Assessing the restoration needs of the San Francisco Estuary using a target fish community analysis

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Abstract

Historically, aquatic ecosystem restoration has attempted to return a region to past or pristine conditions, which is often unachievable. Here I examine a different approach using a target fish community analysis that efficiently reveals aspects of the ecosystem that are most important for site improvement. The target community is comprised of the relative proportions of fish species that should be at a location based on fish present in biologically similar reference sites considered to be ecologically acceptable. Comparison with the current proportions of species at the restoration site reveals specific objectives on which ecologists can focus in order to maximize restoration efforts. This study examines the effectiveness of target fish community analysis in the San Francisco Bay, the largest estuary on the Pacific coast, using four coastal estuaries: Columbia Estuary, WA/OR; Tillamook Bay, OR; Morro Bay, CA; and Santa Monica Bay, CA. Trawl data from South San Francisco Bay conducted by the Marine Science Institute in Redwood City, CA from 1970 - present were used for the comparison. Data revealed no changes in species abundances through time, and benthic species were consistently underrepresented relative to the target. In addition, pelagic Northern Anchovy were overabundant even though they were the most prevalent species in the target. I propose that the dominant Northern Anchovy benefits from eutrophic conditions and increasing food availability, which lowers benthic oxygen and results in lower fish abundance. In addition, toxins such as mercury and polychlorinated bisphenols buried in sediment could contribute to low abundances of benthic species. The study showed that restoration efforts should focus on eutrophication and sediment toxicity as important aspects of the San Francisco Bay that impact fish communities and that the target community analysis has great potential for systems with appropriate reference sites.

Introduction

Many efforts in natural resource and aquatic restoration have focused on imitating historically natural conditions. Yet such an objective might be impractical, if not impossible, when considering the extent to which humans have altered the landscape, climate, and waterways. In addition, a once pristine ecosystem might be firmly incorporated into modern societies, and human involvement could be viewed as a natural component of the system. It is therefore increasingly difficult for managers of aquatic environments to propose reasonable goals that are both effective and realistic. An alternative to focusing on ideal restoration conditions is to use the target community concept of Bain and Meixler (2008), a methodology that has previously been applied to fish. The aim of a target fish community analysis is to establish a reasonable restoration goal for the system in need of restoration, given current and future needs of both society and the environment. The target community is modeled after observed communities in biogeographically similar sites that are in acceptable environmental condition within the context of human societies. The fish communities and relative species abundances of such reference sites are compiled to construct an expected target community for the restoration site. The target list is then compared with a list of fish species and proportions currently present in the restoration site to identify deviations from the target. Further analysis provides explanations for why such deviations are present, and suggests specific objectives on which ecologists can focus in order to maximize restoration efforts within the system.

The target community methodology has been implemented previously in rivers in the northeastern United States by Bain and Meixler (2008) and an estuarine portion of the

Hudson River (Bain unpublished) and is seen as an effective tool for ecologists and managers involved in river restoration (Bain and Meixler 2008; Petts 2009). Although the methodology relies on previously-studied reference systems that are not identical to the system in question, the development of a target community allows for efficient analysis of the "Where do we want to go?" management component. The target community approach quickly identifies the most influential aspects of an ecosystem to suggest realistic improvements. The target community, coupled with scientific research on specific aspects of the community, is a practical and appropriate tool in aquatic resource management.

The San Francisco Bay (the Bay) in northern California provides an appropriate test of the target community method because it is a popular Pacific coast location that receives a great deal of attention from both residents and visitors. Public education regarding the natural status of the Bay is common. There have been numerous scientific publications outlining the status of Bay organisms and their habitats, as well as suggesting areas in need of improvement (Cohen and Carlton 1998; Dallas and Barnard 2009; Leidy 1984; Martin 2004; Rosenfield and Baxter 2007; van Geen and Luoma 1999; Watson and Byrne 2009). Because the target community approach is a relatively new concept, the previously published knowledge regarding the fish communities present in the Bay through time can be a useful check on the validity of this method. Results from such ecological studies can be compared with my outcomes to see whether or not there is a substantial difference. Finding little or no difference would show that the same conclusions can be drawn from this faster, cheaper, and less laborious method. Furthermore, because of the environmental and social importance of the Bay, there have been many long-term studies of the fish communities found in different sub-regions of the estuary (*i.e.* upper delta, South Bay, and San Pablo Bay) (Bennett 2005; Grimaldo et al. 2009; Hobbs et al. 2006; Kimmerer 2006). These provide the opportunity to suggest site-specific recommendations for restoration goals and objectives.

Goals of this study were to (1) apply the target community method to an urban estuary to review its execution and success in such a system; (2) determine if findings and interpretations are consistent with known changes in the Bay; (3) evaluate whether or not results are applicable and informative over time; and (4) identify benefits and possible limits of using the target community method.

Analysis revealed that the Bay is in fair environmental standing, with main species of the target community present in the Bay. However, pelagic species represent a larger proportion of the community and benthic species represent a smaller proportion of the community than predicted by the target. These results have been documented in scientific literature as occurring in the Bay. I propose that these findings are explained by (1) pelagic eutrophication leading to benthic hypoxia, and (2) high sediment toxicity. The target community is therefore an effective tool for restoration management in the San Francisco Bay.

