HULL BIOFOULING OF JAMES RIVER RESERVE FLEET VESSEL MISSISSINEWA BEFORE AND AFTER IN-WATER CLEANING

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Prepared by

Roberto J. Llansó
Kristine Sillett

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

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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 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.

This study examines the extent of biofouling on the hull of the USNS MISSISSINEWA, a Neosho-class fleet oiler built in 1954 that was transferred to the James River Reserve Fleet (JRRF) in 1991 and dismantled in 2007. The study examined the biota associated with the underwater surfaces of the vessel before and after in-water cleaning. In-water hull cleaning of obsolete vessels is one management option implemented by the Maritime Administration to reduce the risk of transferring non-native species to new coastal regions where they could become established as a result of their ship disposal program. Although the transfer of the MISSISSINEWA from the James River to the Port of Brownsville does not represent an inter-oceanic event, the potential of non-native species introductions into the Gulf of Mexico exists.

The MISSISSINEWA was surveyed prior to hull cleaning on January 10 and 11, 2007, and immediately after cleaning on January 14 and 15, 2007. The vessel departed the JRRF on January 30 for Brownsville, Texas. No post-transit survey was conducted on the vessel in Texas. As with other biological surveys conducted on Reserve Fleet vessels, samples were collected with the help of professional divers using a stratified random sampling protocol consisting of transects along the hull and sampling positions at three depths (below the waterline, mid-depth, and bottom). In addition, samples were taken from underwater stern appendages (stern tube, rudder, and propellers), and the cofferdam. A total of 100 samples were divided equally between the two surveys; 99 were analyzed for species abundance and composition. Also, photos of the biota covering the hull were taken at each sampling location.

A total of 23 taxa were recorded in the biological samples. The samples consisted mostly of mussels (the hooked mussel and Conrad's false mussel), barnacles, and encrusting bryozoans. Hydroids, amphipods, crabs, and polychaete worms were also abundant in the pre-cleaning samples. In addition, 55% of the samples had oysters. Mussels and barnacles formed a thick layer over most of the hull which provided three-dimensional habitat for amphipods, crabs, and worms. Only one of the species recorded, the hydroid *Garveia franciscana*, was nonindigenous in Chesapeake Bay. Two species were not known to be established in the Gulf of Mexico, but the remaining were known to occur in Gulf of Mexico waters, and none were invasive in those waters.

Species densities and frequency of occurrence differed between surveys; however, the same assemblage of organisms was present in the biological samples before and after cleaning. In-water hull cleaning was successful at removing on average 85% of the

biofouling cover, substantially reducing the thick cover of mussels and barnacles. However, hard-shelled organisms were not entirely removed, and provided ample coverage for amphipods, crabs, and worms. Hooked mussels occurred in 74% of the post-cleaning samples, barnacles occurred in 82%, and encrusting bryozoans in 100%. Hard-shelled organisms provide three-dimensional structure in which many species hide; thus, the potential for transfer of species to destination ports was high given that hull cleaning did not achieve a more thorough removal of the base layer of these organisms.

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1.0 INTRODUCTION

The USS MISSISSINEWA, a Neosho-class fleet oiler built in 1954, was commissioned in 1955 and served for 21 years. It was decommissioned in 1976 and placed in service with Military Sealift Command as USNS MISSISSENEWA. The vessel was added to the National Defense Reserve Fleet (NDRF) in the James River, Virginia, in 1991. The NDRF at James River, also referred to as the James River Reserve Fleet (JRRF), is one of three fleets in the United States maintained by the U.S. Maritime Administration. Based on the Maritime Administration's Property Management and Archive Record System, the MISSISSINEWA remained inactive until it departed the JRRF in January of 2007 for dismantling at International Shipbreaking, LTD in Brownsville, Texas, as part of the Maritime Administration's non-retention vessel disposal program. Dismantling of the ship was completed in February of 2008.

Prior to its departure from the JRRF, the hull of the MISSISSINEWA was sampled for biological fouling and cleaned. In-water hull cleaning of obsolete vessels is one management option implemented by the Maritime Administration to reduce the risk of transferring nonnative species to new coastal regions where they could become established as a result of the ship disposal program. Although the transfer of the MISSISSINEWA from the James River to the Port of Brownsville does not represent an inter-oceanic event, the potential for nonnative species introductions into the Gulf of Mexico exists. This risk is higher for obsolete ships than active ships, because the hulls of obsolete ships have not been maintained and usually are heavily fouled with aquatic organisms. Many ships also have a long residence time at their destination ports before they are dismantled.

In this study we examined the biota associated with the underwater surfaces of the MISSISSINEWA before and after in-water cleaning of the hull in the James River prior to the vessel being towed into the Port of Brownsville for dismantling. We identified and quantified species and examined their geographic distributions with respect to their possible transfer from the Chesapeake Bay to the Gulf of Mexico. This study is similar in scope to the pilot assessment conducted on another JRRF vessel, the ORION (Davidson el al. 2007), and provides additional information about the composition and abundance of biological assemblages associated with JRRF vessels. We were also able to consider seasonal differences in biological fouling because the ORION was sampled during summer 2006 and the MISSISSINEWA in January 2007. No biological sampling was conducted after the MISSISSINEWA arrived in Brownsville.

