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STRUCTURE, SAMPLING GEAR AND ENVIRONMENTAL ASSOCIATIONS, AND HISTORICAL CHANGES IN THE FISH ASSEMBLAGE OF THE SOUTHERN SACRAMENTO-SAN JOAQUIN DELTA

FREDERICK FEYRER
Aquatic Ecology Section
California Department of Water Resources
3251 S Street
Sacramento, CA 95816-7017
e-mail: ffeyrer@water.ca.gov

MICHAEL P. HEALEY
Central Valley Bay-Delta Branch
California Department of Fish and Game
4001 North Wilson Way
Stockton, CA 95205-2486

We sampled fishes at 11 fixed sites monthly from January 1993 through December 1994 in the southern Sacramento-San Joaquin Delta. Using three different sampling gears (boat electrofishing, gillnets, and hoopnets), we obtained 988 samples and collected 27,791 fishes representing 33 species. Overall, the catch was heavily dominated by alien species which represented 99% of the total number of fishes we collected. We used partial canonical correspondence analysis (pCCA) to examine the effect of gear type and environmental variables on fish assemblage structure. Gear type strongly influenced the observed assemblage structure accounting for 59% of the variation explained by pCCA. Ictalurids dominated the hoopnet catches. Ictalurids, striped bass, *Morone saxatilis*, and splittail, *Pogonichthys macrolepidotus*, dominated the gillnet catches, while centrarchids dominated the electrofishing catches. Electrofishing collected approximately 50% more species than the other two gear types, suggesting that it may be the most favorable of the three to assess presence-absence, although it apparently did not sample large mobile fishes very well. After accounting for the effect of gear type, flow and water temperature had the strongest influence on assemblage structure. The south Delta fish assemblage has changed greatly since it was first described 30 years prior to our study. Two native species have apparently been extirpated and at least eight alien species have established reproducing populations. Our results (1) suggest that, depending upon the goals of the study, the use of a single sampling gear may provide a biased assessment of the south Delta fish assemblage and (2) corroborate the hypothesis that highly altered habitats are vulnerable to the invasion and establishment of alien species.

INTRODUCTION

Fish assemblages are increasingly being used as indicators of perturbation in aquatic ecosystems in California's Central Valley (Brown and Moyle 1993, Brown 2000, Moyle 2002, May and Brown 2002). The findings of recent studies suggest that water management practices have significant effects on fish assemblages in that highly disturbed habitats typically are dominated by alien species (Saiki 1984, Brown 2000, Saiki et al. 2001, May and Brown 2002). The point of drainage for California's Central Valley is the Sacramento-San Joaquin Delta (Delta), a highly altered system (Nichols et al. 1986).

The Delta consists of over 1,000 km of waterways with a drainage area encompassing approximately 40% of California's surface area (Nichols et al. 1986). In any given year, up to 65% (73 x 10^8 m^3) of the Delta's natural discharge is diverted for agricultural and municipal consumption at large pumping facilities in the south Delta by the State Water Project and Central Valley Project (Nichols et al. 1986). Due to degraded physical habitat, hydrodynamics, and water quality associated with water diversion facilities and flood control projects, the south Delta is arguably the most degraded region of the San Francisco Estuary (Arthur et al. 1996).

The purpose of this paper is to provide a comprehensive assessment of the structure of the south Delta fish assemblage by examining fish monitoring data that incorporated three different sampling gears. By incorporating data from three different gear types in our analyses, we expanded upon the community analysis conducted by Feyrer and Healey (2003) who relied solely on electrofishing data. Further, we employed multivariate statistical techniques to examine the effect of gear type on fish catches, and while accounting for the effect of gear type, examine how species abundances related to environmental variables. We also compared our results of species occurrences to that of Turner and Kelley (1966) to provide a general assessment of how the south Delta fish assemblage has changed 30 years after it was first described.

STUDY SITE

We sampled fishes at 11 sites in the south Delta: 3 sites each in Old River, Middle River, Grant Line Canal, and 2 sites in the San Joaquin River (Figure 1). These waterways, referred to locally as sloughs, are approximately 1 to 5 meters in depth, tidally influenced, and are constricted within flood control levees. Rock-reinforced banks (riprap) dominate riparian habitats and non-native submerged aquatic vegetation, primarily the Brazilian waterweed, *Egeria densa*, is prevalent in the littoral zone. The primary source of freshwater for the south Delta is the San Joaquin River. Agriculture is the dominant land use activity beyond the channel levees and hundreds of small local agricultural diversion facilities are scattered within the region.

