Demersal Fisheries Response to the 2004 Channel Deepening Project in San Diego Bay: Supplemental Fish Sampling

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Abstract

The effects of a clamshell dredge project in San Diego Bay on demersal fish, epibenthic invertebrate, and benthic infaunal invertebrate have previously been reported on in the Demersal Fisheries Response to the 2004 Channel Deepening Project in San Diego Bay (M&A 2009). The original sampling was performed prior to the dredge project in September 2004 and following the dredge project in September 2005, 2006, and 2007. Data were analyzed with regards to biomass, density, species richness, community similarity, and infaunal community indices. Results indicated that demersal fish took between 14 and 22 months to recover. Benthic infauna recovered within 5 months relative to density and biomass, but examination of community indices indicated that full recovery of community structure may have taken 17 to 24 months. Epibenthic invertebrates recovered within 29 to 35 months in terms of density and biomass. However, the epibenthic invertebrate community composition was still changing or had achieved an alternate stable state near the end of the study.

While the results of the initial study were relatively robust with regards to studying the effects of the dredge project, there was a notable decline in fish abundance over the duration of the study. The sponsoring agencies involved with the study decided to fund an additional two years of fish sampling to determine if fish numbers were truly declining within San Diego Bay. Data were collected in September 2008 and 2009. The new data were added to the previous data set and analyzed. Results indicate that fish populations were simply variable over the temporal sampling scale employed rather than suffering from a significant decline.

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Introduction

San Diego Bay

San Diego Bay is the largest estuary south of San Francisco Bay along the southern California coastline. The bay forms a long narrow crescent that has only one point of tidal exchange with the Pacific Ocean. The bay's entrance at Point Loma is approximately 1.4 kilometers (km) (0.9 miles [mi]) wide. San Diego Bay is approximately 25 km (15 mi) long and varies from approximately 1 to 4 km (0.6 to 2.5 mi) in width. Although San Diego Bay is often classified into four eco-regions (Allen 1999), for simplicity it can be thought of as being comprised of a narrow and deep outer bay (north San Diego Bay) and a wide, shallow inner bay (south San Diego Bay).

The relatively shallow and expansive south San Diego Bay creates a warm saline environment during the summer and fall. This region supports several fish species that are more common in sub-tropical bays and lagoons located further south along the Baja Peninsula and within the Sea of Cortez. The South Bay species group overlaps somewhat with a more open coast fish assemblage inhabiting the North Bay environments. Thus, the potential exists to capture a diverse assemblage of fish and benthic invertebrate species within San Diego Bay.

Purpose

In 2004, the San Diego Unified Port District (Port) and USACE implemented the San Diego Bay Channel Deepening Project (Dredge Project). The Dredge Project consisted of dredging the central navigation channel from the aircraft turning basin to the Coronado Bay Bridge (**Figure 1**). The pre-dredge water depth was -12.5-meters (m) (-41 feet [ft]) mean lower low water (MLLW), and the project target depth was -12.8 m (-42 ft) MLLW with a 0.6 m (2 ft) overdredge allowance. Dredging occurred between October 18, 2004 and April 2, 2005, using a clamshell dredge, and removed approximately 420,505 m^3 (550,000 yd^3) of sediments from the 107-hectare (264-acre) Dredge Project footprint (hereafter referred to as the Study Site).

The Dredge Project afforded an opportunity to study the effects of a dredge event on demersal fish, epibenthic invertebrates, and benthic infauna. The results of pre-dredge and three years of post-dredge data were previously reported on in the Demersal Fisheries Response to the 2004 Channel Deepening Project on San Diego Bay (M&A 2009) and used to determine whether or not the Dredge Project significantly altered the distribution of demersal fish, epibenthic invertebrates, and benthic infauna within the Study Site. The original demersal fish dataset showed declines in fish abundance for both the Study Site and the Control Site over all sampling

Figure 1. Aerial view of the project boundary for the 2004 San Diego Bay Channel Deepening Project.

years. In response to this observation, the sponsoring agencies decided to fund an additional two years of demersal fish sampling. This document reports on the addition of the two additional sampling years to the demersal fish dataset. Specifically, this document addresses the hypothesis that demersal fish are declining in San Diego Bay.

Methods

Study Site

The Study Site followed the central navigation channel within central San Diego Bay, a 107-hectare (264-acre) area extending from the Coronado Bay Bridge to the south and the Midway Aircraft Carrier Museum to the north (**Figure 1**).

Control Site

Although the initial Project was completed, the Control Site was still sampled to retain a consistent sampling strategy and maintain a robust dataset.

