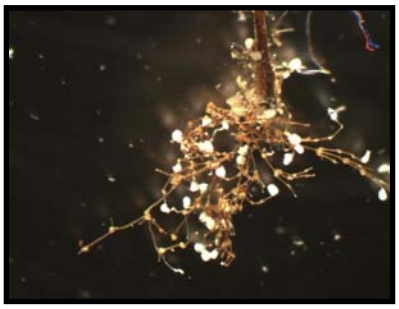
HULL BIOFOULING OF BEAUMONT RESERVE FLEET VESSELS PIONEER CONTRACTOR, MOUNT VERNON, AND CAPE FLORIDA



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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 has implemented in-water hull cleaning as one management option to reduce the risk of transferring nonnative species to new coastal regions where they may become established.

The extent of biofouling on the vessels PIONEER CONTRACTOR, MOUNT VERNON, and CAPE FLORIDA, was examined at the Beaumont Reserve Fleet, Texas. This study is one in a series that examines the biological growth on obsolete vessels and evaluates the effectiveness of in-water hull cleaning as a vector management option. The three vessels were sampled for biological characterization, and the PIONEER CONTRACTOR was sampled before hull cleaning and after hull cleaning.

The sampling design for this study was similar to that implemented on previous biological surveys. Fifty samples per sampling iteration were collected by divers from the underwater surfaces of the vessels using a stratified random sampling design consisting of transects and starboard to port locations within transect. At each location, a 6-inch diameter PVC sampler was used to scrape approximately a 182 cm^2 area of the hull. Samples were stored in cloth bags, examined and photographed at the fleet, and transferred to the laboratory for sorting, enumeration, and identification of organisms.

The biological samples were accompanied by underwater photographs of the biota (photo-quadrats) and video. The system used for the photo quadrats consisted of an underwater camera and a “clear-water box” that provided a standard image area for all photographs. Samples were analyzed for differences in species abundance and composition across ships, surveys, transects, and locations using univariate and multivariate analyses. Photo-quadrats were analyzed by the point-count method to determine percent cover of biofouling species (mussels, barnacles, hydroids, algae, etc.) and bare hull. Videos were examined to characterize type and extent of coverage.

A total of 61 taxa were found, 28 of which were identified to species level. Freshwater and brackish water species predominated in the samples. The biofouling community was numerically dominated by Conrad’s false mussel, *Mytilopsis leucophaeata*, and the barnacle *Balanus subalbidus*. These two species accounted for 71% and 9% of total abundance, respectively. Mussels and barnacles were common on all vessels, followed by an unidentified leptoplanid flatworm, the hydroid *Garveia franciscana*, the bryozoan *Bowerbankia gracilis*, the flatworm *Stylochus ellipticus*, and the freshwater sponge *Ephydatia fluviatilis*. The amphipods *Hourstonius laguna* and *Apocorophium lacustre* were abundant but occurred less frequently in the samples.

Mean abundance per sample differed significantly among ships, but mean species numbers did not differ significantly. Vessel age did not appear to be a factor in the observed differences among ships. There were no consistent differences in abundance or species composition by transect, but the bottom of the hull exhibited higher percent hydroid cover than other hull surfaces.

All but four of the species found in the present surveys were either native or cryptogenic, and all of the genera and higher level taxa had native species in Texas. The four nonnative species were the bryozoan *Conopeum chesapeakensis*, the hydroids *Cordylophora caspia* and *Garveia franciscana*, and the polychaete *Ficopomatus enigmaticus*. These results are similar to those of the 2007 surveys conducted on the DUTTON and three other vessels. Except for *C. chesapeakensis*, the nonnative species are likely to occur elsewhere along the Gulf of Mexico. The presence of *C. chesapeakensis* in the Neches River estuary is of concern, since it constitutes a range extension for this species outside of its native region.

In-water hull cleaning of the PIONEER CONTRACTOR was not successful at removing abundant hydroid cover, and associated species, from the bottom of the hull. On average, hull cleaning removed 54% of the biofouling cover. Densities and species numbers were significantly reduced by hull cleaning, but a majority of the species found in the pre-cleaning survey were also found in the post-cleaning survey, and many occurred frequently after hull cleaning. An inability of hull cleaning to remove most species increases the risk of species transfers and introductions.

TABLE OF CONTENTS

Page

ACKNOWLEDGEMENTS ..... **III**

EXECUTIVE SUMMARY ..... **V**

1.0 INTRODUCTION **1-1**

2.0 METHODS **2-1**
- 2.1 WATER CHARACTERISTICS 2-1
- 2.2 BIOLOGICAL SURVEYS 2-2
- 2.3 SAMPLE PROCESSING AND TAXONOMY 2-4
- 2.4 ANALYSIS 2-5

3.0 RESULTS AND DISCUSSION **3-1**
- 3.1 WATER CHARACTERISTICS 3-1
- 3.2 SPECIES ASSEMBLAGES 3-1
- 3.3 DIFFERENCES BETWEEN SHIPS, SURVEYS AND LOCATIONS ON THE HULL 3-7
- 3.4 RISK OF SPECIES INTRODUCTIONS 3-15

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

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LIST OF FIGURES

Figure No. **Page**

2-1. Map of the Beaumont Reserve Fleet showing the locations of the ships and the biological and water quality characterization sites. 2-1

2-2. Sampling design. Samples and photo-quadrats were taken at 8 transects across the hull of the vessels 2-3

2-3. Sampler constructed from a 6-inch diameter PVC pipe with a 4 inch adapter. 2-4

2-4. Grid of random points superimposed on an underwater photograph taken from the upper starboard side of Transect 1 of the PIONEER CONTRACTOR prior to hull cleaning 2-6

3-1. Salinity, temperature, and dissolved oxygen of the water at the Beaumont Reserve Fleet during the biological surveys of the PIONEER CONTRACTOR, MOUNT VERNON, and CAPE FLORIDA 3-2

3-2. Underwater photographs taken from the hull of the PIONEER CONTRACTOR prior to hull cleaning and the CAPE FLORIDA, showing barnacles, mussels, and soft growth 3-8

3-3. Multivariate analysis of presence-absence data showing no differences in biofouling community organization (i.e., no separate groups of samples in the diagram) among ships, and between the pre-cleaning and post-cleaning surveys of the PIONEER CONTRACTOR. 3-9

3-4. Differences in mean abundance and mean number of species per sample (+/- one standard error) of biofouling organisms in three Beaumont Reserve Fleet vessels, tested by ANOVA.. 3-10

3-5. Differences in mean abundance and mean number of species per sample (+/- one standard error) of biofouling organisms between the pre-cleaning and post-cleaning hull surveys of the PIONEER CONTRACTOR, tested by ANOVA.. 3-11

3-6. Biofouling percent cover of PIONEER CONTRACTOR before hull cleaning and after hull cleaning.. 3-12

3-7. Biofouling percent cover of MOUNT VERNON. 3-13

3-8. Biofouling percent cover of CAPE FLORIDA.. 3-14

3-9. Multivariate analysis of photo-quadrat data.. 3-16

1.0 INTRODUCTION

As part of its non-retention vessel disposal program, the U.S. Maritime Administration oversees transfers of ships from National Defense Reserve Fleet (NDRF) locations to ship-breaking facilities. The vessels are towed from their fleet to other geographic locations where ship breaking takes place. Because many vessels have been laid up for long periods of time, their underwater surfaces can be heavily fouled by aquatic organisms and their transfer may create a risk of biological invasion at destination ports. This report is the sixth in a series that documents the biofouling of NDRF vessels, and assesses the effectiveness of in-water hull cleaning as a vector management option.

In this study, the extent of biofouling on the hull of three Beaumont Reserve Fleet (BRF) vessels, PIONEER CONTRACTOR, MOUNT VERNON, and CAPE FLORIDA, is examined. The MOUNT VERNON and CAPE FLORIDA were sampled to provide biological characterization of BRF vessels. The PIONEER CONTRACTOR was sampled for extent of biofouling before hull cleaning and after hull cleaning. As in previous surveys, the objecttives were to: 1) identify and quantify the biota associated with the underwater surfaces of BRF vessels, 2) describe differences in biofouling between the pre-cleaning and post-cleaning biological surveys, and (3) examine the biogeographic status and distribution of species with respect to their possible transfer from the BRF to destination ports. The present report complements and amplifies the information presented in a previous study of BRF vessels. In that study, biological characterization was provided for four vessels: DUTTON, DEL VALLE, HATTIESBURG VICTORY, and PIONEER CRUSADER (Versar 2008d).

The PIONEER CONTRACTOR was built in 1962 and entered the BRF in May 1981 where it was assigned to military sealift support. Downgraded from the Ready Reserve Fleet in 2001, it was sold to a ship-breaking company and transferred to Brownsville, Texas, for dismantling in February 2009.

The MOUNT VERNON was built in 1961 and entered the BRF in January 1988, one of the Military Sealift Command's thirteen common user oil tankers. It was transferred from the Ready Reserve Fleet to the NDRF in October 1994 and slated for disposal.

The CAPE FLORIDA was built in 1970 as a barge carrier and named SS DELTA CARIBE. It entered the Ready Reserve Fleet in February 1987 and renamed CAPE FLORIDA. As of June 30, 2009, this ship remained active in the BRF, providing military support and emergency sealift.

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2.0 METHODS

2.1 WATER CHARACTERISTICS

The BRF is located in the Neches River estuary near Beaumont, Texas. The salinity in this reach of the river is in the tidal freshwater to oligohaline range. Salinity, conductivity, temperature, dissolved oxygen, and pH were measured on-site to characterize the environment encountered by the biota at the time of sampling. Data were collected at 3 locations near the ships: two in the shallower portion (17 feet) of the basin where the fleet is located, and one in the deeper portion (28 feet) of the basin (Figure 2-1). A Yellow Springs Instrument (YSI Inc., Yellow Springs, Ohio) multiparameter probe with automatic temperature and salinity compensation was deployed at approximately 1 meter intervals from the surface of the water to the maximum lightweight draft of the vessels. These data characterized local conditions at the time of sampling, but these conditions are likely to vary over the course of the year depending on river flow.

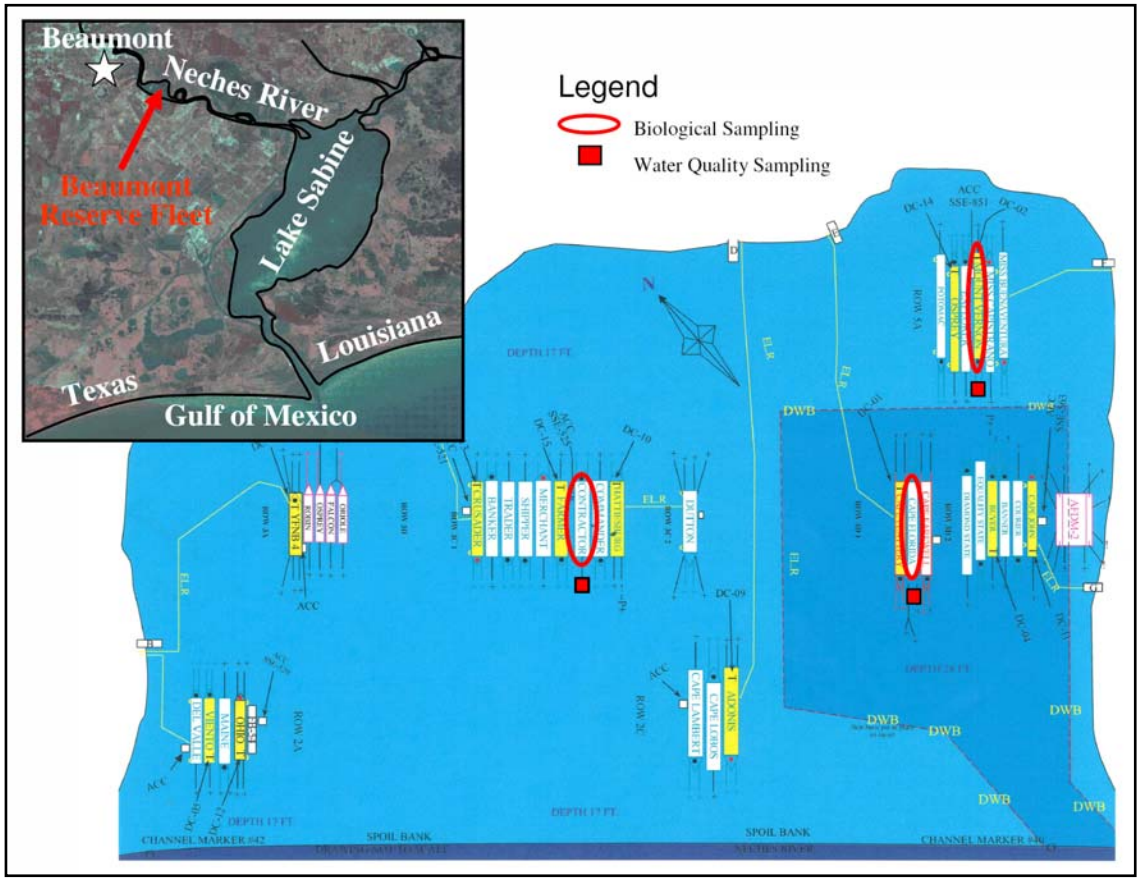


Figure 2-1. Map of the Beaumont Reserve Fleet showing the locations of the ships and the biological and water quality characterization sites.

