BIOFOULING SURVEY OF THE EARLHAM VICTORY IN DRY DOCK

Prepared for

U. S. Maritime Administration
Office of the Environment
Washington, D.C.

Prepared by

Roberto J. Llansó
Kristine Sillett

Versar, Inc.
Ecological Sciences and Applications
9200 Rumsey Road
Columbia, Maryland 21045

FINAL
June 2010

ACKNOWLEDGEMENTS

This document, "Biofouling Survey of the EARLHAM VICTORY in Dry Dock", was prepared by Versar at the request of Dr. Carolyn Junemann of the U.S. Maritime Administration, under Contract # GS-00F-0007L between Versar, Inc., and the U.S. Maritime Administration. We appreciate the assistance of Bryan Vogel and Jeff Siragusa during the sampling effort.

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 reports evaluated the effectiveness of in-water hull cleaning. This report examines the type and extent of biofouling on the EARLHAM VICTORY in dry dock and evaluates hull cleaning by pressurized water.

The sampling design for this study was similar to that implemented on previous biological surveys, except that the sampling was conducted while the vessel was in dry dock. 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 43 distinct taxa, most identified to species level, was found in the biological surveys. Fifty-four percent of the taxa was nonindigenous to California, 14% was native, and 5% was cryptogenic (of uncertain origin). Forty percent of the total number of taxa recorded from the EARLHAM VICTORY was not known to occur in the Gulf of Mexico. The biofouling community was numerically dominated by the nonindigenous barnacle *Balanus improvisus* (21% of total abundance), the nonindigenous isopod *Synidotea laticauda* (29%), the native isopods *Gnorimosphaeroma oregonensis* and *G. insulare* (27%), and the native isopod *Uromunna ubiquita* (9%). In terms of frequency of occurrence, barnacles and isopods occurred in most samples. In addition, the amphipod *Incisocalliope derzhavini*, the polychaete *Boccardiella ligerica*, the hydroid *Garveia franciscana*, and the bryozoan *Conopeum chesapeakensis*, were common in the samples and nonindigenous in San Francisco Bay. The invasive clam *Corbula amurensis* was found in both the pre-cleaning and post-cleaning surveys.

Although the stern appendages and the upper surfaces of the hull tended to have a higher abundance of biofouling organisms, mean abundance and mean number of species per sample did not differ significantly among sampling locations. Barnacles and bryozoans formed a uniform matrix over the hull, which was thicker 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 steel and rust. Most organisms were also removed from the stern appendages, but remnant pockets of biofouling between the rudder and the rudder post harbored numerous species that were not dislodged. 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.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ..... **iii**

EXECUTIVE SUMMARY ..... **v**

1.0 INTRODUCTION **1-1**

2.0 METHODS **2-1**
2.1 BIOLOGICAL SURVEYS 2-1
2.2 SAMPLE PROCESSING AND TAXONOMY 2-3
2.3 ANALYSIS 2-3

3.0 RESULTS **3-1**
3.1 PATTERNS OF BIOFOULING – BEFORE HULL CLEANING 3-1
3.2 AFTER HULL CLEANING 3-2
3.3 SPECIES ASSEMBLAGES 3-3
3.4 DIFFERENCES BETWEEN SURVEYS AND LOCATIONS ON THE HULL 3-7
3.5 IMPLICATIONS FOR SPECIES TRANSFER AND INTRODUCTIONS 3-9

4.0 SUMMARY AND CONCLUSIONS **4-1**

5.0 REFERENCES **5-1**

APPENDICES

A SPECIES ABUNDANCES A-1

B SPECIES BIOGEOGRAPHY AND LIFE HISTORY INFORMATION B-1

LIST OF FIGURES

Figure No. **Page**

2-1. Sampling design consisting of 8 transects across the hull of the vessel (a) and five samples per transect (b) 2-2

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 2-2

3-1. Photographs taken during the drydocking of the EARLHAM VICTORY prior to hull cleaning, December 3, 2009 3-1

3-2. The EARLHAM VICTORY showing long bryozoan strands covering the hull; the bryozoan *Conopeum chesapeakensis* forms ribbon-shaped strands and laminar fronds 3-2

3-3. Photographs taken during the drydocking of the EARLHAM VICTORY after hull cleaning with pressurized seawater, December 5, 2009 3-3

3-4. Differences in mean abundance and mean number of species per sample of biofouling organisms by sampling location on the hull for the pre-cleaning (a, b) and post-cleaning (c, d) surveys 3-8

3-5. Multivariate analysis of presence-absence data showing differences between the pre-cleaning and the post-cleaning samples, and between post-cleaning sampling locations 3-8

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 EARLHAM 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. Biofouling composition was compared to previous Suisun Bay vessels sampled in a similar manner (Versar 2008a, b).

The EARLHAM VICTORY was launched in Richmond, CA, in June 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 July 1970, it remained at the fleet for 39 years. The ship was towed to the San Francisco BAE Systems shipyard on December 3, 2009, for drydocking, and left San Francisco Bay on December 15 on its final tow to Brownsville, TX, for dismantling.

2.0 METHODS

2.1 BIOLOGICAL SURVEYS

Biological surveys on the EARLHAM VICTORY were conducted in dry dock on December 3, 2009, prior to hull cleaning, and on December 5, 2009, after hull cleaning. The pre-cleaning survey started at 7:00 PM immediately after the draining of the dry dock, and was completed by 10:30 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 post 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 using a stereo dissecting microscope.