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2.0 METHODS

2.1 WATER CHARACTERISTICS

Several water column parameters were measured on-site to characterize the environment that the biota encountered at the time of sampling. Parameters included temperature, salinity, conductivity, dissolved oxygen, and pH. Data were collected over the course of the biological surveys using a YSI multiparameter probe with automatic temperature and salinity compensation (Yellow Springs Instruments, Inc., Yellow Springs, Ohio). Water parameter measurements were recorded at 1 meter intervals from the water surface to the bottom of the hull of the vessel. These data characterized local conditions at the time of sampling, but did not provide information about long-term exposure or conditions during towing of the vessel to its final destination.

2.2 VESSEL SURVEY

The MISSISSINEWA was surveyed over two separate dives. Biological surveys were completed on the MISSISSINEWA prior to in-water hull cleaning on January 10 and 11, 2007, and immediately after cleaning on January 14 and 15, 2007. The vessel departed the James River on January 30 for Brownsville, Texas. No post-transit survey was conducted on the vessel in Texas.

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, Inc.

A stratified random sampling design similar to that previously employed to survey other vessels in Suisun Bay (Davidson et al. 2006, Versar 2008) was applied to the MISSISSINEWA. Samples were taken at three depths (near the waterline, mid-depth, and bottom of the hull) along eight transects (Figure 2-1). The MISSISSINEWA was 655 feet long and transects were positioned 80 feet apart from each other across the hull. 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. Ten additional samples were taken from the underwater appendages of the vessel, including the stern tube, rudder, and propellers. The cofferdam was also sampled during the post-cleaning survey. The vessel was moored in the middle of the James River. Sampling was conducted from a barge positioned on the port side. The divers swam under the vessel to the starboard side and back to complete two sampling transects.

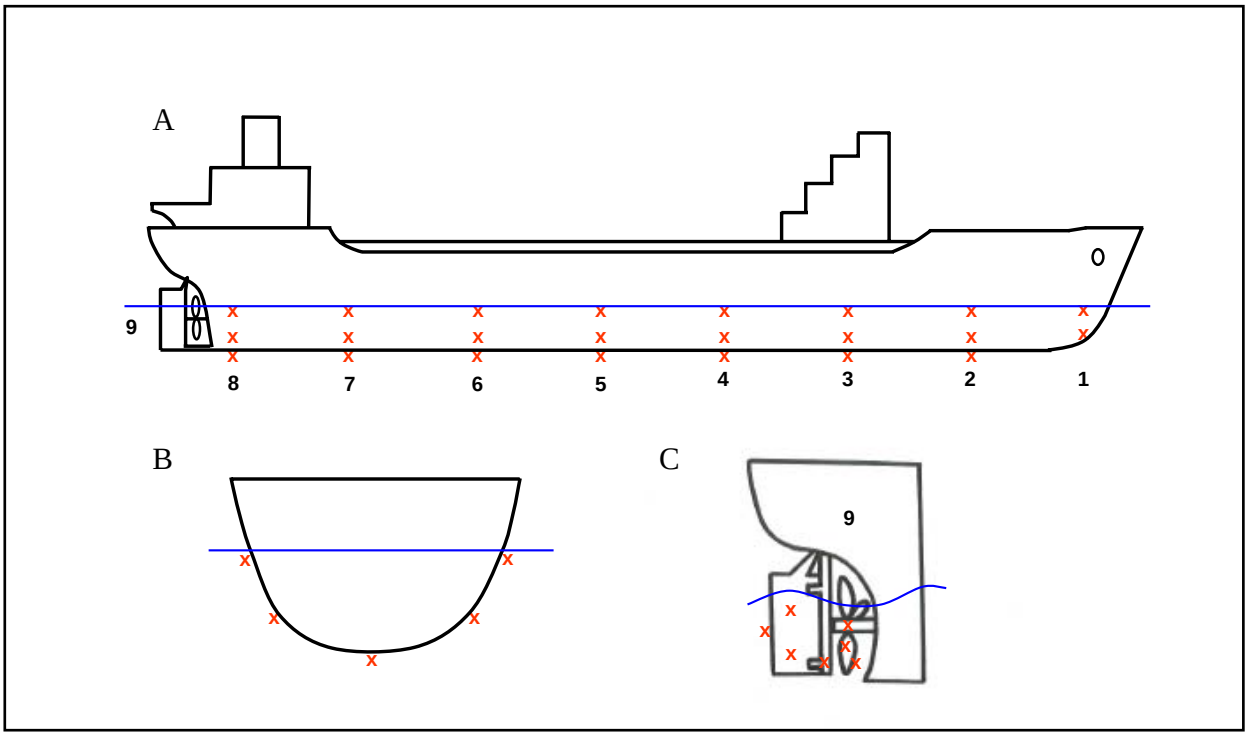

Figure 2-1. Sampling locations. Samples and photo-quadrats were taken at 8 transects across the hull of the MISSISSINEWA (A). Five samples per transect were collected: starboard upper, starboard lower, bottom, port lower, and port upper (B). The first transect did not have a flat bottom; therefore, only four samples were collected from this transect. In addition, samples were collected from the underwater appendages of the vessel (C) including the stern tube, propellers, rudder, and cofferdam (post-cleaning only). Underwater appendage locations are labeled as Transect 9.