The Control Site consisted of a 118-hectare (292-acre) area of the navigation channel along the northwestern shoreline of Naval Air Station North Island adjacent to Shelter Island (**Figure 1**). The Control Site was not located immediately adjacent to the Study Site because the Study Site occurs along a narrow section of central San Diego Bay that opens to wider portions of the bay at either end. Instead, this portion of north San Diego Bay with similar hydrology was chosen. The hydrology at both the Study Site and Control Site results in bottom shear forces that scour the bottom and result in substrates with greater sandy fractions relative to adjacent portions of the bay. Previous studies of hydrology, fish communities, substrate, and benthic infauna were used to support the selection of the Control Site as a relevant reference to the Study Site (Chadwick et al. 1996, SCCWRP 1998, Allen 1999).

Fish and Epibenthic Sampling

Two supplemental years of demersal fish sampling occurred in September 2008 and 2009. Sampling was conducted using a 3.2-m (10-ft) semi-balloon otter trawl with 0.8-centimeter (cm) (0.3-inch [in]) mesh in the body and 0.6-cm (0.2 in) mesh in the cod end. The otter trawl was deployed using a 22-ft (6.7-m) vessel traveling between 1.5 and 2 knots along permanently established 250-m (820 ft) transects. There were 14 replicate transects at both the Study Site and Control Site. Each replicate transect was sampled both day and night during each sampling event. Occasionally, debris items or other factors prevented the completion of the entirety of a given transect. In those cases, the biomass and density data were adjusted accordingly.

Fish were sorted and identified in the field whenever possible. The data recorded for fishes captured in each haul included species and individual counts, standard length, and weight. If greater than 100 individuals of a species were caught in a replicate of any gear type, a batch sampling procedure was used. First, the standard length and weight was determined for 30 randomly selected individuals. Then, the batch weight was determined for 100 additional randomly selected individuals. Finally, the batch weight was determined for all of the

remaining, uncounted individuals caught in the replicate. The number of uncounted individuals was then estimated using the batch weight of the 100 randomly selected individuals.

All surviving individuals were released following data collection. Occasionally, fish that were not identified in the field were vouchered and returned to the Merkel & Associates taxonomic laboratory for identification and inclusion into the dataset.

Data Analysis

Species Richness

Comparisons of species richness between the Study Site and the Control Site were obtained by calculating sample-based rarefaction curves (*sensu* Gotelli and Colwell 2001). Repeated random sampling of the pool of sampled individuals produces rarefaction curves. The process of rarefaction was used to calculate the expected number of species in a collection of *n* individuals drawn at random from the pool of *N* individuals (modified after Simberloff 1978)

Species richness rarefaction curves were calculated using EstimateS® (Version 8) for Windows® (Colwell 2006). Expected species accumulation (Mao Tau) values for each sample were calculated in EstimateS. The Mao Tau values were then plotted against the accumulated number of individuals (Gotelli and Colwell 2001) using Statistica 9® for Windows®.

Density and Biomass

Differences in density (individuals/m^2) and biomass (g/m^2) between sites, day/night sampling, and sampling period (year) were analyzed for the entire catch. This represents an expansion of the original dataset from one pre-construction year and three post-construction years to one pre-construction and five post-construction years. Repeated-measures analysis of variance (ANOVA) was used to test for differences among factors and the repeated measures. ANOVA model factors included study site (2 levels; Study Site, Control Site), and for fish sampling, time of day (2 levels; day, night). The repeated measures consisted of sampling periods (year) over which the study occurred. All factors and the repeated measures were analyzed as fixed effects in the ANOVA model. The data were analyzed and plotted using Statistica 9® software for Windows®.

The time of day factors were included in the ANOVA models for analyses of fish data because they were believed to contribute a significant and explainable portion of the variance in the measured parameters. Their effects were not plotted in figures because these factors did little to explain differences among the study sites. Their inclusion in the study design was intended to maximize the fish catch by including species and individuals temporally occupying different habitats.

Results

Captured Fish Species

Thirty-three species of fish were captured during the first four years of the study. The inclusion of two more sampling years resulted in the capture of an additional six fish species (**Table 1**).

Table 1. Fish species captured throughout the duration of the study. Totals represent the total number of individuals of a given species captured throughout the study at Control and Study Sites. Shaded boxes for each species by sampling year combination represent the relative catch for each sampling year by site combination relative total catch across all years for the corresponding site.