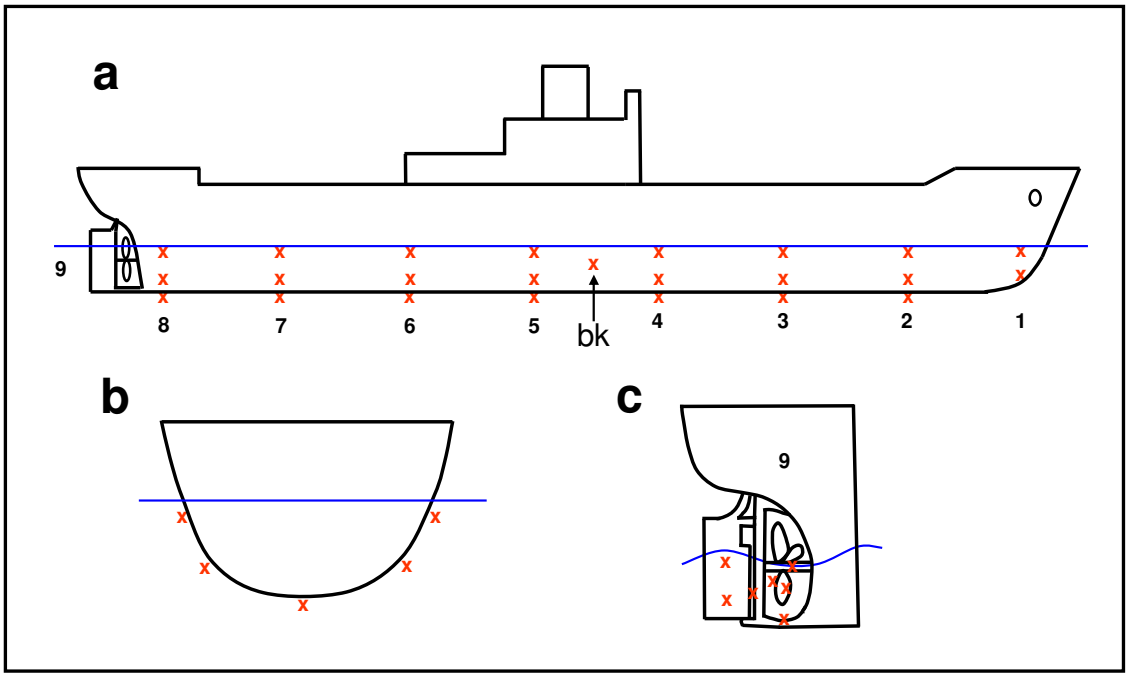

Figure 2-1. Sampling design consisting of 8 transects across the hull of the vessel (a) and five samples per transect (b). The first transect did not have a flat bottom; therefore only four samples were collected from this transect. Additionally, samples were collected from the stern appendages of the vessel (c), and the bilge keel (bk).

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 plastic jars (3-5 bags per jar), 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.

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 barnacles and a thick mat of colonial organisms, with predominance of the encrusting bryozoan *Conopeum chesapeakensis*, a nonindigenous species (Figure 3-2). 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 3-1d). Barnacles and bryozoans appeared to cover the hull uniformly, but with increasing thickness toward the bottom of the hull (Figure 3-1c). The stern appendages and surfaces were also covered by barnacles and bryozoans. 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.

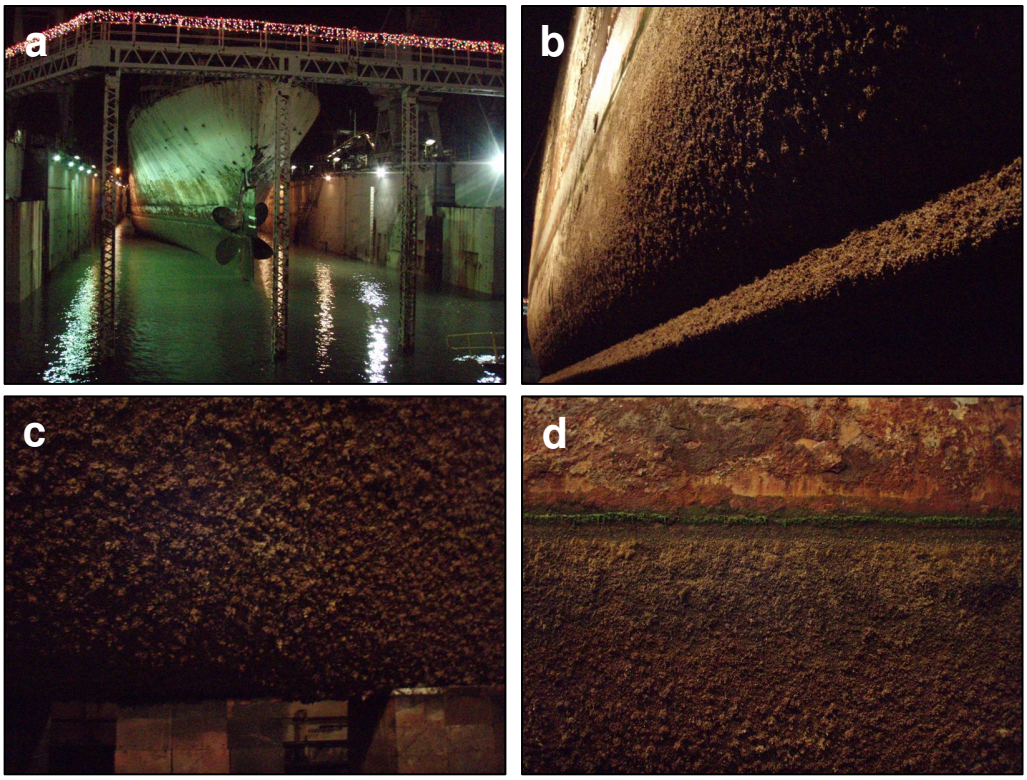

Figure 3-1. Photographs taken during the drydocking of the EARLHAM VICTORY prior to hull cleaning, December 3, 2009. (a) The EARLHAM VICTORY shortly after entering the dry dock; (b) starboard bilge keel showing the thick mat of barnacles and soft growth; (c) denser barnacle and soft growth cover toward the bottom of the hull; (d) algae on the waterline.

