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Rapid Assessment Survey for exotic organisms in southern California bays and harbors, and abundance in port and non-port areas

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Abstract

In recent decades, the world has witnessed an array of harmful invasions by exotic marine organisms. To provide the public and policymakers with better information on the status of exotic species in southern California waters, and to assess differences between port and non-port areas, a Rapid Assessment Survey of selected habitat types in sheltered waters between San Diego and Oxnard was conducted in the summer of 2000. The objectives included comparing the prevalence of exotic species among habitats and regions and between recent and past surveys; obtaining reference data for future assessments of changes in invasion status and the effectiveness of prevention or control efforts; detecting new invasions; and documenting significant range extensions. Twenty-two sites were sampled to include the three major commercial port areas in southern California, non-port-area marinas and lagoon sites. Sampling included dock fouling and adjacent soft-bottom benthos, nearby intertidal sites, and selected subtidal lagoon habitats. Samples were collected by a variety of manual techniques. Sixty-nine of the species collected are exotic, including representatives from two algal divisions and six invertebrate phyla. Ascidians are especially well-represented (14 exotic species) and widely occurring, and some bivalves and bryozoans also occur very widely. The numbers and proportions of exotic taxa were not significantly greater in port areas than in non-port areas.

Introduction

Over the past decade, several literature reviews and field surveys have documented the number and extent of exotic species in different marine and estuarine regions, and the role of commercial shipping in transporting exotic species to new regions in ballast tanks and as hull fouling (Cohen and Carlton 1995, 1998; Cohen et al. 1998, 2001; Ruiz et al. 2000; Wasson et al. 2001). One commonly suggested invasion pattern holds that the importance of commercial shipping as a pathway should produce a greater density and diversity of exotic organisms near port areas (e.g. Wasson et al. 2001).

In August 2000 we conducted a field survey for exotic species in selected habitats of southern California bays and harbors. Our objectives were to develop a list of exotic species; to detect newly-arrived species and document range extensions; to compare the number and percentage of exotic species in different habitats and regions; and to develop reference data for future assessments of both native and exotic species and of the effectiveness of prevention or control efforts. To produce as complete a species list as possible given the resources available, we used non-quantitative, 'directed-search' sampling by a team of taxonomic experts. We report here on the survey's general results and on exotic species abundance in port and non-port areas.

Materials and methods

Twenty-two sites were sampled to represent the three commercial port areas in southern California (San Diego, Los Angeles/Long Beach and Port Hueneme), non-port-area marinas and lagoon sites from about 32.5° to 34° N latitude (Table 1; Figure 1). Site co-ordinates were measured with a hand-held Garmin-12 GPS unit and near-surface salinity and temperature were measured with two refractometers and thermometers and averaged. At each site, samples were collected during a period of approximately one hour using a variety of manual techniques. The survey participants (co-authors on this paper) attempted to sample the full range of biotic assemblages represented by the available substrates and microhabitats in order to maximize the number of species collected. Float fouling (organisms growing on the sides and undersides of floating docks and associated bumpers, tires, ropes, etc.) and fouling on fixed subtidal and intertidal structures (pilings, bridge supports, etc.) were sampled with scrapers and other hand implements. Benthic samples were taken with a $0.0225\ m^2$ Ponar grab and washed onto a 0.5 mm sieve, and at two sites intertidal and shallow subtidal benthic mollusks were sampled by hand. The samples were transported on ice in insulated coolers to laboratories at the Natural History Museum of Los Angeles County (NHMLAC) and the San Diego Ocean Monitoring Laboratory, where they were sorted and identified to lowest possible taxon. Specimens were fixed and preserved by appropriate techniques and deposited with NHMLAC.

Organisms were classified by origin status as native, cryptogenic or exotic. Organisms that were not identified to a sufficiently low taxon to determine their origin status were classified as indeterminate. In most cases determinate organisms were identified to species, but in a few cases higher taxon identification allowed determination of origin status (for example, identification to genus when the genus is known only from other ocean regions [and therefore exotic status], or when all known species in the genus are native to the study region [and therefore native status]). Criteria 1–3 and 6–9 of Chapman and Carlton (1994) were used to determine origin status (1. was previously unknown in the region; 2. has expanded its range in the region; 3. is associated with a human dispersal mechanism; 6. has a restricted or discontinuous distribution in the region compared to native species; 7 and 8. has a disjunct global distribution not explained by its natural dispersal capability; 9. belongs to an otherwise exotic taxonomic group). Criterion 4, 'association with or dependency on other introduced species,' was used as evidence of exotic status only if the association or dependency appeared to be obligate or near-obligate. We did not consider criterion 5, 'prevalence on or restriction to new or artificial environment(s),' to be sufficiently discriminatory to use as evidence of exotic status.