2.2 BIOLOGICAL SURVEYS

The PIONEER CONTRACTOR was surveyed over two separate dives in Beaumont. The vessel was surveyed on August 8 and 9, 2008, prior to hull cleaning, and on August 25 after hull cleaning. The vessel departed the BRF for final disposition on January 2009. A post-transit survey in Brownsville was not conducted. Biological sampling on the MOUNT VERNON and CAPE FLORIDA was conducted on August 10 and 11, 2008, respectively. The location of the vessels in the BRF at the time of sampling is shown in Figure 2-1.

Samples were collected with the help of professional divers. Diving was conducted using surface-supplied air and real-time audio and visual communications with the surface team. The surface team included a diver master and two scientists who directed two of the divers toward the locations where samples and photo-quadrats were to be taken. Diving services were provided by Underwater Services International (Gainesville, Florida). The sampling design was similar to that employed in previous surveys (Davidson et al. 2006; Versar 2008a, b, c, d; Versar 2009). Samples were taken at three depths (near the waterline, mid-depth, and bottom of the hull) along eight transects positioned at 75 feet (PIONEER CONTRACTOR), 95 feet (MOUNT VERNON), and 106 feet (CAPE FLORIDA) intervals from anchor chain to stern, depending on ship length (Figure 2-2). The length of these vessels were 561 feet, 736 feet, and 820 feet, respectively. Five samples were collected per transect: starboard upper, starboard lower, bottom, port lower, and port upper. The first transect near the bow did not have a flat bottom; therefore, only four samples were collected from this transect. Eleven additional samples were taken from the underwater appendages of each vessel, including the stern tube, rudder, propellers, and the upper and lower surfaces of the bilge keel.

At each sampling location, one diver positioned an underwater camera against the surface of the hull and photographed the biota covering the hull. The second diver then collected a sample from a random point within approximately a one-meter radius of the photo-quadrat location. A sampler constructed from a 6-inch (15.2 cm) diameter PVC pipe with a 4-inch adapter to attach the sample bag, was used to collect the biota (Figure 2-3). A diver placed the 6-inch end of the sampler against the hull of the ship and attached a numbered cloth bag to the opposite end. A 3-inch scraper applied between the hull and the sampler was used to remove the biological material from the hull, which was then collected in the sample bag. The PVC sampler was curved at a 45 degree angle, so that the sample would fall straight down into the bag. The bag was twisted closed and tied off before being removed from the sampler to minimize sample loss.

An area of approximately 182 cm^2 of hull was scraped for each sample. The bag number was relayed to the surface so that detailed notes could be taken on the location at which each sample was collected. Sample bags were stored in a mesh dive bag and returned to the surface, usually in groups of 10 bags corresponding to 2 sampling transects. Upon retrieval, all bags were immediately transferred to 5-gallon buckets with in situ marine water. Protexo bags manufactured by HUBCO (Hutchinson, Kansas) were

used. Each bag was made of tightly woven white cotton cloth, and measured 10 x 17 inches (25.4 x 43.2 cm). Each bag included a drawstring that, in addition to a rubber band, kept the bag closed after sample collection. A total of 200 samples (50 samples per survey) were collected for analysis of species abundance and composition.

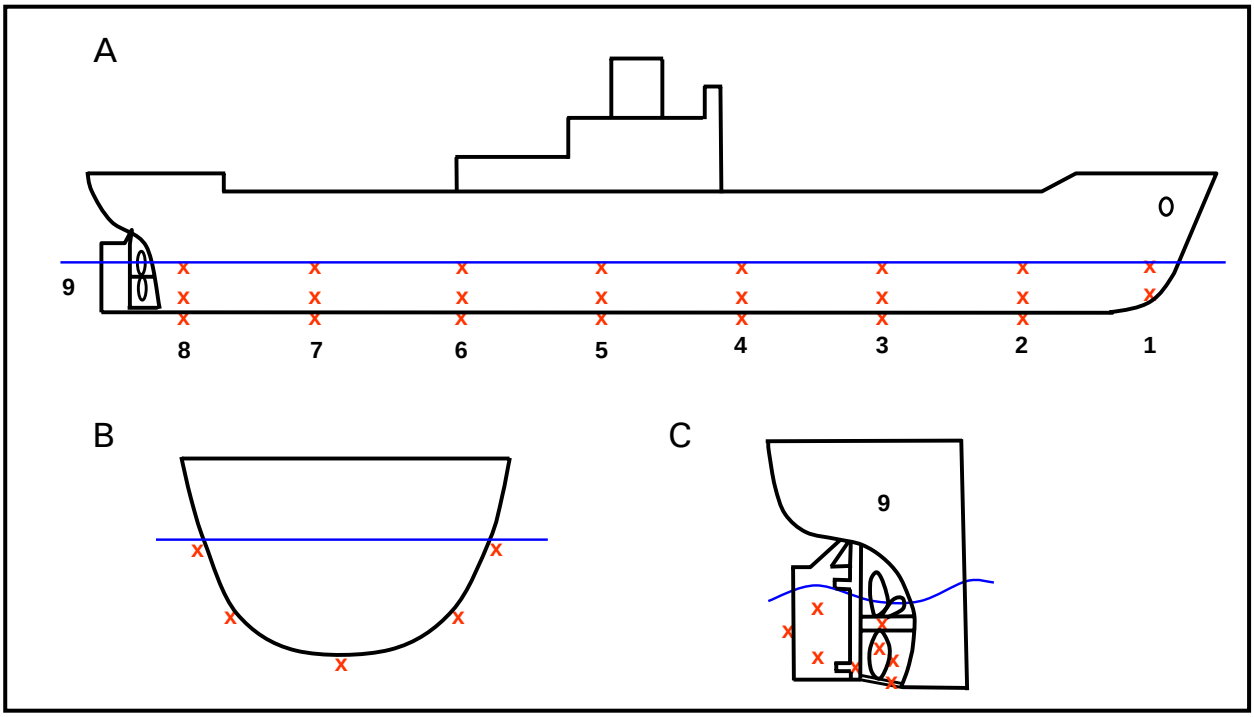


Figure 2-2. Sampling design. Samples and photo-quadrats were taken at 8 transects across the hull of the vessels (A). Five samples per transect were collected: starboard upper, starboard lower, bottom, port lower, and port upper (B). The first transect did not have a flat bottom; therefore, only four samples were collected from this transect. Additionally, samples were collected from the underwater appendages of the vessels (C) and the bilge keel, labeled as Transect 9.

The system used for the photo-quadrats consisted of an underwater camera with a "clear-water box" attached to the front of the lens and two strobe lights mounted above the box at 45 degree angles. This system provided a standard image area for all photographs. In addition, the divers carried a video camera that provided real-time visual communication with the surface and video footage of the hull and the associated biota.

Figure 2-3. Sampler constructed from a 6-inch (15.2 cm) diameter PVC pipe with a 4 inch adapter. A diver placed the 6-inch end of the sampler against the hull of the ship, and attached a numbered cloth bag to the 4-inch end. A scraper was used to remove the biological material from the hull, which was then collected in the cloth bag.

2.3 SAMPLE PROCESSING AND TAXONOMY

A visual examination of each sample was carried out in the field. Bags were opened, inverted, and rinsed 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 (potential live versus dead material), and the general kinds and quantity of organisms. This general procedure was conducted on as many samples as possible. Some samples could not be photographed on site because of time constraints. Live species were 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 then tightly closed 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 stored for later examination. The 250-μm fraction was sorted under dissecting microscopes to separate organisms into major categories (i.e., mussels, barnacles, micro-crustaceans, etc.). Organisms in these major categories were identified to species level whenever possible and counted (non-colonial species). 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.

Due to time constraints, live and dead material were not separated in the field; however, the bulk component of each sample consisted of organisms that were alive at the time of collection. No obvious signs of dead material (e.g., exo-skeletons of crustaceans) were found in the samples upon examination in the field or in the laboratory, except for the empty tests of barnacles.

2.4 ANALYSIS

Samples were analyzed for differences in species composition and abundance by transect and position (waterline, mid-depth, bottom, stern appendages) across the hull of the ship using multivariate analysis methods. Plots were constructed to examine sample configuration and to identify any tendency for samples to form groups according to the location from where they were taken from the hull. Species counts, $\log(x+1)$ transformed, were subjected to non-metric multidimensional scaling (MDS) ordination on a Bray-Curtis similarity matrix using routines in the PRIMER (Plymouth Routines in Multivariate Ecological Research) v.6 statistical package (Clarke and Gorley 2006). The Group Average method was used to link samples in the analysis. 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 and abundance are placed in close proximity to one another, whereas dissimilar samples are placed further apart. Because abundance for colonial species (sponges, hydroids, and bryozoans) cannot be provided, the MDS analysis was repeated for presence/absence data using the full matrix of species and Sørensen's similarity index (Clarke and Gorley 2006). MDS and Analysis of Variance (ANOVA) was also conducted to identify gradients in species abundance and composition between surveys within ships (i.e., between PIONEER CONTRACTOR pre-cleaning and post-cleaning samples) and among ships (i.e., between PIONEER CONTRACTOR, MOUNT VERNON, and CAPE FLORIDA samples).

Photo-quadrats were examined by quantifying the percent cover of eight distinguishable categories of biofouling in each image: algae, barnacle, barnacle seat/ organism remnant, bryozoan, hydroid, sponge, bare hull, and "other" (including mussels). Images were analyzed using the point count method to determine percentage cover of each category by superimposing a grid of 8 rows by 12 columns and populating each cell by 1 random point for a total of 96 random points. The area of hull analyzed from the image was approximately 210 cm^2 (11.8 x 17.8 cm), for a density of 1 point for every 2.2 cm^2 of hull (Figure 2-4). Points that were indistinguishable because the image was too dark were removed from the analysis. Thus the analysis provides percent cover of observable hull. Percent cover data (arcsine square-root transformed) were analyzed by MDS.

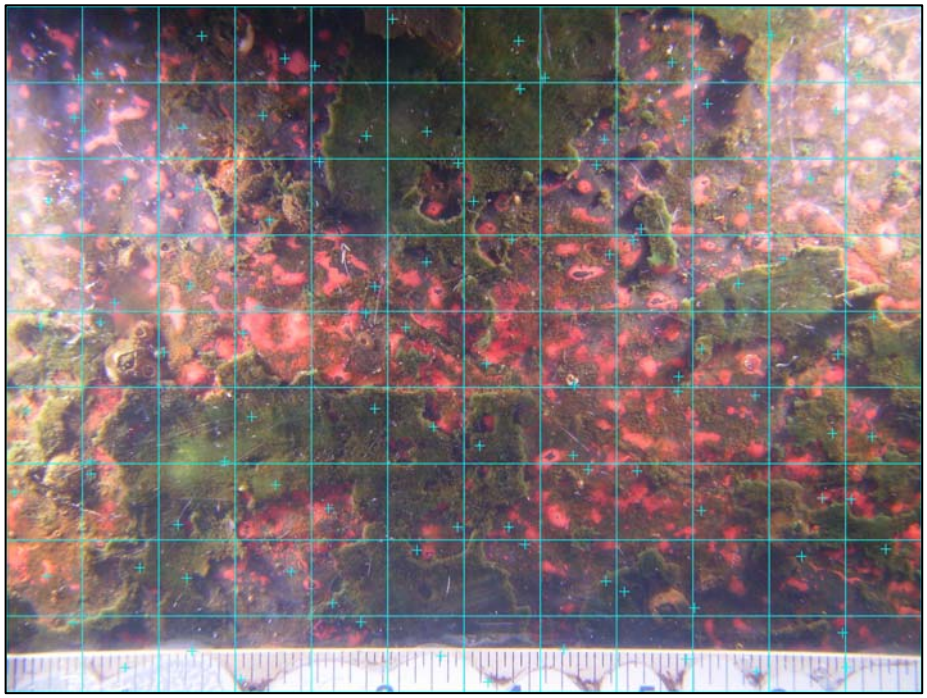


Figure 2-4. Grid of random points superimposed on an underwater photograph taken from the upper starboard side of Transect 1 of the PIONEER CONTRACTOR prior to hull cleaning. Images were analyzed using the point count method to determine percentage cover of each of 8 categories of biofouling. Algal mats, barnacles, and bare hull can be observed in this image.