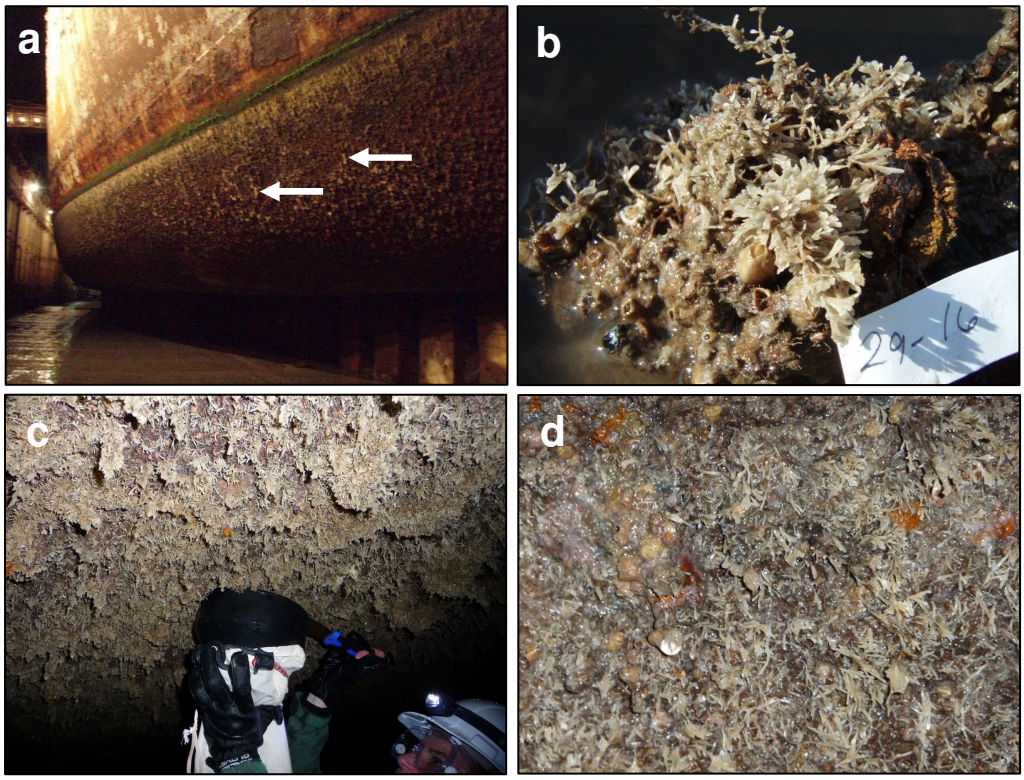

Figure 3-2. The EARLHAM VICTORY showing long bryozoan strands covering the hull (white arrows in panel a); the bryozoan *Conopeum chesapeakensis* forms ribbon-shaped strands and laminar fronds (panels b, c, and d).

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. Abundant biofouling remained under the ship support blocks (Figure 3-3d). 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 (15 isopods, 3 amphipods, 1 polychaete, bryozoans, and algae). However, two pillbug isopods (*Gnorimosphaeroma* spp.), among 3 individuals found in this material, were alive at the time of collection.

