BIOFOULING SURVEY OF THE RIDER VICTORY IN DRY DOCK

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EXECUTIVE SUMMARY

As part of its non-retention vessel disposal program, the U.S. Maritime Administration oversees transfers of ships from reserve fleet locations to ship-breaking facilities. These vessels may pose a high risk of hull-mediated invasions because their underwater surfaces can be heavily fouled by aquatic organisms, and many of the vessels have a long residence time at their destination ports before they are dismantled. As a result, the Maritime Administration is drydocking Suisun Bay Reserve Fleet vessels and using pressure washing to remove biofouling and reduce the risk of transferring nonindigenous species to new coastal regions where they may become established.

This study is one in a series that examines the biological growth on obsolete vessels and evaluates the effectiveness of hull cleaning as a vector management option. Previous studies evaluated the effectiveness of in-water hull cleaning. This report examines the type and extent of biofouling on the RIDER VICTORY in dry dock and evaluates hull cleaning by pressurized water. The RIDER VICTORY is the second Suisun Bay Reserve Fleet vessel sampled in dry dock. The first dry dock evaluation was conducted on the EARLHAM VICTORY.

The sampling design for this study was similar to that implemented on previous biological surveys of reserve fleet vessels. Samples were collected from the underwater surfaces of the vessel using a stratified random sampling design consisting of transects and starboard to port locations within transects. Additionally, samples were collected from the stern appendages and niche areas. At each location, a 6-inch diameter rubber pipe connector was used to scrape approximately a 182 cm^2 area of the hull. Fifty samples were collected before hull cleaning and 15 samples were collected after hull cleaning. Samples were stored in cloth bags, examined and photographed at the dock, and transferred to the laboratory for sorting, enumeration, and identification of organisms.

A total of 41 distinct taxa, most identified to species level and referred here as to species, was found in the biological surveys. Forty-two percent of the species was nonindigenous to California, 15% was native, and <1% (one species) was cryptogenic (of uncertain origin). The remaining taxa (42%) could only be identified to genus or higher level and had native species present in California. Thirty-two percent of the total number of species recorded from the RIDER VICTORY was not known to occur in the Gulf of Mexico.

The biofouling community was numerically dominated by barnacles and isopods. Among the nonindigenous species, the barnacle *Balanus improvisus* accounted for 29% of total abundance. Other nonindigenous species accounted for 5% or less of total abundance. The native isopods *Gnorimosphaeroma oregonensis* and *G. insulare* (as a group) and *Uromunna ubiquita*, accounted for 20% and 38% of total abundance, respectively. The bryozoan *Conopeum chesapeakensis* and the hydroids *Garveia*

franciscana and *Cordylophora caspia* provided biomass cover. In terms of frequency of occurrence, barnacles and isopods occurred in most samples. In addition, *Conopeum chesapeakensis*, *Garveia franciscana*, the polychaete *Boccardiella ligerica*, and the amphipod *Gammarus daiberi* were common in the samples and nonindigenous in San Francisco Bay. The invasive Asian clam *Corbula amurensis* was found in both the pre-cleaning and post-cleaning surveys.

Fouling abundance and number of species per sample did not differ significantly among sampling locations on the hull. Barnacles and bryozoans appeared to cover the hull uniformly, but with increasing thickness toward the bottom of the hull. This three-dimensional matrix provided cover for numerous other species.

Pressure washing was effective at removing the biofouling of the exposed surfaces of the hull, leaving bare metal and rust. Most organisms were also removed from the stern appendages of the vessel, but pockets of biofouling remained on sheltered areas of the hull: in the propeller shaft, between the rudder and the rudder post, and on the rudder shoe. These areas formed crevices that harbored various species. Oligochaetes and the nonindigenous cumacean *Nippoleucon hinumensis* were exclusively found in the propeller shaft during the post-cleaning survey. Additionally, biofouling remaining under the ship support blocks contributed approximately to 1,540 square feet (143 m^2) of hull surface left unclean, or 5-10% of the submerged area of the hull. Future hull management activities should focus on the more protected or sheltered areas of the hull, and the areas under the ship support blocks. These areas may provide refuge for invasive species, such as the Asian clam, and therefore warrant special consideration.

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1.0 INTRODUCTION

The U.S. Maritime Administration maintains the National Defense Reserve Fleet with locations in various homeports of the Atlantic, Gulf, and Pacific coasts of the U.S., including Suisun Bay, CA. The fleet serves as a reserve for national defense and national emergency purposes. Older ships that are no longer serviceable are transferred to the non-retention vessel disposal program and slated for recycling. Many of these vessels have been laid up for long periods of time, and their underwater surfaces can be heavily fouled by aquatic organisms. Their transfer from the fleet to ship-breaking facilities in other geographic locations of the U.S. creates a risk of biological invasions at destination ports. The Maritime Administration has therefore established mitigation strategies to reduce the risk of nonindigenous species transfers. In-water hull cleaning has been conducted on ships towed from the James River (VA) and Beaumont (TX) reserve fleets. In California, because of environmental concerns with exfoliating paints, ships are being drydocked and cleaned to remove the topside paint and the marine growth from their hulls.

In the present study, surveys were conducted on the RIDER VICTORY to characterize type and extent of biofouling prior to hull cleaning, and to assess the effectiveness of hull cleaning at removing biological growth in dry dock. Pressure washing (3,500-5,000 p.s.i.) was used to clean the hull. Special emphasis was placed in assessing areas of limited access to pressure washing and "niche" areas where organisms may remain after hull cleaning. The RIDER VICTORY is the second Suisun Bay Reserve Fleet vessel sampled in dry dock. The first dry dock evaluation was conducted on the EARLHAM VICTORY (Versar 2010). This report compares the biofouling composition of these two vessels and of previous Suisun Bay vessels sampled in a similar manner (Versar 2008a, b).

The RIDER VICTORY was built at the California Shipbuilding Corporation Yards in Wilmington, CA, and launched in March 1945. It served as a cargo transport vessel during the last days of World War II and in the Korean and Vietnam wars before deactivation. Transferred to the Suisun Bay Reserve Fleet in January 1971, it remained at the fleet for 40 years. The ship was towed to the San Francisco BAE Systems shipyard on March 8, 2010, for drydocking, and left San Francisco Bay three weeks later on its final tow to Brownsville, TX, for dismantling.

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2.0 METHODS

2.1 BIOLOGICAL SURVEYS

Biological surveys on the RIDER VICTORY were conducted in dry dock on March 8, 2010, prior to hull cleaning, and on March 10, 2010, after hull cleaning. The pre-cleaning survey started at 6:00 PM immediately after the draining of the dry dock, and was completed by 8:00 PM. Samples were collected with assistance of Maritime Administration personnel using two teams. Each team consisted of one person on the ground and one in a manlift with capacity for a scientist and the driver. The manlift was used to access parts of the hull that were inaccessible from ground level.

Sampling design was similar to that used in previous surveys of reserve fleet vessels, and consisted of transects and starboard to port locations within transect (Figure 2-1). Eight transects positioned 55 feet apart were established along the hull of the vessel, from anchor chain to stern. At each transect five samples were collected: two near the waterline (port and starboard upper), two at mid-depth (port and starboard lower), and one from the bottom of the hull. The first transect near the bow did not have a flat bottom; therefore, only four samples were collected from this transect. Additionally, eleven samples were collected from the bilge keel (upper surface), propeller shaft, propeller blades, rudder, and skeg.

At each location, a sampler constructed from a 6-inch to a 4-inch diameter rubber pipe adaptor was used to scrape approximately a 182 cm^2 area of the hull (Figure 2-2). A 3-inch scraper applied between the hull and the 6-inch (15.2 cm) end of the sampler was used to remove the biological material from the hull, which was collected in labeled cloth bags. Protexo bags manufactured by HUBCO (Hutchinson, Kansas) were used. Each bag measured 10 x 17 inches (25.4 x 43.2 cm) and was made of tightly woven white cotton cloth. After the sample was collected, each bag was tightly closed with a drawstring and rubber band and placed in a 5-gallon bucket with in-situ filtered marine water (64-μm sieve). The bag number was relayed to the team member on the ground so that detailed notes could be taken on the location at which each sample was collected. A total of 50 samples was collected during the pre-cleaning survey.

