Melosira sp.* and the chlorophyte *Enteromorpha sp.* (Moyle 1976). These explain the high correlation with algae cover. Dissolved oxygen concentration was the primary determinant of Chinook salmon abundance. Although anadromous salmonids tolerate physiological stress as they move through the dynamic conditions of the estuary, they still rely on well-oxygenated water. Anoxic conditions in estuaries are detrimental to salmonid survival (Birtwell et al. 1983).

Classical models primarily use abiotic factors to explain habitat selection by fish; however, recent models take into account biotic factors (Craig and Crowder 2000). Food resources and refuge from predators are now given equal consideration with abiotic factors as having primary importance in marsh habitat selection by fish. Other factors are bioenergetics and competition. Of particular interest in Tillas and Islas Sloughs is competition by the staghorn sculpin. Staghorn sculpin are clearly a dominant species, not only in numerical abundance, but also in relation to the population structure of other species. The population of the staghorn in the sloughs peaked in June and July, when abundance of all other species was relatively low. As the staghorn population diminished, other species began to increase in number. Shiner surfperch, surfsmelt, prickly sculpin, Pacific herring, topsmelt, and stickleback peak abundances occurred later, and simultaneously in some species, indicating an inability to successfully dominate the fish community as the staghorn sculpin appeared to do.

Although the lower reach of the Smith River estuary has been hypothesized to serve only as a migration corridor for anadromous salmonids (Zajanc 2003), salmonid use of the slough channels may have been overlooked in this hypothesis. Significant numbers of Chinook salmon were found in the sloughs, which extend away from the main channel, necessitating contranatant movement by the fish away from the migratory corridor and into a backwater environment. Distinct peaks of juvenile Chinook salmon numbers indicate that the salmon were utilizing the sloughs in May in 2000 and June in

2001. The salmon were likely utilizing the sloughs for a short time in a last attempt to feed and seek refuge in the estuary before entering the ocean. Because our sampling did not commence until the end of May 2000, fishes were sampled only once in this month, while in June 2001 the usual protocol of two sampling events were carried out. Thus, 2001 produced a higher yield than 2000, as the salmon may have been using the sloughs in May 2000 prior to the sampling season. Other explanations as to why 2001 showed an increase in Chinook salmon catch by nearly an order of magnitude are speculative. Lower river discharge in 2001 may have allowed more fish to swim against the flow in the main channel and enter the sloughs. Also, the ocean foraging success or reproductive health of the 2001 adult spawning population may have been improved in comparison to preceding years. Finally, since the juvenile Chinook salmon population in the sloughs appeared to be dependent upon dissolved oxygen concentration, possible improved water quality may also explain the increase.

It is important to note that the sampling events that yielded the highest numbers of Chinook salmon, however unplanned, took place prior to the first hatchery release of juvenile Chinook by the Rowdy Creek Fish Hatchery (Smith 2003, personal communication). In 2000, 72,250 fingerling and yearling Chinook were released on May 28 and in 2001, 150,799 were released on June 14. Therefore, it can be concluded that during the peak of habitat use of the sloughs by juvenile Chinook salmon, all of the fish were of natural origin. No marked peaks in Chinook catch were observed in any month after the peak months even though a total of 287,692 and 302,740 hatchery Chinook were released in 2000 and 2001, respectively. It can be suggested from this that hatchery

Chinook salmon utilize the sloughs only minimally or not at all in a rapid migration to the ocean. In the Cowichan River, British Columbia, hatchery Chinook salmon were residing in the estuary within only one week of release from the hatchery (Nagtegaal et al. 1999). Peak captures of hatchery-released spring Chinook salmon in Coos Bay, Oregon, occurred within 10 days of release indicating a short residence time (Fisher and Pearcy 1990).

The benthic community of the sloughs, comprised largely of invertebrates, is not as easily described as the fish community. Although estuarine fishes may be classified by life history criteria (McHugh 1967) or habitat selectivity criteria (Craig and Crowder 2000), benthic assemblages have no such classification schemes. Furthermore, the benthic community changes very slowly (Day et al. 1989) in comparison to assemblages of the more mobile fishes. However, an analysis of the invertebrate community can reveal more direct information about trophic ecology and productivity.