Methods

Development of the target community

The first step in the development of the target community was to choose reference sites that are biogeographically similar to the San Francisco Bay. These reference sites were considered to be in acceptable condition in comparison to the Bay, with similar temperature and salinity values. Four reference sites were chosen based on (1) the EPA West Coast Coastal Condition Report III summaries of environmental stressor and response data for approximately 200 coastal water sites along the Pacific Coast (USEPA

2008); (2) the possible ranges of coastal fish species found within the San Francisco Bay (Burgess 1984, (Goodson 1988), Moyle 2002); and (3) measured salinity levels of the estuary. For this analysis, I chose the Lower Columbia River Estuary, Tillamook Estuary, Morro Bay, and Santa Monica Bay as reference sites (Figure 1). These four estuaries met the above qualifications, and were the most similar to the Bay in terms of human impact.

Figure 1. Map of the Pacific coast of the United States. The San Francisco Estuary (outlined) and reference sites are shown.

Second, fish data for each site were obtained from the NOAA Estuarine Living Marine Resources (ELMR) online database (NOAA 2005). The ELMR program compiles and maintains a database of distribution, abundance, and life history characteristics of fish and invertebrates of United States estuaries. Data are based on information from published and unpublished expert sources (Emmett 1991). Since the ELMR database contained inconsistent life stage data for the four reference sites and only adults were recorded in the Bay community dataset, only adult life stages were considered when developing the target community. ELMR abundances are also divided into three salinity zones: Tidal Fresh (0.0-0.5 parts per trillion [ppt]), Mixing (0.5-25.0 ppt), and Seawater (>25.0 ppt). Since data I used from the Bay included salinity levels that span the entire available spectrum (0.0 - >25.0 ppt), fish abundances from all salinity zones were considered. Next, for each of the four reference sites, abundance values of each species were averaged across time to calculate annual abundance for each salinity zone. Annual abundance values were then averaged across salinity zones to create one abundance value for each species at each location. The average of the abundances at each location was then calculated to determine a mean abundance value for each species that should be found in the Bay.

Abundance values of species were then compiled into a final list and ranked in descending order. Species with identical abundance values were listed alphabetically.

Species ranks were then converted into reciprocals (1/rank) and summed. Finally, each species' reciprocal rank was divided by the sum of all reciprocal ranks to produce a proportion value for that species. This procedure creates a log-log line that transforms ranks into weighted proportions (Bain 1987; Bain and Meixler 2008). The resulting distribution reflects a power law distribution, a fundamental pattern reported in nature in a wide variety of contexts (e.g. Richter scale, population densities, city development) (Mandelbrot 1983, Bak 1996, Solè and Goodwin 2000). Because of the prevalence of this pattern in natural systems, it was assumed to be operating in the Bay fish community structure as well. The final product was a target list of species with accompanying proportions representing abundance (Appendix A). Because this is a compilation of the similar reference sites, the list of target species presents a possible community structure for the fish assemblage of the San Francisco Bay.

Restoration study area

The San Francisco Bay (37° 43′ 0″ N, 122° 17′ 0″ W, Figure 1) is an urban estuary known to be an essential nursery for many marine fishes (Brown 2006, Ostrach *et al.* 2008). The San Joaquin Delta and Sacramento River that feed into the Bay experience high recreational and industrial use. Two of the largest water diversion pumps in the world lie along the river and its tributaries (Grimaldo et al. 2009). The reduction of endangered species such as the Delta Smelt has been contributed to the large pumps and diversion systems used to sustain water demands in nearby regions of the state (Bennett 2005; Hobbs et al. 2006; Moyle et al. 1992; Nobriga et al. 2005; Rosenfield and Baxter 2007). Northern California trade and commerce have allowed invasive species from all over the world to colonize the Bay and delta (Cohen and Carlton 1998). Mercury contamination and the presence of polychlorinated bisphenols (PCBs) are also of concern. Levels of more than ten times the accepted limit of PCBs have been recorded in sport fish from the Bay, and the presence of environmental and biological mercury originated with mining in the Sierra Nevada (Davis et al. 2007; Hornberger et al. 1999). More recently, the U.S. Fish and Wildlife Service, California Department of Fish and Game, and the California Coastal Conservancy have formed the South Bay Salt Pont Restoration to restore the industrial salt marshes of the South San Francisco Bay (Martin 2004).

Development of current community structure

The target community is only helpful when compared with the community structure present within the Bay. These data were obtained from the Marine Science Institute (MSI) in Redwood City, CA. Since 1970, MSI has been conducting daily trawls of the South San Francisco Bay between the San Mateo and Dumbarton Bridges in order to identify which species are present in this particular region of the estuary. Samples are collected with a 21 foot long trawl net with 1 ½ inch netting and ½ inch cod end. Each trawl lasts an average of 12 minutes. The area is mapped out into many grids, and all possible grid locations are sampled at least once throughout the year.