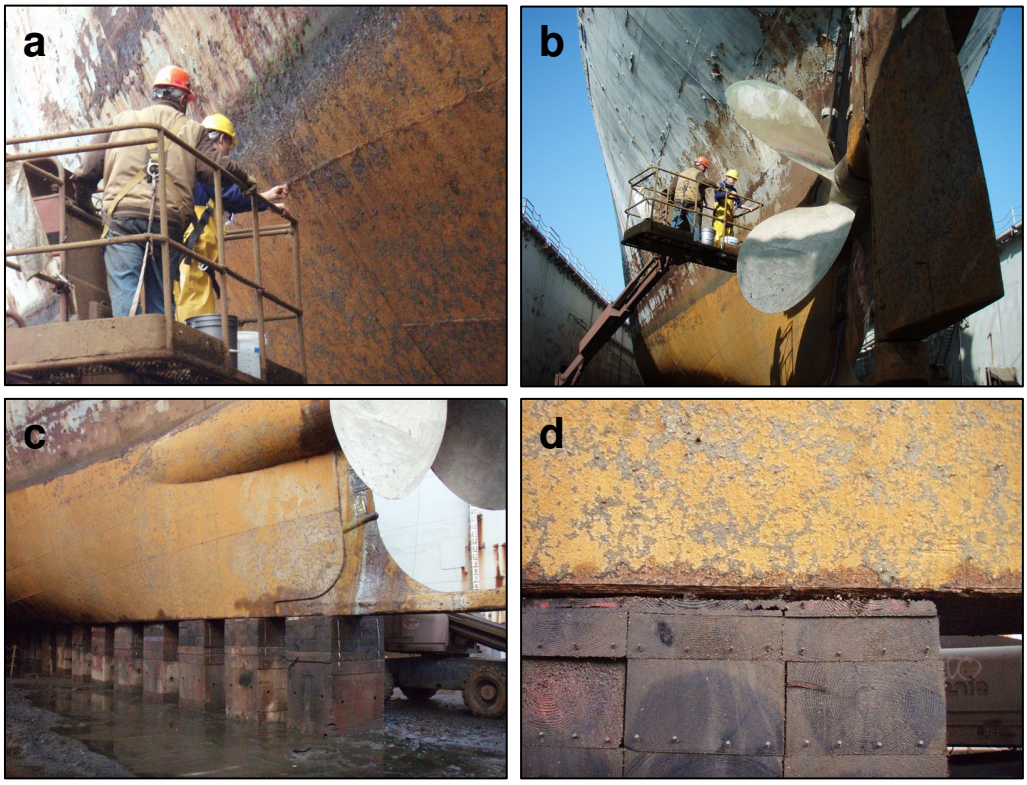

Figure 3-3. Photographs taken during the drydocking of the EARLHAM VICTORY after hull cleaning with pressurized seawater, December 5, 2009. (a) and (b), inspection of the hull; (c) stern area showing bare metal and rust; (d) biofouling organisms remained between the hull and the ship support blocks.

3.3 SPECIES ASSEMBLAGES

Forty-three distinct taxa (hereafter referred as to species) were found in the samples collected from the EARLHAM VICTORY (Table 3-1). Isopod crustaceans were the most abundant. The nonindigenous isopod *Synidotea laticauda* accounted for 8,710 individuals and 29% of total abundance, the native pillbug isopods *Gnorimosphaeroma oregonensis* and *G. insulare* accounted for 7,944 individuals and 27% of total abundance, and the also native isopod *Uromunna ubiquita* accounted for 2,555 individuals and 9% of total abundance. The next most common species was the nonindigenous barnacle *Balanus improvisus*, which accounted for 6,155 individuals and 21% of total abundance. All other species accounted for 5% or less of the total abundance.

In terms of frequency of occurrence, barnacles (*B. improvisus*) and isopods were present in all (*S. laticauda*, G. *oregonensis*, and *G. insulare*) or most (*U. ubiquita*) of the pre-cleaning samples (Table 3-1). Other frequently occurring species were the amphipod crustacean *Incisocalliope derzhavini*, the polychaete *Boccardiella ligerica*, the bryozoan *Conopeum chesapeakensis*, and the hydroid *Garveia franciscana*, all nonindigenous in San Francisco Bay.

Appendix B presents the biogeographic status and life history characteristics of all the species found in the biological surveys. Twenty-three species, or 54% of the total number of species recorded from the EARLHAM VICTORY prior to hull cleaning, were nonindigenous in California waters. These included 5 amphipods, 3 isopods, 4 polychaetes, and 4 bivalves, in addition to species from other invertebrate groups, including one decapod (Table 3-1, Appendix B). Six species (14%) were native, and two species (5%) were cryptogenic (of uncertain origin). The remaining taxa were genus or higher level identifications with species present in California, but some of these species (e.g., the sea anemone) may also be nonindigenous. Thus, nonindigenous species predominated in the biofouling community of the EARLHAM VICTORY.

Eleven of the nonindigenous species were not known to occur in the Gulf of Mexico, and another six species that were native to California were also unknown in the Gulf of Mexico. In all, 40% of the total number of species recorded from the EARLHAM 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 EARLHAM 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 1990). Juveniles of *C. amurensis* were found in 14% of the pre-cleaning samples, and in one of the post-cleaning samples. *C. amurensis* was found also on other Suisun Bay vessels (Versar, 2008b).

Most of the nonindigenous species present on the EARLHAM VICTORY were found in previous Suisun Bay hull surveys (Table 3-1, Versar 2008a, b). Two isopods and three mussels were new findings in the present study. The isopods were the burrower *Sphaeroma quoianum* and a commensal species, *Iais californica*. Both are commonly found in estuaries of northern California but are native to Australia and New Zealand (Rotramel 1972). *Sphaeroma quoianum* excavates burrows in a variety of substrates, including wood and consolidated mud. It can attain high densities and has been blamed for creating erosion in marshes and mud banks and damaging marine structures (Talley et al. 2001).

The three mussels were the ribbed mussel *Geukensia demissa*, the green mussel *Musculista senhousia*, and unidentifiable juvenile specimens of *Mytilus* sp., most likely the Mediterranean mussel, *Mytilus galloprovincialis*. *Geukensia demissa* is a common inhabitant of oyster reefs and salt marshes along the east coast of North America, its native range. In San Francisco Bay, *Geukensia demissa* lives semi-buried in mud and along the lower fringes of salt marshes, and is sometimes found attached to structures. *Musculista senhousia* is native to China and Japan. It forms dense aggregations on the