METHODS

Each site was sampled for fishes at least once per month with each gear type from

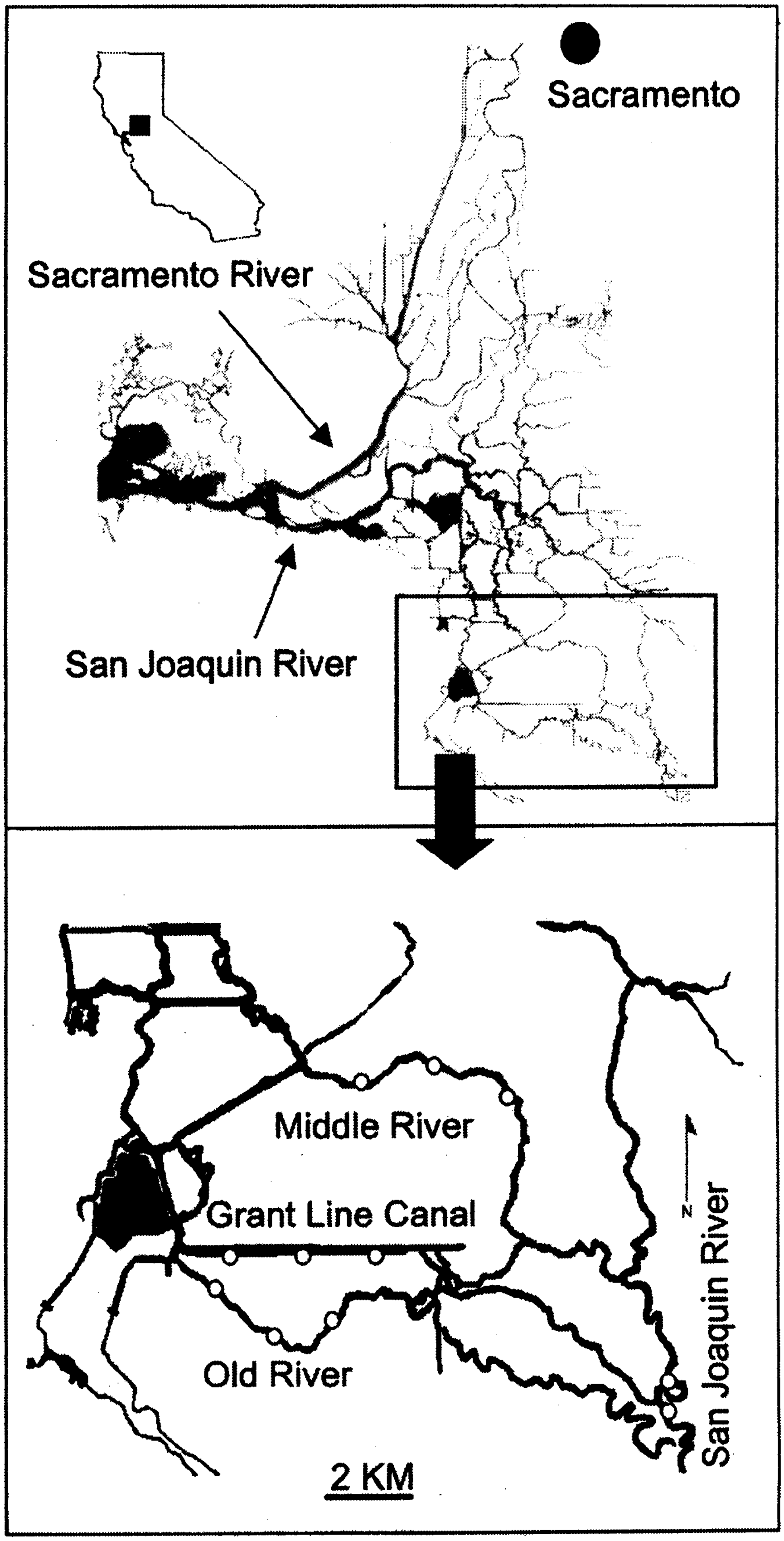

Figure 1. Fish sampling sites (open circles) in the southern Sacramento-San Joaquin Delta.