The post-cleaning survey consisted of the close inspection of the hull from a manlift and the collection of 15 samples. Because a majority of the biological growth was removed by pressure washing, fewer samples were collected after hull cleaning. "Niche" areas and the perimeter of the wood blocks upon which the ship rested were targeted. Visual examination of extra live material removed from the hull during the pre-cleaning and post-cleaning surveys was conducted at the dry dock site using a stereo dissecting microscope.

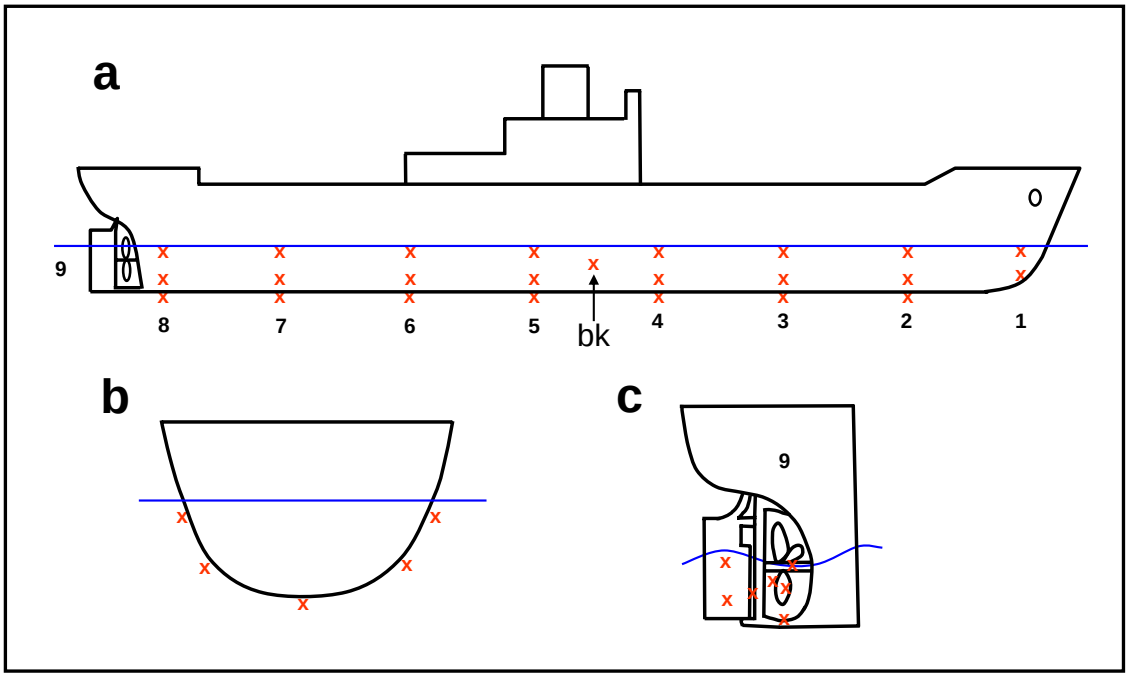

Figure 2-1. Sampling design consisting of 8 transects across the hull of the vessel (a) and five samples per transect (b). The first transect did not have a flat bottom; therefore only four samples were collected from this transect. Additionally, samples were collected from the stern appendages of the vessel (c), and the bilge keel (bk). Ship's length: 455 feet; beam: 62'; lightweight draft: 9.5'.

Figure 2-2. Sampler constructed from a 6-inch (15.2 cm) to a 4-inch diameter rubber pipe adaptor, to which a numbered cloth bag was attached to the 4-inch end. A 3-inch scraper was inserted between the hull and the sampler to remove the biological material from the hull, which was then collected in the cloth bag.

2.2 SAMPLE PROCESSING AND TAXONOMY

A visual examination of representative samples was carried out in the field. Bags were opened, inverted, and rinsed with filtered seawater (64-μm sieve) into a plastic dissecting tray (12 x 18 inches, 2.5 inch deep), and the sample was examined and photographed. Notes were taken as to the condition of the biota (live versus dead material), and the general kinds and quantity of organisms. The extra live material (not part of the sample) was examined with a Wild stereo dissecting microscope (Wild Heerbrugg, Switzerland) with a 6x to 50x magnification zoom.

After examination, the contents of the tray were carefully poured back into the sample bag, and a label was added to the inside of the bag. Bags were tightly closed and secured with twist ties and rubber bands, and transferred to a propylene phenoxytol (POP) solution to relax the organisms for easier identification. A 0.15 % solution was made by adding 15 ml of POP to1 L of warm tap water, and then mixing 9 L of in situ water into the solution (Green and Lambert 1994). After 30-60 min in the relaxant, bags were placed in 1-gallon Nalgene® high-density polyethylene wide mouth bottles (3-5 bags per bottle), and a buffered solution (10%) of formalin in seawater was added to preserve the organisms. In the laboratory, samples were stored in formalin until further processing and identification of organisms.

In the laboratory, samples were washed through nested 250-μm and 64-μm sieves. The finer 64-μm fraction of the sample was retained and archived. The 250-μm fraction was sorted under dissecting microscopes to separate organisms into major categories (i.e., barnacles, bivalves, crustaceans, etc.). Organisms in these major categories were identified to species level whenever possible and counted (non-colonial species only). Some organisms required further examination by specialist taxonomists for identification or confirmation. Voucher specimens of these organisms were placed in separate vials and sent to the specialists.

2.3 ANALYSIS

Samples were analyzed for differences in species numbers, abundance, and composition by location on the hull and survey using univariate (Analysis of Variance) and multivariate analysis methods. Using multivariate ordination methods, plots were constructed to examine sample configuration and to identify any tendency for samples to form groups according to the location where they were taken from the hull. Species presence-absence data were subjected to non-metric multidimensional scaling (MDS) ordination on a Sørensen similarity matrix using routines in the PRIMER (Plymouth Routines in Multivariate Ecological Research) v.6 statistical package (Clarke and Gorley 2006). Non-metric MDS constructs a plot in which samples are arranged in rank order according to their relative similarity. Samples that are similar in species composition are placed in close proximity to one another, whereas dissimilar samples are placed further apart. Bar charts were constructed to provide visualization of data results.

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3.0 RESULTS

3.1 PATTERNS OF BIOFOULING – BEFORE HULL CLEANING

A quick inspection of the hull prior to sampling revealed abundant biological growth covering the underwater surfaces of the ship (Figure 3-1). No assessment of the proportion of bare hull was made; however, bare hull was not observed in the areas that were closely inspected. The hull was covered by a thick layer of barnacles and colonial organisms, with predominance of the encrusting bryozoan *Conopeum chesapeakensis*, a nonindigenous species (Figure 3-2). Bryozoan biomass appeared to be greater than in the EARLHAM VICTORY. The bryozoan was attached to the barnacles and formed vertical ribbon-shaped strands and laminar fronds, although it also encrusted the barnacles. At the waterline, algal growth was observed (Figure 3-1, d). Barnacles and bryozoans appeared to cover the hull uniformly, but with increasing thickness toward the bottom of the hull. These organisms formed a three-dimensional matrix that provided cover for other species, particularly abundant amphipod and isopod crustaceans. Sea chests were externally blanked and therefore did not provide areas for organisms to hide or sediment to accumulate.