We used non-parametric Spearman rank coefficients to check site latitudes, salinities and temperatures for significant correlations. We treated the number of species classified as exotic, and the number classified as either exotic or cryptogenic ('exotic/cryptogenic'), as low and high estimates, respectively, of the true number of exotic species among those collected and identified, and included both in our analyses. We used non-parametric Wilcoxon rank sums to assess differences in the number of exotic species and the percentage of determinate species that are exotic in port area sites (sites in San Diego Bay, Los Angeles/Long Beach harbors or Port Hueneme)

Table 1. Sampling sites.

Site number	Site name (location)	County	Latitude (N)	Longitude (W)	Date sampled	Area type	Salinity (ppt)	Temperature (°C)
01	Chula Vista Boat Ramp (San Diego Bay)	San Diego	32°37′16″	117°06′11″	8/26/2000	Port	36.5	27
02	Fiddler's Cove (San Diego Bay)	San Diego	32°39′07″	117°08′58″	8/26/2000	Port	35.5	26
03	Shelter Island (San Diego Bay)	San Diego	32°42′36″	117°14′03″	8/26/2000	Port	35.5	23.5
04	Seaforth Landing (Mission Bay)	San Diego	32°45′52″	117°14′17″	8/28/2000	Non-port	34.5	21
05	San Dieguito Lagoon	San Diego	32°58′04″	117°15′35″	8/28/2000	Non-port	18.5	24
06	Snug Harbor Marina (Agua Hedionda Lagoon)	San Diego	33°08′52″	117°19′56″	8/28/2000	Non-port	35	23
07	Oceanside Harbor	San Diego	33°12′34″	117°23′41″	8/28/2000	Non-port	34.5	22.5
08	Huntington Harbor Yacht Club (Anaheim Bay)	Orange	33°42′45″	118°03′40″	8/31/2000	Non-port	34	22.5
09	Long Beach Yacht Club (Alamitos Bay)	Los Angeles	33°45′13″	118°06′51″	8/31/2000	Non-port	34	20.8
10	Colorado Lagoon (Alamitos Bay)	Los Angeles	33°46′16″	118°08′05″	8/31/2000	Non-port	34	22
11	Long Beach Downtown Marina	Los Angeles	33°45′29″	118°11′22″	8/30/2000	Non-port	35	21
12	Pilots' Dock (Long Beach Harbor)	Los Angeles	33°44′50″	118°12′56″	8/30/2000	Port	34.5	19.5
13	Impound Marina (Long Beach Harbor)	Los Angeles	33°45′50″	118°14′40″	8/30/2000	Port	34.5	20.5
14	Newmarks Yacht Harbor (Los Angeles Harbor)	Los Angeles	33°45′52″	118°14′59″	8/24/2000	Port	34	22
15	Island Yacht Anchorage (Los Angeles Harbor)	Los Angeles	33°46′22″	118°14′52″	8/24/2000	Port	31.5	22.5
16	Watchorn Basin (Los Angeles Harbor)	Los Angeles	33°43′13″	118°16′35″	8/24/2000	Port	34.5	21.5
17	Cabrillo Beach Boat Ramp (Los Angeles Harbor)	Los Angeles	33°42′47″	118°16′06″	8/24/2000	Port	35	20
18	King Harbor	Los Angeles	33°50′47″	118°23′49″	8/29/2000	Non-port	34.5	24
19	Marina del Rey	Los Angeles	33°58′20″	118°27′08″	8/29/2000	Non-port	34.5	23
20	Hueneme Sportfishing Dock (Port of Hueneme)	Ventura	34°08′53″	119°12′07″	8/25/2000	Port	35	19
21	Jack's Landing (Channel Islands Harbor)	Ventura	34°09′49″	119°13′22″	8/25/2000	Non-port	35.5	20
22	Anacapa Isle Marina (Channel Islands Harbor)	Ventura	34°10′23″	119°13′37″	8/25/2000	Non-port	35	20