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. Two types of samplers were used for the surveys. The sampler constructed from a 6-inch (15.2 cm) diameter, T-shaped PVC pipe connector used in the OCCIDENTAL VICTORY (Versar 2008), was used here to collect the biota from the lower and upper sides of the hull.

The sampler for collecting biota from the bottom of the hull in this study was modified from the T-shaped design. It consisted of a 6-inch (15.2 cm) diameter PVC pipe with a 4-inch adapter at one end to attach the sample bag (Figure 2-2). 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 scraper applied between the hull and the sampler was used to remove the biological material from the hull, which was then collected in the cloth bag.

The updated design allowed the sample to 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. Fifty samples for each of the pre-cleaning and post-cleaning surveys were collected. Each sample was accompanied by a photo-quadrat. One pre-cleaning sample was lost during the diving and could not be re-taken; therefore, 99 samples were processed for species abundance and composition.

Figure 2-2. 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.

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.

2.3 SAMPLE PROCESSING AND TAXONOMY

A visual examination of each sample was carried out on the diver's barge. 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.

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 to 1 L 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 fix 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., barnacles, mussels, annelids, crabs, micro-crustaceans, and others). Organisms in these major categories were counted (non-colonial species only) and identified to species by primary taxonomists whenever possible. Some organisms required further examination by specialist taxonomists for identification or confirmation. Voucher specimens of these organisms were put 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 to look for differences in species numbers, composition, and abundance by transect and position (waterline, mid-depth, bottom, 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 their location along the hull. Species counts (square-root transformed and untransformed) 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 (bryozoans and hydroids) 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). The analysis was conducted on the pre-cleaning and post-cleaning samples to identify gradients in species abundance and composition.

Photo-quadrats were examined by quantifying the percent cover of 13 distinguishable categories in each image: mussel, oyster, barnacle, barnacle on mussel, barnacle on oyster, hydroid, hydroid on mussel, algae, biofilm, encrusting species, barnacle seat/ organism remnant, hull, and "other". Images were analyzed using the point count method to determine percentage cover of each category by superimposing a grid of 7 rows by 13 columns and populating each cell by 1 random point for a total of 91 random points. The area of hull analyzed from the image was 158 cm^2 (approximately 9.5 x 17 cm), for a density of 1.7 points per cm^2 of hull (Figure 2-3). 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 were analyzed by MDS.