Proportions of each species for a given year of collection were calculated by dividing each species sum by the total sum of fish caught that year. In order to eliminate variation caused by environmental factors such as drought or El Nino events, proportions for each species were grouped into periods of approximately five years, and a mean proportion was calculated for each period. Because there was a gap in data collection at MSI in the 1980’s, abundance proportions from years 1980-1989 were grouped and averaged together. The proportions were then ranked in descending order, with the most abundant fish species ranked first.

Comparison of target and Bay communities

The target fish community was then compared with the actual community of fish present within the San Francisco Bay. In order to determine whether a species was significantly over- or underrepresented relative to the target, 95% confidence intervals were calculated using the difference between the predicted target proportion and the observed Bay proportion for a given species. If the confidence interval excluded zero, the difference was considered significant. Species not over-or underrepresented were considered to be present in the expected frequencies of the target community.

A variety of different references were consulted to obtain information on over- and underrepresented species, including Bay Fishes of Northern California (Bane and Bane 1971), Inland Fishes of California (Moyle 2002), and Fishes of California and Western Mexico (Burgess and Axelrod 1984). Life history traits, depth, habitat, ecological niche, diet, along with salinity, temperature, and pollution tolerance were analyzed for each species. Species with similar ecological characteristics were clustered together into groups, and then patterns in over-or underrepresented species were identified within each. Since statistical analyses are not appropriate for these groups, a 2/3 majority of either over- or underrepresented species group was considered noteworthy.

Results

Target community

Retrieved ELMR data from the four reference sites (Columbia River Estuary, Tillamook Bay, Morro Bay, and Santa Monica Bay) included between 38 and 40 species per site. Overall, the reference sites contain similar species of fish. Different salmon species were collapsed into a general salmon category. The compiled target fish community consisted of 35 species that should be represented within the Bay, of which an average of 20 can be found in the Bay during each time period sampled. Seven species were never found in the Bay, and these include barred sand bass, kelp bass, pacific sand lance, deep-body anchovy, cutthroat trout, steelhead, and eulachon.

The proportions of the top ten most abundant species of the target community are as follows: Northern Anchovy (NA), 0.241; Pacific Staghorn Sculpin (SHS), 0.120; Shiner Surfperch (SSP), 0.080; Topsmelt (TS), 0.060; Arrow Goby (AG), 0.048; Threespine Stickelback (TSS), 0.040; Pacific Herring (PH), 0.034; California Halibut (CH), 0.030; Leopard Shark (LS), 0.027; and Jacksmelt (JS), 0.025 (Figure 2). Refer to Appendix B for a comprehensive list of species codes and proportions.

Bay community

MSI conducted a total of 9970 trawls over 33 years from 1970-2008. There were no trawl data for the years 1983-84, 1987-88, and 1990-91, and very little data for 1982, 1985-86, and 1989. There was a mean of 256 trawls per year, and the mean number of different species caught per trawl was 40 species. On average 23,660 fish were caught each year. Refer to Appendix C for a comprehensive listing of the data.