		Control						Control Total	Study						Study Total
Scientific Name	**Common Name**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**		**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	
Paralabrax nebulifer	Barred Sand Bass	1	19	11	10	7	1	**49**	1	7	4	2	3	2	**19**
Ophidion scrippsae	Basketweave cusk-eel	1	2	1				**4**		6					**6**
Hypsoblennius gentilis	Bay Blenny						1	**1**							
Cheilotrema saturnum	Black Croaker	17	8	11	21	17	11	**85**	77	34	24	51	40	15	**241**
Centropristis striata	Black Sea Bass												1		**1**
Myliobatis californica	California Bat Ray	1	3	1	2		1	**8**	1	1	2	2	2	2	**10**
Gymnura marmorata	California Butterfly Ray	1	1		1			**3**	1		1				**2**
Menticirrhus undulatus	California Corbina									2		1			**3**
Paralichthys californicus	California Halibut	76	71	26	30	15	10	**228**	54	46	42	10	16	9	**177**
Synodus lucioceps	California lizardfish	3	357	8	5	12	17	**402**		81					**81**
Scorpaena guttata	California Scorpionfish	19	26	22	1	12	11	**91**	2	2				1	**5**
Symphurus atricauda	California Tonguefish	13	75	67	16	19	1	**191**		24	1		9		**34**
Tridentiger trigonocephalus	Chameleon Goby								1						**1**
*Gobiidae**	CIQ Goby	209		34	10	3		**256**	167	1	77	1	36	15	**297**
Dasyatis brevis	Diamond Stingray										1				**1**
Pleuronichthys guttulata	Diamond Turbot	5	4	3	3	6	4	**25**	14	13	10	1	9	15	**62**
Xystreurys liolepis	Fantail Sole	2	22	1	3	5		**33**							
Heterostichus rostratus	Giant Kelpfish						1	**1**							
Mustelus californicus	Grey Smoothhound		1	2				**3**	1	1				1	**3**
Heterodontus francisci	Horn Shark									1	1				**2**
Pleuronichthys verticalis	Hornyhead Turbot	27	33	84	21	25	48	**238**	2	30	20	15	15	16	**98**
Paralabrax clathratus	Kelp Bass						1	**1**			4				**4**
Porichthys notatus	Plainfin Midshipman								1						**1**
Seriphus politus	Queenfish	1	37	2	18	25	10	**93**	1	11	6	6	1		**25**
Halichoeres semicinctus	Rock Wrasse						2	**2**							
Urolobatus halleri	Round Stingray	71	41	279	37	26	154	**608**	94	238	179	51	34	260	**856**
Xenistius californiensis	Salema													8	**8**
Rhinobatis productus	Shovelnose Guitarfish			2		2	2	**6**	1	1	1		1	2	**6**
Porichthys myriaster	Specklefin Midshipman	180	173	56	12	51	8	**480**	253	91	82	24	253	113	**816**
Roncador stearnsii	Spotfin Croaker								8						**8**
Chilara taylori	Spotted Cusk-Eel	1	3					**4**							
Paralabrax maculatofasciatus	Spotted Sand Bass	9	6	6		6	1	**28**	57	36	33	6	24	17	**173**
Pleuronichthys ritteri	Spotted Turbot	54	5				3	**62**	10						**10**
Leptocottus armatus	Staghorn Sculpin													1	**1**
Playrhinoides triseriata	Thornback		2	14	1	2	1	**20**	1						**1**
Genyonemus lineatus	White Croaker					1		**1**	2						**2**
Umbrina roncador	Yellowfin Croaker		1	3	2		6	**12**	7	45	11	13	9	10	**95**
	Totals	691	890	633	193	234	294	**2935**	756	671	499	183	453	487	**3049**

Three of the captured species are similarly appearing species of gobies (arrow goby, cheekspot goby, and shadow goby) and were grouped as CIQ Gobies for purposes of analysis. Thus, for comparative purposes within this study, the total number of species captured was 37. Of the 37 captured species, 28 and 32 species were captured at the Control Site and the Study Site, respectively (**Table 1**).

Fish species overlap was notable between the sites, with 23 fish species in common. The remaining 14 species not shared between the sites were rare species that accounted for less than 1% of the total catch (**Table 1**).

The three most abundant fish species caught were round stingray, specklefin midshipman, and CIQ Goby at 24%, 22%, and 9%, respectively. These are the same three species listed as most abundant in the original report; however, round stingray moved from third to first in terms of relative abundance (**Table 1**).

Fish Density

Fish density did not vary by treatment ($F_{(1, 52)} = 0.460$, $P = 0.501$) (Table 2). There were significant effects noted for sampling year ($F_{(5, 260)} = 23.129$, $P < 0.001$) (Table 2), year by time of day interaction ($F_{(5, 260)} = 3.678$, $P = 0.003$), and year by treatment interaction ($F_{(5, 260)} = 2.470$, $P = 0.003$) (**Table 2**). There was no difference between the Study Site and the Control Site in terms of fish density. However, the interaction between the study sites and year is best explained by a decrease in fish capture at the Study Site following the Dredge Project and an increase in fish capture at the Study Site relative to the Control Site during the two supplemental sampling years (**Figure 2**).