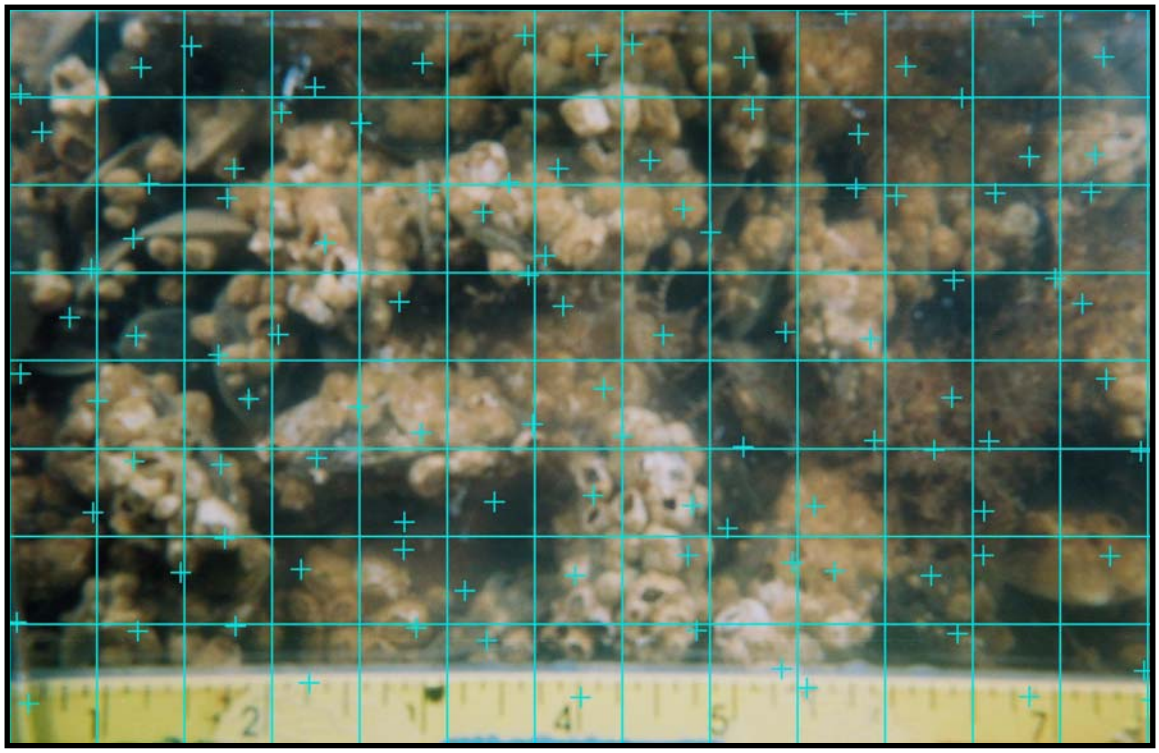

Figure 2-3. Grid of random points superimposed on an underwater photograph taken from the lower starboard side of Transect 4 (mid-ship) prior to hull cleaning. Images were analyzed using the point count method to determine percentage cover of each of 13 categories. The area of hull analyzed from the image (first seven rows), was 158 cm^2 (approximately 9.5 x 17 cm). A ruler in inches was added to the lower edge of the clear-water box.

3.0 RESULTS AND DISCUSSION

3.1 WATER CHARACTERISTICS

Salinity in the James River at the JRRF is in the oligohaline to low mesohaline range. In January 2007, salinity ranged from 0.96 to 2.9 psu near the surface, and from 1.7 to 6.4 psu at a depth of 6 m, based on 6 deployments between low and high tide over two days (Figure 3-1). Water temperature ranged between 10 °C and 11 °C and dissolved oxygen was high near saturation, ranging between 10.2 and 10.9 mg/L. Salinity and temperature at the destination port in Brownsville, Texas, are typically much higher at this time of the year, 32 psu and 17 °C, respectively (based on measurements taken in January 2008).

3.2 SPECIES ASSEMBLAGE

The biological samples collected from the hull of the MISSISSINEWA yielded at total of 23 taxa, and consisted mostly of mussels (the hooked mussel, *Ischadium recurvum*, and Conrad's false mussel, *Mytilopsis leucophaeata*), barnacles (the Bay barnacle, *Balanus improvisus*), and encrusting bryozoans (*Conopeum chesapeakensis*) (Table 3-1). Mussels and barnacles provided habitat for several other organisms, including amphipods (*Apocorophium lacustre*, *Gammaus daiberi*, and *Melita nitida*), crabs (*Eurypanopeus depressus* and *Rhithropanopeus harrisii*), and worms (mostly *Neanthes succinea*). Five species occurred in 100% of the pre-cleaning samples: *A. lacustre*, *B. improvisus*, *C. chesapeakensis*, *I. recurvum*, and *N. succinea*. In addition, all pre-cleaning samples had very small nematodes, and 55% of the samples had oysters (*Crassostrea virginica*). The hydroid *Garveia franciscana* occurred frequently. The remaining of the species consisted of algae, arrow worms (Cheatognatha), flat worms (Turbellaria), and copepods (Table 3-1). The ORION (Davidson et al. 2007) had more species possibly because that vessel was sampled in summer.

Mussels and barnacles formed a thick layer over most of the hull (Figures 3-2 and 3-3), but not uniformly. In mid sections of the ship, about 35% of the hull was visible in photo quadrats (see Section 3.4). This layer provided three-dimensional habitat and structure for amphipods, crabs, and worms. Large and small hooked mussels were abundant, but false mussels and oysters occurred in very small numbers (Table 3-2).

Of the taxa that could be classified according to their status in Chesapeake Bay, 14 were native, 4 had native species present, 2 were cryptogenic (of uncertain origin), and 1 was introduced (Table 3-1). The hydroid *G. franciscana* was the only nonnative species recorded in the samples. *G. franciscana* has a worldwide distribution, and its native range is uncertain, possibly originating in the Indian Ocean. See Appendix A for invasion status, distribution, habitat, and life history information of the species found in this study. All of the species recorded in the samples except two (*C. chesapeakensis* and *G. daiberi*), are

known to occur in Gulf of Mexico waters, and none are invasive or have the characteristics that would make them potentially invasive in those waters.

Table 3-1. Species recorded in biological samples. The frequency of occurrence (percent of samples) in the pre-cleaning and post-cleaning surveys, the biogeographic status of species in Chesapeake Bay, and whether the species was present in the ORION vessel (Davidson et al. 2007) is shown. Frequency of occurrence for copepod species is not provided. Status: I = introduced (nonnative species); C = cryptogenic; N = native; NP = native species present; ? = undetermined (species not identified).