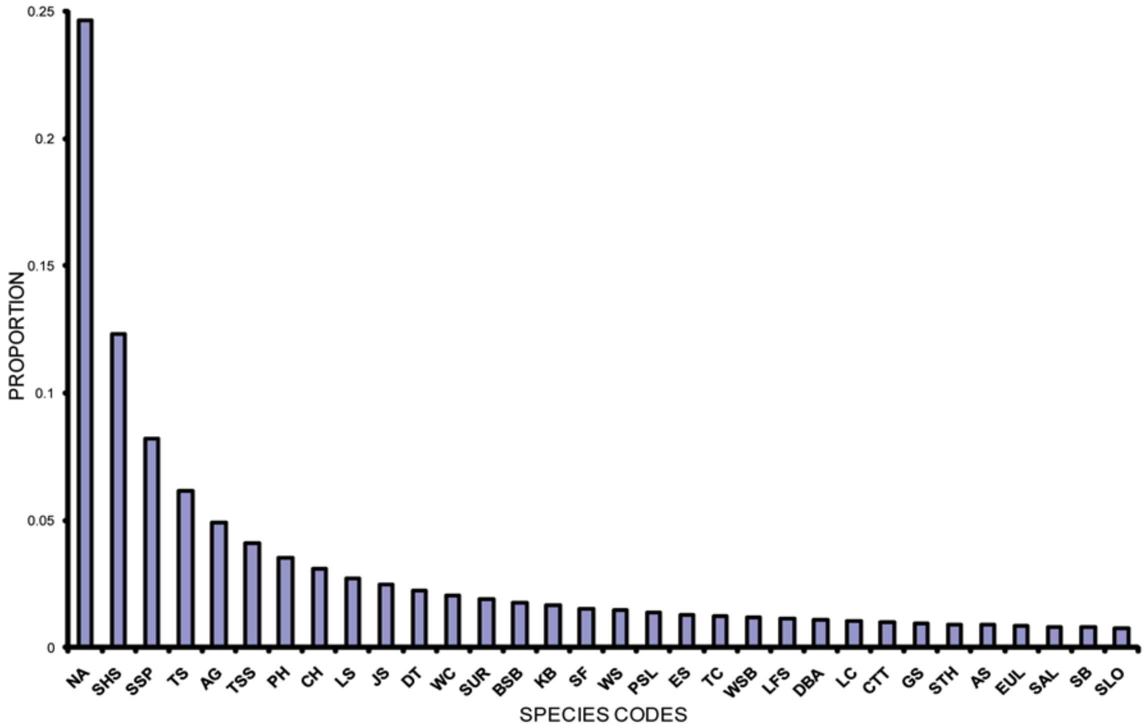

Figure 2. The target fish community for the San Francisco Bay. Species codes are shown along the x-axis. These species are predicted to be found within the San Francisco Estuary and represented in approximately the proportions shown on the y-axis. A list of species and codes can be found in Appendix B.

Comparison

Northern Anchovy (NA) and English Sole (ES) were substantially overrepresented in the San Francisco Bay for a majority of the time periods (Figure 3). There were no large changes in overrepresented species abundances through time, although abundances did fluctuate slightly. For years examined from 1970-1979, overrepresented species were Northern Anchovy, Shiner Surfperch (SSP), and English Sole. During 1980-1989, White Croaker (WC) and English Sole were overrepresented. From 1992-1995, as well as 2005-2008, Northern Anchovy was the only overly abundant

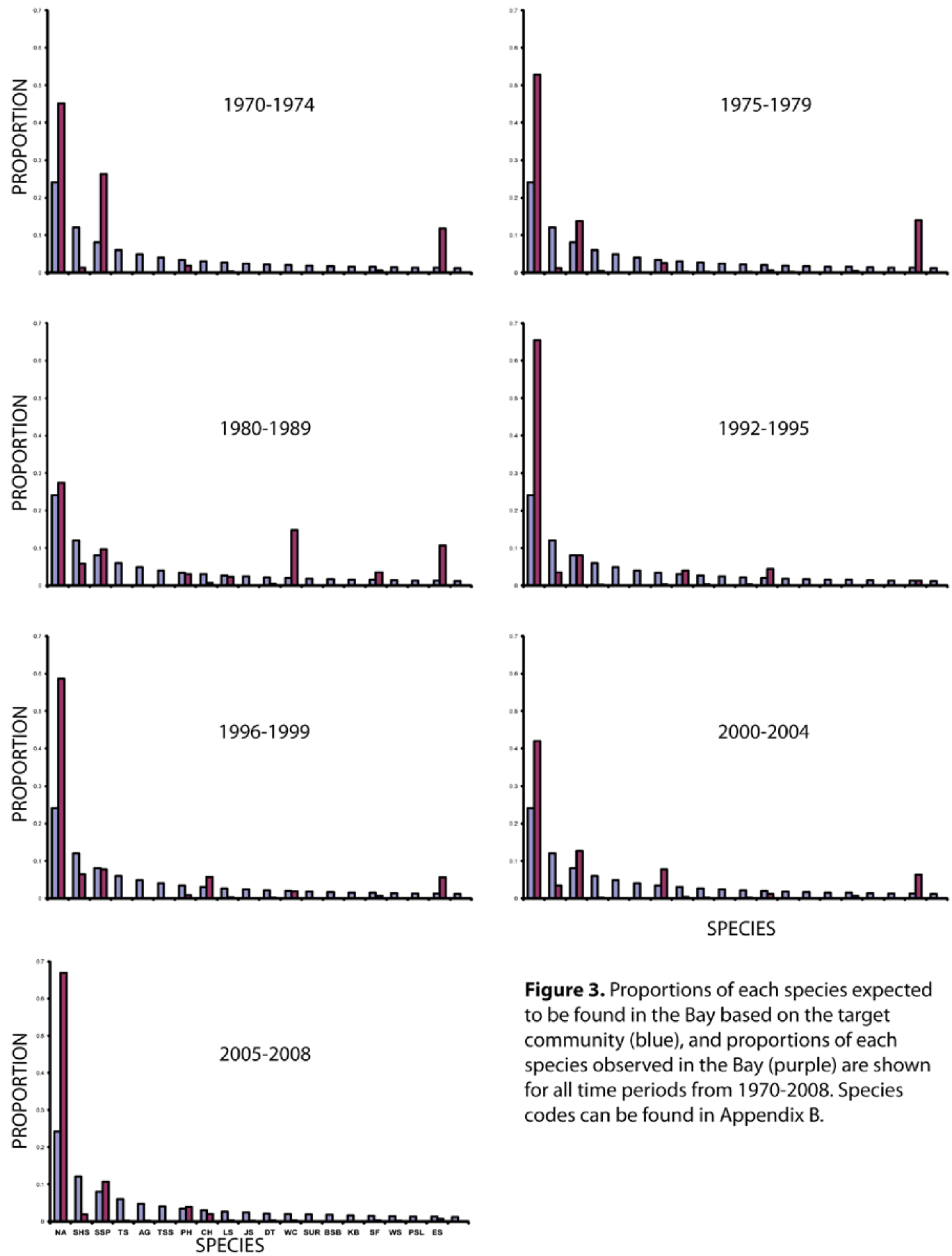

Figure 3. Proportions of each species expected to be found in the Bay based on the target community (blue), and proportions of each species observed in the Bay (purple) are shown for all time periods from 1970-2008. Species codes can be found in Appendix B.

species. From 1996-1999, Northern Anchovy and English Sole were overrepresented.