3.0 RESULTS AND DISCUSSION

3.1 WATER CHARACTERISTICS

The salinity at the BRF in August 2008 ranged between 4.5 and 8 psu, from surface to 6-m depth (Figure 3-1). In the deep basin near the CAPE FLORIDA, salinity ranged between 5 and 13 psu, from surface to 9-m depth (Figure 3-1). Water temperature ranged between 29.2 and 31.4 °C, and dissolved oxygen ranged between 6.9 and 1.2 mg/L. Salinity and dissolved oxygen concentration in the Neches River estuary at the BRF is likely to fluctuate with river flow (Versar 2008d), and influence the composition and abundance of biofouling organisms. Low salinity associated with periods of high river flow is likely to favor insect and oligochaete species, which are usually abundant in freshwater systems but tend to decrease in number in brackish waters. Indeed, insects and oligochaetes were more abundant in September 2007 during the sampling of the DUTTON than in the present study (see Section 3.2 below). In the 2007 surveys salinity was lower, between 2 and 8 psu in the deep basin.

During the August 2008 surveys dissolved oxygen was low, below 2 mg/L at 9 m. Dissolved oxygen concentrations below 2 mg/L are usually stressful to marine organisms, and tend to occur near the bottom in estuaries where freshwater flows over salt water with little mixing between the two layers. The low dissolved oxygen concentrations observed during the present study may not have affected the biofouling communities because of the low lightweight draft of the vessels and the resulting shallow communities. However, at other times, more of the water column may be influenced by low dissolved oxygen, which may then affect the biofouling community, changing its species composition.

3.2 SPECIES ASSEMBLAGES

The total number of taxa recorded in the present surveys was 61, of which 28 were species-level identifications (Table 3-1). The most common species was Conrad's false mussel, *Mytilopsis leucophaeata*, which accounted for 71% of total abundance and 34,553 individuals. The next two most common species were the barnacle *Balanus subalbidus*, which accounted for 9% of total abundance and 4,473 individuals, and a leptoplanid flatworm (Turbellaria sp. A), which accounted for 7% of total abundance and 3,564 individuals. Secondary numerical dominants were the amphipods *Hourstonius laguna* and *Apocorophium lacustre*, juvenile Spionidae and Nereididae polychaetes, the flatworm *Stylochus ellipticus*, and the polychaete *Boccardiella ligerica*, each accounting for 1-2% of total abundance.

In terms of frequency of occurrence, *M. leucophaeata* and *B. subalbidus* were present in 100% and 73% of the pre-cleaning samples, respectively, and the leptoplanid flatworm, in 59% of the samples (Table 3-1). Other commonly occurring species were the

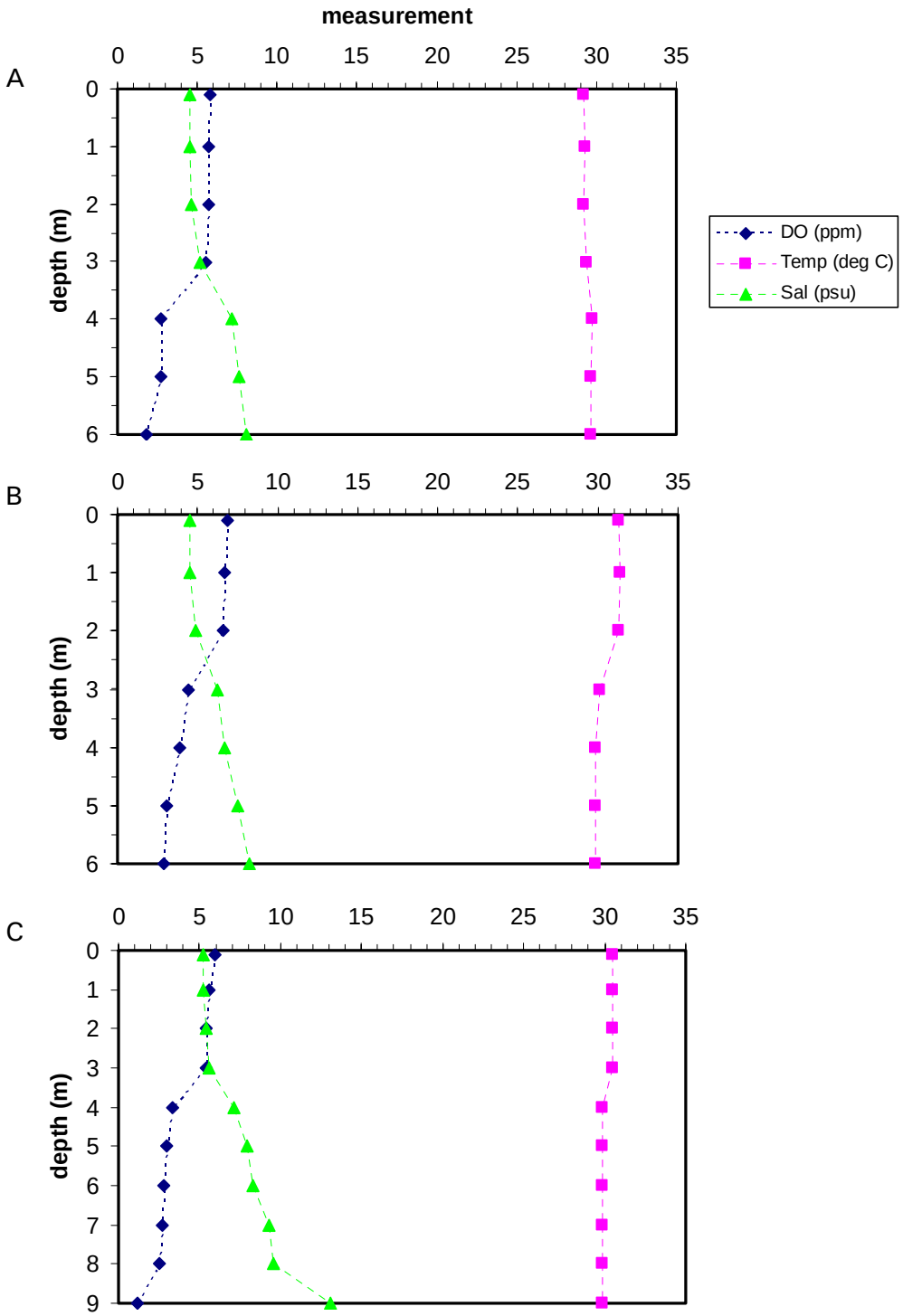


Figure 3-1. Salinity, temperature, and dissolved oxygen of the water at the Beaumont Reserve Fleet during the biological surveys of the PIONEER CONTRACTOR (A), MOUNT VERNON (B), and CAPE FLORIDA (C). Readings were taken on August 9-11, 2008, between 7:45 and 9:00 a.m.

Table 3-1. Species recorded in the biological samples of three Beaumont Reserve Fleet vessels. The frequency of occurrence (percent of samples) in each survey and the biogeographic status of species in Texas is shown. Frequency of occurrence of copepods is that of the 250-μm samples. 64-μm samples were archived but not examined. Species found in the 2007 Beaumont surveys (Versar 2008d) are indicated in the last column.

Species	Pioneer Contractor		Mt. Vernon	Cape Florida	Status in TX	In 2007 Beaumont Surveys?
	Pre-Cleaning	Post-Cleaning				
Acari (Mites)						
Acari spp. (juv.)	0	2	0	0	native species present	x
Algae						
Algae sp. A	14	4	8	6	?	x
mat-like algae	4	2	0	0	?	
Amphipods						
Apocorophium lacustre	42	32	44	18	cryptogenic	x
Cerapus sp.	0	0	0	2	native species present	
Grandidierella bonnieroides	0	0	0	2	native	(*)
Hourstonius laguna	40	54	22	82	native	x
Melita nitida	24	30	14	4	native	x
Bivalves						
Mytilopsis leucophaeata	100	96	100	100	native	x
Chaetognatha (Arrow Worms)						
Chaetognatha spp.	0	0	0	6	native species present	(*)
Cirripedia (Barnacles)						
Balanus subalbidus	78	72	74	66	native	x
barnacle cypris	18	8	2	8	native species present	x
Copepods						
Acartia sp.	12	4	2	4	native species present	x
Acartia tonsa	36	62	22	62	native	x
Calanoida spp. Indeterminant	0	0	0	2	native species present	x
Coullana canadensis	0	2	0	0	native	x
Cyclopoida spp. Indeterminant	0	2	0	0	native species present	x
Halicyclops sp.	28	28	32	22	native species present	x
Harpacticoida spp.	28	8	40	20	native species present	x
Nitokra sp.	14	14	22	10	native species present	x
Schizopera sp.	0	4	10	6	native species present	x

Table 3-1. (Continued)

Species	Pioneer Contractor		Mt. Vernon	Cape Florida	Status in TX	In 2007 Beaumont Surveys?
	Pre-Cleaning	Post-Cleaning				
Decapods (Shrimps & Crabs)						
Brachyura spp. Indeterminant	38	10	26	42	native species present	x
Callinectes sp. (juv.)	2	4	10	10	native species present	x
Penaeidae spp. (juv.)	2	0	2	4	native species present	Penaeidea spp.
Rhithropanopeus harrisii	14	6	20	26	native	x
Ectoprocta (Bryozoans)						
Bowerbankia gracilis	80	66	88	60	native	x
Conopeum chesapeakensis	56	50	36	34	introduced	x
Fredericella indica	6	8	34	24	cryptogenic	x
Entoprocta (Kamptozoans)						
Barentsia sp. A	28	22	8	42	cryptogenic	x
Urnatella gracilis	6	0	0	0	native	x
Fishes						
Fish larvae	2	0	0	0	native species present	
Gobiosoma bosc	0	4	0	0	native	Gobiosoma sp.
Gastropods						
Hydrobiidae spp.	0	0	2	0	native species present	
Nudibranchia spp. (juv.)	12	0	2	6	native species present	
Valvata sp.	2	0	0	2	native	
Hydroids						
Cordylophora caspia	46	8	14	30	introduced	x
Garveia franciscana	76	82	86	92	introduced	x
Leptomedusae spp.	0	0	0	2	native species present	
Insects						
Dicrotendipes sp.	0	2	0	0	native species present	x
Parachironomus directus	0	2	0	0	native	
Rheotanytarsus sp.	2	0	0	0	native species present	
Isopods						
Crustacean parasite	0	0	0	2	native species present	
Mysids (Fairy Shrimps)						
Americamysis almyra	0	0	0	4	native	
Americamysis sp. (juv.)	0	0	0	2	native species present	
Nematodes (Roundworms)						
Nematoda spp.	56	44	50	58	native species present	x
Oligochaetes						

Table 3-1. (Continued)

Species	Pioneer Contractor		Mt. Vernon	Cape Florida	Status in TX	In 2007 Beaumont Surveys?
	Pre-Cleaning	Post-Cleaning				
Dero sp.	2	0	4	0	native species present	x
Polychaetes						
Boccardiella ligerica	50	20	36	42	cryptogenic	x
Ficopomatus enigmaticus	26	28	2	26	introduced	x
Neanthes succinea	0	0	0	8	native	Nereididae spp.
Nereididae spp. (juv.)	74	40	32	52	native species present	x
Nereis cf. falsa	36	20	24	26	cryptogenic	x
Polydora cornuta	16	2	14	18	native	Polydora sp.(*)
Serpulidae sp. A	10	4	0	4	?	
Serpulidae spp. Indeterminant	36	38	12	40	native species present	x
Spionidae spp. (juv.)	82	58	36	52	native species present	x
Stenoninereis martini	0	0	0	2	native	
Streblospio benedicti	2	0	0	6	native	(*)
Porifera (Sponges)						
Ephydatia fluviatilis	64	40	62	48	native	x
Tanaids						
Sinelobus stanfordi	2	0	0	0	cryptogenic	x
Turbellarians (Flatworms)						
Stylochus ellipticus	48	40	68	66	native	Stylochus sp.
Turbellaria sp. A	60	32	76	40	?	x
Unidentified Group						
seeds or egg cases?	2	2	0	0	?	

(*) Post-transit only

hydroid *Garveia franciscana* (85%), the bryozoan *Bowerbankia gracilis* (76%), the flatworm *S. ellipticus* (61%), and the freshwater sponge *Ephydatia fluviatilis* (58%).

Colonial species in the 2008 BRF surveys were hydroids (*Cordylophora caspia* and *G. franciscana*), bryozoans (*B. gracilis*, *Conopeum chesapeakensis*, and *Fredericella indica*), kamptozoans (*Barentsia* sp. and *Urnatella gracilis*), and sponges (*E. fluviatilis*). Except for *U. gracilis*, these species were relatively common in the biological samples, and also occurred frequently in the samples of the 2007 Beaumont surveys (Versar 2008d).