January 1993 through December 1994; 988 total samples were obtained (Table 1). To minimize potential temporal biases in the sampling, the three gear types were usually used within the same calendar week. Each sampling gear was used at each site as follows. Boat-employed pulsed AC electrofishing was conducted after dark at fixed transects set along one bank at each site. The transects were approximately 500 m in length, and to the extent possible, equal effort (shock time) was made each time an individual transect was sampled. All fishes that were collected were retained alive in tubs of water on the sampling boat until a transect was completed. Thereafter, fishes were identified to species and released. Hoopnet sampling was conducted on banks opposite or adjacent to the electrofishing transects. Two hoopnets, each measuring 5 m in length with 25 mm-stretch-mesh netting and 1-m diameter hoops, were set in-line, approximately 50-100 m apart, and parallel to the shoreline. The hoopnets were set during the day at depths ranging from 3-5 m and retrieved after 40-48 hr. Gillnet sampling was also conducted on banks opposite or adjacent to the electrofishing transects. Two monofilament gillnets, each measuring 50 m in length and 4 m in depth with 50 to 100-mm variable mesh, were set in the late afternoon and into the evening. The two gillnets were fished simultaneously in hour-long sets with one oriented parallel to shore and the other oriented perpendicular to shore. The two gillnets were normally set approximately 10-50 m apart from each other. At least two gillnet sets (two nets per set) were normally completed during each outing. As with the electrofishing, all fishes collected by hoopnet and gillnet were identified to species and released. Water temperature (°C), specific conductance (μS), and turbidity (NTU), were measured when fish samples were obtained and tidally averaged daily flow ($m^3 s^{-1}$) for each location was obtained from the California Department of Water Resources CALSIM hydrology model.

Table 1. Total number of samples by month for the period January 1993 through December 1994 in the southern Sacramento-San Joaquin Delta. E = electrofishing, G = gillnet, H = hoopnet.

	1993			1994		
Month	E	G	H	E	G	H
January	15	12	15	14	16	15
February	15	13	15	14	10	15
March	14	14	15	15	7	10
April	13	17	15	14	15	15
May	15	12	15	15	18	13
June	15	14	15	15	12	15
July	15	17	15	15	13	15
August	14	15	15	15	7	11
September	15	12	11	15	8	12
October	15	9	19	15	9	15
November	9	9	15	15	14	15
December	15	8	15	15	14	15

We used canonical correspondence analyses (CCA) to examine the effect of gear type and environmental variables on species abundances. CCA is a multivariate direct ordination technique that extracts synthetic environmental gradients that maximize niche separation within assemblages, thereby facilitating the interpretation of how species abundances relate to environmental variables (ter Braak and Verdonschot 1995). The CCAs were run with the CANOCO software program (ter Braak & Smilauer 1998) with untransformed environmental and fish relative abundance data. To reduce the influence of rare species and therefore minimize the possibility of misleading interpretations of the resulting ordination diagrams, we only included species that occurred in at least 5% of the samples for each gear type (Table 2). We conducted an

Table 2. Species, total number, and percent number (if ≥ 1%) of fishes captured by electrofishing, gillnet, and hoopnet sampling, January 1993 through December 1994 in the southern Sacramento-San Joaquin Delta. Species are listed in order of overall abundance. Asterisk indicates native species.

Species	Electrofishing No.	Gillnet No.	Hoopnet No.	Totals No.	%No.
White catfish *Ameiurus catus*	2,271[1]	864[1]	7,316[1]	10,451	38
Bluegill sunfish *Lepomis macrochirus*	5,757[1]	80[1]	348[1]	6,185	22
Redear sunfish *Lepomis microlophus*	2,902[1]	102[1]	183[1]	3,187	12
Largemouth bass *Micropterus salmoides*	2,030[1]	100[1]	5	2135	8
Golden shiner *Notemigonus crysoleucas*	1,162[1]	26[1]	3	1,191	4
Channel catfish *Ictalurus punctatus*	119[1]	90[1]	808[1]	1017	4
Striped bass *Morone saxatilis*	607[1]	255[1]	42[1]	904	3
Inland silverside *Menidia beryllina*	635[1]	0	0	635	2
Threadfin shad *Dorosoma petenense*	459[1]	1	0	403	2
Brown bullhead *Ameiurus nebulosus*	67[1]	14	322[1]	403	2
Common carp *Cyprinus carpio*	203[1]	33[1]	141[1]	377	1