Table 3-1. Species recorded in the biological samples (250-μm sieve) of the EARLHAM 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, or JASON 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 or Jason?
	Pre-Cleaning	Post-Cleaning		
Algae				
Algae sp. A	8	20	?	x
Algae sp. B	18	0	?	x
Algae sp. D	28	7	?	x
macroalga	2	0	NP	
Amphipods				
Americorophium spinicorne	8	0	N	x
Ampithoe valida	14	7	I	x
Corophiidae spp. (juv.)	22	0	NP	x
Grandidierella japonica	16	0	I	x
Incisocalliope derzhavini	96	93	I	x
Melita nitida	76	13	I	x
Monocorophium acherusicum	10	0	I	x
Anthozoans (sea anemones)				
Actiniaria spp.	2	0	NP	x
Ascidians (sea squirts)				
Molgula manhattensis	24	20	I	
Bivalves (clams and mussels)				
Bivalvia spp. Indeterminant	2	0	NP	x
Corbula amurensis	14	7	I	x
Geukensia demissa	2	0	I	
Modiolus capax? (juv.)	2	7	N	
Musculista senhousia	10	13	I	
Mytilidae spp. (juv.)	2	0	NP	x
Mytilus sp. (possibly *M. galloprovincialis*)	12	7	I	
Cirripedia (barnacles)				
Balanus improvisus	100	100	I	x
barnacle cypris	4	0	NP	x
barnacle nauplius	4	0	NP	
Decapods (crabs)				
crab zoea	14	7	NP	crab megalop
Rhithropanopeus harrisii	2	0	I	x
Ectoprocts (bryozoans)				
Conopeum chesapeakensis	90	100	I	x
Gastropods (snails)				
Nudibranchia spp. Indeterminant	2	0	NP	x

Table 3-1. (Continued)

Species	% Samples		Status	Present in OV, QV or Jason?
	Pre-Cleaning	Post-Cleaning		
Okenia plana	58	27	I	x
Hydroids				
Garveia franciscana	88	100	I	x
Insects				
Dolichopodidae spp.	0	7	NP	
Telmatogeton sp.	4	7	NP	
Isopods				
Gnorimosphaeroma oregonensis /insulare	100	33	N	x
Iais californica	18	0	I	
Sphaeroma quoianum	32	0	I	
Synidotea laticauda	100	87	I	x
Uromunna ubiquita	96	67	N	x
Mysids (fairy shrimps)				
Mysidae spp.	2	0	NP	x
Oligochaetes				
Enchytraeidae spp.	48	7	NP	Oligochaeta
Tubificidae spp.	4	0	NP	Oligochaeta
Plants				
Eriophorum gracile	8	7	N	
Polychaetes (bristle worms)				
Boccardiella ligerica	90	20	I	x
Ficopomatus enigmaticus	22	27	I	x
Neanthes succinea	64	13	I	x
Polydora cornuta	54	27	C	x
Streblospio benedicti	2	0	I	Spionidae juv.
Syllidae (Autolytinae) spp. (juv.)	2	0	NP	Syllidae
Pycnogonids (sea spiders)				
Anoplodactylus sp. (juv.)	0	7	NP	
Tanaids				
Sinelobus stanfordi	18	7	I	x
Turbellarians (flatworms)				
Stylochus franciscanus	74	47	N	x
Turbellaria sp. A (Leptoplanidae)	64	13	C	x

sediment surface of estuaries, constructing mats that have been claimed to have adverse impacts on aquaculture operations, sea grass beds, and the biodiversity of macrofaunal benthic communities (Global Invasive Species Database, www.issg.org, accessed 5 May 2010). *Mytilus galloprovincialis* appeared in southern California between 1900 and 1947, and displaced the native populations of *Mytilus trossulus* (Cohen and Carlton 1995). The Mediterranean mussel is abundant in northern San Francisco Bay, although it can only be identified through morphometric and molecular analysis. Hybridization occurs frequently among the nonindigenous and the native species. None of the mussel species found in the present surveys is known to occur in the Gulf of Mexico.

In addition to the above species, the sea grape *Molgula manhattensis*, was also found on Suisun Bay hull surveys for the first time. Since its introduction in the 1950s, *Molgula manhattensis* has become abundant in San Francisco Bay and is now commonly found on rocks, shells, pilings, and boat hulls (Cohen and Carlton 1995). It is native to the North Atlantic ocean and the Gulf of Mexico. It tolerates wide fluctuations of salinity and pollution, and can foul marine structures in dense aggregations. It was one of the most abundant fouling organisms on hulls of James River Reserve Fleet vessels (Versar 2009).

3.4 DIFFERENCES BETWEEN SURVEYS AND LOCATIONS ON THE HULL

The stern appendages and the upper surfaces of the hull tended to have a higher abundance of biofouling organisms, but differences between locations were not statistically significant (ANOVA; $F = 1.83$, $p = 0.155$) (Figure 3-4,a,b). The mean number of species per sample was also slightly higher on the stern appendages and the upper surfaces of the hull, but differences were not significant ($F = 0.76$, $p = 0.522$). No biomass data were collected, but on-site observations suggest that biofouling cover was thicker on the bottom of the hull than the side surfaces.

Post-cleaning samples showed marked differences between the rudder hinge and the support blocks (Figure 3-4,c,d). We collected ten times as many individuals and four times as many species at the base of the rudder hinge than around the support blocks. Although these differences may simply reflect differences in sample size and collection effort between the rudder and the support blocks, the higher number of species found at the base of the rudder hinge suggests that this area is a niche location. It forms a crevice between the rudder and the rudder post where organisms find protection and can escape exposure to pressure washing. The multivariate analysis also indicated differences in community organization between the rudder hinge and the support block samples (Figure 3-5). On average, 9 species (± 1.4) were found in each of the samples collected from the post-cleaning survey, and a total of 29 species was found in the survey.

