The prevalence of non-indigenous species in southern California embayments and their effects on benthic macroinvertebrate communities

Tim K. Mikel[1], Ronald G. Velarde[2], J. Ananda Ranasinghe, Stephen B. Weisberg, David E. Montagne[3], Donald B. Cadien[4], Robert W. Smith[5], and Ann Dalkey[6]

ABSTRACT - The prevalence of non-indigenous species (NIS) in southern California embayments was assessed from 123 Van Veen grab samples collected in nine bays and harbors during the summer of 1998. NIS occurred in all but two samples. They accounted for only 4.3% of the 633 taxa but contributed 27.5% of the abundance. There was no significant difference in the proportion of NIS abundance among ports harboring large vessels, small boat marinas, and areas where boats were not moored. Three species accounted for 92% of the NIS abundance: a spionid polychaete worm *Pseudopolydora paucibranchiata*, a mytilid bivalve *Musculista senhousia*, and a semelid bivalve *Theora lubrica*. The NIS did not appear to have a negative impact at the overall community level since NIS abundance was positively correlated with the abundance and richness of other species. This may be due to biogenic structures built by *P. paucibranchiata* and *M. senhousia* that enhance the abundances of other macrofauna.

INTRODUCTION

Non-indigenous species (NIS) represent a potential threat to the integrity of natural ecosystems. They have been known to change community structure through elimination of native species, change primary production and nutrient cycling, and even alter weather patterns (Grosholz *et al.* 2000). The Asian Clam *Potamocorbula amurensis* invasion of San Francisco Bay was closely correlated with the shutdown of the spring plankton bloom (Alpine and Cloern 1992); primary production was transferred from the pelagic ecosystem to the benthic ecosystem as a result of suspension feeding by the clam. Intense grazing by the introduced periwinkle *Littorina littorea* in Rhode Island affected sediment accumulation and changed the local environment from soft sediments to hard substrate (Bertness 1984). The estimated cost of NIS-induced damage has been estimated at $314 billion per year (Pimentel *et al.* 2001).

Marine and estuarine systems are particularly vulnerable to NIS invasion, stemming, in part, from human-mediated transport of non-native species in the ballast water of ships (Grosholz 2002). Global movement of ballast water appears to be the largest single vector of NIS (Ruiz *et al.* 1997). Fouling organisms such as barnacles, bryozoans and hydroids, and wood-boring bivalves are also transported on the hulls of ships (Cohen and Carlton 1995).

Non-indigenous species assessments of marine and estuarine systems on the west coast of the United States have focused mostly on San Francisco Bay (Carlton 1979, Grosholz 2002). There have been few assessments of southern California since Carlton (1979) recognized the problem, despite the presence of some of the world's largest ports. Los Angeles/ Long Beach Harbor is home to the busiest port in the United States, San Diego is a major base for the U.S. Navy, and Marina Del Rey Harbor is the largest artificial small craft harbor in the world. Here, we assess the prevalence of NIS in benthic

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[1] *Aquatic Bioassay and Consulting Laboratories, Inc., 29 North Olive St., Ventura, CA 93001*

[2] *City of San Diego, 4918 N. Harbor Dr., Ste 101, San Diego, CA 92106*

[3] *County Sanitation Districts of Los Angeles County, P.O. Box 4998, Whittier, CA 90607*

[4] *Private consultant, P.O. Box 1537, Ojai, CA 93024*

[5] *City of Los Angeles, Environmental Monitoring Div., 12000 Vista del Mar, Playa del Rey, CA 90293*

macroinvertebrate communities of southern California bays and harbors and their potential impacts on native communities.

METHODS

Benthic samples were collected from 123 sites in 9 southern California bays and harbors between July 13 and September 16, 1998. Sampling sites were selected using a stratified random design with port areas that service large ocean-going ships, small boat marinas with recreational vessels, and other areas where boats were not moored as the strata. At each sampling site, sediment samples for benthic infaunal analysis were collected using a 0.1 m^2 Van Veen grab and sieved through a 1 mm mesh screen. Only samples penetrating at least 5 cm into the sediment and with no evidence of washout or slumping were processed. Material retained on the screen was placed in a relaxant solution of 1 kg $MgSO_4$ or 30 ml propylene phenoxytol per 20 L of seawaterfor at least 30 minutes and preserved in 10% sodium borate buffered formalin. In the laboratory, specimens were transferred to 70% ethanol, sorted, identified to the lowest practical level (most often species), and enumerated.