Goldfish *Carassius auratus*	120[1]	4	5	129	1
Warmouth *Lepomis gulosus*	90[1]	1	1	92	
Splittail* *Pogonichthys macrolepidotus*	5	74[1]	3	82	
Tule perch* *Hysterocarpus traski*	67[1]	2	12	81	
Smallmouth bass *Micropterus dolomieui*	59[1]	2	0	61	
Sacramento sucker* *Catostomus occidentalis*	49[1]	6	1	57	
Black bullhead *Ameiurus melas*	22	3	30[1]	55	
Black crappie *Pomoxis nigromaculatus*	29[1]	6	17	52	
Yellowfin goby *Acanthogobius flavimanus*	50[1]	0	0	50	
Green sunfish *Lepomis cyanellus*	35[1]	0	0	35	
Shimofuri goby *Tridentiger bifasciatus*	34[1]	0	0	34	
Chinook salmon* *Oncorhynchus tshawytscha*	24	6	0	30	
American shad *Alosa sapidissima*	20	5	1	26	
Mosquitofish *Gambusia affinis*	19	0	0	19	
Bigscale logperch *Percina macrolepida*	12	0	0	12	
Sacramento blackfish* *Orthodon microlepidotus*	6	6	0	12	
White crappie *Pomoxis annularis*	0	0	7	7	
Sacramento pikeminnow* *Ptychocheleius grandis*	5	1	0	6	
Prickly sculpin* *Cottus asper*	2	0	0	2	

Yellow bullhead *Ameiurus natalis*	0	1	1	2
Steelhead* *Oncorhynchus mykiss*	1	0	0	1
White sturgeon* *Acipenser transmontanus*	0	0	1	1
Total species	30	23	20	33
Total no.	16,861	1,683	9,247	27,791

[1]Included in statistical analyses - occurred in at least 5% of the samples for the specified sampling gear.

initial CCA that included each of the environmental variables (gear type, month, year, site, flow, temperature, specific conductance, and turbidity) and discovered that gear type had the greatest overall influence on the observed assemblage structure. Therefore, we then conducted partial CCAs (pCCA) to partition the amount of variance (inertia) associated with gear type and the other remaining variables (Økland and Eilertsen 1994). Two pCCAs were run: the first was run with gear type as a covariable and the remaining variables as the environmental variables and the second was run with gear type as an environmental variable and the remainder as covariables. This allowed us to factor out the amount of variance explained by gear type alone, the amount of variance explained by the other environmental variables separate from gear type, and also the amount of variance jointly explained by these two groups. For all models, sampling gear, site, and month were coded as categorical variables as follows: electrofishing = 1, gillnet = 2, hoopnet = 3, San Joaquin River = 1, Middle River = 2, Old River = 3, Grant Line Canal = 4, January = 1, February = 2, etc. We used the forward selection procedure with Monte Carlo simulations (199 permutations) provided by CANOCO to constrain each of the models to only include environmental variables significant at $p < 0.05$ (ter Braak & Smilauer 1998).

RESULTS

Our sampling effort captured 27,791 fishes, primarily age-1 and above, representing 33 species (Table 2). The catch was dominated by alien species, especially by centrarchids and ictalurids, which comprised 73% of the species and 99% of the individuals collected. The most abundant native resident species were splittail, *Pogonichthys macrolepidotus*, tule perch, *Hysterocarpus traski*, and Sacramento sucker, *Catostomus occidentalis*, each of which, however, represented less than 1% of the total individuals collected (Table 1).