Group	Species	% Samples		Status	Present in Orion
		Pre-cleaning	Post-cleaning		
Algae	Algae sp. A	4	4	?	x
Algae	Algae sp. B	0	2	?	x
Amphipoda	*Apocorophium lacustre*	100	82	N	x
Cirripedia	*Balanus improvisus*	100	82	N	x
Polychaeta	*Boccardiella ligerica*	18	8	C	
Chaetognatha	Chaetognatha	2	0	NP	
Ectoprocta	*Conopeum chesapeakensis*	100	100	N	x
Bivalvia	*Crassostrea virginica*	55	14	N	x
Turbellaria	*Euplana gracilis*	2	0	N	*Euplana* ?
Decapoda	*Eurypanopeus depressus*	53	8	N	x
Copepoda	*Eurytemora affinis*	–	–	N	copepods
Amphipoda	*Gammarus daiberi*	37	26	N	
Hydrozoa	*Garveia franciscana*	39	46	I	x
Copepoda	*Halicyclops* sp.	–	–	NP	copepods
Bivalvia	*Ischadium recurvum*	100	74	C	x
Amphipoda	*Melita nitida*	76	22	N	*Melita* sp.
Bivalvia	*Mytilopsis leucophaeata*	59	18	N	x
Polychaeta	*Neanthes succinea*	100	30	N	x
Nematoda	Nematode sp.	100	10	NP	x
Polychaeta	*Polydora cornuta*	63	12	N	*Polydora* sp.
Decapoda	*Rhithropanopeus harrisii*	10	2	N	x
Turbellaria	*Stylochus ellipticus*	6	0	N	x
Decapoda	Xanthidae (juv.)	0	2	NP	x

Table 3-2. Average and range of species abundance in samples where the species occurred. Colonial species (bryozoans, hydroids, algae) and meiofaunal species (copepods, nematodes) were not quantified and are excluded from the table.

Species	Pre-Cleaning			Post-Cleaning		
	Average	Min.	Max.	Average	Min.	Max.
Apocorophium lacustre	66.4	8	420	16.3	1	218
Balanus improvisus	302.2	59	624	74.6	2	324
Boccardiella ligerica	1.1	1	2	1.0	1	1
Chaetognatha	-	-	5	0	0	0
Crassostrea virginica	1.7	1	5	1.0	1	1
Euplana gracilis	-	-	1	0	0	0
Eurypanopeus depressus	2.6	1	7	2.5	1	5
Gammarus daiberi	4.6	1	18	3.8	1	12
Ischadium recurvum	51.4	9	122	13.9	1	78
Melita nitida	18.2	1	159	3.3	1	17
Mytilopsis leucophaeata	1.9	1	5	1.3	1	2
Neanthes succinea	15.8	2	60	5.8	1	12
Polydora cornuta	3.2	1	13	1.8	1	4
Rhithropanopeus harrisii	1.6	1	4	1.0	1	1
Stylochus ellipticus	1.0	1	1	0	0	0