Most of the species recorded in the present surveys were also recorded in the 2007 surveys of the DUTTON, DEL VALLE, HATTIESBURG VICTORY, and PIONEER CRUSADER (Table 3-1). However, many oligochaete and insect species that were common in 2007 were not recorded in 2008. Oligochaetes and insect larvae are abundant in freshwater systems and may also be found in low salinity regions of estuaries, but their species numbers decrease rapidly as salinity increases. The water at the BRF was saltier in August 2008 than in September 2007, and this probably accounts for the difference between surveys. In all, 46% of the taxa recorded in 2007 were not recorded in the present surveys.

By ship, 35 species and 19,300 individuals were collected from the PIONEER CONTRACTOR in the pre-cleaning survey, 39 species and 12,000 individuals were recorded from the CAPE FLORIDA, and 31 species and 10,800 individuals were recorded from the MOUNT VERNON, based on distinct species counts. The PIONEER CONTRACTOR had higher abundance of *Mytilopsis leucophaeata* but not higher abundance of other organisms than the other two vessels, and the number of species was similar among vessels. It is worth noting that, like in the 2007 surveys, the specimens of *M. leucophaeata* were very small and were attached to the shells of barnacles. We did not find large mussels and, generally, mussels were not attached to the hull.

Of the 61 taxa collected in the present surveys, 20 were native to Texas, 6 were cryptogenic, and 4 were introduced (Table 3-1). Of the remaining taxa, 27 were genus or higher level identifications with native species present in Texas, and 4 were of undetermined status.

The introduced species consisted of one bryozoan, *Conopeum chesapeakensis*; two hydroids, *Cordylophora caspia* and *Garveia franciscana*; and the Australian shipworm *Ficopomatus enigmaticus*. These species were also found in the 2007 surveys and are discussed in the report of those surveys (Versar 2008d). *C. caspia, G. franciscana*, and *F. enigmaticus* are probably of wide distribution in the Gulf of Mexico. The specimens of *C. chesapeakensis* constitute a range extension for this species and await taxonomic confirmation. Versar (2008d) also discusses the yet unidentified species of *Barentsia*. A photo of this very small kamptozoan is presented on the front cover of this report.

3.3 DIFFERENCES BETWEEN SHIPS, SURVEYS AND LOCATIONS ON THE HULL

Barnacles, mussels, hydroids, bryozoans, and sponges were prominent biological features on the hulls of BRF vessels (Figure 3-2). As in the previous BRF surveys, the barnacles did not cover the hull uniformly, but large areas of hull were occupied by soft growth, predominately from hydroids and sponges (Figure 3-2b and c). The sponge *Ephydatia fluviatilis* was more common in 2008 than in 2007. The barnacles were generally encrusted by a thin layer of bryozoans and by numerous small mussels. Occasionally, the hull was also encrusted by small mussels, and in 2008 by serpulid polychaete worms (Figure 3-2d).

Multivariate analyses of abundance and presence-absence data showed no differences in community organization among ships (Figure 3-3a), or between the pre-cleaning and post-cleaning surveys of the PIONEER CONTRACTOR (Figure 3-3b). There were no differences among transects; however, the bottom samples of all vessels tended to group in the diagrams separately from the samples taken near the waterline or the stern appendages (MDS diagrams not shown). This tendency for bottom samples to differ from waterline and stern samples was due to increased hydroid growth on the bottom of the hull relative to the other hull surfaces.

Species abundance was significantly higher ($p = 0.037$ on log-transformed data) on the PIONEER CONTRACTOR than on the CAPE FLORIDA, but did not differ between these two ships and the MOUNT VERNON (Figure 3-4a). Mean species numbers did not differ significantly ($p = 0.085$) among ships (Figure 3-4b). Although the MOUNT VERNON may have been inactive at the fleet longer than the PIONEER CONTRACTOR, we consider both ships of similar age. There was not enough information to determine recent activities for these ships, such as maintenance activations, sea trials, repairs, or drydocking, that may have affected biofouling growth on their hulls.

In comparing the pre-cleaning and post-cleaning surveys of the PIONEER CONTRACTOR, the multivariate analyses of abundance and species composition showed no differences among surveys (Figure 3-3b). These results indicate that the organization of the community was similar before and after hull cleaning. Most of the species recorded in the pre-cleaning survey were also recorded in the post-cleaning survey, and many occurred frequently in both surveys (Table 3-1). However, mean abundance ($p < 0.0001$) and mean number of species ($p = 0.003$) decreased significantly after hull cleaning (Figure 3-5b).

The photo-quadrat analysis revealed no consistent patterns in percent cover of organisms across transects (i.e., no patterns of increased or decreased percent cover from bow to stern). However, there were differences in percent cover between the waterline and the bottom of the hull (Figures 3-6 through 3-8). Hydroid cover was higher on the bottom than near the waterline. Barnacles and bryozoans showed the opposite trend, but this is likely because their presence on the bottom is concealed in the photographs by the

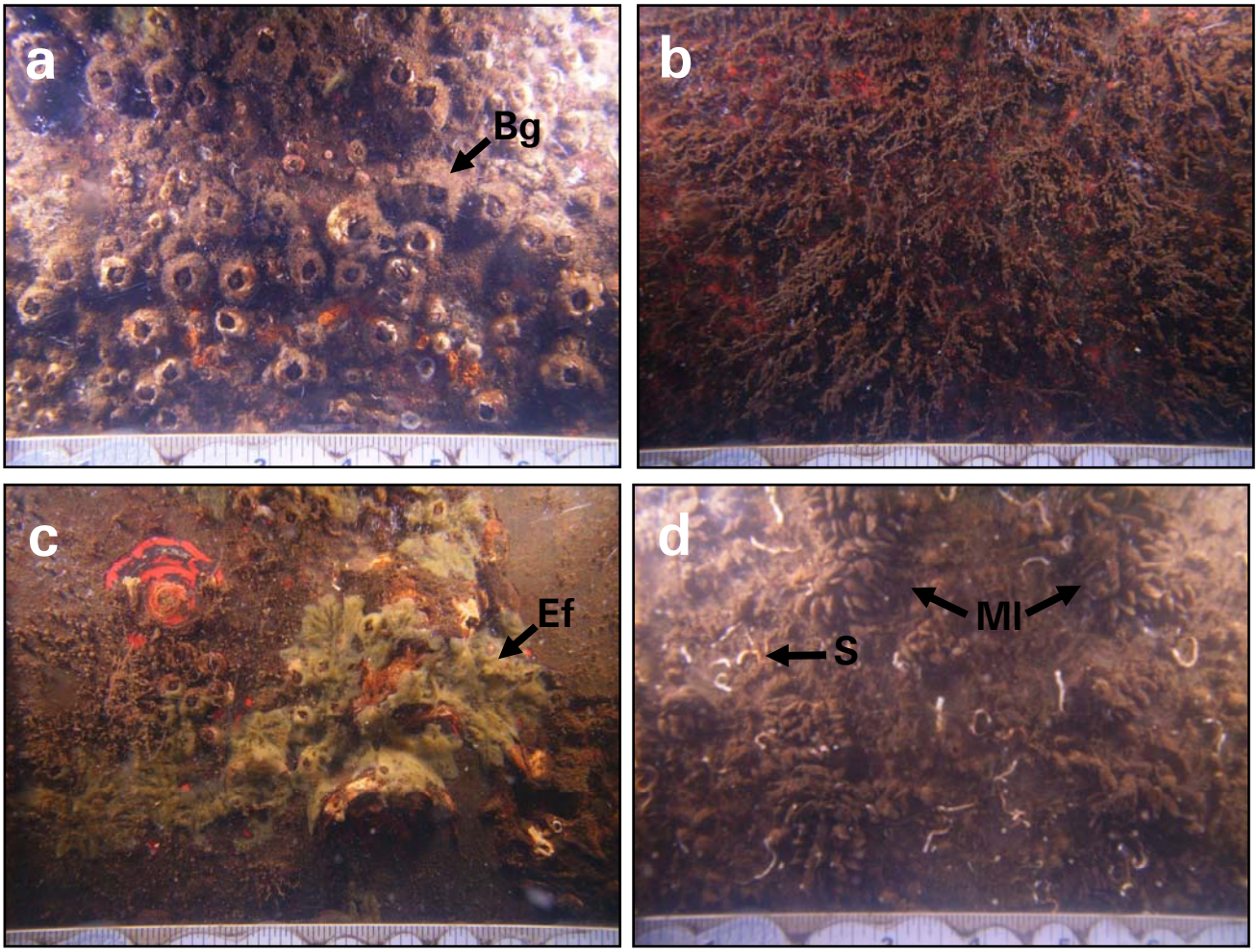


Figure 3-2. Underwater photographs taken from the hull of the PIONEER CONTRACTOR prior to hull cleaning (a) and the CAPE FLORIDA (b-d), showing barnacles, mussels, and soft growth. In photograph a, the barnacles and much of the hull are covered by a thin layer of bryozoans (*Bowerbankia gracilis*, Bg). Photograph b shows a dense cover of the hydroid *Garveia franciscana*. Photograph c shows a sponge (*Ephydatia fluviatilis*, Ef); and in photograph d, mussels (*Mytilopsis leucophaeata*, Ml) and the white calcareous tubes of serpulid polychaetes (S) can be seen.

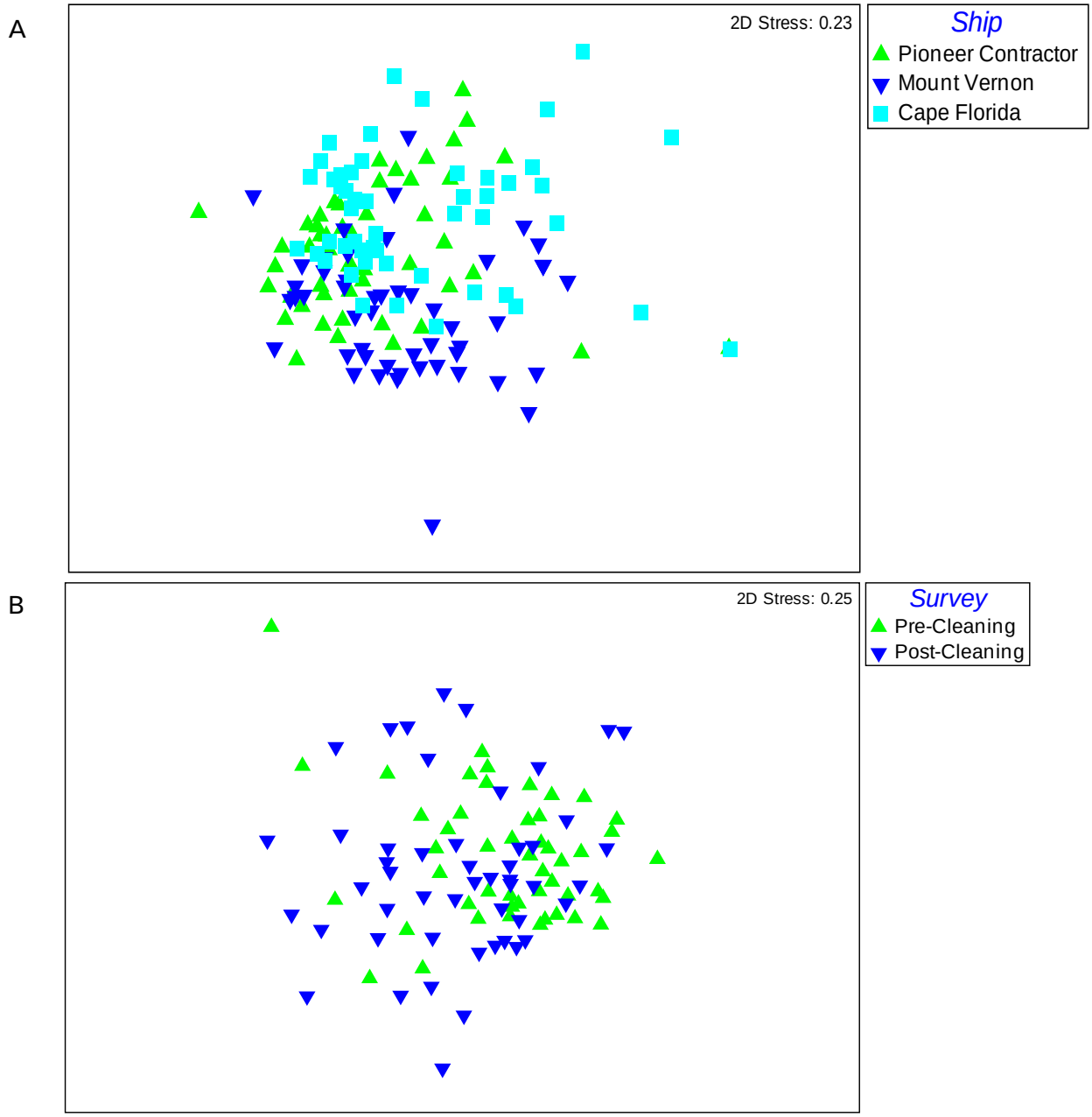
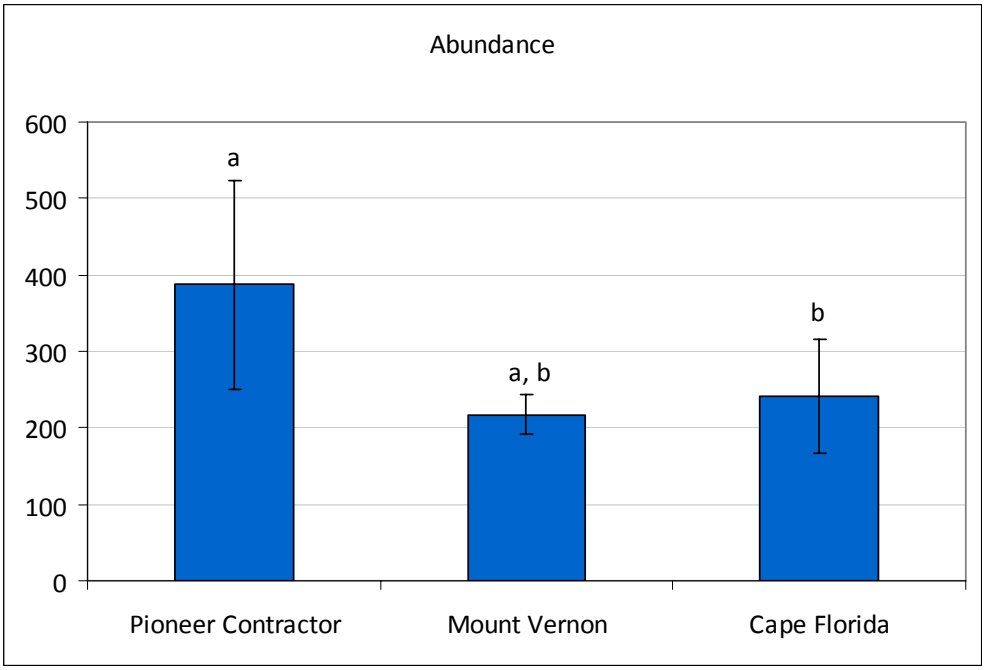