The year effect for fish density in the ANOVA model was further analyzed with Tukey's Honestly Significant Difference Test (Tukey's HSD). The results of the Tukey's HSD test show that the first two sampling years resulted in a significantly greater fish catch relative to all other sampling years. It also shows that the 2007 fish catch was similar to the two supplemental sampling years (2008 and 2009). However, the fish catch during two supplemental sampling years was high enough to be statistically similar to the 2006 fish catch (**Figure 3**).

Fish Biomass

Fish biomass did not vary relative to the treatment ($F(1, 52) = 0.404$, $P = 0.528$) (Table 2). The mean fish biomass captured did vary based on sampling year ($F(5, 260) = 7.713$, $P < 0.001$). Statistical interactions were significant for year by treatment by time of day ($F(5, 260) = 3.017$, $P = 0.012$) and year by time of day ($F(5, 260) = 3.374$, $P = 0.006$). The year by treatment interaction was not significant ($F(5, 260) = 1.818$, $P = 0.110$). However, the graph of biomass over time for each of the treatments is relevant to the study questions and illuminates the source of most of the variation driving the other statistical results (**Figure 4**). Similar to density, Tukey's HSD test was used to determine which study years varied with regards to biomass of captured fish. The results indicate that the drop in biomass between sampling years 2006 and 2007 was significant (**Figure 5**). Those are the only two sampling years where no overlap in similarity occurs. These results also show that in terms of biomass, the two supplemental fish sampling years were similar to the biomass captured at the beginning of the Project.

Table 2. Repeated measures analysis of variance for the density (top) and biomass (bottom) of all captured fish Statistical significance and power calculations based on α of 0.05.

Model Term	Degrees of Freedom	MS	F	p	Power
Treatment	1	0.000	0.460	0.501	0.102
Time of Day	1	0.024	25.945	**0.000**	0.999
Treatment*Time of Day	1	0.003	3.784	0.057	0.480
Error I	52	0.001			
Year	5	0.016	23.129	**0.000**	1.000
Year*Treatment	5	0.002	2.470	**0.033**	0.772
Year*Time of Day	5	0.002	3.678	**0.003**	0.927
Year*Treatment*Time of Day	5	0.001	2.158	0.059	0.705
Error II	260	0.001			

Model Term	Degrees of Freedom	MS	F	p	Power
Treatment	1	5.761	0.404	0.528	0.096
Time of Day	1	475.010	33.319	**0.000**	1.000
Treatment*Time of Day	1	0.375	0.026	0.872	0.053
Error I	52	14.256			
Year	5	77.384	7.713	**0.000**	0.999
Year*Treatment	5	18.242	1.818	0.110	0.618
Year*Time of Day	5	33.856	3.374	**0.006**	0.901
Year*Treatment*Time of Day	5	30.266	3.017	**0.012**	0.860
Error II	260	10.033			