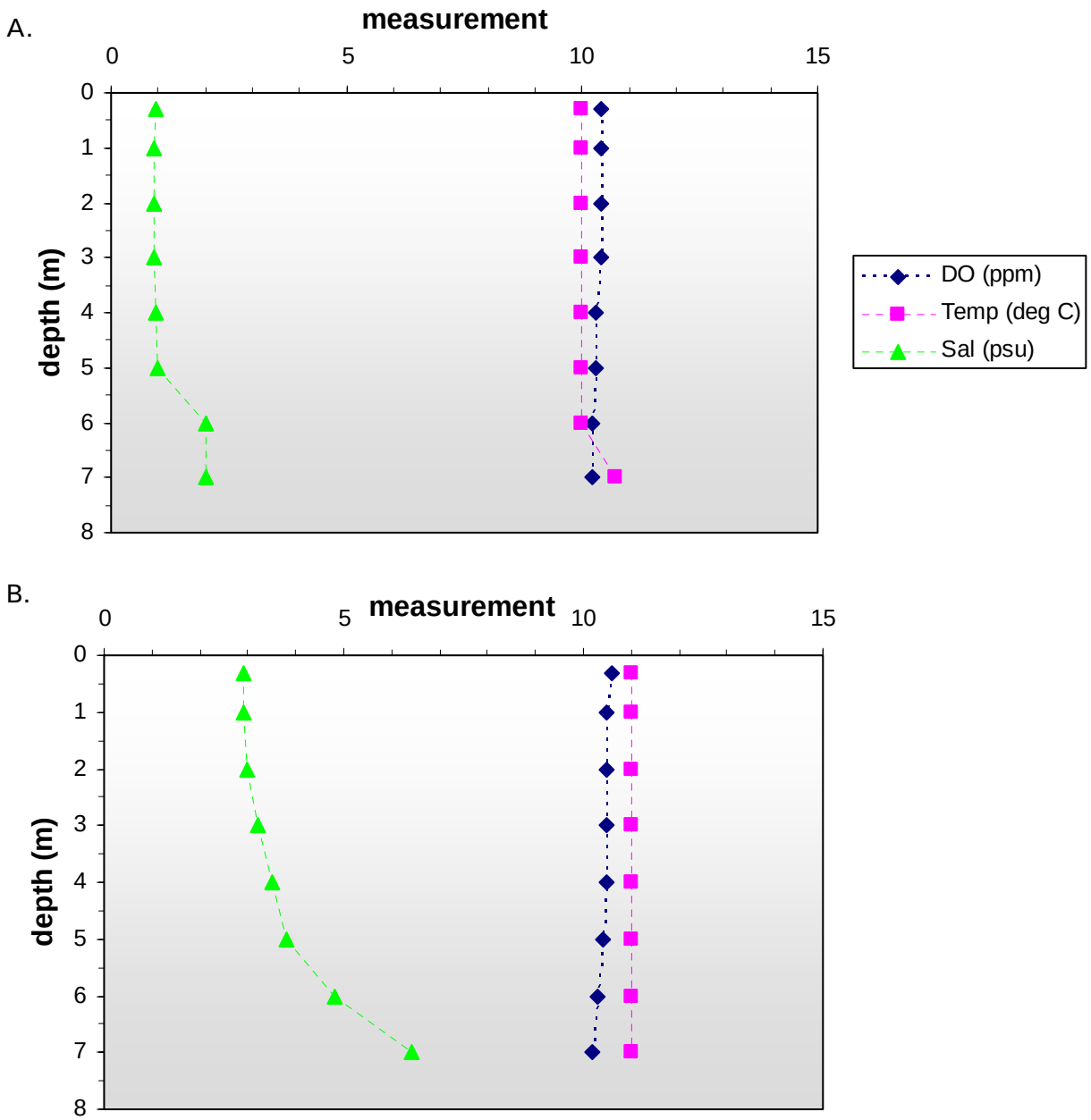

Figure 3-1. Salinity, temperature, and dissolved oxygen during (A) the pre-cleaning survey of the MISSISSINEWA on January 14, 2007, near low tide, and (B) the post-cleaning survey on January 15, 2007, near high tide at the JRRF. Measurements were taken at 1 meter intervals to the maximum depth of draft using a YSI multiparameter probe.