Figure 3-3. Multivariate analysis of presence-absence data showing no differences in biofouling community organization (i.e., no separate groups of samples in the diagram) among ships (A), and between the pre-cleaning and post-cleaning surveys of the PIONEER CONTRACTOR (B).

A



B

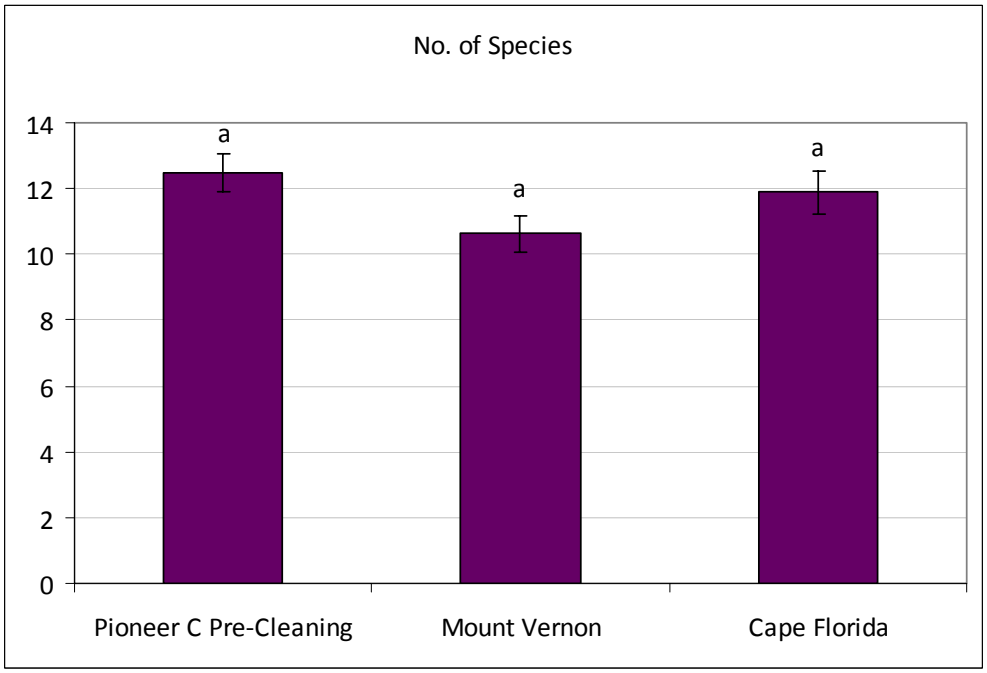
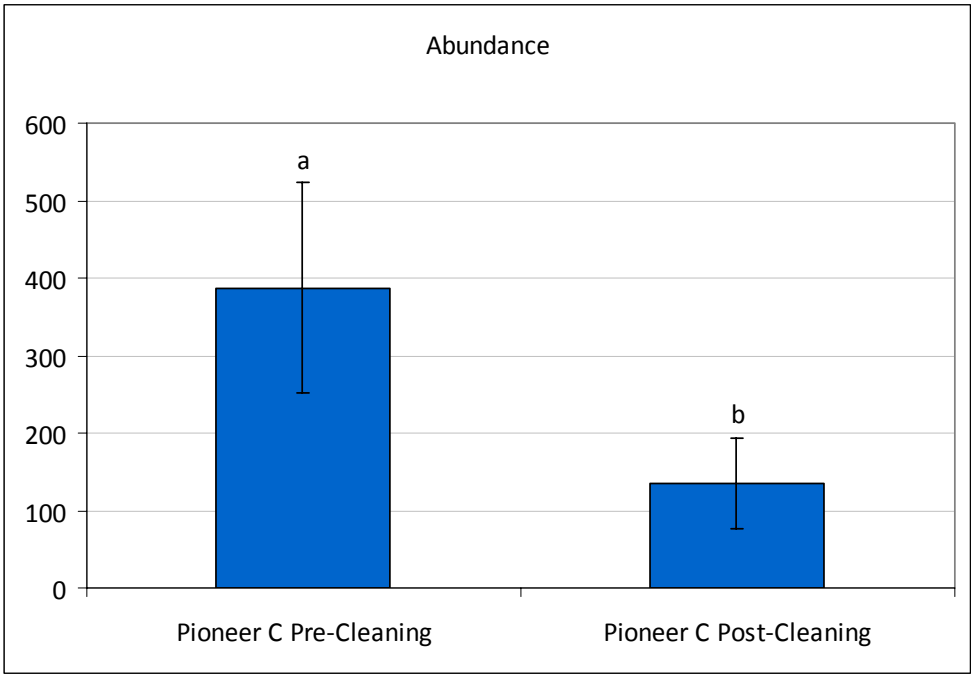


Figure 3-4. Differences in mean abundance (A) and mean number of species (B) per sample (+/- one standard error) of biofouling organisms in three Beaumont Reserve Fleet vessels, tested by ANOVA. The letters indicate the results of the Duncan test, whereby mean abundance and mean number of species did not differ significantly for ships with the same letter. The abundance data was log-transformed in the analysis; species numbers remained untransformed. Distinct species only.

A



B

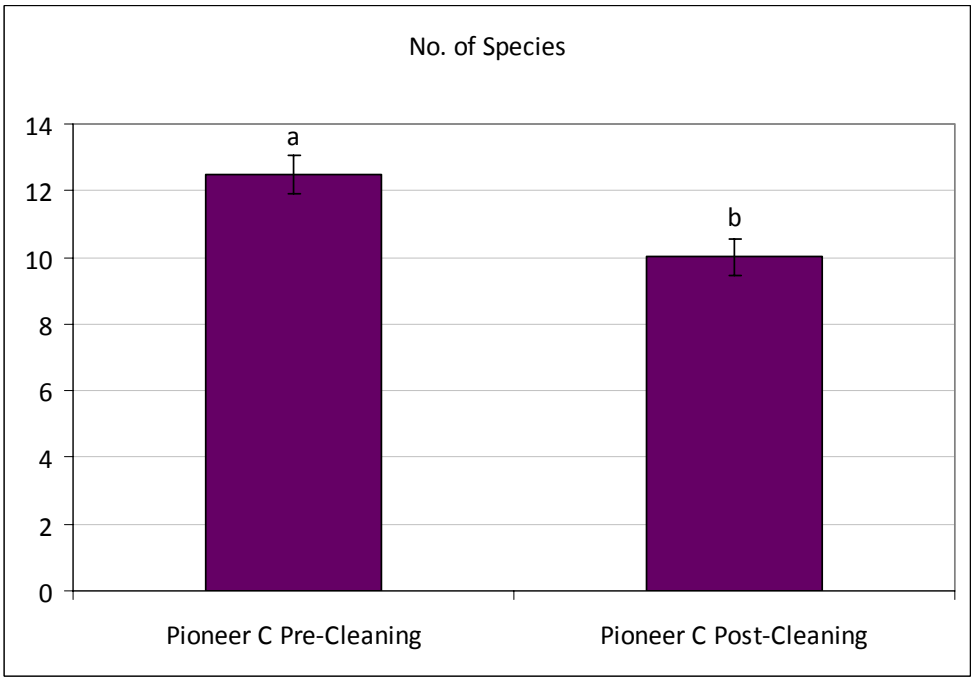


Figure 3-5. Differences in mean abundance (A) and mean number of species (B) per sample (+/- one standard error) of biofouling organisms between the pre-cleaning and post-cleaning hull surveys of the PIONEER CONTRACTOR, tested by ANOVA. Different letters indicate statistical significance. The abundance data was log-transformed in the analysis; species numbers remained untransformed. Distinct species only.

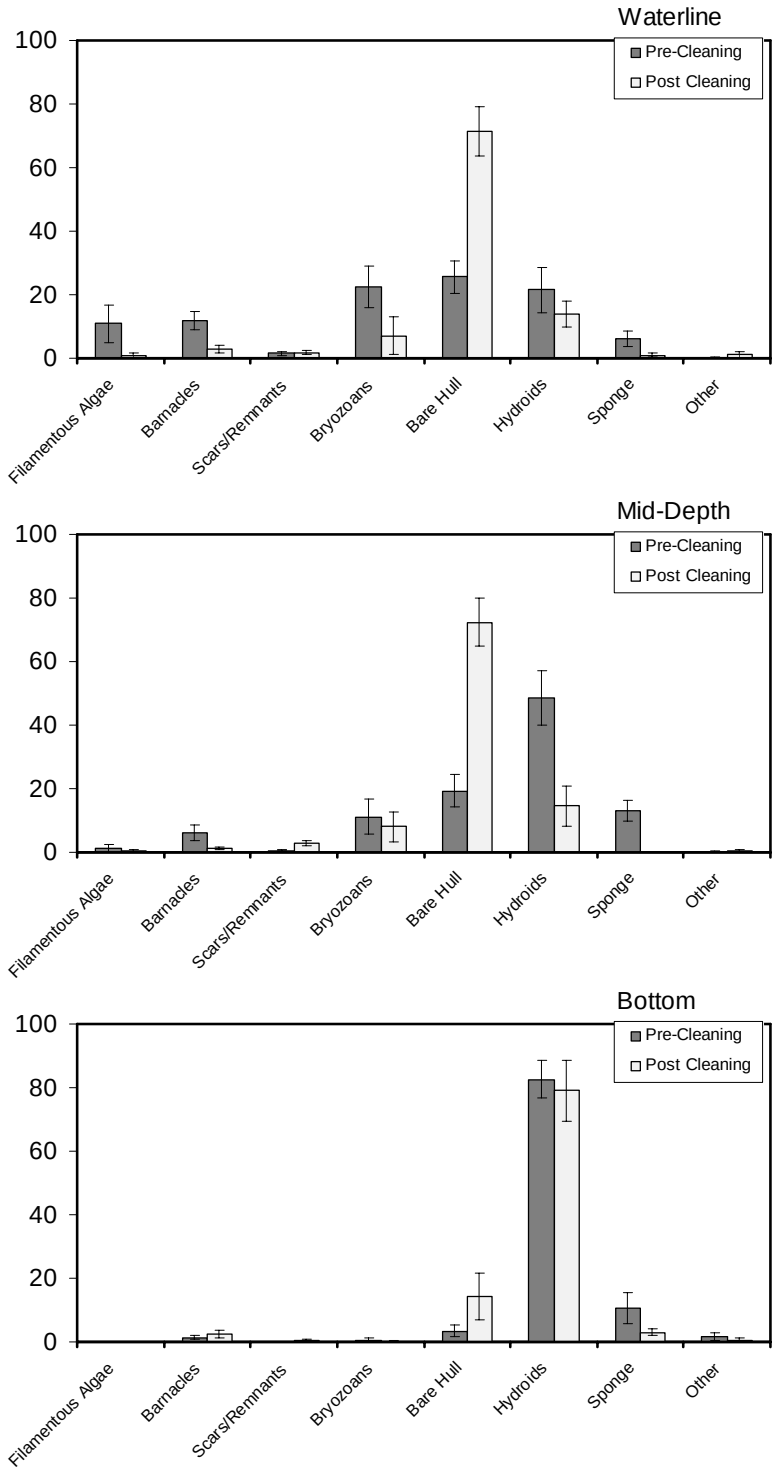


Figure 3-6. Biofouling percent cover of PIONEER CONTRACTOR before hull cleaning and after hull cleaning. Shown is the mean +/- one standard error of 8 prominent categories of biofouling estimated from photo-quadrats.