From 2000-2004, Northern Anchovy, English Sole, Shiner Surfperch and Pacific Herring

Table 1. A summary of fish that were found to be over- or under-represented in the San Francisco Bay as compared with the target community. Includes habitat, pollution tolerance, and life history information.

YEAR	SPECIES	HABITAT	PISCIVORE	POLLUTION	SALINITY
Overrepresented					
1970-1974	NA	Pelagic (P)	No	-	High
	SSP	P	No	-	Low
	ES	Benthic (B)	No	-	Low
1975-1979	NA	P	No	-	High
	SSP	B	No	-	Low
	ES	B	No	-	Low
1980-1989	WC	B	Yes	-	High
	ES	B	No	-	Low
1992-1995	NA	P	No	-	High
1996-1999	NA	P	No	-	High
	ES	B	No	-	Low
2000-2004	NA	P	No	-	High
	SSP	P	No	Low	Low
	ES	B	No	-	Low
	PH	P	No	-	High
2005-2008	NA	P	No	-	High

YEAR	SPECIES	HABITAT	PISCIVORE	POLLUTION	SALINITY
Underrepresented					
1970-1974	SHS	B	Yes	Low	High
	TS	P	No	-	Low
	AG	B	No	-	Low
	TSS	B	No	High	High
1975-1979	SHS	B	Yes	Low	High
	TS	P	No	-	Low
	AG	B	No	-	Low
	TSS	B	No	High	High
1980-1989	SHS	B	Yes	Low	High
	TS	P	No	-	Low
	AG	B	No	-	Low
	TSS	B	No	High	High
1992-1995	SHS	B	Yes	Low	High
	TS	P	No	-	Low
	AG	B	No	-	Low
	TSS	B	No	High	High
	PH	P	No	-	High
1996-1999	SHS	B	Yes	Low	High
	TS	P	No	-	Low
	AG	B	No	-	Low
	TSS	B	No	High	High
2000-2004	SHS	B	Yes	Low	High
	TS	P	No	-	Low
	AG	B	No	-	Low
	TSS	B	No	High	High
2005-2008	SHS	B	Yes	Low	High
	TS	P	No	-	Low
	AG	B	No	-	Low
	TSS	B	No	High	High

(PH) were all overrepresented. A summary of the overrepresented species can be found in Table 1.

Pacific Staghorn Sculpin (SHS), Topsmelt (TS), Arrow Goby (AG), and Threespine Stickelback (TSS) were underrepresented for all years sampled. In addition to these, Pacific Herring (PH) was also underrepresented during 1992-1995. There were no changes in underrepresented species abundances through time, although abundances did fluctuate slightly. A summary of the underrepresented species can be found in Table 1.

In general, both over-and underrepresented species included predators of other fish as well as planktivores and herbivores. Only two underrepresented species, Topsmelt and Jacksmelt, occupied pelagic habitats. California Halibut and English Sole were the only benthic species overrepresented during a time period. Species with high salinity tolerance were represented evenly by both over-and underrepresented species. The life history and ecological characterization of each over- and underrepresented species is compiled in Table 1.

Discussion

The first ten species within the target community represent 72% of the community, with the other 28% comprised of 25 different species. The community contains a fairly even mixture of pelagic and benthic species, which can be seen in the first ten species. More than 44% of the community is comprised of the three most common species: Northern Anchovy, Pacific Staghorn Sculpin and Shiner Surfperch.

The community actually observed in the Bay included Northern Anchovy, Pacific Staghorn Sculpin, and Shiner Surfperch as three of the most common species, with between 80% (1975-1979) and 54% (2000-2004) of the community comprised of just

Northern Anchovy and Shiner Surfperch. Northern Anchovy was the most common species in the Bay during each time period sampled, and both Pacific Staghorn Sculpin and Shiner Surfperch were within the top 8 most common species during all time periods.

Although there were similarities in presence of species between the expected target and the observed Bay communities, there were differences in the relative abundances of each. In general, benthic species tended to be less abundant relative to the target community while pelagic tended to be overrepresented. This is clearly seen through the dominance of Northern Anchovy, leaving Pacific Staghorn Sculpin to occupy 0.1% of the community despite being the third most abundant species in the Bay from 1996-1999.