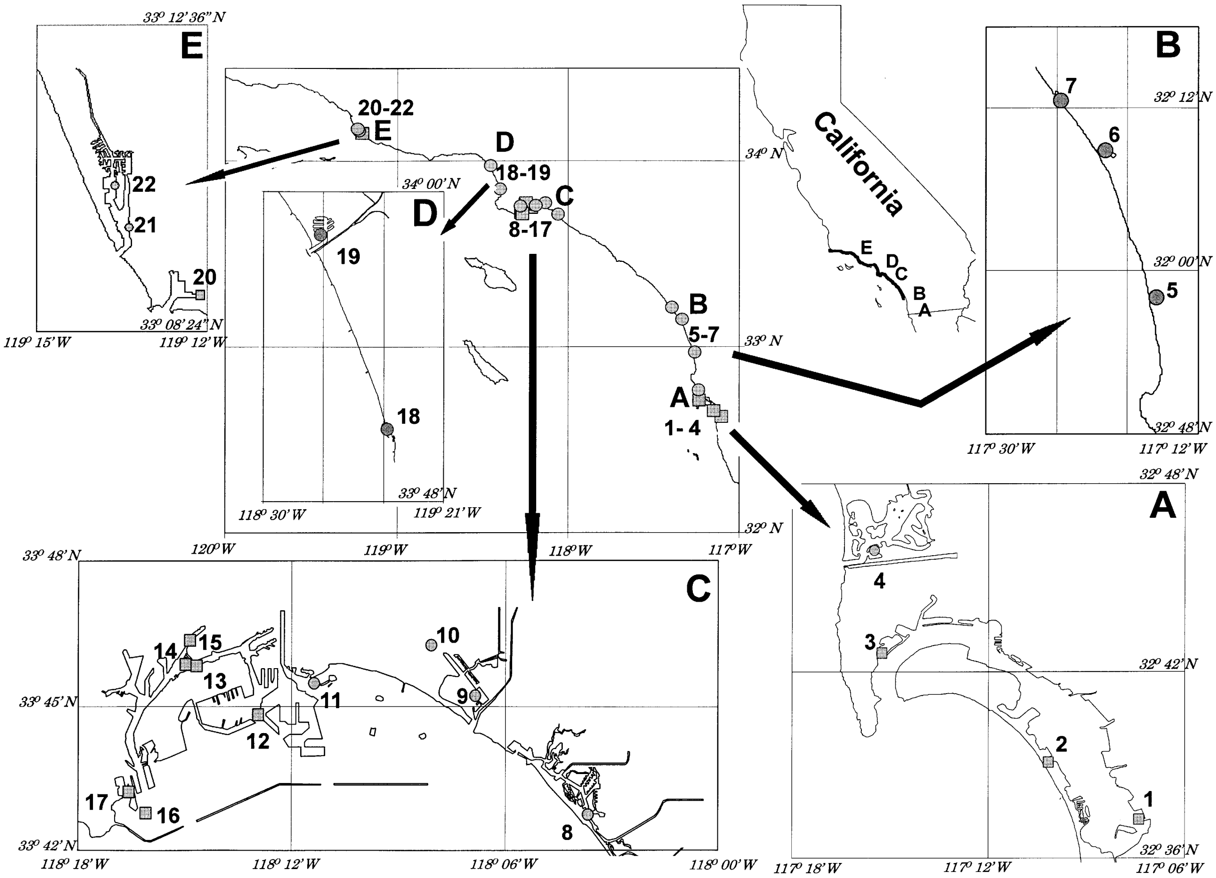

Figure 1. Sampling sites, numbered as in Table 1. Port area sites marked by squares, and non-port area sites by circles.

vs non-port area sites (all others). To test departures from expected counts of the total number of native, cryptogenic and exotic species in port and non-port area sites, we applied likelihood-ratio (chi-squared) tests to the species unique to either port or non-port areas, since shared species provide no information on differences between these areas. All statistical analyses were conducted with JMP version 5 software.