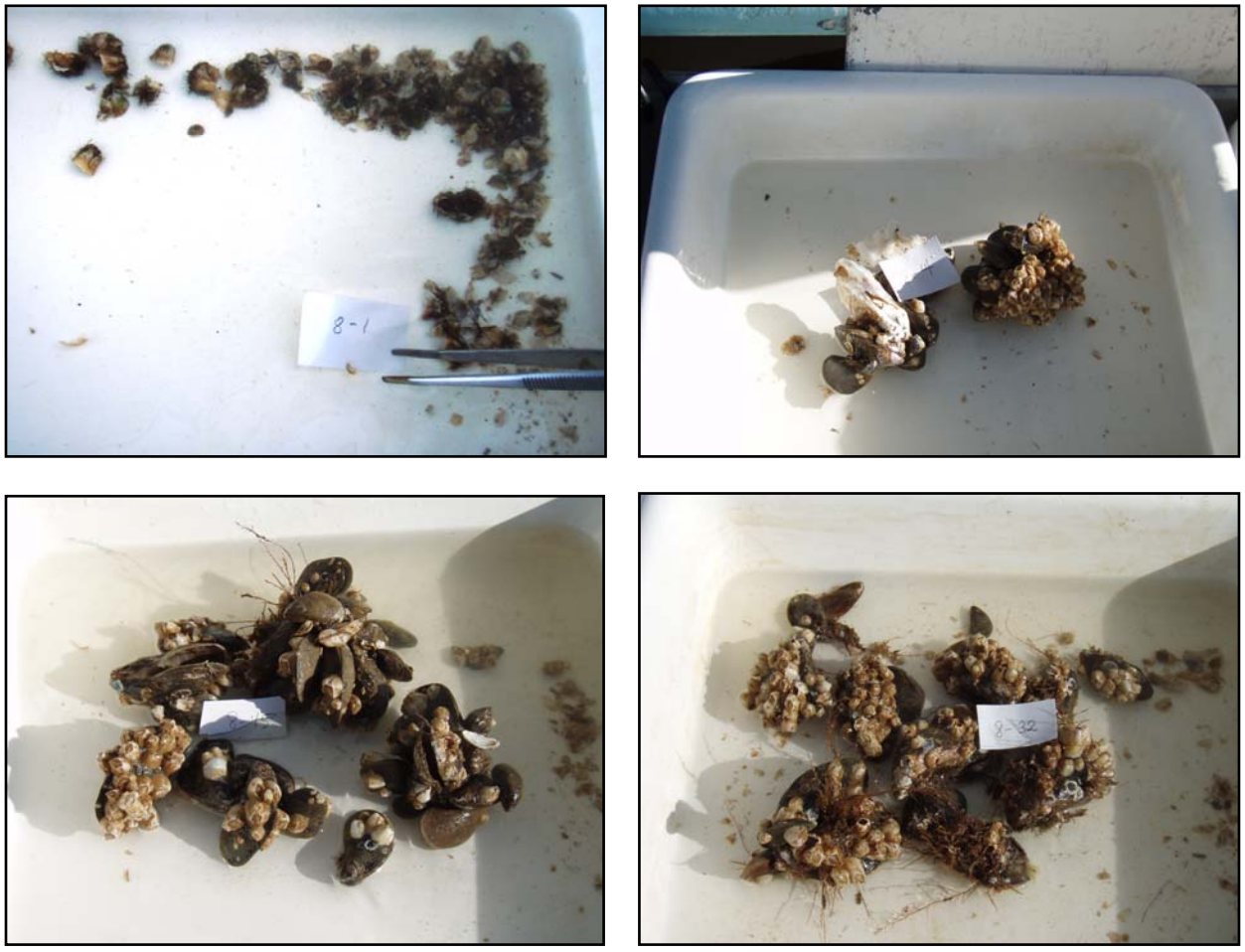

Figure 3-2. Photographs of samples taken from the pre-cleaning survey of the MISSISSINEWA showing the range of coverage observed on the hull. Clockwise from the top left corner: Sample 8-1 collected from Transect 1 near the waterline, starboard side, contains mostly barnacles; Sample 8-4, also from Transect 1 near the waterline, port side, has clumps of mussels, barnacles, and a few oysters; Sample 8-32 collected from Transect 7 mid-depth, and Sample 8-45 from the rudder, contain large clumps of mussels with barnacles and hydroids. The tray measures 12 x 18 inches.

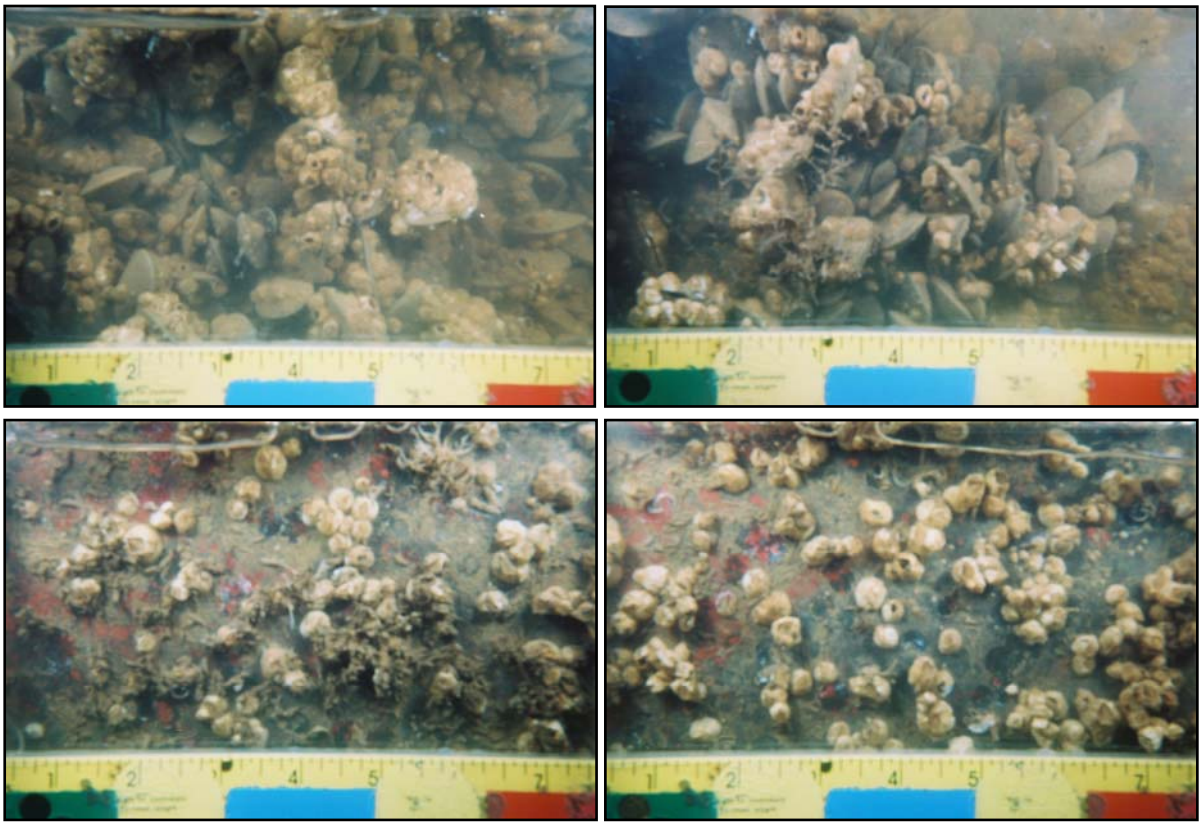

Figure 3-3. Underwater photographs taken from the hull of the MISSISSINEWA prior to hull cleaning showing a thick layer of mussels and barnacles (top 2 images), and lighter barnacle and bryozoan cover near the waterline (bottom 2 images). Clockwise from the top left: Transect 4 bottom; rudder; Transect 6 upper starboard side; and Transect 7 upper port side.