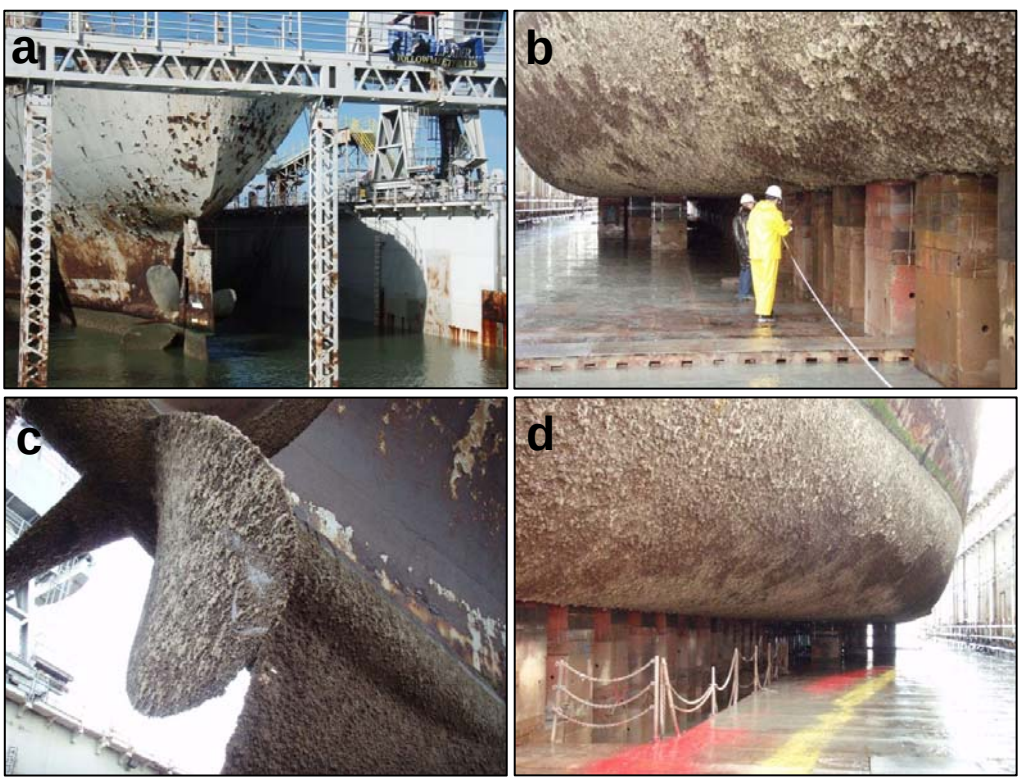

Figure 3-1. Photographs taken during the drydocking of the RIDER VICTORY prior to hull cleaning, March 8, 2010. (a) The RIDER VICTORY shortly after entering the dry dock; (b) setting-up the transects; (c) heavy barnacle and soft growth cover on propellers and propeller shaft; (d) starboard side view showing algae near the waterline.

Figure 3-2. The RIDER VICTORY showing heavy barnacle and bryozoan cover (a, b); the bryozoan *Conopeum chesapeakensis* forms ribbon-shaped strands and laminar fronds (center, c); thick layers of biofouling-encrusted paint peeled off during the drydocking (arrow in panel d).

3.2 AFTER HULL CLEANING

Pressure washing removed most of the organisms that contributed to the biofouling of the hull. A close inspection of the hull after cleaning revealed bare metal and rust (Figure 3-3). With the exception of some empty barnacle tests, which remained attached to the hull, no organisms were found on the exposed surfaces of the hull. Potential niche areas in the propeller shaft and rudder post contained some barnacle and bryozoan growth. Samples of this material were collected for processing in the laboratory, and the results are reported below (Figure 3-3 b, d). Abundant biofouling remained under the ship support blocks. The wood blocks, each measuring 3.5 x 4 feet, contributed approximately to 1,540 square feet (143 m^2) of hull surface that was left unclean. Samples taken from the perimeter of the blocks were examined at the dock site and contained mostly dead organisms (barnacles, 4 amphipods, 4 isopods, 2 polychaetes, bryozoans). However, one amphipod and one isopod were alive at the time of collection. Additionally, four pillbug isopods (*Gnorimosphaeroma* spp.) were collected alive from the rudder pintle and the propeller shaft.

Figure 3-3. Photographs taken during the drydocking of the RIDER VICTORY after hull cleaning with pressurized seawater, March 10, 2010. (a) inspection of the hull; (b) sampling 'niche' areas; (c) stern area showing bare metal and rust; (d) biofouling organisms remained between the rudder and the rudder post.

3.3 SPECIES ASSEMBLAGES

Forty-one distinct taxa (hereafter referred as to species) were found in the samples collected from the RIDER VICTORY (Table 3-1). Four species comprised 87% of the total abundance. The native isopod *Uromunna ubiquita* accounted for 6,187 individuals and 38% of total abundance, the nonindigenous barnacle *Balanus improvisus* accounted for 4,725 individuals and 29% of total abundance, and the also native pillbug isopods *Gnorimosphaeroma oregonensis* and *G. insulare* accounted for 3,216 individuals and 20% of total abundance. All other species accounted for 5% or less each of the total abundance. *Uromunna*, *Balanus*, and *Gnorimosphaeroma* were also density dominants in the EARLHAM VICTORY fouling community (Versar 2010), but the nonindigenous isopod *Synidotea laticauda*, which was the most abundant species on the EARLHAM VICTORY, comprised only 0.1% of total abundance in the present surveys. Four other species (the amphipods *Incisocalliope derzhavini* and *Ampithoe valida*, the polychaete *Polydora cornuta*, and a Leptoplanid flatworm) which were relatively common in the EARLHAM VICTORY samples, were not found on the RIDER VICTORY.

In terms of frequency of occurrence, isopods (*Uromunna*, *Gnorimosphaeroma*) and barnacles (*Balanus*) were the most common species in the samples, occurring in 98-100% of the pre-cleaning samples (Table 3-1). Other frequently occurring species were the bryozoan *Conopeum chesapeakensis* (98% of the samples), the hydroid *Garveia franciscana* (98% of the samples), the polychaete *Boccardiella ligerica* (94% of the samples), and the amphipod *Gammarus daiberi* (90% of the samples), all four species nonindigenous in San Francisco Bay.

Appendix B presents the biogeographic status and life history characteristics of all the species found in the biological surveys. Seventeen species, or 42% of the total number of species recorded from the RIDER VICTORY prior to hull cleaning, were nonindigenous in California waters. These included 4 polychaetes, 3 amphipods, 2 isopods, and 2 hydroids, in addition to species from other invertebrate groups, including the Asian clam, *Corbula amurensis*, and the Japanese cumacean *Nippoleucon hinumensis* (Table 3-1, Appendix B). Six species (15%) were native, and one species (<1%) was cryptogenic (of uncertain origin). The remaining taxa were genus or higher level identifications with native species present in California, but some of these (e.g., *Mediomastus* sp.) may also be nonindigenous. Thus, nonindigenous species predominated in the biofouling community of the RIDER VICTORY.

Eight of the nonindigenous species were not known to occur in the Gulf of Mexico, three were also nonindigenous in the Gulf of Mexico, and two were cryptogenic. Additionally, five species that were native to California were also unknown in the Gulf of Mexico. In all, 32% of the total number of species recorded from the RIDER VICTORY was unknown in the Gulf of Mexico. Some of these species were abundant on the hull. Therefore, a significant risk for species transfers would have existed if the vessel had entered a different biogeographic area without hull cleaning.

Among the nonindigenous species found on the RIDER VICTORY, the Asian clam, *Corbula amurensis*, is a notorious invasive in San Francisco Bay. Since its introduction in 1986, *C. amurensis* has changed the ecosystem of northern San Francisco Bay (Carlton et al. 1990, Nichols et al. 1990). It spread rapidly within 2 years of its appearance in the bay, and became very abundant in low salinity regions. It displaced the original benthic community and changed the trophic structure of the ecosystem (Carlton et al.1990). *C. amurensis* was found in 12% of the pre-cleaning samples, and in three (20%) of the post-cleaning samples. *C. amurensis* was also found on the EARLHAM VICTORY and in previous Suisun Bay vessel surveys (Versar, 2008b).