Overall, the target community analysis determined that the Bay is in fair environmental condition. This is in agreement with Moyle (2002) who claims that the presence of Shiner Surfperch in bays is a sign of good environmental quality. My analysis revealed that these species were in fact abundant up until the 1980s, and that they were more prevalent in the Bay from 2000-2004 than predicted by the target. Also, Shiner Surfperch were never underrepresented during other time periods; rather, they were present in proportions predicted by the target. In the section of the South Bay where data were collected, there does not seem to be a significant shortage of Shiner Surfperch. In contrast, Staghorn Sculpin, another indicator of high water quality when present in streams (Moyle 2002), was consistently underrepresented throughout all time periods in relation to the target. However, this is to be expected since freshwater streams enter the Bay in the upper, more northern parts of the estuary rather than the slightly more saline South Bay. Interestingly, the Threespine Sticklback is considered to be a hearty, tolerant fish (Moyle 2002) yet they are also underrepresented for all time periods. This is in disagreement with Leidy (Leidy 1984), who claims that they are one of the most prevalent species in the Bay.

Data reveal that Northern Anchovy are consistently the most overrepresented species in the Bay, both historically and today. This is in agreement with studies that explain high prevalence through abundant food availability for adults, and higher estuarine larvae survival than larvae off the coast at the same latitude (McGowan 1986). The large success of pelagic schooling fishes such as Northern Anchovy could be attributed to increased food availability caused by eutrophic conditions (Persson et al. 1991a; Persson et al. 1991b). In addition, the Pacific Ocean has experienced natural cyclic changes in anchovy abundance due to variations in environmental conditions (Chavez et al. 2003), and the California fish populations are well known to have human-induced peaks and collapses (Jackson et al. 2001). The specific increase in species abundance from 2005-2008 could be explained as a response to food web disruption from the invasive clam *Corbula amurensis*. Kimmerer (Kimmerer 2006) determined that in the North Bay, *C. amurensis* was reducing the phytoplankton blooms on which Northern Anchovy feed. This resulted in Northern Anchovy occupying more saline waters, such as the South Bay, in search of food. Overabundance of Northern Anchovy is therefore consistent with previously published research. Furthermore, Bain and Meixler (2008) found similar results in the Hudson River.

There were no significant differences in temperature tolerance or diet between over and underrepresented species; however, habitat did differ between the two groups. Underrepresented species tend to occupy benthic habitat (TSS, SHS, and AG) rather than pelagic (TS). This result can be explained in several ways. First, pelagic eutrophication could decrease benthic oxygen availability and indirectly cause a decline in macrofauna (Diaz and Rosenberg 1995). Hypoxic conditions reduce the quality of available food types and therefore exhibit bottom-up control on benthic fish. Pelagic food chains in the Chesapeake Bay have been shown to be unaffected by eutrophication, while changes in transfer of primary production and efficiency of nutrient cycling can negatively impact benthic habitats (Kemp et al. 2005). Similar conclusions have been documented in the Bay itself (Cloern 2001), and agree with Epping and Jorgensen's (Epping and Jorgensen 1996) exploration of the benthos. The second explanation is that a decrease in benthic species could be linked to toxic chemicals buried within the sediment. High mercury and PCB levels have been recorded both within the environment and within organisms in the Bay, and could be contaminating benthic fish directly (Davis *et al.* 2007). There are still documented cases of toxin accumulation within English soles in Vancouver Harbor, Canada (Bolton 2004). Their abundance in the Bay might be explained by the efforts of the Pacific Coast Groundfish Fishery Management Plan to maintain a large stock for consumption (NOAA 2008).

According to the target community analysis, restoration goals for the South San Francisco Bay should target pelagic eutrophication as well as sediment toxicity. By concentrating on these two areas of the environment, restoration efforts can focus on the most influential components of the system and hopefully result in greater improvement of the Bay. Benefits of using this methodology include efficient use of management resources, such as time and finances, as well as utilization of a more appropriate restoration goal. Although results from the methodology revealed findings similar to field and experimental studies, caution should be used when utilizing a target community approach to aquatic resource management. Extreme care should go into identifying and choosing reference sites, and if no proper reference sites exist, this methodology is not appropriate. The success of the analysis is therefore limited by the quality of chosen reference sites and available trawl data. The San Francisco Bay is a unique ecosystem on the Pacific coast, and deciding on appropriate, similar reference sites proved challenging. However, I have shown that the methodology is appropriate for estuarine systems as well as river systems, and can be implemented in other geographical locations besides the northeastern United States. Further analyses should be conducted in other aquatic systems in order to confirm its utility and ensure its use in future water resources management of a variety of systems.