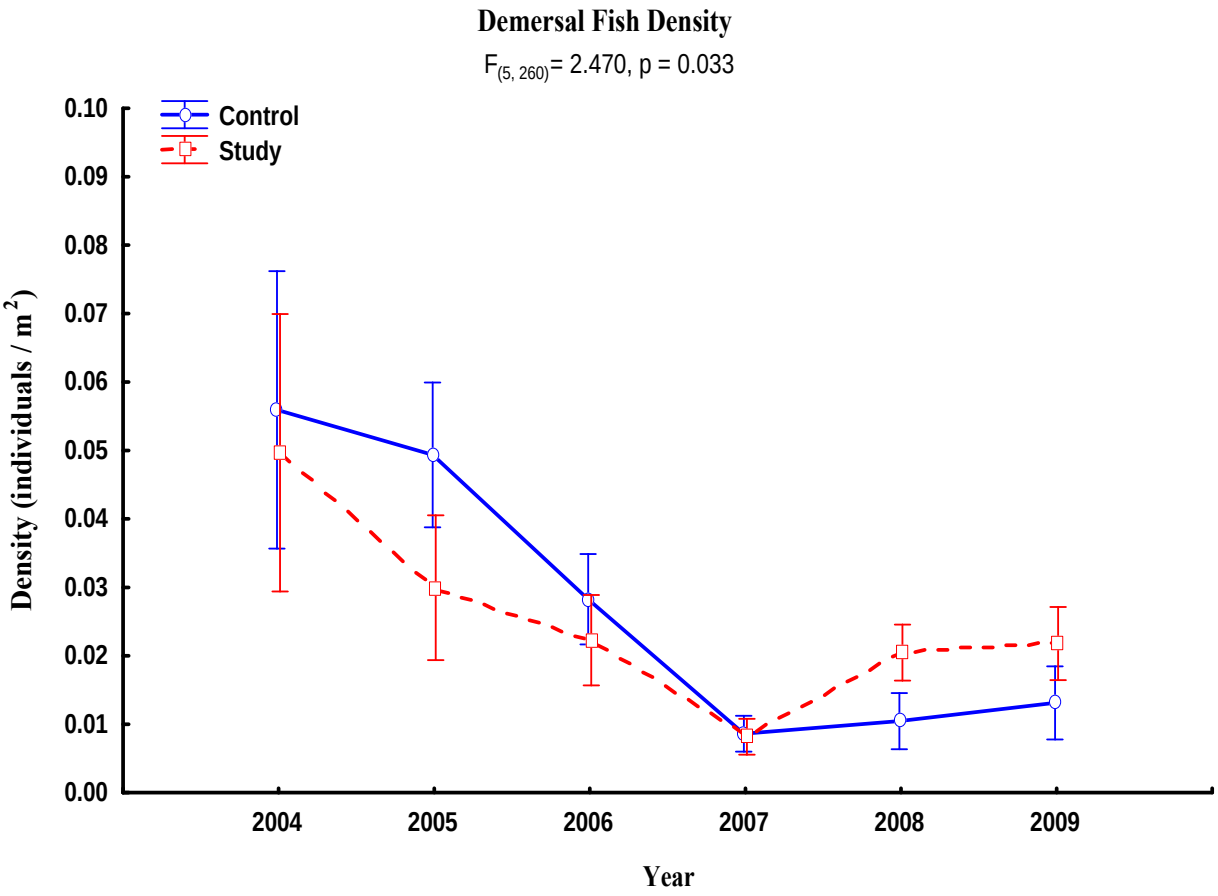

Figure 2. Average fish density for all species of demersal fish captured within each monitoring station by sampling event combination. Error bars are ± 1 standard deviation using the pooled variance across the treatments within each sampling period.

Tukey's HSD Results - Fish Density Year Factor

Year	2007	2008	2009	2006	2005	2004
Mean	0.008	0.015	0.017	0.025	0.040	0.053
Similarity						

Figure 3. Results of Tukey's HSD test for the year factor in the ANOVA model for fish density. Fish catch for each year is ranked from low to high by mean density (fish/m^2). Bars connect factor levels (years) that are statistically similar.