Most of the nonindigenous species present on the RIDER VICTORY were found in previous Suisun Bay hull surveys (Table 3-1, Versar 2008a, b). The burrower isopod *Sphaeroma quoianum* first reported on the EARLHAM VICTORY was also found on the RIDER VICTORY, but its commensal species *Iais californica* or the various nonindigenous mussels first recorded on the EARLHAM VICTORY were not found in the present surveys.

Two nonindigenous species new in the present surveys were the oligochaete worm *Paranais frici* and the hydroid *Cordylophora caspia*, both of Ponto-Caspian origin. *P. frici* is widespread in North America in fresh and brackish waters of the East and West coasts, and the Great Lakes (NEMESIS database, Smithsonian Environmental Research Center), although we have no records of this species in the Gulf of Mexico. It is one of several species of oligochaetes thought to have been introduced in San Francisco Bay (Cohen and Carlton 1995). Oligochaetes are abundant but usually difficult to identify, therefore introduced species may be noted only years or decades after their introduction. The invasion history of *P. frici* in San Francisco Bay and other West Coast estuaries is unknown. It may have arrived in California in ships' solid or water ballast or on ornamental aquatic plants (Cohen and Carlton 1995). It has no known economic or ecological impacts. *Cordylophora caspia*, on the other hand, is an important fouling organism of water intake systems and canals of power plants. *C. caspia* is widely distributed in the world, typically in rivers, streams, and brackish waters of estuaries in temperate and subtropical regions. It has been known in San Francisco Bay since the 1930s, to where it was likely introduced via ship fouling or ballast water (Cohen and Carlton 1995). *C. caspia* is common in the Gulf of Mexico and was frequently found in the fouling community of Beaumont Reserve Fleet vessels (Versar 2008c).

The occurrence of several freshwater species of hydroids, oligochaetes, and insects on the RIDER VICTORY, suggests that prior to sampling the vessel was sitting at the fleet during a period of high freshwater flow. Species typical of higher salinity waters that were abundant on the EARLHAM VICTORY, such as the amphipods *Incisocalliope derzhavini* and *Ampithoe valida*, and the polychaete *Polydora cornuta*, were not found on the RIDER VICTORY. This emphasizes the large variability in biofouling among ships noted in previous surveys. Species assemblages on Suisun Bay ship hulls appear to vary across seasons and within seasons, and with vessel factors such age and length of berthing.

Table 3-1. Species recorded in the biological samples (250-μm sieve) of the RIDER VICTORY. The frequency of occurrence (percent of samples) in pre-cleaning and post-cleaning surveys (n = 50 and 15, respectively); the biogeographic status of species in California waters; and whether the species was present on the OCCIDENTAL VICTORY, QUEENS VICTORY, JASON, or EARLHAM VICTORY is shown. Status: I = introduced (nonindigenous species); C = cryptogenic (of uncertain origin); N = native; NP = native species present; ? = undetermined.

Species	% Samples		Status	Present in OV, QV, Jason or EV?
	Pre-Cleaning	Post-Cleaning		
Algae				
Algae sp. A	6	7	?	x
Algae sp. B	4	0	?	x
Algae sp. D	12	20	?	x
macroalga	4	0	NP	x
Amphipods				
Americorophium spinicorne	22	7	N	x
Corophiidae spp. Indeterminant	16	7	NP	x
Gammarus daiberi	90	27	I	x
Grandidierella japonica	22	7	I	x
Melita nitida	64	7	I	x
Anthozoans (sea anemones)				
anemone	4	0	NP	x
Bivalves (clams)				
Corbula amurensis	12	20	I	x
Cirripedia (barnacles)				
Balanus improvisus	98	93	I	x
Copepods				
Calanoid copepod	0	7	NP	x
Cumaceans				
Nippoleucon hinumensis	0	7	I	x
Decapods (crabs)				
crab zoea	10	0	NP	x
Ectoprocts (bryozoans)				
Conopeum chesapeakensis	98	100	I	x
Entoprocts (kamptozoans)				
Loxosomatid entoproct?	0	7	NP	
Gastropods (snails)				
Gastropoda: Mesogastropoda	2	0	NP	x
Hydroids				
Cordylophora caspia	60	13	I	
Garveia franciscana	98	93	I	x
Insects				
Paratanytarsus sp.	0	7	NP	
Smittia sp.	4	0	NP	

Table 3-1. (Continued)

Species	% Samples		Status	Present in OV, QV, Jason or EV?
	Pre-Cleaning	Post-Cleaning		
Isopods				
Gnorimosphaeroma oregonensis/insulare	98	47	N	x
Sphaeroma quoianum	36	0	I	x
Synidotea laticauda	8	13	I	x
Uromunna ubiquita	100	67	N	x
Nematodes (roundworms)				
Nematoda	6	7	NP	x
Oligochaetes (freshwater worms)				
Enchytraeidae spp.	68	33	NP	x
Naididae spp. Indeterminant	0	7	NP	
Paranais frici	2	7	I	
Paranais litoralis	0	7	N	
Plants				
herbaceous plant material	2	7	NP	x
Polychaetes (bristleworms)				
Boccardiella ligerica	94	33	I	x
Cossura sp. Indeterminant	2	0	NP	
Ficopomatus enigmaticus	8	20	I	x
Mediomastus sp. Indeterminant	2	0	NP	
Neanthes succinea	58	13	I	x
Streblospio benedicti	0	7	I	x
Tanaids				
Leptochelia savignyi	2	0	C	
Sinelobus stanfordi	12	0	I	x
Turbellarians (flatworms)				
Stylochus franciscanus	22	7	N	x
Stylochus sp.?	2	0	NP	x
Other				
unidentified material	4	0	?	x

3.4 DIFFERENCES BETWEEN SURVEYS AND LOCATIONS ON THE HULL

Differences in abundance and number of species among locations on the hull prior to hull cleaning were not statistically significant (ANOVA; log of abundance, $F = 0.71$, $p = 0.55$; number of species, $F = 1.29$, $P = 0.29$) (Figure 3-4,a,b). Bryozoan cover appeared to be thicker toward the bottom of the hull; however, no biomass data were collected to test for differences in biofouling cover.

After hull cleaning, marked differences were noted among the sample locations, not tested statistically because not all locations were replicated (Figure 3-4,c,d). 'Niche' areas (propeller shaft, rudder post, and rudder shoe) had higher abundance and number of species than non-niche areas (hull support blocks and exposed surface of hull). Although these differences may simply reflect differences in sample size and collection effort among locations, the higher number of species found in the propeller shaft and the rudder hinge area suggests that organisms find protection from pressure washing in these areas. Also, the species in these crevices were of different types. This is reflected in the multivariate analysis of species presence-absence data, which shows propeller shaft and rudder hinge samples plotted separately from the support block and exposed hull samples (Figure 3-5). The oligochaetes and the nonindigenous cumacean *Nippoleucon hinumensis* were exclusively found in the propeller shaft during the post-cleaning survey. The propeller shaft and the rudder hinge area also contained polychaetes, amphipods, isopods, nematodes, and the Asian clam, *Corbula amurensis*.