We adopted the techniques and definitions of Lindroth (1957), Carlton (1979), Chapman (1988), Chapman and Carlton (1991, 1994), and T N & Associates Inc. (2001) to identify NIS on our species list based on their taxonomy, biology, and history of occurrence in southern California (Table 1). Native (indigenous) species are populations occurring within their natural range and without the aid of human activities (T N & Associates Inc. 2001). The NIS are populations outside their natural range that were introduced intentionally or accidentally by humans. Introduced species are defined as reproductive populations of species or subspecies established by human activities outside their previous natural range. Cryptogenic organisms are neither demonstrably native nor introduced (Cohen and Carlton 1995).

To assess whether the NIS had an effect on benthic communities, we used correlation analysis to quantify associations between NIS abundance and two community measures: total abundance and number of taxa. The analysis was repeated with NIS removed to assess the effects on native and cryptogenic species only. All measures were log-transformed prior to correlation analysis. The analysis of variance (ANOVA) was used to assess whether vessel traffic affected the proportion of NIS abundance; the arcsine-transformed proportion of NIS abundance was tested among sites in ports, marinas, and other areas.

RESULTS

Twenty-seven of the 633 species collected (4.3%) were NIS. They occurred at 121 of the 123 sites and accounted for 27.5% of the abundance. The percentage of NIS taxa was relatively consistent among the nine bays and harbors (Figure 1, Table 2). The abundance of NIS was more variable and also showed no pattern with respect to size or the type of vessel traffic. There was no significant difference in the relative abundance of NIS between ports, marinas, and other areas.

Three species (*Pseudopolydora paucibranchiata*, a spionid polychaete worm; *Musculista senhousia*, a mytilid bivalve; and *Theora lubrica*, a semelid bivalve) accounted for 91% of NIS abundance (Table 3). *P. paucibranchiata* was the most abundant species at five embayments (Channel Islands Harbor, Dana Point Harbor, Los Angeles/Long Beach Harbor, Marina Del Rey, and Mission Bay) and *M. senhousia* at two embayments (Newport Bay and San Diego Harbor); *T. lubrica* was the abundance dominant only in Anaheim Bay.

The NIS abundance was strongly and positively correlated with total abundance and numbers of species (Table 4). The strongest relationship was with total abundance (r = 0.72). The correlation with number of taxa was weak (r = 0.39) although significant.

To assess effects on native and cryptogenic species, the correlation between NIS abundance and community abundance was repeated with NIS subtracted from the total abundance. The correlation was still positive (r = 0.52) and significant. There was also a significant positive correlation between NIS abundance and the number of native and cryptogenic species (r = 0.34).

DISCUSSION

Embayments in southern California are highly invaded by non-native macrofauna with NIS encountered at 121 of 123 sites. More than a quarter of the animals collected were non-indigenous. Relative abundances in San Francisco Bay, the only west coast area that has been intensively studied, are even

Table 1. Non-indigenous species in southern California embayments. Nomenclature follows SCAMIT (2001). *= First report of taxon as NIS.