Results of the pCCAs indicated that gear type had the greatest influence on fish abundances, accounting for 59.1% (sum of canonical eigenvalues = 0.312) of the variance explained by CCA. The biplot of the full CCA model incorporating all variables (Figure 2) demonstrated how individual species tended be collected with certain gear types. Ictalurids and common carp, *Cyprinus carpio,* were highly associated with the hoopnet samples, while splittail and striped bass, *Morone saxatilis,* were associated with the gillnet samples, and the remaining species were mostly associated with the electrofishing samples. Variables other than sampling gear combined to account for 40.5% (sum of canonical eigenvalues = 0.214) of the variance explained by CCA. Because only 0.4% of the explained variance overlapped between the two groups (sum of canonical eigenvalues = 0.002), the pCCA with gear type as a covariable was effective

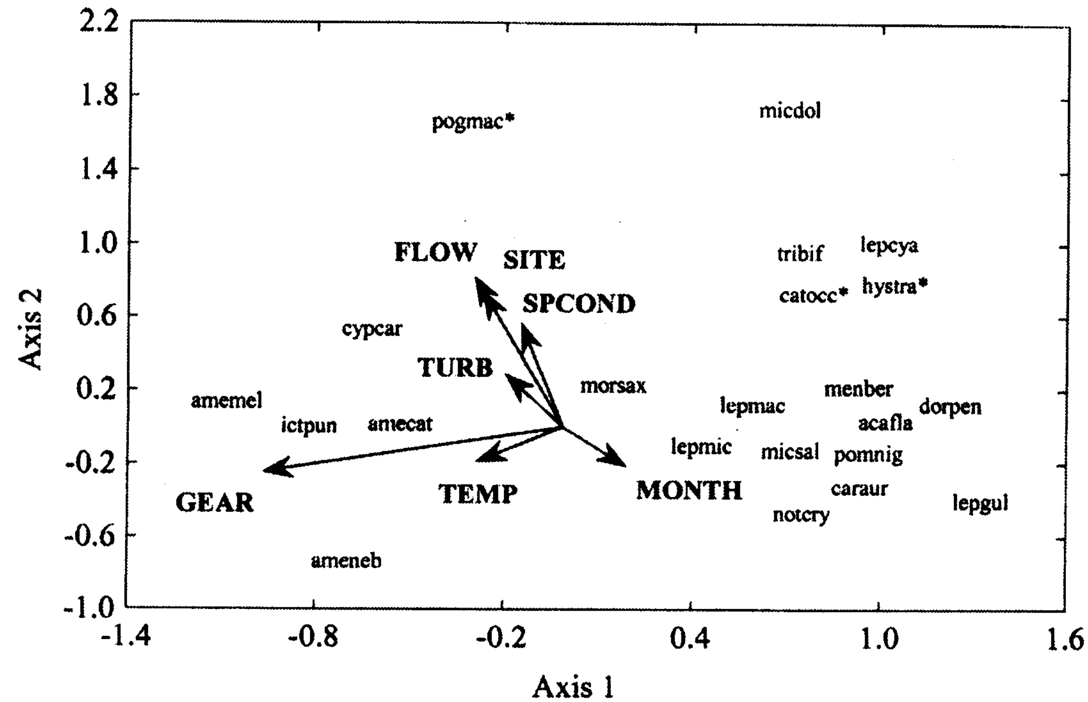

Figure 2. Biplot of the full canonical correspondance analysis model incorporating gear type. Species codes represent the first three letters of the genus and species. Asterisks indicate native species. SPCOND = specific conductance, TURB = turbidity, TEMP = temperature.

at describing how fish abundances related to environmental variables while accounting for the influence of gear type (Table 3). The biplot of this pCCA (Figure 3) demonstrated that species were distributed primarily along an environmental gradient of river flow. The most notable observation was that the native species (splittail, tule perch, and Sacramento sucker), were associated with high river flow relative to the other species. Smallmouth bass, *Micropterus dolomieiu*, green sunfish, *Lepomis cyanellus,* and shimofuri goby, *Tridentiger bifasciatus*, exhibited similar environmental associations. The majority of the remaining species were associated with either low or moderate river flow. These species then differentially clustered primarily along an environmental gradient of water temperature (Figure 3). Striped bass and channel catfish, *Ictalurus*

Table 3. Summary statistics of the partial canonical correspondance analysis run with fish relative abundance and environmental variable data with sampling gear as a covariable. Total inertia = 5.23.