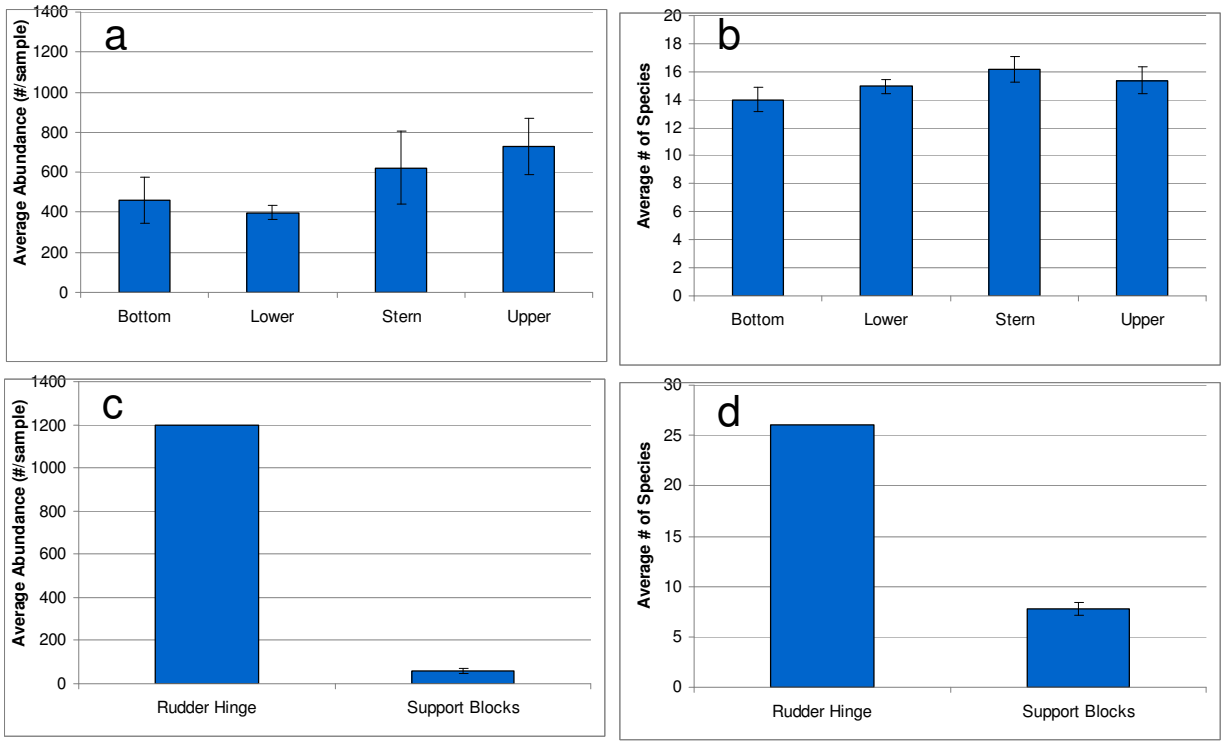

Figure 3-4. Differences in mean abundance and mean number of species per sample (± 1 Standard Error) of biofouling organisms by sampling location on the hull for the pre-cleaning (a, b) and post-cleaning (c, d) surveys. Lower = lower or mid-depth surface; Upper = upper surface, near the waterline; Stern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

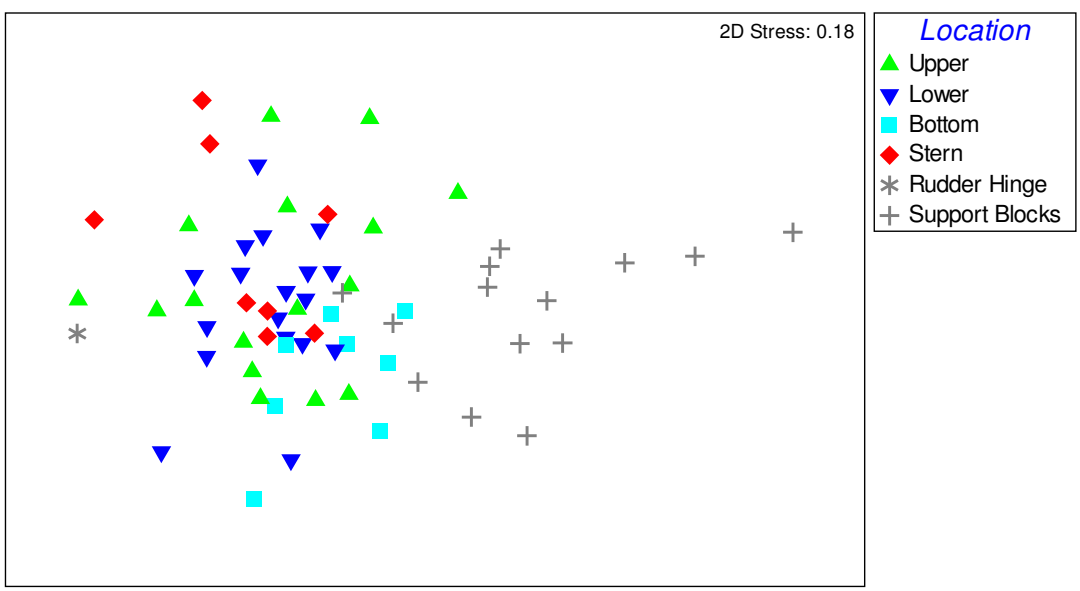

Figure 3-5. Multivariate analysis of presence-absence data showing differences between the pre-cleaning (colored symbols) and the post-cleaning samples (gray symbols), and between post-cleaning sampling locations (rudder hinge different than support blocks).