Taxon	Original Locality	References
Annelida: Polychaeta		
*Brania mediodentata**	Galapagos	Westheide 1974
Diplocirrus sp. SD1*	Probably Arctic	Rowe 1998; Ruff 1996
*Eteone aestuarina**	El Salvador	Hartmann-Schroder 1959
Neanthes acuminata	Unknown	T N & Associates Inc. 2001
*Nephtys simoni**	Florida	Hilbig 1994
Polydora cornuta	U.S. east coast	T N & Associates Inc. 2001
Pseudopolydora paucibranchiata	Japan	T N & Associates Inc. 2001; Carlton 1979
Streblospio benedicti	U.S. east coast	Carlton 1979
Syllis (Typosyllis) nipponica	Japan	T N & Associates Inc. 2001
Arthropoda: Crustacea: Amphipoda		
Aorides secundus	Japan	Cohen *et al.* 2002
Caprella natalensis	Unknown	T N & Associates Inc. 2001
Eochilidium sp. A	Unknown	T N & Associates Inc. 2001
Grandidierella japonica	Japan	T N & Associates Inc. 2001; Chapman and Dorman 1975
Liljeborgia sp. (red/white fouling)	Unknown	Cohen *et al.* 2002
Listriella sp. A*	Unknown	SCAMIT 1987
Paradexamine sp. SD1*	Unknown	Pasko 1999
Sinocorophium heteroceratum	Western Pacific (China)	Chapman and Cole 1994; T N & Associates Inc. 2001
Arthropoda: Crustacea: Isopoda		
Paracerceis sculpta	Unknown	T N & Associates Inc. 2001
Arthropoda: Crustacea: Mysidacea		
Deltamysis sp. A*	Unknown	Possibly *D. holmquistae* Bowman and Orsi 1992
Mollusca: Bivalvia		
Musculista senhousia	Japan	T N & Associates Inc. 2001; Carlton 1979
Theora lubrica	Western Pacific (Japan)	T N & Associates Inc. 2001; Carlton 1979
Venerupis phillippinarum	Japan	T N & Associates Inc. 2001; Carlton 1979
Mollusca: Gastropoda		
Philine auriformis	New Zealand	Gosliner 1995; T N & Associates Inc. 2001
Philine sp. A*	Unknown	SCAMIT 1988
Cnidaria: Anthozoa		
Bunodeopsis sp. A	Gulf of California	Ljubenkov 1998; Cohen *et al.* 2002
Chordata: Ascidiacea		
Microcosmus squamiger	Australia	Lambert and Lambert 1998
Styela plicata	Unknown	Lambert and Lambert 1998

higher. Lee *et al.* (in preparation) found that over 45% of abundance was due to NIS in six of seven San Francisco Bay habitats; NIS accounted for over 90% of abundance in two of them. Comparable levels of invasion in southern California were observed only in Marina Del Rey and Dana Point Harbor. The proportion of diversity contributed by NIS was also higher in San Francisco Bay, where 11% of the species were classified as NIS in contrast to 4% in our study.

Sampling the same southern California embayments in summer 2000, Cohen *et al.* (2002) found much greater diversity of NIS on hard substrates than in the soft-bottom benthos where our samples were collected. They collected 65 NIS from floating structures at 21 sites and only 13 NIS from 13 benthic sampling sites. The 65 species they collected from floating structures at 21 sites was more than double the 27 we found at our 123 benthic sampling sites. Unfortunately, their sampling was non-quantitative so direct comparisons of abundance could not be made.

Ballast water is typically the largest vector of NIS (Ruiz *et al.* 1997), but the patterns of NIS distribution we observed were unrelated to boating and shipping activity. Large ocean-going vessels with ballast water do not enter small-boat marinas such as Marina Del Rey Harbor, so secondary migrations of