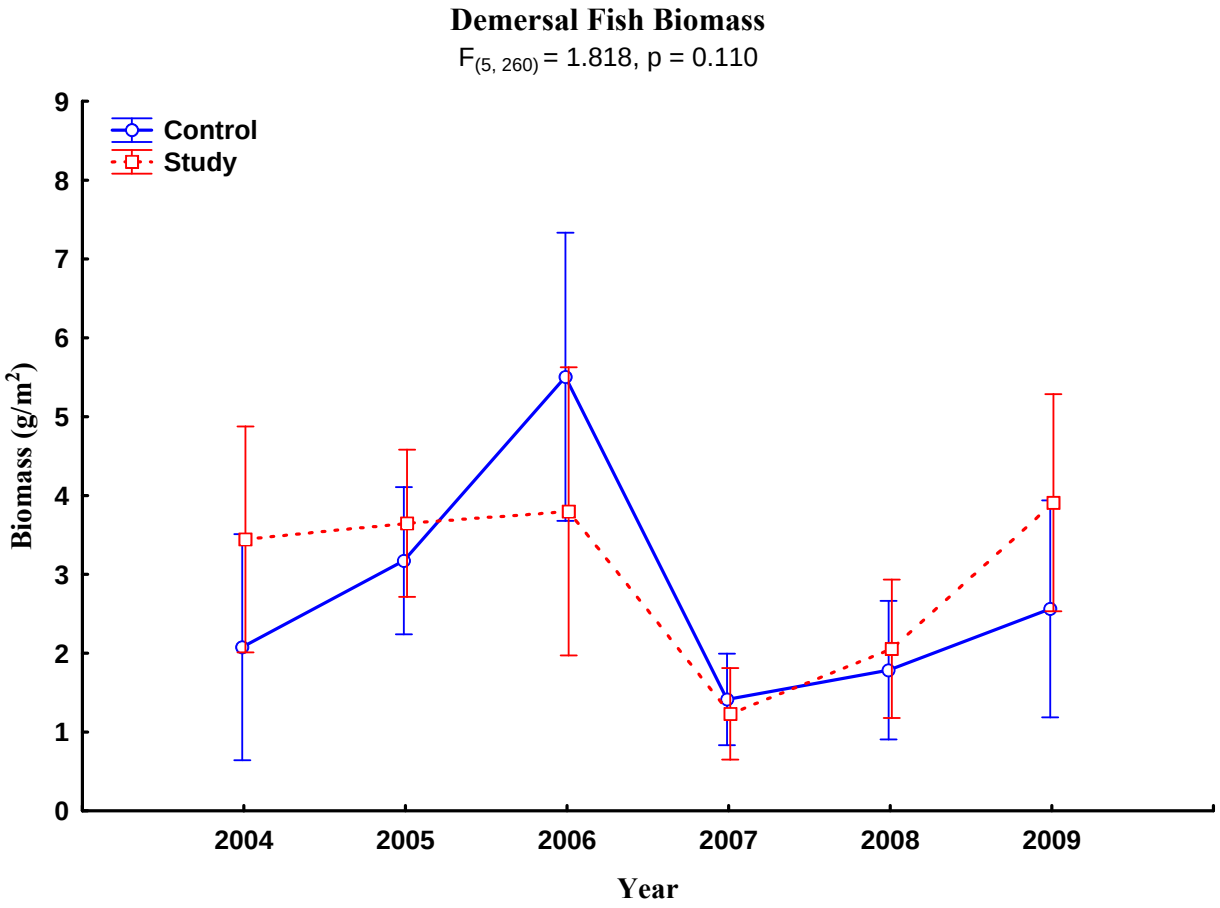

Figure 4. Average fish biomass for all species of demersal fish captured within each monitoring station by sampling event combination. Error bars are ± 1 standard deviation using the pooled variance across the treatments within each sampling period.

Tukey's HSD Results - Fish Biomass Year Factor						
Year	2007	2008	2004	2009	2005	2006
Mean	1.323	1.921	2.761	3.236	3.411	4.653
Similarity						

Figure 5. Results of Tukey's HSD test for the year factor in the ANOVA model for fish biomass. Fish catch for each year is ranked from low to high by mean density (fish/m^2). Bars connect factor levels (years) that are statistically similar.

Species Richness

The Study Site was more species rich overall, with 32 of the 37 encountered species being captured at the Study Site. There were 28 species captured at the Control Site. However, most of the richness at the Study Site was due to relatively species-rich years in 2004 and 2005, during which time accumulation along the species-richness curves achieved 22 and 21 species during 2004 and 2005, respectively in the Control Site (**Figure 6**). Subsequent years showed the Control Site to be more species rich than the Study Site, although richness was generally down overall. The two supplemental sampling years were consistent with the latter years of the initial Project for the Study Site (**Figure 7**). One significant exception to these observations was the notable species richness at the Control Site in 2009. The trajectory of the species-richness curve for the Control Site in 2009 predicts that many more species would have been encountered with additional sampling (**Figure 7**).

Discussion

The relative abundances of the dominant fish encountered throughout this study are similar to those found in other studies within San Diego Bay (Hoffman 1996, Merkel & Associates 1997, Allen 1999). CIQ Gobies and round stingrays are common demersal species found in San Diego Bay. Large numbers of round stingrays were captured with the otter trawl because they are common on unvegetated bottoms and the otter trawls were performed in deep water environments below the lower growth limit of eelgrass. CIQ gobies are common in nearly all soft-bottom habitats in San Diego Bay.

The large capture of specklefin midshipman in this study was in contradiction to previous work. Allen (1999) captured only 79 specklefin midshipman in 5 years of quarterly sampling throughout San Diego Bay, while 1,296 individuals were captured during the present 6-year single sampling season investigation. Differences in gear type could account for some of the discrepancy. Allen sampled with various gear types to produce a comprehensive data set for San Diego Bay. His otter trawl had 8-mm (0.3-in) mesh in the cod end. His beam trawl had a 2-mm (0.08 in) mesh in the cod end; however the beam trawl was only 1.6 m (5.2 ft) wide. The larger mesh in Allen's otter trawl meant it could have missed what were mostly juvenile fish encountered in this study. The smaller size of the beam trawl could have made it less effective at capturing fish than the otter trawl used in this study. Finally, site, seasonal, and interannual variability could account for much of the discrepancy with regards to specklefin midshipman. Most of the specklefin midshipman captured in this study were captured in the 2004 sampling. Moreover, most of the specklefin midshipman captured in this study were juveniles, with only 3% of the catch being more than 5 cm (2 in) in standard length.