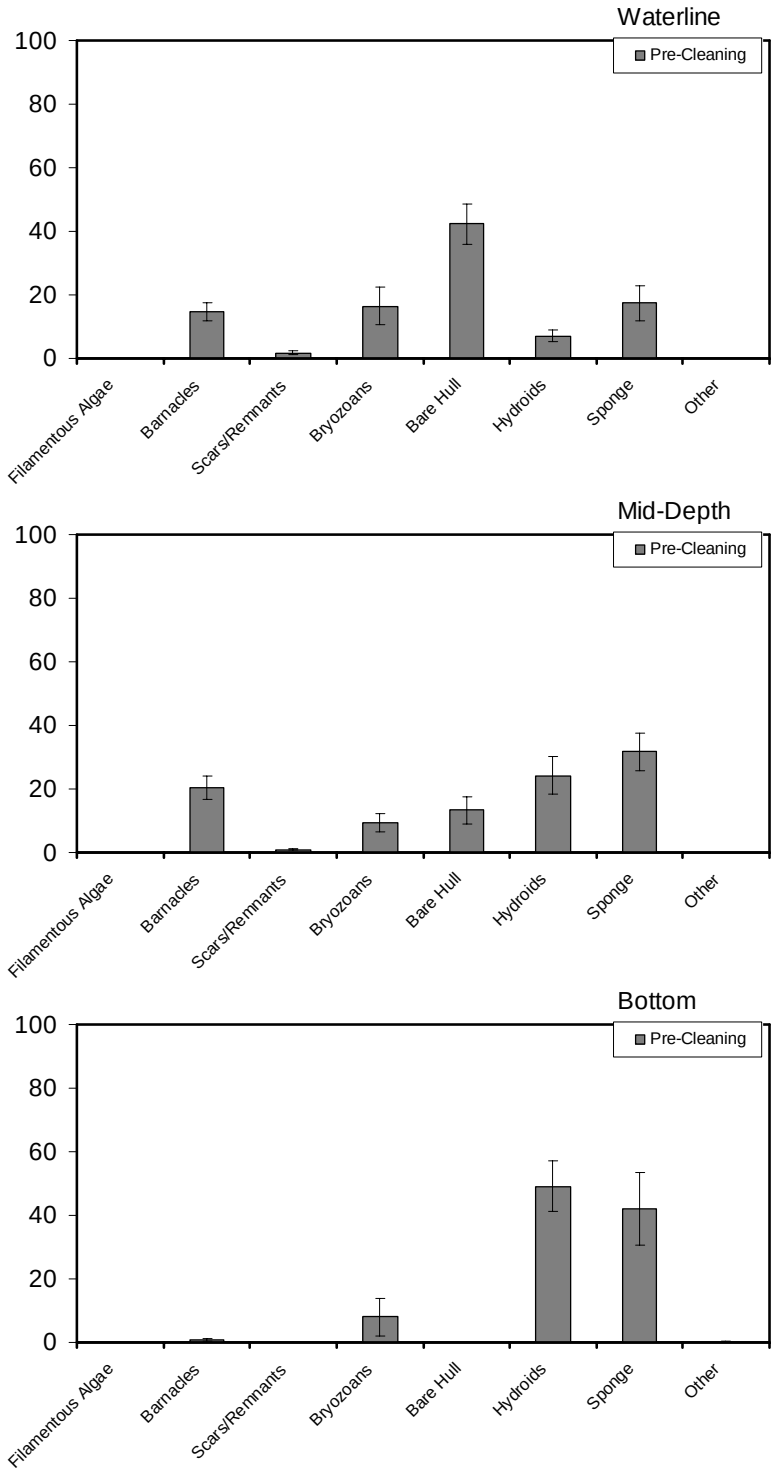


Figure 3-7. Biofouling percent cover of MOUNT VERNON. Shown is the mean +/- one standard error of 8 prominent categories of biofouling estimated from photo-quadrats.

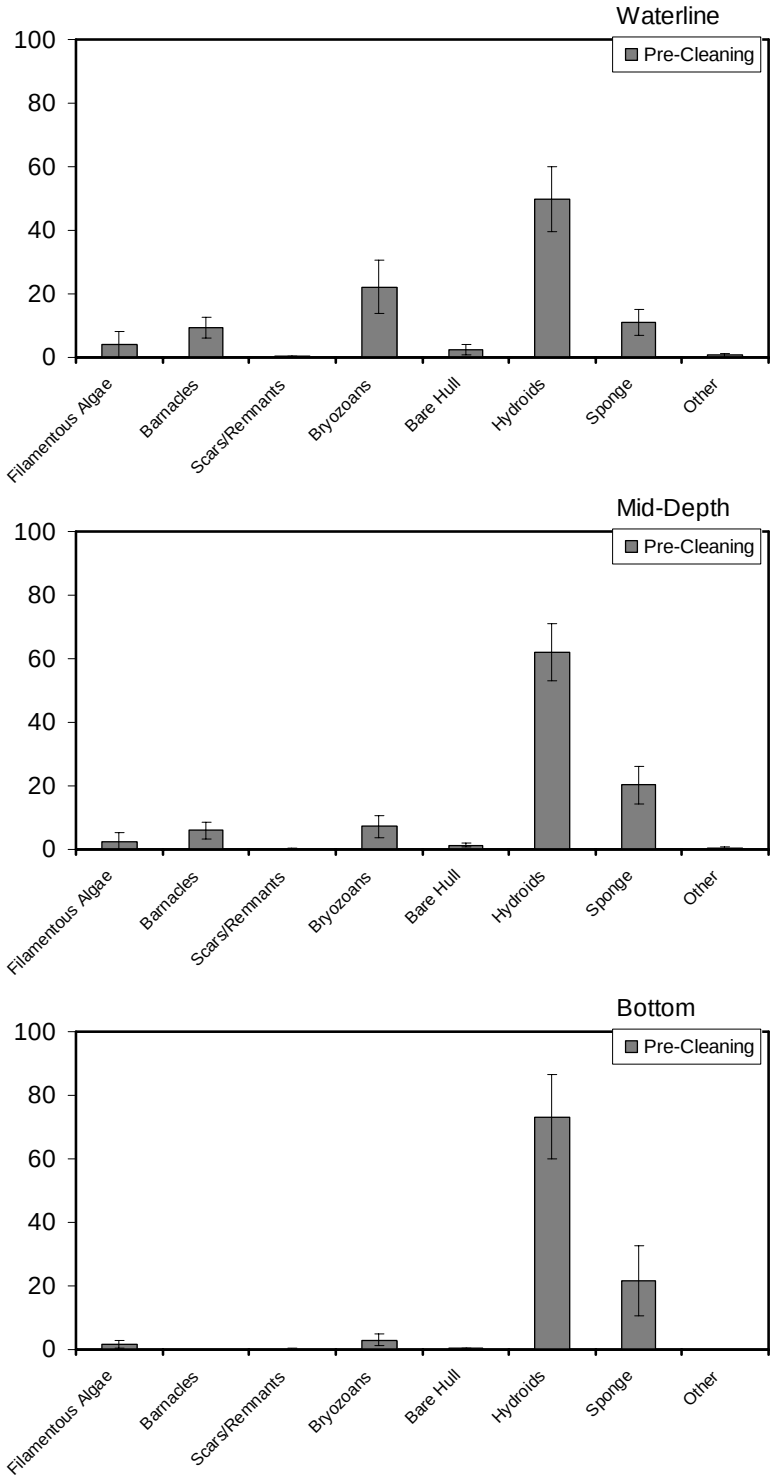


Figure 3-8. Biofouling percent cover of CAPE FLORIDA. Shown is the mean +/- one standard error of 8 prominent categories of biofouling estimated from photo-quadrats.

hydroids. Sponges were also prominent features in the analysis of photo-quadrat data and their percent cover was also higher toward the bottom of the hull (Figures 3-7 and 3-8).

Bare hull predominated in the post-cleaning survey of the PIONEER CONTRACTOR, but, on average, only 54% of the space in the post-cleaning survey was bare hull (Figure 3-6). After hull cleaning, bare hull increased from 26% to 71% near the waterline, from 19% to 72% at mid-depth, and from 3% to 14% on the bottom of the hull (Figure 3-6). Thus, most of the bottom surface of the hull was still covered by epifaunal growth after hull cleaning. Also, only 35% of the stern appendages was represented by bare hull after hull cleaning, with another 7% of the space occupied by barnacle seats.

The MDS analysis of photo-quadrats confirmed the results of the analysis of abundance and presence-absence data. There were no differences in percent cover of bio-fouling organisms among ships (Figure 3-9a), and patterns in the MDS diagrams suggested differences in percent cover between the waterline and the bottom of the hull (e.g., Figure 3-9b). These differences persisted after hull cleaning, and were manifested by considerable overlap between the photo-quadrats of the pre-cleaning and post-cleaning surveys of the PIONEER CONTRACTOR, indicating presence of hydroid growth in both surveys (Figure 3-9c).

3.4 RISK OF SPECIES INTRODUCTIONS

Of the four nonnative species found in the present surveys, three (*Cordylophora caspia*, *Garveia franciscana*, and *Ficopomatus enigmaticus*) are likely to occur elsewhere in the Gulf of Mexico. Therefore, the potential for the spread of these species within the Gulf of Mexico by BRF vessels should not be of high concern. Only one species, the bryozoan *Conopeum chesapeakensis* is of concern, since its presence in the Neches River estuary constitutes a range extension for this species outside of its native region. The specimens found on BRF vessels, however, await taxonomic confirmation. *Conopeum* species are difficult to identify and some species can only be separated on the basis of molecular analyses. Morphological characteristics alone are insufficient for the positive identification of the species.

The hull cleaning of the PIONEER CONTRACTOR was not successful at removing abundant hydroid cover along the bottom of the hull. Elsewhere along the hull, density and species numbers were significantly reduced by hull cleaning, but most species remained on the hull, and many occurred frequently in the samples after hull cleaning. An inability of hull cleaning to remove a majority of species increases the risk that an invasive species not recorded in the surveys might be transferred to other regions within the Gulf. The spread of species such as *C. chesapeakensis* is of concern. A more thorough removal of the base layer of organisms that may harbor potentially invasive species should be achieved before the vessels are allowed to depart the fleet on their final destinations.