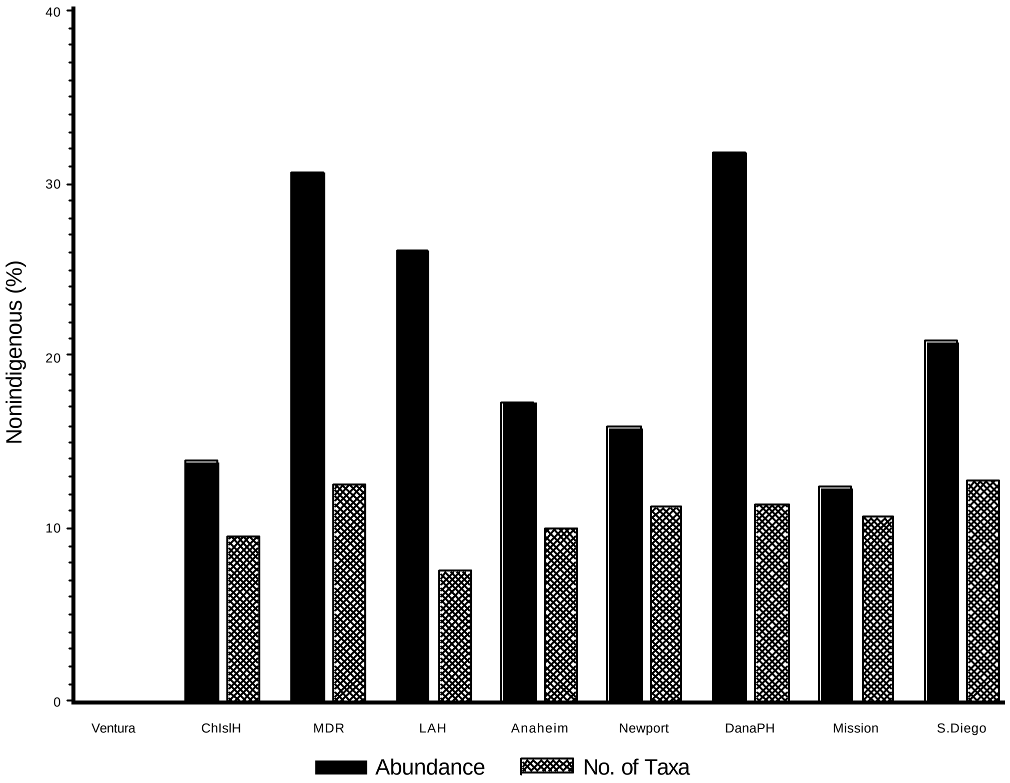

Figure 1. Mean NIS abundance and numbers of taxa for nine southern California embayments. Ventura: Ventura Harbor; ChIslH: Channel Islands Harbor; MDR: Marina Del Rey; LAH: Los Angeles/Long Beach Harbor; Anaheim: Anaheim Bay; Newport: Newport Bay; DanaPH: Dana Point Harbor; Mission: Mission Bay; S. Diego: San Diego Bay.

Table 2. Mean abundances and numbers of non-indigenous species in nine southern California embayments.

		Abundance		No. of Taxa	
Embayment	Sites	Mean (m^{-2})	Percent of Total	Site Mean	Percent of Total
Ventura Harbor	1	0.0	0.0	0	0.0
Channel Islands Harbor	3	440.0	13.9	2.67	9.3
Marina Del Rey	7	5,600.0	30.7	2.43	12.4
Los Angeles/Long Beach Harbor	46	1,165.0	26.2	2.26	7.2
Anaheim Bay	3	560.0	17.3	3.67	9.3
Newport Bay	11	1,033.6	15.9	4.36	10.6
Dana Point Harbor	3	1,143.3	31.9	3.67	10.6
Mission Bay	3	2,503.3	12.5	8.67	9.6
San Diego Bay	46	1,998.5	20.9	5.17	11.7
Overall Mean	123	1,707.6	22.6	3.76	9.7

Table 3. Mean abundances (m^{-2}) of non-indigenous species in southern California embayments. VH= Ventura Harbor; CIH=Channel Islands Harbor; MDR=Marina Del Rey; LA/LB=Los Angeles/Long Beach Harbor; AB=Anaheim Bay; NB=Newport Bay; DPH=Dana Point Harbor; MB=Mission Bay; SDB=San Diego Bay; Percent: Contribution to NIS abundance (%).