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APPENDIX A

Spp Code	Species	Total Spp Abundance	**Rank**	Recip-Rank	**Proportion**	Cumulative Prop
NA	NORTHERN ANCHOVY	3.034722222	**1**	1	**0.24639674**	0.23954625
SHS	PACIFIC STAGHORN SCULPIN	2.472222222	**2**	0.5	**0.12319837**	0.362744622
SSP	SHINER PERCH	2.173611111	**3**	0.3333333	**0.08213225**	0.444876869
TS	TOPSMELT	2.069444444	**4**	0.25	**0.06159919**	0.506476055
AG	ARROW GOBY	1.666666667	**5**	0.2	**0.04927935**	0.555755404
TSS	THREESPINE STICKLEBACK	1.645833333	**6**	0.1666667	**0.04106612**	0.596821528
PH	PACIFIC HERRING	1.5625	**7**	0.1428571	**0.03519953**	0.632021063
CH	CALIFORNIA HALIBUT	1.5	**8**	0.125	**0.03079959**	0.662820656
LS	LEOPARD SHARK	1.3125	**9**	0.1111111	**0.02737742**	0.690198072
JS	JACKSMELT	1.291666667	**10**	0.1	**0.02463967**	0.714837746
DT	DIAMOND TURBOT	1.25	**11**	0.0909091	**0.0223997**	0.73723745
WC	WHITE CROAKER	1.25	**12**	0.0833333	**0.02053306**	0.757770512
SUR	SURF SMELT	1.013888889	**13**	0.0769231	**0.0189536**	0.776724108
BSB	BARRED SAND BASS	1	**14**	0.0714286	**0.01759977**	0.794323875
KB	KELP BASS	1	**15**	0.0666667	**0.01642645**	0.810750325
SF	STARRY FLOUNDER	1	**16**	0.0625	**0.0153998**	0.826150121
WS	WHITE STURGEON	1	**17**	0.0588235	**0.01449393**	0.840644047
PSL	PACIFIC SAND LANCE	0.8125	**18**	0.0555556	**0.01368871**	0.854332755
ES	ENGLISH SOLE	0.75	**19**	0.0526316	**0.01296825**	0.867301005
TC	PACIFIC TOMCOD	0.75	**20**	0.05	**0.01231984**	0.879620842
WSB	WHITE SEABASS	0.75	**21**	0.047619	**0.01173318**	0.89135402
LFS	LONGFIN SMELT	0.569444444	**22**	0.0454545	**0.01119985**	0.902553872
DBA	DEEPBODY ANCHOVY	0.5	**23**	0.0434783	**0.0107129**	0.913266774
LC	LINGCOD	0.5	**24**	0.0416667	**0.01026653**	0.923533305
CTT	CUTTHROAT TROUT (KELT)	0.4375	**25**	0.04	**0.00985587**	0.933389175
GS	GREEN STURGEON	0.4375	**26**	0.0384615	**0.0094768**	0.942865973
STH	STEELHEAD (WINTER)	0.395833333	**27**	0.037037	**0.00912581**	0.951991778
AS	AMERICAN SHAD	0.375	**28**	0.0357143	**0.00879988**	0.960791662
EUL	EULACHON	0.354166667	**29**	0.0344828	**0.00849644**	0.969288101
SAL	SALMON, SPP	0.335277778	**30**	0.0333333	**0.00821322**	0.977501326
SB	STRIPED BASS	0.291666667	**31**	0.0322581	**0.00794828**	0.985449608
SLO	SLOUGH ANCHOVY	0	**32**	0.03125	**0.0076999**	0.993149506
	Totals:	33.50194444		4.0584952		

APPENDIX B

Code	Common Name	Code	Common Name
AG	ARROW GOBY	ES	ENGLISH SOLE
AS	AMERICAN SHAD	EUL	EULACHON
BBC	BROWN BULLHEAD CATFISH	GBY	GOBY SP.
BDG	BEARDED GOBY	GRF	GRASS ROCKFISH
BFP	BAY PIPEFISH	GRU	CALIF (SILVERSIDE) GRUNION
BG	BAY GOBY	GS	GREEN STURGEON
BHS	BONYHEAD SCULPIN	HB	HALIBUT SP.
BLP	BIG SCALE LOG PERCH	HH	HORNYHEAD TURBOT
BOC	BOCACCIO ROCKFISH	HMP	HALF MOON PERCH
BP	BLACK PERCH	HNG	HORSENECK GAPER
BR	BAT RAY	IRL	IRISH LORD
BRF	BOLINAS ROCKFISH	JS	JACKSMELT
BRO	BROWN ROCKFISH	KB	KELP BASS
BS	BROWN SMOOTHHOUND	KF	KELP FISH
BSB	BARRED SAND BASS	KG	KELP GREENLING
BSC	BUFFALO SCULPIN	KP	KELP PIPEFISH
BSF	BLACKTAIL SNAILFISH	KS	KING SALMON
BSK	BIG SKATE	LC	LINGCOD
BSP	BARRED SURFPERCH	LFS	LONGFIN SMELT
CAL	CALICO SURFPERCH	LS	LEOPARD SHARK
CBZ	CABEZON	LSD	LONGFIN SANDDAB
CC	CHANNEL CATFISH	MFE	MONKEY FACE EEL
CG	CHAMELEON GOBY	MS	MUDSUCKER
CH	CALIFORNIA HALIBUT	NA	NORTHERN ANCHOVY
CK	CHINOOK SALMON	NFC	NO FISH CAUGHT
CK	CHINOOK SALMON (FALL)	NMS	NORTHERN MIDSHIPMAN
CK	CHINOOK SALMON (LATE FALL)	NP	NET PROBLEMS
CK	CHINOOK SALMON (SPRING)	NS	NIGHT SMELT
CK	CHINOOK SALMON (SUMMER)	NUL	NULL CATEGORY
CK	CHINOOK SALMON (WINTER)	OC	OCTOPUS
COT	C-O TURBOT	OLN	OVERLOADED NET
CRF	COPPER ROCKFISH	OP	OPALEYE PERCH
CRL	CURLFIN TURBOT	PB	PACIFIC BUTTERFISH
CSG	CHEEKSPOT GOBY	PEN	PENPOINT GUNNEL
CT	CALIFORNIA TONGUEFISH	PER	PACIFIC ELECTRIC RAY
CTT	CUTTHROAT TROUT (ADULT)	PET	PETRALE SOLE
CTT	CUTTHROAT TROUT (KELT)	PH	PACIFIC HERRING
DBA	DEEPBODY ANCHOVY	PHB	PACIFIC HALIBUT
DLS	DELTA SMELT	PL	PACIFIC LAMPREY
DSP	DOVER SOLE	PM	PACIFIC MACKEREL
DSP	DWARF SURFPERCH	PMS	PLAINFIN MIDSHIPMAN
DT	DIAMOND TURBOT	POM	POMPANO
EP	EEL POUT	PP	PRICKLEBREAST POACHER