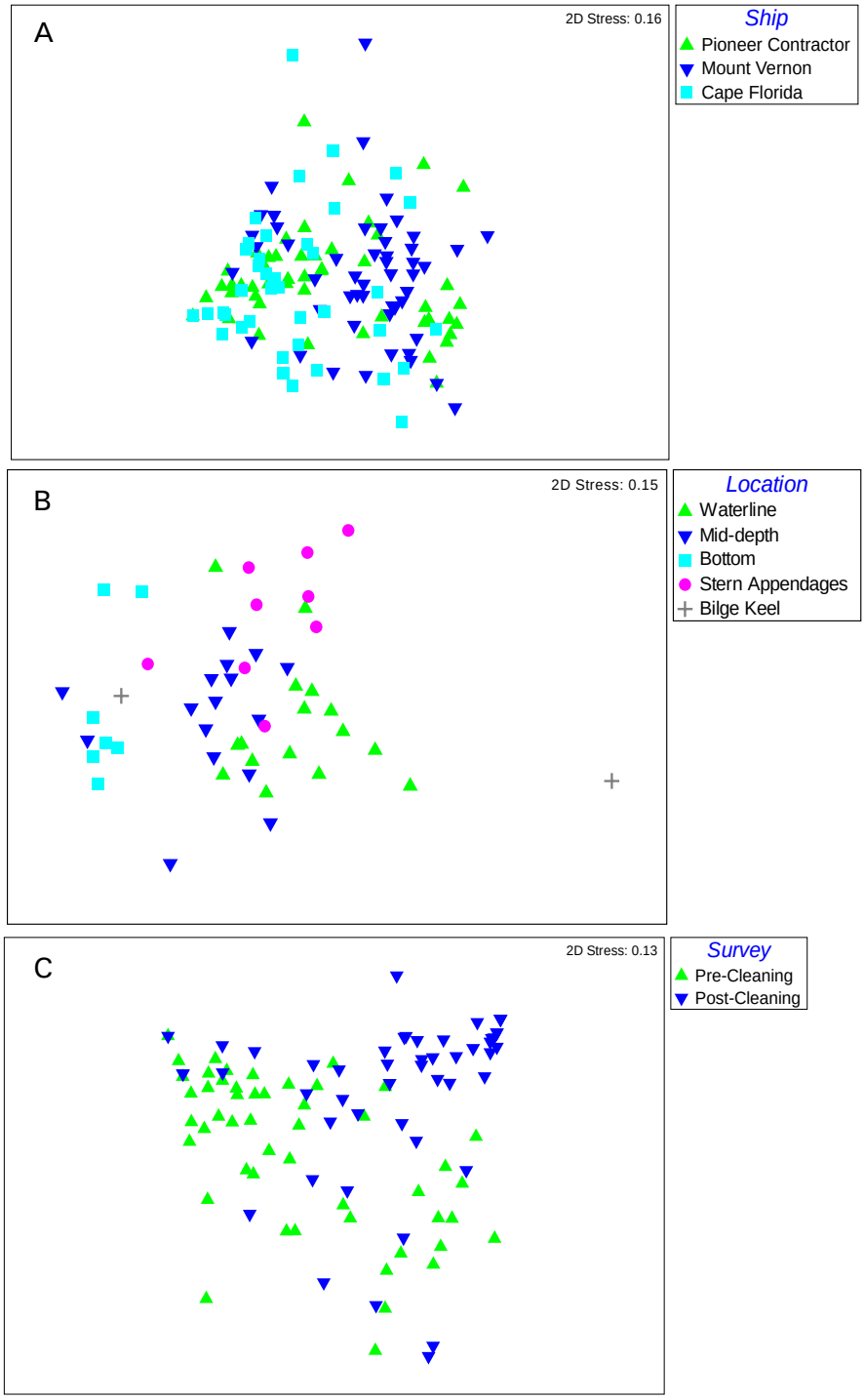


Figure 3-9. Multivariate analysis of photo-quadrat data. No differences were observed in percent cover of biofouling organisms among ships (A); however, differences in percent cover between locations are suggested for the MOUNT VERNON (B), and overlap between the surveys of the PIONEER CONTRACTOR indicates hydroid presence in both surveys (C).

4.0 SUMMARY AND CONCLUSIONS

1. Biological characterization surveys were conducted on the hull of three Beaumont Reserve Fleet vessels, PIONEER CONTRACTOR, MOUNT VERNON, and CAPE FLORIDA. The extent of biofouling was also examined on the PIONEER CONTRACTOR after hull cleaning. The surveys yielded a total of 61 taxa, 28 of which were identified to species level. Freshwater and brackish water species predominated, but many of the oligochaete and insect species that were recorded in the 2007 surveys were not found in 2008. Higher salinities in August 2008 probably accounted for the fewer freshwater species recorded in 2008.

2. The biofouling community was dominated by Conrad's false mussel, *Mytilopsis leucophaeata*, and the barnacle *Balanus subalbidus*. Numerically, *M. leucophaeata* accounted for 71% of total abundance, and *B. subalbidus* for 9%. Mussels and barnacles were common on all vessels, followed by an unidentified leptoplanid flatworm, the hydroid *Garveia franciscana*, the bryozoan *Bowerbankia gracilis*, the flatworm *Stylochus ellipticus*, and the freshwater sponge *Ephydatia fluviatilis*. The amphipods *Hourstonius laguna* and *Apocorophium lacustre* were abundant but occurred less frequently in the samples. There were no consistent differences in abundance or species composition by transect, but the bottom of the hull exhibited higher percent hydroid cover than other hull surfaces.

3. Mean abundance per sample differed significantly among ships, but mean species numbers did not differ significantly. Vessel age did not appear to be a factor in the observed differences among ships. A history of activities for these ships that might explain the observed differences in abundance could not be established.

4. All but four of the species found at the BRF were either native or cryptogenic, and all of the genera and higher level taxa had native species in Texas. These results are similar to those of the 2007 surveys. Of the four introduced species, three are likely to occur elsewhere in the Gulf of Mexico. Only one species, the bryozoan *Conopeum chesapeakensis* is of concern, since its presence in the Neches River estuary constitutes a range extension for the species outside of its native region. The specimens found in Beaumont await taxonomic confirmation.

5. In-water hull cleaning of the PIONEER CONTRACTOR was not successful at removing abundant hydroid cover along the bottom of the hull. On average, hull cleaning removed 54% of the biofouling cover. Density and species numbers were significantly reduced by hull cleaning, but a majority of the species remained on the hull, and many occurred frequently after hull cleaning. An inability of hull cleaning to remove most species increases the risk of species transfers and introductions.

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5.0 REFERENCES

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

Bousfield, E.L. 1973. Shallow-water Gammaridean Amphipoda of New England. Cornell University Press, Ithaca, New York.

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

Cohen, A.N. 2005. Guide to the Exotic Species of San Francisco Bay. San Francisco Estuary Institute, Oakland, California. On line: www.exoticsguide.org.

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).

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.

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.

Day, J.H. 1973. New Polychaeta from Beaufort, with a key to all species recorded from North Carolina. NOAA Technical Report NMFS CIRC-375.

Dineen, J.F. and A.H. Hines. 1994. Effects of salinity and adult extract on settlement of the oligohaline barnacle *Balanus subalbidus*. Marine Biology 119:423-430.

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.

Hudson, P.L., D.R. Lenat, B.A. Caldwell, and D. Smith. 1990. Chironomidae of the Southeastern United States: A Checklist of Species and Notes on Biology, Distribution, and Habitat. Fish and Wildlife Research 7, U.S. Fish and Wildlife Service, Washington, D.C.

Hyman, L.H. 1940. The Polyclad Flatworms of the Atlantic Coast of the United States and Canada. Proceedings of the U.S. National Museum 89:449-495.

Johnson, W.S. and D.M. Allen. 2005. Zooplankton of the Atlantic and Gulf Coasts. Johns Hopkins University Press, Baltimore, Maryland.

Kennedy, V.S., R.I.E. Newell and A.F. Eble (eds.). 1996. The Eastern Oyster, *Crassostrea virginica*. Maryland Sea Grant College, College Park, Maryland.

LeCroy, S. 2002. An Illustrated Identification Guide to the Nearshore Marine and Estuarine Gammaridean Amphipoda of Florida. Volume 2. Florida Department of Environmental Protection, Tallahassee, Florida.

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.

Merritt, R.W. and K.W. Cummins. 1996. An Introduction to the Aquatic Insects of North America. Kendall/Hunt Publishing Company, Dubuque, Iowa, 3rd Edition.

Mills, E.L., D.L. Strayer, M.D. Scheuerell, and J.T. Carlton. 1996. Exotic species in the Hudson River Basin: A history of invasions and introductions. Estuaries 19:814-823.

Pennak, R. W. 1989. Fresh-Water Invertebrates of the United States, Protozoa to Mollusca. John Wiley & Sons, New York, 3rd. Edition.

Poirrier, M.A. 1974. Ecomorphic variation in gemmoscleres of *Ephydatia fluviatilis* Linnaeus (Porifera: Spongillidae) with comments upon its systematics and ecology. Hydrobiologia 44:337-347.

Poirrier, M.A. and M.R. Partridge. 1979. The barnacle, *Balanus subalbidus*, as a salinity bioindicator in the oligohaline estuarine zone. Estuaries 2:204-206.

Price, W. W. and R.W. Heard. 2009. Mysida (Crustacea) of the Gulf of Mexico. pp. 929-939 *In*: Felder, D.L. and D.K. Camp (eds.), Gulf of Mexico. Origin, Waters, and Biota. Volume 1, Biodiversity. Texas A&M University Press, College Station, TX.

Schuchert, P. 2004. Revision of the European athecate hydroids and their medusae (Hydrozoa, Cnidaria): Families Oceanidae and Pachycordylidae. Revue Suisse de Zoologie 111:315-369.

Thorp, J.H. and A.P. Covich. 2001. Ecology and Classification of North American Freshwater Invertebrates. Academic Press, New York. 2nd Edition.

Uebelacker, J.M. and P.G. Johnson. 1984. Taxonomic Guide to the Polychaetes of the Northern Gulf of Mexico. Final Report to the U.S. Department of the Interior, Minerals Management Service, 7 vols.

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 James River Reserve Fleet Vessel Mississinewa Before and After In-water Cleaning. Report to U.S. Maritime Administration, Office of the Environment, Washington D.C. Versar, Inc., Columbia, Maryland.

Versar, Inc. 2008c. 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. 2008d. Hull Biofouling of Beaumont Reserve Fleet Vessels Dutton, Del Valle, Hattiesburg Victory, and Pioneer Crusader. 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.

Verween, A., M. Vincx, and S. Degraer. 2007. The effect of temperature and salinity on the survival of *Mytilopsis leucophaeata* larvae (Mollusca, Bivalvia): The search for environmental limits. Journal of Experimental Marine Biology and Ecology 348:111-120.

Wasson, K. 1997. Systematic revision of colonial kamptozoans (ectoprocts) of the Pacific coast of North America. Zoological Journal of the Linnean Society 121:1-63.

Weise, J.G. 1961. The ecology of *Urnatella gracilis* Leidy: Phylum Endoprocta. Limnology Oceanography 6:228-230.

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

Wood, T.S. and B.T. Backus. 1992. Differentiation of North American and European forms of *Fredericella sultana* (Blumenbach) (Ectoprocta: Phylactolaemata). Hydrobiologia 237:185-1992.

APPENDIX A

SPECIES ABUNDANCES
(See DVD for Electronic Data)