In the primary study report, it was determined that the Dredge Project altered the density and community structure of demersal fish in the Study Site. Overall fish density was significantly lower at the Study Site relative to the Control Site during the 2005 sampling event, which occurred five months after the completion of the Dredge Project. During this same time period, the community similarity between the Study Site and the Control Site was the lowest of all sampled years. Thus, both the numbers of fish present at the Study Site and the relative

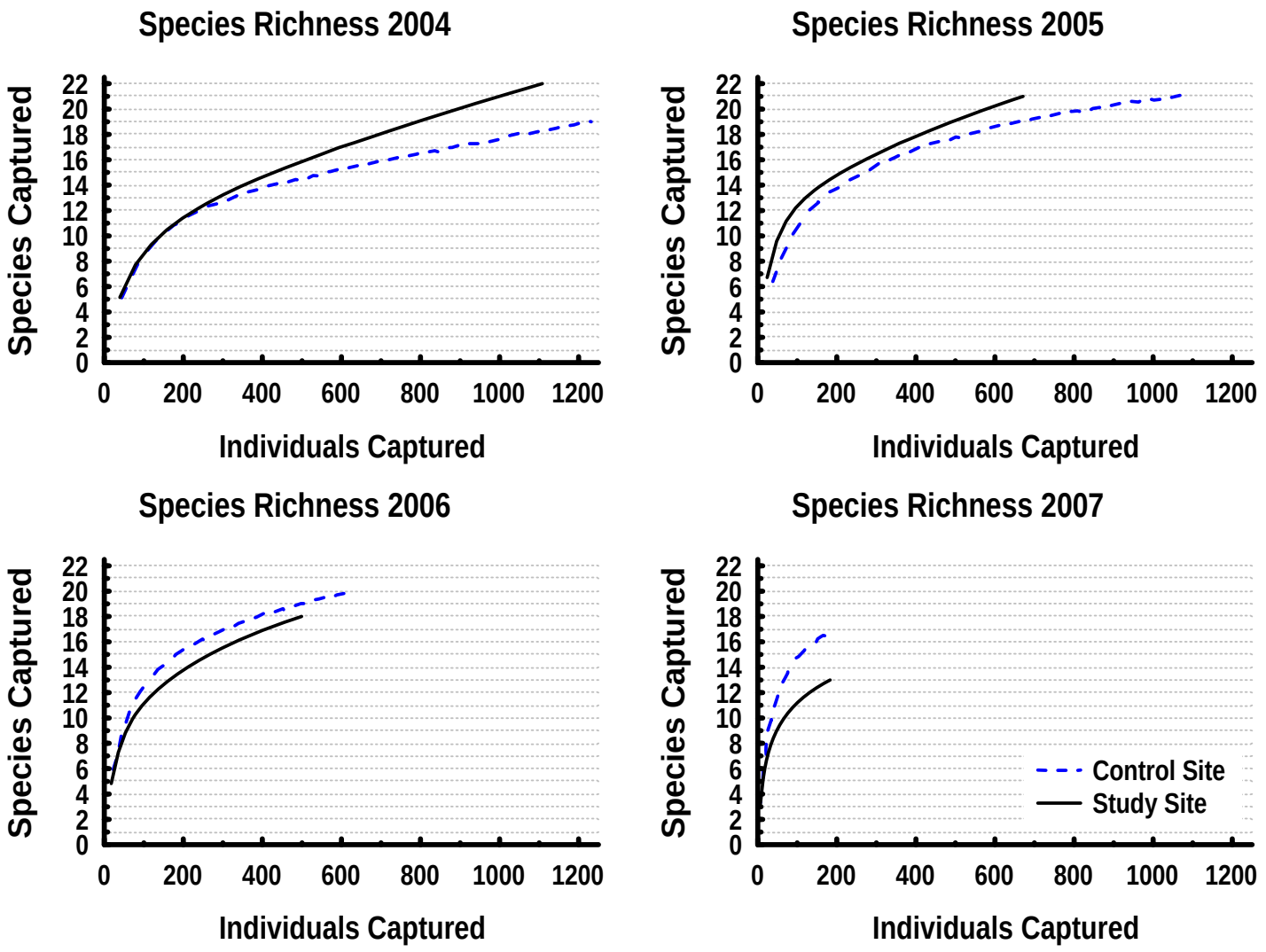

Figure 6. Species richness curves for demersal fish captured during first 4 years of the study. The presented curves are calculated sample-based rarefaction curves with the species data plotted as a function of the accumulated number of individuals captured.