APPENDIX B cont'd

Code	Common Name	Code	Common Name
PS	PACIFIC SARDINE	SQ	SQUID
RS	REX SOLE	SRF	SPECKLED ROCKFISH
PSD	PACIFIC SANDDAB	SS	SAND SOLE
PSL	PACIFIC SAND LANCE	SSD	SPECKLED SANDDAB
PSP	PILE SURFPERCH	SSN	SHOWY SNAILFISH
PT	PACIFIC TOMCOD	SSP	SHINER SURFPERCH
RED	REDTAIL SURFPERCH	SST	SACRAMENTO SPLIT TAIL
RF	ROCKFISH	STR	STRIPED SURFPERCH
RH	ROUND HERRING	STU	STURGEON SPECIES
RL	RED IRISH LORD	SUR	SURF SMELT
RP	REEF PERCH	TC	TOMCOD
RSP	RAINBOW SURFPERCH	TF	TREEFISH
RUB	RUBBERLIP SURFPERCH	TFS	THREADFIN SHAD
SAL	CHUM SALMON	THS	THORNY SCULPIN
SAL	COHO SALMON	TP	TULE PERCH
SAL	PINK SALMON	TPS	TIDEPOOL SCULPIN
SAL	SALMON SPECIES	TR	THORNBACK RAY
SAL	SOCKEYE SALMON	TS	TOPSMELT
SB	STRIPED BASS	TSS	THREESPINE STICKLEBACK
SBG	SADDLEBACK GUNNEL	UG	UNKNOWN GOBY SPECIES
SC	SCULPIN SP.	UMS	UNIDENTIFIED MIDSHIPMAN
SCA	SCALYFIN SOLE	US	UNKNOWN SOLE SPECIES
SD	SANDDAB SP.	USP	UNKNOWN SURFPERCH
SDF	SPINY DOGFISH	WBS	WHITEBAIT SMELT
SF	STARRY FLOUNDER	WC	WHITE CROAKER
SFS	SPOTFIN SURFPERCH	WHS	WHITE SURFPERCH
SGF	SHOVELNOSE GUITARFISH	WOS	WOOLY SCULPIN
SGS	SEVENGILL SHARK	WS	WHITE STURGEON
STH	STEELHEAD (FALL)	WSB	WHITE SEABASS
STH	STEELHEAD (HALF POUNDER)	WSP	WALLEYE SURFPERCH
STH	STEELHEAD (SUMMER)	YG	YELLOWFIN GOBY
STH	STEELHEAD (WINTER)	YR	YELLOWTAIL ROCKFISH
SH	UNIDENTIFIED SHAD		
SHI	SHIMOFURI GOBY		
SHO	SHOKIHAZE GOBI		
SHS	PACIFIC STAGHORN SCULPIN		
SIL	SILVER SURFPERCH		
SIS	SILVERSIDE		
SLO	SLOUGH ANCHOVY		
SM	SMELT SP.		
SMS	SPECKED FIN MIDSHIPMAN		
SN	SNAILFISH SP.		
SPT	SPOTTED TURBOT		

APPENDIX C

Year	Trawls	Species Caught	Fish Caught
1970	43	45	3688
1971	387	77	32212
1972	464	56	49401
1973	362	53	103173
1974	261	46	41086
1975	318	61	23998
1976	382	53	20803
1977	335	61	11783
1978	278	50	52167
1979	260	50	36950
1980	279	45	19579
1981	279	49	53217
1982	1	7	9
1983	0	0	0
1984	0	0	0
1985	35	26	296
1986	111	38	2685
1987	0	0	0
1988	0	0	0
1989	1	2	8
1990	0	0	0
1991	0	0	0
1992	154	37	14921
1993	607	46	37629
1994	603	45	34042
1995	547	40	68659
1996	461	44	25291
1997	482	50	42023
1998	594	45	42673
1999	370	53	14718
2000	194	41	10251
2001	230	48	17570
2002	456	68	45548
2003	284	63	27197
2004	241	66	16538
2005	251	51	19489
2006	281	43	28611
2007	240	51	16056
2008	179	47	10460