Name	VH	CIH	MDR	LA/LB	AB	NB	DPH	MB	SDB	%
Pseudopolydora paucibranchiata		283.3	5,520.0	619.6	83.3	267.3	763.3	773.3	720.0	51.855
Musculista senhousia			2.9	0.2	10.0	434.6		503.3	854.6	21.740
Theora lubrica		13.3	12.9	476.3	353.3	200.0	13.3	336.7	255.9	18.150
Diplocirrus sp. SD1					16.7			100.0	86.7	2.066
Grandidierella japonica		106.7	34.3	9.4		3.6	353.3	76.7	28.7	1.733
Neanthes acuminata Complex		20.0	1.4			0.9	6.7	463.3	2.6	0.767
Sinocorophium cf heteroceratum				33.5						0.733
Polydora cornuta			14.3	10.7		38.2			3.7	0.562
Paradexamine sp. SD1			1.4			40.9	6.7	16.7	9.4	0.457
Bunodeopsis sp. A								120.0	6.7	0.319
Brania mediodentata								40.0	11.5	0.310
Paracerceis sculpta						3.6		50.0	7.0	0.243
Venerupis philippinarum				0.2		35.5				0.190
Philine auriformis		16.7		6.5		1.8				0.176
Eochelidium sp. A				3.3	70.0					0.171
Eteone aestuarina								6.7	5.2	0.124
Philine sp. A				4.4	10.0	2.7				0.124
Streblospio benedicti			12.9			4.6			0.4	0.076
Syllis (Typosyllis) nipponica				0.9					2.2	0.067
Deltamysis sp. A					16.7				0.9	0.043
Nephtys simony									1.7	0.038
Aoroides secundus								13.3		0.019
Listriella sp. A									0.7	0.014
Microcosmus squamiger								3.3	0.2	0.010
Caprella natalensis				0.2						0.005
Liljeborgia sp.									0.2	0.005
Styela plicata									0.2	0.005

Table 4. Pearson correlation coefficients between NIS abundance and numbers of taxa and other community measures. ***: $p<0.001$; **: $p<0.01$.

	Total Abundance (sample^{-1})	Non-NIS Abundance (sample^{-1})	No. of Taxa (sample^{-1})	Non-NIS Taxa (sample^{-1})
NIS Abundance (sample^{-1})	0.72***	0.52***	0.39***	0.34***
No. of NIS taxa (sample^{-1})	0.68***	0.58***	0.32***	0.24**

NIS from initial points of introduction in larger harbors are likely mechanisms. Small boats transiting from larger harbors such as Los Angeles, Long Beach, and San Diego may be a source of NIS invasions, although there is no direct evidence to support this. Secondary movements of NIS from initial points of introduction have been documented frequently, but mechanisms must be established on a case-by-case basis. Applying the recently developed DNA methods (Bagley and Geller 2000) in future studies would be one way to determine whether sources of new populations are native habitat or previously invaded embayments.

The NIS species, while generally very good colonizers with high reproductive potential, are not typically the best competitors. When resources are limiting, better-adapted native species should gradually outcompete introduced species. Food and space are probable arenas of conflict between native and NIS taxa. Where disturbance is frequent, opening new space for colonization, NIS should rapidly colonize and monopolize the spatial resource to the detriment and potential exclusion of natives. This imbalance would gradually be redressed in the absence of further disturbance by the competitive disadvantage of NIS taxa. Disturbance at intermediate levels could potentially keep these two opposed influences in balance, allowing persistence of diverse native and large NIS populations within the same benthic community.

In many previous studies, NIS were found to have a negative impact on native species (Englund 2002, Grosholz *et al.* 2000, Nichols *et al.* 1990). In contrast, we found NIS to be associated with higher native and cryptogenic diversity and abundance. There are several possible explanations for the observed coexistence of large NIS populations with a diverse native community. One possibility is that resources are not limiting and, consequently, there is little or no direct competition between NIS and natives. Alternatively, disturbance at intermediate levels, as previously discussed, may be maintaining and enhancing both populations. A third and most likely possibility is that the presence of NIS increases available resources, enhancing native abundance. Gallagher *et al.* (1983) found that several benthic animals, including species of *Pseudopolydora* (*P. paucibranchiata* was the most abundant NIS in southern California), enhanced native recruitment on artificially created azoic patches by modifying the physical environment. *Pseudopolydora* is a small tube-dwelling worm and the aggregates of its tubes substantially enhance benthic habitats, especially when present in large numbers as in our study. *M. senhousia*, the second most abundant NIS in our study, weaves thick mats of byssal threads. Crooks and Khim (1999) and Mistri (2002) found that mussel mats of *M. senhousia* facilitate the presence of other macrofaunal taxa.

Despite the apparent stimulation of southern California benthic abundance and diversity by NIS, it is possible that one or more individual native species are being negatively impacted. Our results are based on overall abundance and diversity at a gross community level. The possibility that NIS are negatively impacting individual native species or otherwise negatively affecting southern California's bay and harbor macrofaunal communities should not be dismissed without more species-specific examination.

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