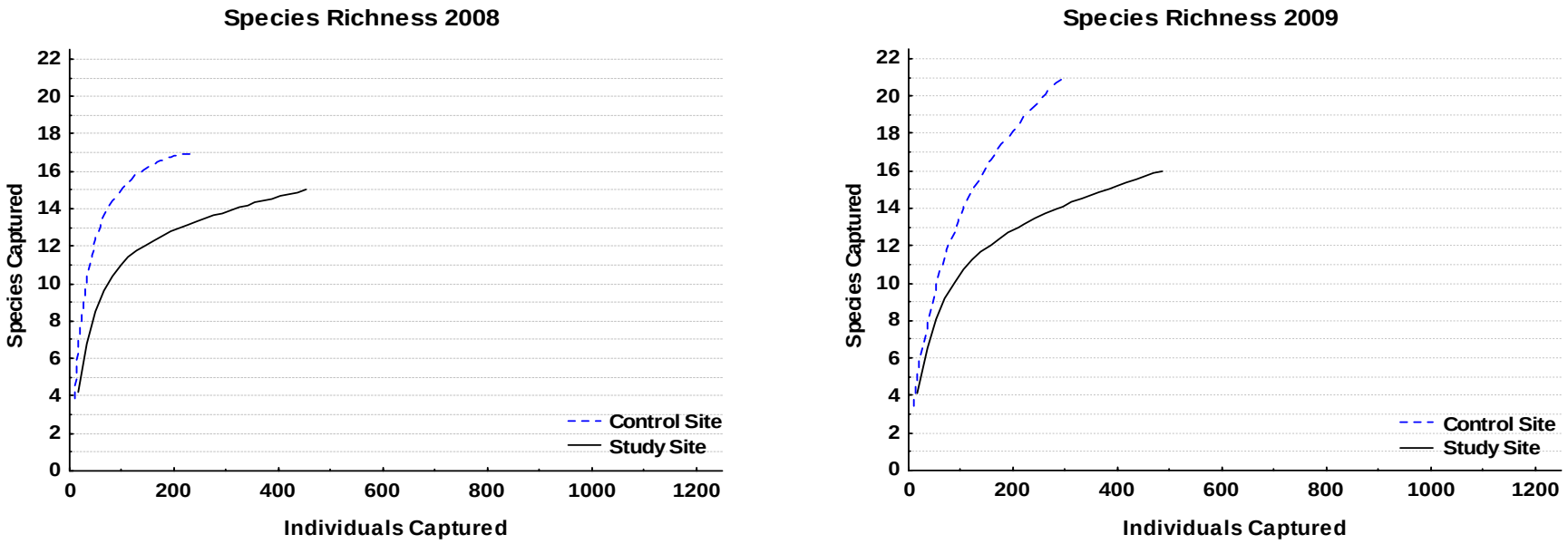

Figure 7. Species richness curves for demersal fish captured during the two supplemental sampling years. The presented curves are calculated sample-based rarefaction curves with the species data plotted as a function of the accumulated number of individuals captured.

abundance of the species present were altered by the Dredge Project. These observations are not diminished by the inclusion of two supplemental years of fish data.

The primary study report highlighted a decreasing trend in fish abundance over the four study years. The supplemental data collection was performed to specifically explore the potential decline. The additional two years of data can be interpreted as a leveling off of a short-term decline or even a slight increase over the 2007 fish catch. Captured fish density was similar in 2008 and 2009 to the 2007 fish capture. For biomass, the 2008 and 2009 capture was similar to that captured in 2004. These observations suggest that annual variation in capture resulting from both sampling error and variable fish community structure are influencing the data. It is likely that the timing and success of spawning events have significant influence on the density data, while capture (or lack thereof) of larger species and adults drive variation in the biomass data. Although the annual sampling timing was consistent during this study, variation in spawning events of just a couple of weeks can have significant influence over the density of fish captured. If spawning occurs early, high mortality may result in few juveniles being captured. If spawning occurs late, juveniles may be missed in the sampling. Larger fish are often more motile. These fish may occasionally not be present within the area being sampled, or they may be better able to evade capture. The highly variable capture between day and night sampling highlights these effects on the study. Thus, given the high variability across years in fish density relative biomass, it is not likely that larger fish are being lost from San Diego Bay.

Species richness was also slightly higher in 2008 and 2009 relative to 2007. This is particularly true relative to the Control Site in 2009, where 22 species were captured. The most notable species added to the dataset was a black seabass (*Centropristis striata*), captured at the Study Site in 2008. The species richness information does not support the idea that fisheries are exhibiting a decline in San Diego Bay; at least not on the temporal scale of the investigation.

Commercial fisheries studies have long been hampered by high variation in fish capture, sliding baselines, and temporal sampling scale (Pauly 1995, Dayton et al. 1998). Simply put, it is difficult to assess fish populations, particularly without having a consistent, long-term data set. Determination of population trends are no different in this study. Given that densities did not continue to fall in 2008 and 2009, we can be relatively certain that a short-term loss of fish is not occurring. It is possible that 2004 and 2005 were exceptional years with regards to demersal fish in San Diego Bay. Without a consistent and long-term dataset, however, it is not possible to place the capture of fish in this study within the larger context of annual, decadal, or longer trends in fish abundance and biomass. Concerns over the potential of a fisheries collapse prompted the sponsoring agencies to expand the data collection under this study. Although it is unlikely that a collapse across all the species studied is occurring, the concerns and the lack of sufficient data to address them illustrates the need for periodic and consistent sampling programs for fisheries research in southern California bays and harbors.

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