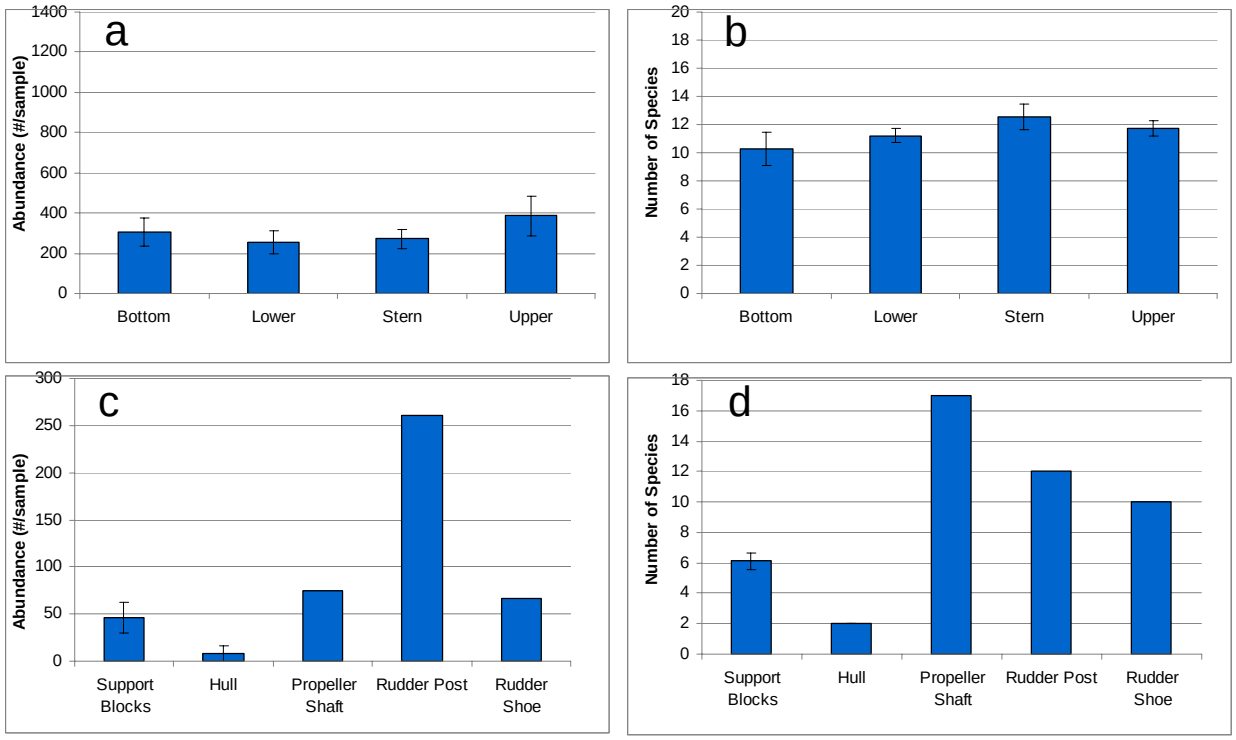

Figure 3-4. Differences in mean abundance (number of individuals per sample) and mean number of species per sample (± 1 Standard Error) of biofouling organisms by sampling location on the hull for the pre-cleaning (a, b) and post-cleaning (c, d) surveys. Lower = lower or mid-depth surface; Upper = upper surface, near the waterline; Stern = stern appendages.

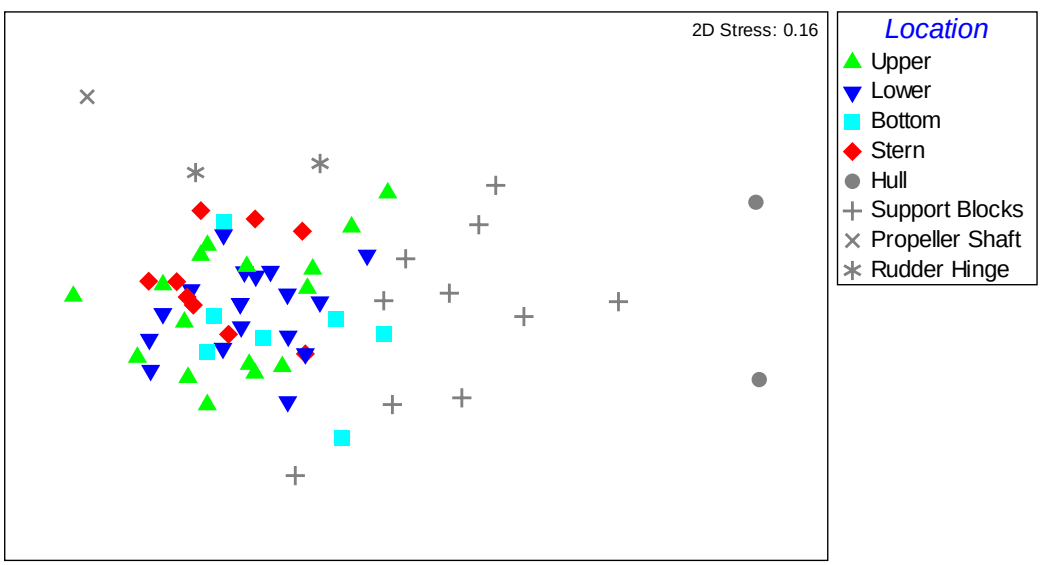

Figure 3-5. Multivariate analysis of presence-absence data showing differences between the pre-cleaning (colored symbols) and the post-cleaning samples (gray symbols), and between post-cleaning sampling locations (propeller shaft and rudder hinge different than support blocks).

3.5 IMPLICATIONS FOR SPECIES TRANSFER AND INTRODUCTIONS

The cleaning of the RIDER VICTORY in dry dock removed the biological growth covering the exposed underwater surfaces of the hull. Prior to cleaning, the underwater surfaces were covered by a thick layer of barnacles and soft growth (bryozoans and hydroids) which provided three-dimensional cover to isopods, amphipods, polychaetes, and other fouling species. Seventeen (42%) of the species found in the present surveys were nonindigenous in San Francisco Bay, and many of these species were either nonindigenous, cryptogenic, or not known to occur in the Gulf of Mexico. Another five species native to San Francisco Bay were not known to occur in the Gulf of Mexico. Therefore, if the hull had not been cleaned, the risk of species transfers and potential introductions would have been significant.

Hull cleaning in dry dock was more effective at removing biological growth than in-water hull cleaning. Whereas in-water hull cleaning of reserve fleet vessels was unable to remove much of the barnacle cover from the stern appendages and other protected areas of the hull (Versar 2008a, b), cleaning by pressurized water in dry dock left a smooth surface of bare metal and rust on the exposed areas of the hull. Except for the occasional barnacle shell, no organisms were found in these exposed areas during the post-cleaning inspection of the hull. Similar results were obtained after the cleaning of the EARLHAM VICTORY. However, as with the EARLHAM VICTORY, crevices around the rudder post and in the propeller shaft served as hiding areas for various species. A total of 30 species, or 73% of the original assemblage, was recovered from niche areas and around the perimeter of the ship support blocks after pressure washing, and 12 of these species were unknown from the Gulf of Mexico.

The visible biofouling remaining after hull cleaning was concentrated under and around the ship support blocks. We estimate that these areas represent between 5-10% of the submerged area of the hull, and therefore they represent a significant total amount of area left unclean. Relative to bare hull, these areas may also exhibit a higher rate of colonization of new taxa during the ship's tow to Texas. While the biofouling left under the ship support blocks may be an inevitable consequence of the drydocking procedure, alternative hull husbandry procedures that address difficult to reach areas under the docking blocks should be explored. Although examination of 'live' material collected from the perimeter of the blocks revealed mostly dead organisms, the condition and viability of biofouling beyond the area immediately affected by the pressurized water is unknown. The blocks may provide refuge to small bivalve species. Small bivalves can withstand adverse conditions during the drydocking by keeping their shells closed. In view of the presence of the Asian clam on Suisun Bay Reserve Fleet hulls, the importance of biofouling under the ship support blocks cannot be over stressed.

The potential for sheltered areas of the hull to serve as vectors for the transfer of nonindigenous species to Texas is suggested by the various species found in the crevices formed by the propeller shaft and the rudder hinge. These areas provide suitable habitat for both sessile and motile species, and they may also accumulate sediment (for example,

at the base of the rudder) that can serve as additional substrate for mud dwelling species or the resting stages of phytoplankton organisms. Removal of biofouling from sheltered areas should receive special attention. High-pressure water blasting directed to crevices and the use of brushes in hard to reach areas may be all that is needed to remove the organisms except perhaps the most recalcitrant-cemented barnacles. For ships returning to the fleet after drydocking, recolonization will likely occur first in these areas. Therefore, future hull management activities should focus on the more protected or sheltered areas.