3.5 IMPLICATIONS FOR SPECIES TRANSFER AND INTRODUCTIONS

The cleaning of the EARLHAM VICTORY in dry dock removed most of the biological growth covering the exposed surfaces of the hull. Prior to cleaning, the underwater surfaces of the hull exhibited a thick layer of barnacles and soft growth that provided three-dimensional cover to isopods, amphipods, and other biofouling species. More than half of the species found in the present surveys were nonindigenous in San Francisco Bay. Many of these species, 40% of the total, were not known to occur in the Gulf of Mexico. Therefore, the risk for species transfers and introductions at destination ports would have been significant if vector management had not been conducted. Drydocking was more effective at removing biofouling on reserve fleet vessels than in-water hull cleaning (Versar 2008a, b). Bare metal and rust was all that was left in the exposed areas of the hull after drydocking. However, a total of 29 species, or 67% of the original assemblage, was recovered from niche areas after pressure washing, and 12 of these species were unknown from the Gulf of Mexico.

The 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 not cleaned. 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 close their shells and withstand adverse conditions during the drydocking. 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 house biofouling was made clear by the finding of numerous species inhabiting the crevices left between the rudder and the rudder post. 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 provide 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 may represent a challenge, but provided that these areas are reached, pressure washing should be able to remove most organisms except the most recalcitrant-cemented barnacles. These areas are likely to be the first ones to be recolonized by biofouling organisms if the ships return to the fleet after drydocking. Therefore, future hull management activities should focus on the more protected or sheltered areas.

4.0 SUMMARY AND CONCLUSIONS

1. Pre-cleaning and post-cleaning hull surveys of biofouling were conducted on the Suisun Bay Reserve Fleet vessel EARLHAM VICTORY in dry dock. The surveys yielded a total of 43 distinct species. Fifty-four percent of the species was nonindigenous to California, 14% was native, and 5% was cryptogenic (of uncertain origin). Forty percent of the total number of species recorded from the EARLHAM VICTORY was unknown in the Gulf of Mexico.

2. The biofouling community was numerically dominated by barnacles and isopods, and the bryozoan *Conopeum chesapeakensis* provided abundant biomass cover. Among the nonindigenous species, the barnacle *Balanus improvisus* accounted for 21% of total abundance, and the isopod *Synidotea laticauda* accounted for 29% of total abundance. The native isopods *Gnorimosphaeroma oregonensis* and *G. insulare* (as a group) and *Uromunna ubiquita* accounted for 27% and 9% of total abundance, respectively. Frequently occurring species in the samples were barnacles, isopods, the amphipod *Incisocalliope derzhavini*, the polychaete *Boccardiella ligerica*, the hydroid *Garveia franciscana*, and the bryozoan *Conopeum chesapeakensis*, all nonindigenous in San Francisco Bay. The invasive clam *Corbula amurensis* was found in both the pre-cleaning and post-cleaning surveys.

3. The stern appendages and the upper surfaces of the hull tended to have a higher abundance of biofouling organisms, but the differences among the sampling locations were not statistically significant. Barnacles and bryozoans formed a uniform matrix over the hull, with increasing thickness toward the bottom of the hull.

4. Pressure washing removed the biofouling of the exposed surfaces of the hull. The hull after cleaning showed bare steel and rust. Most organisms were also removed from the stern appendages of the vessel, but pockets of biofouling remained on sheltered areas of the ship, such as in between the rudder and the rudder post. 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.

5.0 REFERENCES

Blake, J.A. 1969. Reproduction and larval development of *Polydora* from northern New England (Polychaeta: Spionidae). Ophelia 7:1-63.

Boyd, M.J., T.J. Mulligan, and F.J. Shaughnessy. 2002. Non-Indigenous Marine Species of Humboldt Bay, California. A Report to the California Department of Fish and Game. Humboldt State University, Arcata, California.

Bushek, D. and S. Boyd. 2006. Seasonal abundance and occurrence of the Asian isopod *Synidotea laevidorsalis* in Delaware Bay, USA. Biological Invasions 8:697-702.

CA Fish & Game. 2002. A Survey of Non-Indigenous Aquatic Species in the Coastal and Estuarine Waters of California. California Department of Fish & Game, Office of Spill Prevention and Response, Sacramento, California.

Carlton, J.T. 1979. Introduced Invertebrates in San Francisco Bay. Pp. 427-444 *In*: San Francisco Bay: The Urbanized Estuary; Investigations into the Natural History of San Francisco Bay and Delta with Reference to the Influence of Man. Pacific Division of the American Association for the Advancement of Science, San Francisco, California.

Carlton, J.T., J.K. Thompson, L.E. Schemel, and F.H. Nichols. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. I. Introduction and dispersal. Marine Ecology Progress Series 66:81-94.

Chapman, J.W. and J.T. Carlton. 1994. Predicted discoveries of the introduced isopod, *Synidotea laevidorsalis* (Miers, 1881). Journal of Crustacean Biology 14:700-714.

Clarke, K.R. and R.N. Gorley. 2006. PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth Marine Laboratory, Plymouth, United Kingdom.

Coan, E.V. and P. Valentich-Scott. 2007. Bivalvia Pp. 807-859 *In*: Carlton, J.T. (ed.), The Light and Smith Manual. Intertidal Invertebrates from Central California to Oregon. Fourth Edition. University of California Press, Berkeley, California.

Cohen, A.N. 2005. Guide to the Exotic Species of San Francisco Bay. San Francisco Estuary Institute, Oakland, California. Available online: www.exoticsguide.org [Accessed: May 2010].