Results

The salinity ranged from 34 to 36.5 ppt at most sites, with lower values of 31.5 ppt at Site 15 (Island Yacht Anchorage, at the mouth of the Dominguez Channel in Los Angeles Harbor) and 18.5 ppt for Site 5 (San Dieguito Lagoon) (Table 1). Surface water temperature ranged from 19.5 to 27 °C (Table 1) and was negatively correlated with latitude (Spearman's $r_s = -0.53$, $P = 0.012$). We collected and identified float fouling at 20 sites, organisms in benthic grabs at 11 sites, intertidal barnacles on pilings and benthic mollusks each at 9 sites, and subtidal fixed-structure fouling at 2 sites.

Of the 286 determinate taxa, 69 (24%) were classified as exotic and 51 (18%) as cryptogenic (Table 2). The exotic organisms included representatives of eight high-level taxonomic groups, with mollusks (all of them bivalves), arthropods (mainly crustaceans), bryozoans, tunicates and annelids (all polychaetes) being especially widespread (Table 3). The most widely-occurring species were the mussel *Mytilus galloprovincialis*[1] (collected at all 22 sites), the cheilostome bryozoans *Watersipora subtorquata* (20 sites) and *Bugula neritina* (17 sites), and the sea squirts *Ciona intestinalis* (19 sites), *Styela clava* (19 sites), *Styela plicata* (19 sites), *Botrylloides violaceus* (16 sites)

Table 2. Number of taxa collected by habitat, and exotic and cryptogenic fractions of determinate taxa. For each habitat, data are given for: all sites/port area sites/non-port area sites.

	Floats	Benthic grabs	Other benthic mollusks	Intertidal barnacles on pilings	Subtidal fixed structures	All habitats/methods
Number of sites sampled	20 / 10 / 10	11 / 5 / 6	9 / 3 / 6	9 / 4 / 5	2 / 0 / 2	22 / 10 / 12
Native taxa	132 / 95 / 91	35 / 16 / 23	16 / 1 / 16	2 / 2 / 2	8 / – / 8	166 / 109 / 118
Cryptogenic taxa	47 / 40 / 31	11 / 6 / 8	0 / 0 / 0	0 / 0 / 0	3 / – / 3	51 / 43 / 34
Exotic taxa	65 / 59 / 49	13 / 9 / 10	2 / 1 / 1	1 / 1 / 1	21 / – / 21	69 / 61 / 55
Total determinate taxa	244 / 194 / 171	59 / 31 / 41	18 / 2 / 17	3 / 3 / 3	32 / – / 32	286 / 213 / 207
Exotic fraction	0.27 / 0.30 / 0.29	0.22 / 0.29 / 0.24	0.11 / 0.50 / 0.06	0.33 / 0.33 / 0.33	0.66 / – / 0.66	0.24 / 0.29 / 0.27
Cryptogenic fraction	0.19 / 0.21 / 0.18	0.19 / 0.19 / 0.20	0 / 0 / 0	0 / 0 / 0	0.09 / – / 0.09	0.18 / 0.2 / 0.16
Indeterminate taxa	103 / 76 / 60	33 / 27 / 12	2 / 1 / 1	1 / 0 / 1	10 / – / 10	123 / 91 / 72

Table 3. Species diversity and frequency of collection, by major taxonomic groups.

Major taxon	Number of taxa collected			Number of sites where collected		
	Native	Cryptogenic	Exotic	Native	Cryptogenic	Exotic
Chlorophyta (green algae)	1	4	0	1	5	0
Phaeophyta (brown algae)	3	1	2	8	1	6
Rhodophyta (red algae)	9	3	1	7	2	3
Other Protoctista	0	1	0	0	1	0
Porifera (sponges)	1	2	0	15	11	0
Cnidaria (hydroids, anemones, etc.)	12	4	3	14	8	12
Platyhelminthes (flatworms)	3	0	0	5	0	0
Nemertea (ribbon worms)	1	0	0	1	0	0
Annelida (segmented worms)	21	13	13	20	17	19
Mollusca (clams, etc.)	51	2	5	22	6	22
Arthropoda (crustaceans, etc.)	37	13	26	21	19	22
Bryozoa	8	3	5	18	9	21
Echinodermata (sea stars, etc.)	4	0	0	8	0	0
Tunicata (sea squirts)	8	4	14	21	17	21
Chordata: Pisces (fish)	7	0	0	4	0	0

Table 4. Fraction of determinate species that are exotic or exotic/cryptogenic.