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4.0 SUMMARY AND CONCLUSIONS

1. Pre-cleaning and post-cleaning hull surveys of biofouling were conducted on the Suisun Bay Reserve Fleet vessel RIDER VICTORY in dry dock. The surveys yielded a total of 41 distinct species. Forty-two percent of the species was nonindigenous to California, 15% was native, and <1% (one species) was cryptogenic (of uncertain origin). Thirty-two percent of the total number of species recorded from the RIDER VICTORY was unknown in the Gulf of Mexico.

2. The biofouling community was numerically dominated by barnacles and isopods. The bryozoan *Conopeum chesapeakensis* and the hydroids *Garveia franciscana* and *Cordylophora caspia* provided biomass cover. Among the nonindigenous species found on the RIDER VICTORY, the barnacle *Balanus improvisus* accounted for 29% of total abundance. Other nonindigenous species accounted for 5% or less of total abundance. The native isopods *Gnorimosphaeroma oregonensis* and *G. insulare* (as a group) and *Uromunna ubiquita* accounted for 20% and 38% of total abundance, respectively. In addition to barnacles and isopods, frequently occurring species in the samples were *Conopeum chesapeakensis*, *Garveia franciscana*, the polychaete *Boccardiella ligerica*, and the amphipod *Gammarus daiberi*, all nonindigenous in San Francisco Bay. The invasive Asian clam *Corbula amurensis* was found in both the pre-cleaning and post-cleaning surveys.

3. There were no statistical significant differences in abundance or species numbers per sample among sampling locations on the hull. Barnacles and bryozoans appeared to cover the hull uniformly, but with increasing thickness toward the bottom of the hull. This three-dimensional matrix provided cover for numerous other species.

4. Pressure washing removed the biofouling of the exposed surfaces of the hull. The hull after cleaning showed bare metal and rust. Most organisms were also removed from the stern appendages of the vessel, but pockets of biofouling remained on sheltered areas of the hull: in the propeller shaft, between the rudder and the rudder post, and on the rudder shoe. Oligochaetes and the nonindigenous cumacean *Nippoleucon hinumensis* were exclusively found in the propeller shaft during the post-cleaning survey. Additionally, biofouling remaining under the ship support blocks contributed to approximately 1,540 square feet (143 m^2) of hull surface left unclean, or 5-10% of the submerged area of the hull.

5. While drydocking is an efficient method for vector management, future hull management activities should focus on the more protected or sheltered areas of the hull. Hull cleaning procedures that address difficult to reach areas under the ship support blocks should be explored. The viability of biofouling beyond the perimeter of the blocks is not known. However, these areas may provide refuge for invasive species, such as the Asian clam, and therefore warrant special consideration.

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APPENDIX A

SPECIES ABUNDANCES

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	Sample (3100 = Pre-cleaning; 3200 = Post-cleaning; P = Present)																		
Species	3101	3102	3103	3104	3105	3106	3107	3108	3109	3110	3111	3112	3113	3114	3115	3116	3117	3118	3119
Algae sp. A				P															
Algae sp. B	P																		
Algae sp. D	P				P	P										P		P	
Americorophium spinicorne																1			
anemone																			
Balanus improvisus	83	157	20	56	53	33	71	44	50	177	11	93	137	79		26	21	20	17
Boccardiella ligerica	6	6	6	12	7	3	9	3	5	5		15	4	4		7	3	4	7
Calanoid copepod																			
Conopeum chesapeakensis	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Corbula amurensis												2							
Cordylophora caspia	P		P	P		P							P	P	P	P	P	P	P
Corophiidae spp. indeter.		1		1									1				1		
Cossura sp. indeter.				1															
crab zoea	1					1													1
Enchytraeidae spp.	12		3		1	31			12	17		8	2		5			2	
Ficopomatus enigmaticus					1										1				
Gammarus daiberi	22	10	61	3	7	44	3	19	28	8	18	31	6	5	27	40	4	9	2
Garveia franciscana	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Gastropoda: Mesogastropoda																			
Gnorimosphaeroma oregonensis/insulare	1016	76	91	16	10	120	11	10	151	22	2	228	10	13	4	113	10	2	47
Grandidierella japonica			1						1									1	
herbaceous plant material			P																
Leptochelia savignyi														1					
Loxosomatid entoproct?																			
macroalgae	P																		
Mediomastus sp. indeter.						1													
Melita nitida	1	3	13	2	4		2		2	1		3	6	1		4	1		4
Naididae																			
Neanthes succinea	5		1	3	1	2	3		1	3		1	2	1			1	1	
Nematoda					P														
Nippoleucon hinumensis																			
Paranais frici																			
Paranais litoralis																			
Paratanytarsus sp.																			
Sinelobus stanfordi	296																		
Smittia sp.									1							1			
Sphaeroma quoianum		1	2	1		1	1		1			1				2			
Streblospio benedicti																			
Stylochus franciscanus			1	1								1							
Stylochus sp.?																			
Synidotea laticauda																			
unidentified material				1															
Uromunna ubiquita	285	41	378	146	570	465	41	162	103	121	65	106	60	5	210	142	16	201	183
TOTAL	**1727**	**295**	**577**	**243**	**654**	**701**	**141**	**238**	**355**	**354**	**96**	**489**	**228**	**109**	**247**	**336**	**57**	**240**	**261**

Species	3120	3121	3122	3123	3124	3125	3126	3127	3128	3129	3130	3131	3132	3133	3134	3135	3136	3137	3138
Algae sp. A	P																		
Algae sp. B										P									
Algae sp. D			P																
Americorophium spinicorne	1	1			1		1								1			1	1
anemone		1																	
Balanus improvisus	227	66	93	80	240	82	50	162	104	74	56	57	34	11	49	49	89	59	80
Boccardiella ligerica	2	11	5	9	4	1	5	10	5	5	2		15	4	10	2	2	5	4
Calanoid copepod																			
Conopeum chesapeakensis	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Corbula amurensis								2											
Cordylophora caspia	P	P	P	P	P		P	P	P	P	P		P						
Corophiidae spp. indeter.			1									1							
Cossura sp. indeter.																			
crab zoea	1																		
Enchytraeidae spp.		6		15		1	11	6		1		12		11	1	2	7	1	3
Ficopomatus enigmaticus																	1		
Gammarus daiberi	45	25	15	9	19		9	2	15	1	6		44		2	1		2	3
Garveia franciscana	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Gastropoda: Mesogastropoda																			
Gnorimosphaeroma oregonensis/insulare	24	9	38	44	12	34	45	43	32	224	25	89	35	1	20	37	3	38	20
Grandidierella japonica	9			2				2					2						
herbaceous plant material																			
Leptochelia savignyi																			
Loxosomatid entoproct?																			
macroalgae														P					
Mediomastus sp. indeter.																			
Melita nitida	1	4		2	5	2		3					19			1			2
Naididae																			
Neanthes succinea	1		1		1	1	1	1					1			1			
Nematoda																			
Nippoleucon hinumensis																			
Paranais frici																			
Paranais litoralis																			
Paratanytarsus sp.																			
Sinelobus stanfordi						1	1			49		8							
Smittia sp.																			
Sphaeroma quoianum	1					1	1			1		5		2		2		1	
Streblospio benedicti																			
Stylochus franciscanus				2				1					1						1
Stylochus sp.?					1														
Synidotea laticauda				2	2								1						
unidentified material					1														
Uromunna ubiquita	202	115	154	31	142	8	215	13	41	53	37	31	942	2	43	8	6	36	42
TOTAL	**514**	**238**	**307**	**196**	**428**	**131**	**339**	**245**	**197**	**408**	**126**	**203**	**1094**	**31**	**126**	**103**	**108**	**143**	**156**