In this study, unusual extremes in benthic faunal density can be attributed to extremes of various biotic factors such as predation by fish, competition, habitat selection, and reproductive behavior by benthic invertebrates in the sloughs. An extremely low density of individuals was found at Station 1 in Tillas Slough in October 2000. The month of October in 2000 also produced unusually high numbers of fish including stickleback, surfsmelt, Pacific herring, and topsmelt as well as the peak abundance of saddleback gunnels in Tillas Slough (Figure 8). The high fish production by many species at this time and place may explain the depletion of benthic invertebrates. This mass exploitation, in turn, may explain the subsequent drastic decrease in numbers of these fish species in the following month. Earlier that year, July reflected an extremely high density of benthic fauna at Tillas Slough, Station 2. Throughout the study period from May 2000 to November 2001, this station was observed to have a gradually increasing population of the amphipod *Corophium spinicorne* densely compacted together in tube dwellings within the sandy substrate. In addition, particularly high densities of benthic fauna were present in the muddy-bottom backwaters (Station 3) of both sloughs in September 2001. These dense benthic assemblages were made up of an extreme abundance of ostracods. High densities of amphipods and ostracods reflected large numbers of juveniles inhabiting a small amount of space at this time and probably mark the reproductive peak of these species in their respective habitats and substrates. Finally, a notable peak in benthic fauna also occurred in Islas Slough at Station 1 in August 2000. This was due to high numbers of the isopod *Gnorimosphaeroma insulare*. Excessive grass cover characterized this station, especially during this time of year, and throughout the study, *G. insulare* was clearly found to be associated with grass bed habitat.

As with the fish, the benthic population was dominated by a very few species of invertebrates (Tables 10, 12, and 14). Multiple regressions of environmental parameters with benthic fauna revealed no significant relationships, perhaps because these organisms are very tolerant to the harsh conditions of a dynamic estuarine ecosystem (Robert and Matta 1984). This conclusion supports the pattern of high productivity and low diversity of organisms in estuarine conditions. The few species of organisms that dominate the benthic assemblage are highly adaptive and are not significantly affected by changes in environmental parameters. Although the diversity of benthic fauna did not change a great deal with time and the diversity between the two sloughs reflected little difference, the backwater environments of both sloughs were more diverse than the stations closer to the main channel. In such backwater habitats, McCabe et al. (1997) attributes a higher standing crop of benthic invertebrates to diminished river flow velocity. Further, it appears that increased diversity in the backwaters of sloughs may be attributable to diminished flushing conditions and the stability of the substrate (Méndez 2002). Further, the backwater habitat of Tillas Slough consistently supported high grass production which probably increased niche accessibility.

Clearly, tube-dwelling amphipods, *Corophium sp.*, in Tillas Slough and oligochaete worms in Islas Slough occurred in the greatest abundance. Tillas Slough was characterized by sand and mud with few larger substrates mixed in, a habitat ideal for *C. spinicorne* and *C. salmonis* (Rudy and Rudy 1983). In comparison, Islas Slough had a higher incidence of cobble-sized substrate. The summer decomposition of vascular plants in Islas Slough may have resulted in the emergence of low oxygen tolerant organisms, especially oligochaetes (McLusky 1989). The assortment of species collected only rarely most likely originated from passive transport into the sloughs from the marine or terrestrial environment (Robert and Matta 1984).

Overall, more individuals were found in Tillas Slough (61%) than in Islas Slough (39%), and more were found in 2000 (63%) than in 2001 (37%). A possible explanation for this is that benthic invertebrate abundance was lowest when fish abundance was highest. The greater numbers of fish in Islas Slough and the higher fish yields in 2001 resulted in a greater exploitation of prey. Past studies of fish that dominate sloughs reveal that the diets are made up mainly of those invertebrates, benthic and neustonic, commonly found in Tillas and Islas Sloughs. Threespine stickleback prey upon *Corophium sp.*, ostracods, copepods, insect larvae, and annelids (Manzer 1976, Wolf et al. 1983, Birtwell et al. 1984). Staghorn sculpin prey upon *Corophium sp.*, *Eogammarus confervicolus*, *Neanthes sp.*, and *Crangon sp.* (Jones 1962, Wolf et al. 1983, Birtwell et al. 1984). In addition, shiner surfperch feed on gammarid amphipods, polychaetes, isopods, and insects (Odenweller 1975, Birtwell et al. 1984), Pacific herring feed on crustaceans, and sufsmelt feed on zooplankton (Emmett et al. 1991). Finally, larval and adult insects have been reported to be the primary prey of Chinook salmon (Healey 1982, Shreffler et al. 1992, Quiñones 2003) along with decapods, mysids, amphipods, and copepods (Healey 1982). In Elkhorn Slough, California, Barry et al. (1996) found that the diets of fishes reflected patterns in prey abundance and that the benthic prey availability likely influenced the local fish distribution and abundance. In addition, environmental factors were, in fact, found to regulate the diversity and abundance of prey resources for both fish and invertebrates.