	Floats	Benthic grabs	Other benthic mollusks	Intertidal barnacles on pilings	Subtidal fixed structures
Exotic					
Per site[a]	0.28–0.69	0–0.67	0–1.00	0–1.00	0.58–0.67
Overall mean[b]	0.43	0.30	0.11	0.40	0.64
Exotic/cryptogenic					
Per site[a]	0.41–0.83	0–0.83	0–1.00	0–1.00	0.75–0.79
Overall mean[b]	0.60	0.48	0.11	0.40	0.78

[a]The number of exotic (or exotic/cryptogenic) species divided by the number of determinate species at a single site; the ranges are given.
[b]The mean number of exotic (or exotic/cryptogenic) species at all sites divided by the mean number of determinate species at all sites.

and *Botryllus schlosseri* (15 sites). These findings are consistent with previous reports of the common occurrence of exotic sea squirts in southern California boat harbors (Lambert and Lambert 1998, 2003).

Sixty-five of the exotic and 47 of the cryptogenic taxa were found on floating docks and associated structures, 13 exotic and 11 cryptogenic taxa in benthic grabs, and 21 exotic and 3 cryptogenic taxa on fixed subtidal structures (Table 2). We found the exotic barnacle *Balanus amphitrite* at 6 of the 9 sites where we took intertidal scrapings from pilings. We collected the Atlantic mussel *Geukensia demissa* in the intertidal zone on the beach at site 10 and the Japanese oyster *Crassostrea gigas* in shallow water at sites 15 and 17.

The largest number of taxa were found on floating docks (which was the most intensively sampled habitat), with means of 20.1 exotic, 8.2 cryptogenic and 18.7 native taxa per float site. Float sites also had a relatively high fraction of their determinate taxa classified as exotic (or exotic/cryptogenic), with the percentage at a site ranging 28–69% (41–83%), with an overall mean of 43% (60%) (Table 4). Fixed subtidal structures ranked higher with an overall mean of 64% (78%), but only two such structures were sampled.

The median number of exotic/cryptogenic taxa, and the median percentages of exotic and exotic/cryptogenic taxa collected on floating docks were lower at port area than at non-port area sites. The median number of exotic taxa was slightly higher at port area sites (20.5 taxa) than at non-port area sites (20 taxa), but the difference was not significant ($P > 0.762$). The median numbers and median percentages of exotic and of exotic/cryptogenic taxa collected in benthic grabs, among benthic mollusks and among intertidal barnacles on pilings were higher but not significantly so at port than at non-port sites, though small numbers make these comparisons weak.

The total numbers of native, of cryptogenic and of exotic taxa were higher at port than non-port area sites for organisms collected from floating docks, but not for organisms from other habitats (Table 2). Departures from expected counts were positive but not significant for exotic and cryptogenic taxa collected from floating docks at port area sites ($n = 123$, $\chi^2 = 4.213$, $P > 0.122$). Departures from expected counts were positive but not significant for exotic taxa collected in benthic grabs at port area sites ($n = 46$, $\chi^2 = 0.052$, $P > 0.975$), though low expected counts make the analysis suspect. There were too few determinate taxa to analyze the other habitats.

Discussion

Overall, we found that exotic organisms are a substantial and sometimes dominant presence in the sampled habitats in southern California bays and harbors. We collected 66 exotic invertebrates, compared to a total of 48 exotic invertebrates previously reported for the region in a comprehensive review of literature and records (Carlton 1979, pp. 426, 555, 556, 871–875), reflecting both an increase in the number of exotics and in our knowledge of them. Relative to other recent surveys using similar methods in the northeastern Pacific Ocean, the number of exotic taxa collected (69) was greater than in Puget Sound (39) or Willapa Bay (34) (Cohen et al. 1998, 2001) and about the same as in San Francisco Bay (mean of 70 exotic taxa in 4 surveys, with 99 exotic taxa in all) (A.N. Cohen unpublished data). Although not measured, dominance by exotic taxa (in terms of numbers of individuals) appeared to be generally greater than in Puget Sound and less than in San Francisco Bay.