Species	3139	3140	3141	3142	3143	3144	3145	3146	3147	3148	3149	3150	3201	3202	3203	3204	3205	3206	3207
Algae sp. A					P													P	
Algae sp. B																			
Algae sp. D																P	P		
Americorophium spinicorne			2						2		2								
anemone					1														
Balanus improvisus	295	78	58	65	18	161	185	73	146	110	66	214	16		13	8	141	48	16
Boccardiella ligerica	16	1	1	3	1	1	2	4	7	6	9	12				2		2	
Calanoid copepod																			P
Conopeum chesapeakensis	P	P	P		P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
Corbula amurensis	2								7	3	6					2	1	2	
Cordylophora caspia			P	P	P	P	P		P	P	P								
Corophiidae spp. indeter.										1	3						1		
Cossura sp. indeter.																			
crab zoea										1									
Enchytraeidae spp.	8	3	1	6	1		4	3	8	2	2	16				6		1	1
Ficopomatus enigmaticus												2							1
Gammarus daiberi	18	2	1	23	1	6	25		79	10	93	19				3	7		
Garveia franciscana	P	P	P		P	P	P	P	P	P	P	P		P	P	P	P	P	P
Gastropoda: Mesogastropoda					1														
Gnorimosphaeroma oregonensis/insulare	27		6	37	4	33	27	22	102	30	61	53			1	14	61	10	
Grandidierella japonica						1			4	4	1					20			
herbaceous plant material																P			
Leptochelia savignyi																			
Loxosomatid entoproct?																			
macroalgae																			
Mediomastus sp. indeter.																			
Melita nitida	4	1		2		3	2		32	2	4	7					2		
Naididae																9			
Neanthes succinea	3			1		1	1	1	1		1	1				1	1		
Nematoda	P											P				P			
Nippoleucon hinumensis																3			
Paranais frici				2												2			
Paranais litoralis																1			
Paratanytarsus sp.																			
Sinelobus stanfordi									1										
Smittia sp.																			
Sphaeroma quoianum				1				1											
Streblospio benedicti																4			
Stylochus franciscanus				1		2			1			2							
Stylochus sp.?																			
Synidotea laticauda												1					3	2	
unidentified material																			
Uromunna ubiquita	14	15	18	44	22	46	65	30	176	26	6	50					44	2	13
TOTAL	**387**	**100**	**87**	**185**	**49**	**254**	**311**	**134**	**566**	**195**	**254**	**377**	**16**	**P**	**14**	**75**	**261**	**67**	**31**

Species	3208	3209	3210	3211	3212	3213	3214	3215	**TOTAL**
Algae sp. A									P
Algae sp. B									P
Algae sp. D						P			P
Americorophium spinicorne								1	15
anemone									2
Balanus improvisus	9	3	1	6	156	12	3	14	4725
Boccardiella ligerica	2				1	2			279
Calanoid copepod									P
Conopeum chesapeakensis	P	P	P	P	P	P	P	P	P
Corbula amurensis									27
Cordylophora caspia		P				P			P
Corophiidae spp. indeter.									11
Cossura sp. indeter.									1
crab zoea									5
Enchytraeidae spp.				1			1		234
Ficopomatus enigmaticus				1				2	9
Gammarus daiberi		1						1	834
Garveia franciscana	P	P	P	P	P	P	P	P	P
Gastropoda: Mesogastropoda									1
Gnorimosphaeroma oregonensis/insulare	1					1	1		3216
Grandidierella japonica									48
herbaceous plant material									P
Leptochelia savignyi									1
Loxosomatid entoproct?						P			P
macroalgae									P
Mediomastus sp. indeter.									1
Melita nitida									145
Naididae									9
Neanthes succinea									45
Nematoda									P
Nippoleucon hinumensis									3
Paranais frici									4
Paranais litoralis									1
Paratanytarsus sp.						1			1
Sinelobus stanfordi									356
Smittia sp.									2
Sphaeroma quoianum									26
Streblospio benedicti									4
Stylochus franciscanus					2				16
Stylochus sp.?									1
Synidotea laticauda									11
unidentified material									2
Uromunna ubiquita	5	19		103	11	32	10	15	6187
TOTAL	**17**	**23**	**1**	**111**	**170**	**48**	**15**	**33**	**16222**

APPENDIX B

SPECIES BIOGEOGRAPHY AND LIFE HISTORY INFORMATION

						Geographical Distribution	
Phylum	**Class**	**Species/Taxon Name**	**Common Name**	**California Invasion Status**	**Status in Texas**	**Native range**	**Invaded range**
Cnidaria	Anthozoa	Actiniaria spp.	sea anemone	native species present	native species present		
Chlorophyta		Algae sp. A	filamentous algae	?	?		
Chlorophyta		Algae sp. B	algae	?	?		
Chlorophyta		Algae sp. D	algae	?	?		
Crustacea	Amphipoda	Americorophium spinicorne	amphipod	native	no record/not present	Northeast Pacific	Snake River (Idaho), Pearl Harbor (Hawaii) on hull of USS Missouri
Crustacea	Cirripedia	Balanus improvisus	Bay barnacle	introduced	native	Western Atlantic Ocean	Northeast Atlantic, Caspian Sea, North Pacific Ocean
Annelida	Polychaeta	Boccardiella ligerica	polychaete or bristle worm	introduced	cryptogenic	Northeast Atlantic	Baltic Sea, Northeast Pacific, South Atlantic Ocean, and possibly (cryptogenic range), Northwest Atlantic and Gulf of Mexico
Crustacea	Copepoda (Calanoida)	Calanoida spp. Indeterminant	calanoid copepod	native species present	native species present		
Ectoprocta	Gymnolaemata	Conopeum chesapeakensis	bryozoan or moss animal	introduced	no record/not present	Chesapeake Bay	San Francisco Bay. Newly described species in a taxonomically difficult genus. Species of Conopeum have been reported as invasive in different parts of the world.
Mollusca	Bivalvia	Corbula amurensis	Asian clam	introduced	no record/not present	Northwest Pacific	San Francisco Bay, CA.
Cnidaria	Hydrozoa	Cordylophora caspia	freshwater hydroid	introduced	introduced	Circumglobal in temperate and subtropical regions, usually in brackish waters; native to Caspian and Black Seas	Range extended by shipping
Crustacea	Amphipoda	Corophiidae spp. (juv.)	amphipod	native species present	native species present		
Annelida	Polychaeta	Cossura sp.	polychaete or bristle worm	native species present	native species present		
Crustacea	Decapoda	crab zoea	crab larval stage	native species present	native species present		
Annelida	Oligochaeta	Enchytraeidae spp.	freshwater worms	native species present	native species present		
Annelida	Polychaeta	Ficopomatus enigmaticus	Australian shipworm	introduced	introduced	Indian Ocean	Atlantic Ocean, Gulf of Mexico, Black Sea, Caspian Sea, Mediterranean Sea, Pacific Ocean
Crustacea	Amphipoda	Gammarus daiberi	amphipod	introduced	no record/not present	Northwest Atlantic	San Francisco Bay, CA.
Cnidaria	Hydrozoa	Garveia franciscana	Rope Grass hydroid	introduced	introduced	Unknown, possibly Indian Ocean	Northwest Atlantic, Northeast Atlantic, Southwest Atlantic, Gulf of Mexico, Northeast Pacific, Southwest Pacific, Black Sea, Caspian Sea
Crustacea	Isopoda	Gnorimosphaeroma insulare	pillbug	native	no record/not present	Northeast Pacific	
Crustacea	Isopoda	Gnorimosphaeroma oregonensis	Oregon pillbug	native	no record/not present	North Pacific	
Crustacea	Amphipoda	Grandidierella japonica	amphipod	introduced	no record/not present	Northwest Pacific (Japan)	Northeast Pacific
Plantae		herbaceous plant material		native species present	native species present		
Crustacea	Tanaidacea	Leptochelia savignyi	tanaid	cryptogenic	cryptogenic	Cosmopolitan: Atlantic Ocean, Northeast Pacific, tropical seas, Hawaii	
Entoprocta		Loxosomatidae?	kamptozoans	native species present	native species present		
Chlorophyta		macroalgae		native species present	native species present		
Annelida	Polychaeta	Mediomastus sp.	polychaete or bristle worm	native species present	native species present		
Crustacea	Amphipoda	Melita nitida	amphipod	introduced	native	Northwest Altantic, Caribbean, Gulf of Mexico	Northeast Pacific, Northeast Altlantic
Mollusca	Gastropoda	Mesogastropoda spp.	snails	native species present	native species present		
Annelida	Oligochaeta	Naididae spp. Indeterminant	freshwater worms	native species present	native species present		
Annelida	Polychaeta	Neanthes succinea	pile worm	introduced	native	Atlantic Ocean, Gulf of Mexico	Northeast Pacific, Southwest Pacific
Nematoda		Nematoda spp.	nematodes or roundworms	native species present	native species present		
Crustacea	Cumacea	Nippoleucon hinumensis	cumacean	introduced	no record/not present	Northwest Pacific (Japan)	Northeast Pacific
Annelida	Oligochaeta	Paranais frici	freshwater worms	introduced	no record/not present	Possibly Ponto-Caspian region (Black Sea, Caspian Sea)	Northeast Pacific and possibly (cryptogenic range) North Atlantic, Great Lakes, Northwest Pacific (China)
Annelida	Oligochaeta	Paranais litoralis	freshwater worms	native	native	Cosmopolitan	
Hexapoda	Insecta	Paratanytarsus sp.	non-biting midge	native species present	native species present		
Crustacea	Tanaidacea	Sinelobus stanfordi	tanaid	introduced	cryptogenic	Unknown, cited for the Pacific Ocean, Northwest Atlantic, Caribbean, Gulf of Mexico (but not Texas), Southwest Atlantic and Southeast Atlantic	Possibly Northeast Pacific, Southwest Pacific
Hexapoda	Insecta	Smittia sp.	non-biting midge	native species present	native species present		
Crustacea	Isopoda	Sphaeroma quoianum	isopod	introduced	no record/not present	Australia, New Zealand, Tasmania	Northeast Pacific (OR to Baja CA)
Annelida	Polychaeta	Streblospio benedicti	polychaete or bristle worm	introduced	native	Northwest Atlantic, Gulf of Mexico	Northeast Atlantic, Mediterranean Sea, Black Sea, Northeast Pacific
Platyhelminthes	Turbellaria	Stylochus franciscanus	flatworm	native	no record/not present	Coast of California	
Platyhelminthes	Turbellaria	Stylochus sp.?	flatworm	native species present	native species present		
Crustacea	Isopoda	Synidotea laticauda	isopod	introduced	no record/not present	Northwest Pacific	Northeast Pacific (SF Bay, California Coast, Willapa Bay), Southwest Pacific, North Atlantic (Europe, US Mid-Atlantic States)
Crustacea	Isopoda	Uromunna ubiquita	isopod	native	no record/not present	Northeast Pacific	