Variable	Axis 1	Axis 2
Eigenvalue	0.11	0.06
Species-environment correlation	0.48	0.36
Cumulative percentage of variation		
Explained by species only	2.2	3.4
Explained by species and env. variables	50.3	77.7
Inter-set correlations with axes		
Flow	0.35	0.16
Site	0.33	0.12
Temperature	0.19	-0.32
Specific conductance	0.19	0.17
Turbidity	0.19	0.02
Month	-0.12	-0.07

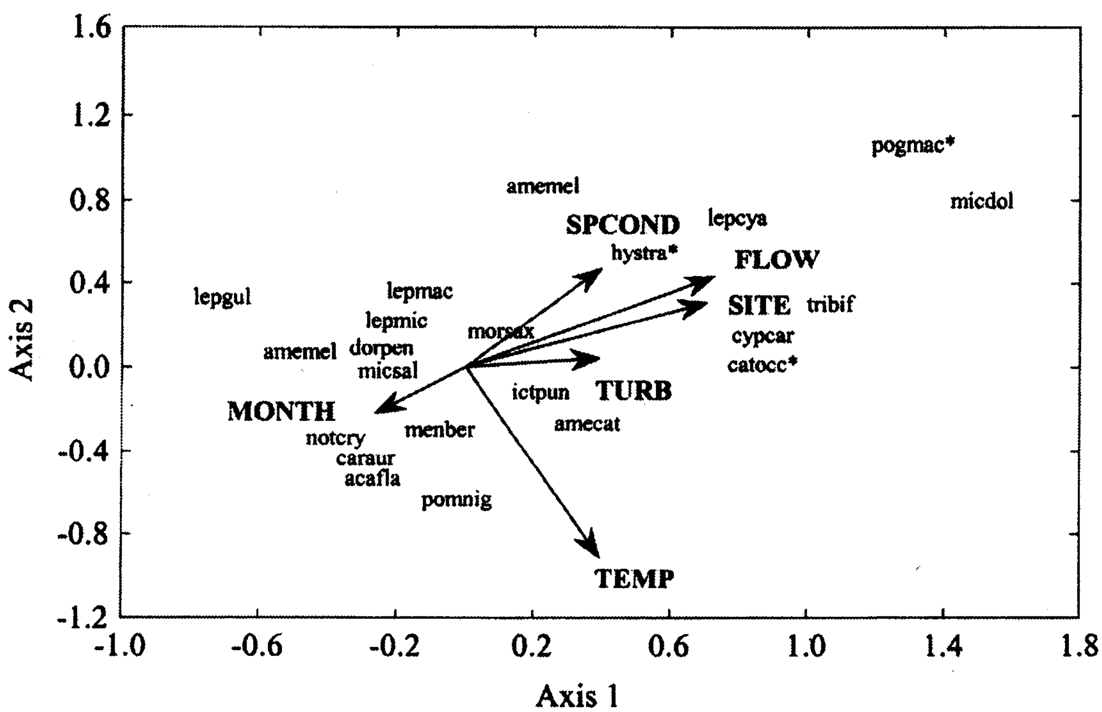

Figure 3. Biplot of the partial canonical correspondance analysis demonstrating the environmental associations of species while accounting for the effect of the three different gear types as a covariable. Species codes represent the first three letters of the genus and species. Asterisks indicate native species. SPCOND = specific conductance, TURB = turbidity, TEMP = temperature.

punctatus, had scores near the origin (Figure 3), indicating that they were relatively evenly distributed in the south Delta in space and time during the sampling period.

DISCUSSION

The south Delta fish assemblage is dominated in numbers by alien species and abundances are structured primarily along environmental gradients of river flow and water temperature. Although native fishes were collected at all locations, they represented only 27% of the species and 1% of the total number of fishes collected over the course of the study. Utilizing electrofishing data, Feyrer and Healey (2003) found that native species remained uncommon in the south Delta through 1999. Our observations of the environmental associations of native and alien species are consistent with those from other studies conducted in the Sacramento-San Joaquin Delta and adjacent areas (Brown 2000, May and Brown 2001, Matern et al. 2002, Feyrer and Healey 2003).

Sampling gear strongly influenced the observed fish assemblage structure, accounting for 59.1% of the variation explained by CCA. We found that hoopnet catches were highly dominated by ictalurids. Pugh and Schramm (1998) evaluated electrofishing and hoopnetting in the lower Mississippi River and similarly found that hoopnet samples were generally dominated by ictalurids. Gillnets were also effective at collecting ictalurids, as well as mobile fishes such as striped bass and splittail. Although electrofishing did not appear to be very effective at collecting the large mobile fishes, it did appear to provide the best overall assessment of species presence-absence as it collected approximately 50% more species than the other two gear types.