The finding that there were not significantly greater numbers or proportions of exotic or exotic/cryptogenic taxa collected in port areas than in non-port areas runs counter to some expectations, but does not necessarily imply that commercial ports are not important or even dominant gateways for the entry of exotic taxa. Other scenarios consistent with this finding include the following: (1) historically active introduction pathways (such as oyster aquaculture) that operated in non-port as well as port areas may mask the current importance of port-related introductions in southern California; (2) exotic taxa initially introduced to southern California port areas may spread (either naturally or anthropogenically) to non-port areas too rapidly for current sampling regimes to detect elevated numbers near port areas; and (3) ports in the northeastern Pacific but outside of southern California may be important gateways with subsequent spread to both port and non-port areas in southern California. Further examination of the pathways and timing of introductions and the rates of subsequent spread in southern California may allow determination of which scenario or combination of scenarios holds.

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Appendix A. Exotic species collected.

Protoctista: Phaeophyta
- *Sargassum muticum*
- *Undaria pinnatifida*

Protoctista: Rhodophyta
- *Lomentaria hakodatensis*

Cnidaria: Anthozoa
- *Bunodeopsis* sp. A of Ljubenkov 1996
- *Diadumene franciscana*
- *Diadumene lineata*

Annelida: Polychaeta
- *Amblyosyllis speciosa* of Imajima 1972 Figure D
- *Bispira* sp. A Harris
- *Branchiomma* sp. A Harris
- *Branchiosyllis exilis*
- *Demonax* sp. A Harris
- *Ficopomatus enigmaticus*
- *Hydroides diramphus*
- *Hydroides elegans*
- *Lumbrineris* sp. G Harris
- *Myrianida pachycera*
- *Nicolea* sp. A Harris
- *Pseudopolydora paucibranchiata*
- *Typosyllis nipponica*

Mollusca: Bivalvia
- *Crassostrea gigas*
- *Geukensia demissa*
- *Musculista senhousia*
- *Mytilus galloprovincialis*
- *Teredo bartschi*

Arthropoda: Chelicerata: Pycnogonida
- *Ammothella hilgendorfi*

Arthropoda: Crustacea: Cirripedia
- *Balanus amphitrite*
- *Balanus eburneus*

Arthropoda: Crustacea: Tanaidacea
- *Sinelobus* cf. *stanfordi*

Arthropoda: Crustacea: Isopoda[a]
- *Ianiropsis tridens*
- *Limnoria tripunctata*
- *Paranthura japonica*
- *Sphaeroma quoyanum*

Arthropoda: Crustacea: Amphipoda: Gammaridea
- *Ampithoe valida*
- *Aoriodes secundus*
- *Chelura terebrans*
- *Elasmopus rapax*
- *Ericthonius brasiliensis*
- *Grandidierella japonica*
- *Jassa marmorata*
- *Leucothoe alata*
- *Liljeborgia* sp. A of Montagne and Cadien 2001

Appendix A. Continued.

Melita sp. A Chapman
Metopella sp. A Chapman
Monocorophium acherusicum
Monocorophium insidiosum
Paradexamine cf. *churinga*
Stenothoe valida
Arthropoda: Crustacea: Amphipoda: Caprellidea
Caprella mutica
Caprella simia
Arthropoda: Crustacea: Decapoda
Palaemon macrodactylus
Bryozoa
Bugula neritina
Cryptosula pallasiana
Watersipora arcuata
Watersipora subtorquata
Zoobotryon verticillatum
Tunicata: Ascidiacea
Ascidia sp. of Lambert and Lambert 1998, 2003
Ascidia zara
Botrylloides perspicuum
Botrylloides violaceus
Botryllus schlosseri
Ciona intestinalis
Ciona savignyi
Microcosmus squamiger
Molgula manhattensis
Polyandrocarpa zorritensis
Styela canopus
Styela clava
Styela plicata
Symplegma reptans

[a] The isopod *Paracerceis sculpta*, which was common in fouling at several sites, was here treated as cryptogenic although considered an exotic in some recent studies.

Note

1. Consistent with recent molecular genetic studies (Sarver and Foltz 1993; Suchanek et al. 1997; Geller 1999), southern California mussels in the *Mytilus edulis*-complex were assumed to be, or to at least include in hybrid form, the Mediterranean mussel *Mytilus galloprovincialis*.

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