	Salinity (psu)		Temperature (ºC)					
Species/Taxon Name	**Range**	**Optimum**	**Range**	**Optimum**	**Substrate Preference-adults**	**Developmental mode**	**Feeding mode**	**Reference**
Actiniaria spp.								
Algae sp. A								
Algae sp. B								
Algae sp. D								
Americorophium spinicorne	tidal fresh to brackish	0-7 reprod. range		8-23	epibenthic tube-building	brooder	herbivore; detritus feeder; suspension feeder	Davidson et al. 2006
Balanus improvisus	0-?	5-25	-2-38	14-30	epibenthic	planktonic larvae	suspension feeder	Davidson et al. 2008
Boccardiella ligerica	0-30	2-20			infaunal	demersal eggs laid in strings in burrows; planktonic larvae	interface feeder	Davidson et al. 2006
Calanoida spp. Indeterminant								
Conopeum chesapeakensis					epibenthic	brooder, planktonic larvae (inferred)	suspension feeder	Davidson et al. 2008
Corbula amurensis	0.1-32	5-25	8-23		infaunal	planktonic larvae	suspension feeder	Davidson et al. 2006
Cordylophora caspia	0-35	0-17	0-30	11-30	epibenthic	brooder; planktonic larvae	suspension feeder; carnivore	Schuchert 2004, NEMESIS database: http://invasions.si.edu/nemesis/chesapeake.html
Corophiidae spp. (juv.)								
Cossura sp.								
crab zoea								
Enchytraeidae spp.								
Ficopomatus enigmaticus	6-35	10-30		>18	epibenthic tube-building	planktonic larvae	suspension feeding	Cohen and Carlton 1995, Cohen 2005
Gammarus daiberi	1-15	1-5	?-32		epibenthic, pelagic	brooder	herbivore; detritus feeder; omnivore	Cohen and Carlton 1995, Davidson et al. 2006
Garveia franciscana	1-35	5-25	0-35	10-32	epibenthic	brooder, planktonic larvae	suspension feeder	Cohen and Carlton 1995, Davidson et al. 2007
Gnorimosphaeroma insulare	freshwater to brackish	0-2			epibenthic	brooder	herbivore; detritus feeder	Davidson et al. 2006
Gnorimosphaeroma oregonensis	brackish to salt				epibenthic	brooder	herbivore; detritus feeder	Davidson et al. 2006
Grandidierella japonica					infaunal and epibenthic tube-building	brooder	herbivore; detritus feeder	Cohen and Carlton 1995
herbaceous plant material								
Leptochelia savignyi					infaunal and epibenthic tube-building	brooder	herbivore; raptorial	Cohen and Carlton 1995 (as *L. dubia*), Boyd et al. 2002, CA Fish & Game 2002
Loxosomatidae?					epibenthic, commensals	planktonic larvae	suspension feeding	
macroalgae								
Mediomastus sp.								
Melita nitida	0-30	3-20			epibiont	brooder	herbivore; detritus feeder; omnivore	Cohen and Carlton 1995, Davidson et al. 2006
Mesogastropoda spp.								
Naididae spp. Indeterminant								
Neanthes succinea	2.5-65		-2-34		Infaunal and epibenthic	planktonic eggs; planktonic larvae	carnivore; detritus feeder; omnivore	Cohen and Carlton 1995, Davidson et al. 2006
Nematoda spp.								
Nippoleucon hinumensis					infaunal and epibenthic	brooder	detritus feeder?	Cohen and Carlton 1995
Paranais frici	freshwater to brackish				Infaunal	asexual reproduction by budding	detritus feeder	Cohen and Carlton 1995, NEMESIS database: http://invasions.si.edu/nemesis/chesapeake.html
Paranais litoralis	freshwater to brackish				infaunal	asexual reproduction by budding	detritus feeder	
Paratanytarsus sp.	freshwater				Larvae: epibenthic	aquatic larvae and pupae, adult terrestrial stage	sprawler	Merritt and Cummins 1996
Sinelobus stanfordi	0-45+	0.5-30			epibenthic	brooder	suspension feeder; detritus feeder	Cohen and Carlton 1995, Davidson et al. 2007
Smittia sp.	freshwater				Larvae: epibenthic, stream sides	semiaquatic larvae and pupae, adult terrestrial stage	collector-gatherer	Merritt and Cummins 1996
Sphaeroma quoianum	3.8-40		5-42		borer in wood, mud, or soft rock	brooder	filter feeder	Rotramel 1972, Cohen and Carlton 1995, Boyd et al 2002, T.M. Davidson 2006
Streblospio benedicti	brackish to euhaline				infaunal tube-building	planktonic larvae	interface feeder	Cohen and Carlton 1995
Stylochus franciscanus					epibenthic	demersal eggs, planktonic larvae	carnivore	Hyman 1953
Stylochus sp.?					epibenthic	demersal eggs, planktonic larvae	carnivore	
Synidotea laticauda					epibenthic, planktonic	brooder	carnivore; ommnivore	Chapman and Carlton 1994, Cohen and Carlton 1995, Bushek and Boyd 2006
Uromunna ubiquita					epibenthic	brooder		CA Fish & Game 2002, Appendix A