Cohen, A.N. and J.T. Carlton. 1995. Nonindigenous Aquatic Species in a United States Estuary: A Case Study of the Biological Invasions of the San Francisco Bay and Delta. Report submitted to the U. S. Fish and Wildlife Service, Washington D.C.

and the National Sea Grant College Program, Connecticut Sea Grant (NOAA Grant Number NA36RG0467).

Cohen, A.N. and 11 authors. 2002. Project Report for the Southern California Exotics Expedition 2000: A Rapid Assessment Survey of Exotic Species in Sheltered Coastal Waters. California Department of Fish and Game, State Water Resource Control Board, and National Fish and Wildlife Foundation.

Colbo, M.H. 1996. Chironomidae from marine coastal environments near St. John's, Newfoundland, Canada. Hydrobiologia 318:117-122.

Davidson, I.C., L.D. McCann, P.W. Fofonoff, M.D. Sytsma, and G.M. Ruiz. 2008. The potential for hull-mediated species transfers by obsolete ships on their final voyages. Diversity and Distributions 14:518-529.

Davidson, I., G. Ruiz, M. Sytsma and P. Fofonoff. 2006. Hull Biofouling on the Vessels POINT LOMA and FLORENCE in the Reserve Fleet at Suisun Bay, CA: A Pilot Study with Respect to Potential Transfer of Non-native Species. Report submitted to the U. S. Maritime Administration, Washington D.C. Aquatic Bioinvasion Research & Policy Institute, Portland, Oregon.

Davidson, I., G. Ruiz, M. Sytsma, P. Fofonoff, B. Mohammad, L. McCann, C. Zabin, and S. Altman. 2007. A Post-Voyage Analysis of Hull Biofouling on the Vessels POINT LOMA and FLORENCE After Transit from California to Texas. Report submitted to the U. S. Maritime Administration, Washington D.C. Aquatic Bioinvasion Research & Policy Institute, Portland, Oregon.

Davidson, T.M 2006. The Invasion of the Australian Burrowing Isopod (*Sphaeroma quoianum*) In Coos Bay, Oregon. Master Thesis, Department of Biology, University of Oregon.

Decker, K., D.R. Culver, and D.G. Anderson. 2006. *Eriophorum gracile* W. D. J. Koch (slender cottongrass): A technical Conservation Assessment. USDA Forest Service, Rocky Mountain Region. Available online: http://www.fs.fed.us/r2/projects/scp/assessments/eriophorumgracile.pdf [Accessed May 2010].

Epler, J.H. 1995. Identification Manual for the Larval Chironomidae (Diptera) of Florida. Florida Department of Environmental Protection, Tallahassee, FL.

Green, G., and P.L. Lambert. 1994. Protocols for Reference and Voucher Collections of Aquatic Invertebrates Stored at the Royal British Columbia Museum. Report submitted to the Royal British Columbia Museum, Victoria, B.C., and Environment Canada, Environmental Conservation Branch, North Vancouver, B.C.

Hyman, L.H. 1953. The Polyclad flatworms of the Pacific Coast of North America. Bulletin of the American Museum of Natural History 100:269-391.

LeCroy, S. 2004. An Illustrated Identification Guide to the Nearshore Marine and Estuarine Gammaridean Amphipoda of Florida. Volume 3. Florida Department of Environmental Protection, Tallahassee, Florida.

Nichols, F.H., J.K. Thompson, and L.E. Schemel. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. II. Displacement of a former community. Marine Ecology Progress Series 66:95-101.

Rotramel, G. 1972. *Iais californica* and *Sphaeroma quoyanum*, two symbiotic isopods introduced to California (Isopoda, Janiridae and Sphaerotomatidae). Crustaceana, Suppl. 3:193-197.

Talley, T.S., J.A. Crooks, and L.A. Levin. 2001. Habitat utilization and alteration by the invasive, burrowing isopod, *Sphaeroma quoyanum*, in California salt marshes, Marine Biology 138:561-573.

Van Name, W.G. 1945. The North and South American Ascidians. Bulletin of the American Museum of Natural History, v. 48.

Versar, Inc. 2008a. Hull Biofouling of Suisun Bay Reserve Fleet Vessel Occidental Victory Before and After Transit from California to Texas. Report to U.S. Maritime Administration, Office of the Environment, Washington D.C. Versar, Inc., Columbia, Maryland.

Versar, Inc. 2008b. Hull Biofouling of Suisun Bay Reserve Fleet Vessels Queens Victory & Jason Before and After Transit from California to Texas. Report to U.S. Maritime Administration, Office of the Environment, Washington D.C. Versar, Inc., Columbia, Maryland.

Versar, Inc. 2009. Biofouling on the Vessels Pride, Scan, and Cape Charles at the James River Reserve Fleet and After Towing to Texas. Report to U.S. Maritime Administration, Office of the Environment, Washington D.C. Versar, Inc., Columbia, Maryland.

Williams, A.B. 1984. Shrimps, Lobsters, and Crabs of the Atlantic Coast. Smithsonian Institution Press, Washington, D.C.

Wonham, M.J. 2004. Mini-review: distribution of the Mediterranean mussel *Mytilus galloprovincialis* and hybrids in the Northeast Pacific. J. Shellfish Res. 23, 535–543.

APPENDIX A

SPECIES ABUNDANCES
(SEE CD FOR ELECTRONIC DATA)

APPENDIX B

SPECIES BIOGEOGRAPHY AND LIFE HISTORY INFORMATION