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APPENDIX B

SPECIES BIOGEOGRAPHY AND LIFE HISTORY INFORMATION

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					Geographical Distribution		Salinity (psu)		Temperature (ºC)		
Phylum	**Class**	**Species/Taxon Name**	**Common Name**	**Status in Texas**	**Native range**	**Invaded range**	**Range**	**Optimum**	**Range**	**Optimum**	**Substrate Preference-adults**
Chelicerata	Arachnida	Acari spp. (juv.)	water mites	native species present							
Crustacea	Copepoda (Calanoida)	Acartia sp.	calanoid copepod	native species present							
Crustacea	Copepoda (Calanoida)	Acartia tonsa	calanoid copepod	native	Atlantic Ocean, Pacific Ocean, Indian Ocean	Caspian Sea; Baltic Sea; Black Sea, European brackish waters	freshwater to hypersaline	5-30			planktonic
Chlorophyta		Algae sp. A	algae	?							
Crustacea	Mysidacea	Americamysis almyra	mysid or fairy shrimps	native	Northwest Atlantic (Chesapeake Bay to FL), Gulf of Mexico		0-32	<20			epibenthic and planktonic
Crustacea	Mysidacea	Americamysis sp. (juv.)	mysid or fairy shrimps	native species present							epibenthic and planktonic
Crustacea	Amphipoda	Apocorophium lacustre	tube-building amphipod	cryptogenic	Northwest Atlantic	Northeast Atlantic	0-25				epibenthic tube-building
Crustacea	Cirripedia	Balanus subalbidus	white barnacle	native	Northwest Atlantic, Gulf of Mexico	Massachusetts	0.5-25	0.5-10			epibenthic
Entoprocta	Entoprocta	Barentsia sp. A	nodding heads	cryptogenic			brackish to euhaline				epibiont
Crustacea	Cirripedia	barnacle cypris	barnacle larval stage	native species present							
Annelida	Polychaeta	Boccardiella ligerica	polychaete or bristle worm	cryptogenic	Northeast Atlantic	Baltic Sea, Northeast Pacific, South Atlantic Ocean, and possibly (cryptogenic range), Northwest Atlantic and Gulf of Mexico	0-30	2-20			infaunal
Ectoprocta	Gymnolaemata	Bowerbankia gracilis	creeping bryozoan	native	Western Atlantic Ocean	Northeast Atlantic, Northeast Pacific, Hawaii, Indian Ocean	3-30				epibenthic
Crustacea	Decapoda	Brachyura spp. Indeterminant	crab megalopa and zoea larval stages	native species present							
Crustacea	Copepoda (Calanoida)	Calanoida spp. Indeterminant	calanoid copepod	native species present							
Crustacea	Decapoda	Callinectes sp. (juv.)	Atlantic swimming crab	native species present							epibenthic
Crustacea	Amphipoda	Cerapus sp.	amphipod	native species present							epibenthic tube-building
Chaetognatha		Chaetognatha spp.	arrow worms	native species present							planktonic
Ectoprocta	Gymnolaemata	Conopeum chesapeakensis	bryozoan or moss animal	introduced	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.					epibenthic
Cnidaria	Hydrozoa	Cordylophora caspia	freshwater hydroid	introduced	Circumglobal in temperate and subtropical regions, usually in brackish waters; native to Caspian and Black Seas	Range extended by shipping	0-35	0-17	0-30	11-30	epibenthic
Crustacea	Copepoda (Harpacticoida)	Coullana canadensis	harpacticoid copepod	native	Northwest Atlantic, Gulf of Mexico	Northeast Pacific (cryptogenic)	0-15	5-10			epibenthic and planktonic
Crustacea	Copepoda (Cyclopoida)	Cyclopoida spp. Indeterminant	cyclopoid copepod	native species present							
Annelida	Oligochaeta	Dero sp.	freshwater worm	native species present							infaunal, epibiont, on submerged aquatic vegetation
Hexapoda	Insecta	Dicrotendipes sp.	non-biting midge, early instar	native species present			freshwater				Larvae: infaunal burrower
Porifera	Demospongiae	Ephydatia fluviatilis	freshwater sponge	native	Cosmopolitan in rivers and lakes; possibly native to North America		0-5		17-33		epibenthic
Annelida	Polychaeta	Ficopomatus enigmaticus	Australian shipworm	introduced	Indian Ocean	Atlantic Ocean, Gulf of Mexico, Black Sea, Caspian Sea, Mediterranean Sea, Pacific Ocean	6-35	10-30		>18	epibenthic tube-building
Ectoprocta	Phylactolaemata	Fredericella indica	bryozoan or moss animal	cryptogenic	Western India	Possibly North America and Europe	freshwater		2-23		epibenthic
Cnidaria	Hydrozoa	Garveia franciscana	Rope Grass hydroid	introduced	Unknown, possibly Indian Ocean	Atlantic Ocean, Gulf of Mexico, Northeast Pacific, Southwest Pacific, Black Sea, Caspian Sea	1-35	5-25	0-37.5	9-34	epibenthic
Chordata	Osteichthyes	Gobiosoma bosc	Naked Gobi	native	Northwest Atlantic (S of Cape Cod), Gulf of Mexico		brackish to salt				demersal
Crustacea	Amphipoda	Grandidierella bonnieroides	amphipod	native	Cosmopolitan in warm temperate and tropical waters		1-40				epibenthic tube-building
Crustacea	Copepoda (Cyclopoida)	Halicyclops sp.	cyclopoid copepod	native species present	Cosmopolitan		brackish to salt				epibenthic and planktonic
Crustacea	Copepoda (Harpacticoida)	Harpacticoida spp. (pending identification)	harpacticoid copepod	native species present							
Crustacea	Amphipoda	Hourstonius laguna	amphipod	native	Gulf of Mexico, Florida						epibenthic
Mollusca	Gastropoda	Hydrobiidae spp.	mud snails	native species present							
Crustacea	Amphipoda	Melita nitida	amphipod	native	Northwest Altantic, Caribbean, Gulf of Mexico	Northeast Pacific, Northeast Altlantic	0-30	3-20			epibiont
Mollusca	Bivalvia	Mytilopsis leucophaeata	Dark False mussel	native	Northwest Atlantic (Chesapeake Bay to FL), Gulf of Mexico	Hudson River, Europe, Baltic Sea, Black Sea	0.1-31	3-22	5-30	10-30	epibenthic
Annelida	Polychaeta	Neanthes succinea	pile worm	native	Atlantic Ocean, Gulf of Mexico	Northeast Pacific, Southwest Pacific	2.5-65	5-50	-2-34		infaunal and epibenthic
Nematoda		Nematoda spp.	roundworms	native species present							
Annelida	Polychaeta	Nereididae spp. (juv.)	pile worms	native species present							
Annelida	Polychaeta	Nereis cf. falsa	pile worm	cryptogenic	Temperate and tropical waters of Atlantic Ocean, Caribbean, Gulf of Mexico, Mediterranean Sea, Black Sea, Indian Ocean	Range possibly extended by rafting, shipping					infaunal and epifaunal
Crustacea	Copepoda (Harpacticoida)	Nitokra sp.	harpacticoid copepod	native species present	Cosmopolitan		brackish to euhaline				infaunal, epibiont
Mollusca	Gastropoda	Nudibranchia spp. (juv.)	sea slugs	native species present							
Hexapoda	Insecta	Parachironomus directus	non-biting midge	native	Lakes and slow-moving rivers and streams of North America		freshwater				Larvae: epibenthic
Crustacea	Decapoda	Penaeidae spp. (juv.)	prawns	native species present							
Annelida	Polychaeta	Polydora cornuta	mud worm	native	North Atlantic, Gulf of Mexico	Possibly introduced with oyster culture, ballast water and on hulls in the NE Pacific (BC to CA), NW Pacific (Russia, Japan, Korea), SW Pacific (Australia, New Zealand), and SE Atlantic (Argentina, Brazil)	brackish to salt				epibenthic tube-building, epibiont
Hexapoda	Insecta	Rheotanytarsus sp.	non-biting midge, early instar	native species present	Widespread in rivers		freshwater				Larvae: epibenthic tube-building
Crustacea	Decapoda	Rhithropanopeus harrisii	white-fingered mud crab	native	Northwest Atlantic (New Brunswick to FL), Gulf of Mexico (Mississippi to Veracruz, Mexico)	Northeast Atlantic, Northeast Pacific, Black Sea, Caspian Sea, Inland Lakes of Texas	0-40	0-20		20-31	epibenthic, among oysters
Crustacea	Copepoda (Harpacticoida)	Schizopera sp.	harpacticoid copepod	native species present	Cosmopolitan		brackish to euhaline				infaunal, epibiont
Annelida	Polychaeta	Serpulidae sp. A	plume worm	?							
Annelida	Polychaeta	Serpulidae spp. Indeterminant	plume worms	native species present							

					Geographical Distribution		Salinity (psu)		Temperature (ºC)		
Phylum	**Class**	**Species/Taxon Name**	**Common Name**	**Status in Texas**	**Native range**	**Invaded range**	**Range**	**Optimum**	**Range**	**Optimum**	**Substrate Preference-adults**
Crustacea	Tanaidacea	Sinelobus stanfordi	tanaid	cryptogenic	Unknown, cited for the Pacific Ocean, Northwest Atlantic, Caribbean Sea, Gulf of Mexico (but not Texas), Southwest Atlantic and Southeast Atlantic	Possibly Northeast Pacific, Southwest Pacific	0-45+	0.5-30			epibenthic
Annelida	Polychaeta	Spionidae spp. (juv.)	polychaete or bristle worms	native species present							
Annelida	Polychaeta	Stenoninereis martini	polychaete or bristle worm	native	Caribbean Sea, Gulf of Mexico		0-30				infaunal in salt marsh, tidal creeks and rivers
Annelida	Polychaeta	Streblospio benedicti	polychaete or bristle worm	native	Northwest Atlantic, Gulf of Mexico	Northeast Atlantic, Mediterranean Sea, Black Sea, Northeast Pacific	brackish to euhaline				infaunal tube-building
Platyhelminthes	Turbellaria	Stylochus ellipticus	flatworm	native	Northwest Atlantic, Caribbean Sea, Gulf of Mexico	Northeast Atlantic	2.7-27	<20			epibenthic, commensal
Platyhelminthes	Turbellaria	Turbellaria sp. A	flatworm	?							
Entoprocta	Entoprocta	Urnatella gracilis	nodding heads	native	Cosmopolitan in rivers and lakes; possibly native to North America	Range possibly extended by shipping	0-5				epibenthic, epibiont
Mollusca	Gastropoda	Valvata sp.	operculate freshwater snails	native	Widespread in rivers in North America		freshwater				epibenthic usually on submerged vegetation

Species/Taxon Name	Developmental mode	Feeding mode	Reference
Acari spp. (juv.)			
Acartia sp.			
Acartia tonsa	eggs released; planktonic larvae	omnivore; suspension feeder	Johnson and Allen 2005
Algae sp. A			
Americamysis almyra	brooder	omnivore	Johnson and Allen 2005, Price and Heard 2009
Americamysis sp. (juv.)	brooder	omnivore	Price and Heard 2009
Apocorophium lacustre	brooder	detritus feeder; suspension feeder	Bousfield 1973, USGS Nonindigenous Aquatic Species database: http://nas.er.usgs.gov/, LeCroy 2004. Note: This species not cited by LeCroy west of the Mississippi River.
Balanus subalbidus	planktonic larvae	suspension feeder	Poirrier and Partridge 1979, Dineen and Hines 1994
Barentsia sp. A	budding; planktonic larvae	suspension feeder	
barnacle cypris			
Boccardiella ligerica	demersal eggs laid in strings in burrows; planktonic larvae	interface feeder	Davidson et al. 2006
Bowerbankia gracilis	brief planktonic larvae	suspension feeder	Winston 1977, Cohen and Carlton 1995
Brachyura spp. Indeterminant			
Calanoida spp. Indeterminant			
Callinectes sp. (juv.)			
Cerapus sp.	brooder		
Chaetognatha spp.			
Conopeum chesapeakensis	brooder; planktonic larvae (inferred)	suspension feeder	Davidson et al. 2008
Cordylophora caspia	brooder; planktonic larvae	suspension feeder; carnivore	Schuchert 2004, NEMESIS database: http://invasions.si.edu/nemesis/chesapeake.html
Coullana canadensis		herbivore; detritus feeder; suspension feeder	Johnson and Allen 2005
Cyclopoida spp. Indeterminant			
Dero sp.	budding	herbivore; detritus feeder	Pennak 1989
Dicrotendipes sp.	aquatic larvae and pupae, adult terrestrial stage	filter feeder; collector-gatherer	Merritt and Cummins 1996
Ephydatia fluviatilis	germination of dormant stages (gemmules); planktonic larvae	filter feeder	Poirrier 1974
Ficopomatus enigmaticus	planktonic larvae	suspension feeding	Cohen and Carlton 1995, Cohen 2005
Fredericella indica	budding and germination of dormant stages (statoblasts); planktonic larvae	suspension feeder	Wood and Backus 1992, Pennak 1989
Garveia franciscana	brooder, planktonic larvae	suspension feeder	Cohen and Carlton 1995, NEMESIS database: http://invasions.si.edu/nemesis/chesapeake.html
Gobiosoma bosc		predator	Fishbase: www.fishbase.org
Grandidierella bonnieroides	brooder	herbivore; detritus feeder	LeCroy 2002
Halicyclops sp.	brooder	herbivore; detritus feeder; suspension feeder	
Harpacticoida spp. (pending identification)			
Hourstonius laguna	brooder	herbivore; detritus feeder	LeCroy 2002
Hydrobiidae spp.			
Melita nitida	brooder	herbivore; detritus feeder; omnivore	Davidson et al. 2006
Mytilopsis leucophaeata	planktonic larvae	suspension feeder	Mills et al. 1996, Verween et al. 2007 and references herein
Neanthes succinea	planktonic eggs; planktonic larvae	carnivore; detritus feeder; omnivore	Davidson et al. 2006, Cohen and Carlton 1995
Nematoda spp.			
Nereididae spp. (juv.)			
Nereis cf. falsa	planktonic eggs; planktonic larvae	carnivore; detritus feeder; omnivore	Day 1973, Uebelacker and Johnson 1984
Nitokra sp.	brooder	herbivore; detritus feeder; suspension feeder	
Nudibranchia spp. (juv.)			
Parachironomus directus	aquatic larvae and pupae, adult terrestrial stage		Hudson et al. 1990, Merritt and Cummins 1996
Penaeidae spp. (juv.)			
Polydora cornuta	brooder (egg capsules attached to tube wall), planktonic larvae	interface feeder	Blake 1969, Cohen and Carlton 1995 (as Polydora ligni)
Rheotanytarsus sp.	aquatic larvae and pupae, adult terrestrial stage	filter feeder	Hudson et al. 1990, Merritt and Cummins 1996
Rhithropanopeus harrisii	brooder, planktonic and benthic larvae	omnivore	Williams 1984, Cohen and Carlton 1995
Schizopera sp.	brooder	herbivore; detritus feeder; suspension feeder	
Serpulidae sp. A			
Serpulidae spp. Indeterminant			

Species/Taxon Name	Developmental mode	Feeding mode	Reference
Sinelobus stanfordi	brooder	suspension feeder; detritus feeder	Cohen and Carlton 1995, Davidson et al. 2007
Spionidae spp. (juv.)			
Stenoninereis martini	planktonic eggs; planktonic larvae	carnivore; detritus feeder; omnivore	
Streblospio benedicti	planktonic larvae	interface feeder	Cohen and Carlton 1995
Stylochus ellipticus	demersal eggs, planktonic larvae	carnivore	Hyman 1940, Kennedy et al. 1996
Turbellaria sp. A			
Urnatella gracilis	budding; planktonic larvae	suspension feeder	Weise 1961
Valvata sp.	egg capsules, direct development	herbivore; filter feeder	Thorp and Kovich 2001, S.W. Ziser's The Aquatic Invertebrates of Texas: http://www.austincc.edu/sziser/txaquaticinverts