Differences in assemblage structure are a common result when incorporating different gear types (Allen 1982, Weaver et al. 1993, Fago 1998, Onorato et al. 1998) and can be attributed to many interacting factors. These include the ability of certain species to avoid or escape certain gears due to morphological and behavioral characteristics, and that the differing sampling gears are not equally effective in all habitats. For example, although each gear sampled the same general sites, they had to be deployed in slightly different microhabitats. Gillnets and hoopnets were used in open water areas generally at least 3 meters in depth. The nets could be set near potential fish cover such as downed trees or submerged aquatic vegetation but could not be set directly in such cover because the nets would foul. Electrofishing, on the other hand, could be conducted in shallow water directly within such cover. Thus, the differences in fish assemblage structure among the gear types are functions of both species-specific avoidance capabilities as well as microhabitat preferences of the fishes. Additionally, different sizes, forms, or deployment methods of the gear types we used could potentially exhibit different catch characteristics. Jackson and Bauer (2000) and Pine (2000) demonstrated that gears of smaller mesh were generally more effective at collecting smaller sized centrarchids than identical gears of larger mesh. Our observations of the strong sampling gear associations of certain species suggest that multiple sampling gears are required to provide a comprehensive inventory of fishes in the south Delta.

There have been notable changes to the south Delta Fish assemblage over the 30 years since it was first described by Turner and Kelly (1966). These changes include the apparent extirpation of two native species and the introduction and establishment of at least eight alien species. Turner and Kelley (1966) utilized gillnets, otter trawls, and midwater trawls to sample fishes in Grant Line Canal (called Fabian Canal by Turner and Kelley) and the San Joaquin River monthly from 1963 through 1964. Although there may be some bias attributable to gear selection and methodology, the intensity and duration of sampling by the two studies provides an opportunity to assess the general changes in the fish assemblage over the course of this 30-year time span. Native fishes collected in the south Delta by Turner and Kelley (1966) which were absent from our samples include hitch, *Lavinia exilicauda*, starry flounder, *Platyichthys stellatus*, and delta smelt, *Hypomesus transpacificus*. Delta smelt were not collected during our study because our sampling gear was unsuitable for capturing this small midwater species. However, sampling gear bias most likely did not contribute to the absence of hitch and starry flounder in our samples because gillnets and electrofishing have collected these species in other regions of the Delta (Baxter 1996[1], Michniuk and Silver 2002[2]). In terms of alien fishes, the shimofuri goby, *Tridentiger bifasciatus* (Matern and Fleming 1995), yellowfin goby, *Acanthogobius flavimanus* (Brittan et al. 1970), bigscale logperch, *Percina macroplepida* (Moyle et al. 1974), inland silverside, *Menidia berrylina*, (Moyle et al. 1974), redear sunfish, *Lepomis microlophus*, and smallmouth bass, *Micropterus dolomieui*, have all been introduced and have established reproducing populations since Turner and Kelley (1966). Additional likely introductions since Turner and Kelley (1966), based upon the observations of Feyrer and Healey (2003), include the fathead minnow, *Pimephales promelas* (Dill and Cordone 1997), and the red shiner, *Cyprinella lutrensis* (Jennings and Saiki 1990). Feyrer and Healey (2003) also observed western mosquitofish, *Gambusia affinis*, whereas Turner and Kelley (1966) did not. However, this was likely due to Turner and Kelley's (1966) sampling protocol as this species probably invaded the Delta long before their study (Dill and Cordone 1997). Turner and Kelley (1966) did not observe yellow bullhead, *Ameiurus natalis*, in the Delta during their study as we did, however the timing of this introduction is uncertain and may have occurred prior to Turner and Kelley (1966) (Dill and Cordone 1997). Most of these alien species introductions are related to intentional or unintentional stockings of sport or baitfish into the Delta or adjacent systems (Dill and Cordone 1997, Moyle 2002). Due to the significant habitat alterations which have occurred in the south Delta since Turner and Kelley (1966), our results provide support for the hypothesis that highly altered habitats are vulnerable to the invasion and establishment of alien species (Moyle 1986, Ross 1991).

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