A sudden emergence of the polychaete annelid *Capitella capitata* occurred in the fall of 2000 (Table 10), the season during which this species was most abundant in a salt marsh habitat on Smith Island, Virginia (Robert and Matta 1984). The worms were found at Station 3 in Tillas Slough, which is characterized by a muddy substrate. The rapid emergence and subsequent disappearance of worms is characteristic of the opportunistic behavior displayed by organisms tolerant to extreme conditions. In particular, *C. capitata* has been found to colonize organically enriched soft-bottom sediments in areas subjected to pollution (Pearson and Rosenberg 1978, Holte and Oug 1996, Cardell et al 1999, and Méndez 2002). Tillas Slough was more highly enriched with nutrients than Islas Slough, and the year 2000 was more highly enriched than the year 2001. Although no statistical correlation was found regarding the *C. capitata* population sampled in the sloughs with the nutrient concentrations, an assessment of organic enrichment, such as sediment oxygen demand (SOD), of the sloughs may reveal that other pollutants contributed to the rise of this species.

Samples of drifting fauna also revealed a community dominated by a very few species, but they did include a diverse collection of infrequent, passive drifters of terrestrial and marine origin. Based on the relative abundance of the dominant taxa in each slough, Islas Slough appeared to be more strongly dominated by a single species. The isopod, *G. insulare* constituted over half of the individuals sampled in two of the stations. The higher abundance of grasses growing in Islas Slough can explain this dominance as the isopod was commonly associated with grass beds. The diversity of drifting fauna in Tillas Slough was clearly higher as none of the stations were strongly dominated by a single species. The relatively large terrestrial constituent of the drifting taxa, consisting mainly of adult insects and spiders, probably inhabited sedge along the shores and were dislodged by the incoming tide. Although high numbers of taxa of terrestrial origin were found in the sloughs, the number of individuals made up only around 0.6% of the total abundance of organisms. Still, juvenile Chinook salmon feeding in the Smith River estuary are shown to prefer insects over amphipods and isopods, even when insects are uncommon, because they are hypothesized as having a higher nutritional value (Quiñones 2003). Furthermore, terrestrial insects, including adult dipterans, hymenopterans, and coleopterans, made up 60% of the identifiable prey of Atlantic salmon post-smolts sampled in nearshore habitats of the Northern Baltic Sea (Salminen et al. 2001), and comprised about 70% of the diet of white-spotted charr sampled above an impassable dam on a tributary of the Ken-Ichi River in Japan (Morita and Suzuki 1999). Thus, these terrestrial insects may be a significant source of food for predatory slough fishes such as the sculpins, stickleback, and shiner surfperch as well as Chinook salmon.

Tillas and Islas Sloughs of the Smith River estuary, California provide habitat for a productive fish assemblage as well as for rich benthic communities with a high density of individuals. The lack of trophic complexity characterized by a predominance of low-order consumers in the sloughs gave evidence of strong dominance by only a few species. The lack of advanced succession characterized by monotypic shoreline vegetation around the sloughs may be a consequence of channelization, habitat loss, and water quality degradation over the past 150 years. In light of recent research emphasizing the importance of marsh type habitats to juvenile anadromous salmonids as well as the dependency of resident fish and seasonal visitors on these habitats, future considerations should be made to maintain the water quality and habitat of these two sloughs and reclaim wetlands around the Smith River estuary to generate additional slough habitats.

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PERSONAL COMMUNICATIONS

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