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3.3 DIFFERENCES BETWEEN SURVEYS AND LOCATIONS ON THE HULL

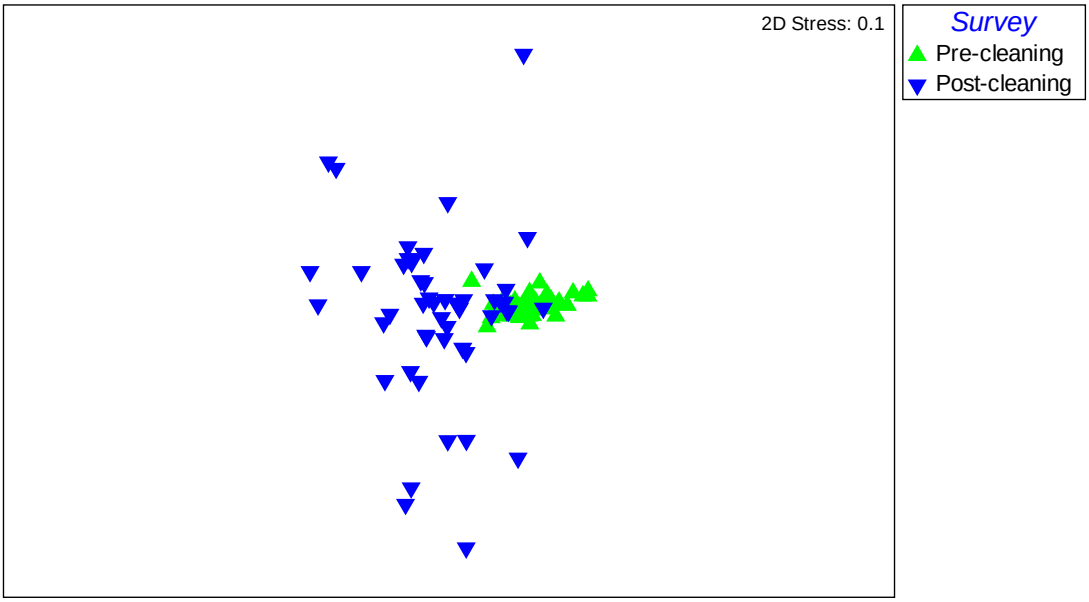
Multivariate analysis of presence-absence and of abundance data revealed no differences among the pre-cleaning or post-cleaning samples based on transect or position on the hull; however, pre-cleaning and post-cleaning samples formed distinct groups in the MDS plots (Figure 3-4). Differences between the pre-cleaning and post-cleaning samples were due to the overall lower abundance and frequency of species in post-cleaning samples. In-water hull cleaning reduced the number of individuals in the samples, but did not reduce the number of species. Except for the flat worms, which were rare in pre-cleaning samples, and the arrow worms, which are planktonic, all the species recorded from the pre-cleaning samples were collected in the post-cleaning samples (Table 3-1). Clumps of hard-shelled organisms remained on the hull after cleaning, as observed in samples (Figure 3-5) and video footage. Hooked mussels occurred in 74% of the post-cleaning samples; barnacles occurred in 82%; and encrusting bryozoans in 100% (Table 3-1). Therefore, the same assemblage of organisms was present in the biological samples before and after cleaning, and was presumably available for transfer to Gulf of Mexico waters.

3.4 PERCENT COVER

Mussels covered between 21% and 80% of the hull prior to hull cleaning (Figure 3-6), depending on transect. Percent cover of mussels was higher along mid ship (Transects 3-5) and in underwater appendages (Transect 9) than near the bow or stern of the ship (but note the large standard errors). Percent cover of mussels was also on average higher at mid-depth than near the waterline or bottom of the hull (Figure 3-6). Barnacle cover varied with mussel cover. However, when all the barnacles were considered together (i.e., barnacles on hull, barnacles on mussels, and barnacles on oysters), percent cover of barnacles remained uniform between 52% and 66% across the hull (Figure 3-6, “all barnacles”). Bare hull ranged from 4% to 37%.

In-water cleaning was effective at removing much of the thick layer of hard-shelled organisms. Bare space was the most prominent feature of the photo-quadrat analysis of the post-cleaning survey (Figure 3-6), with a mean of 75.4% per image after cleaning compared to 18.3% prior to cleaning. An increase in bare space and scars/remnants was consistent across transects, positions, and the vessel’s running gear. Bare space and scar/remnants accounted for 85% of the space after cleaning. Mussels and barnacles, however, were not entirely removed, but tended to persist in strips and small clumps observable in photo-quadrats and video footage. This was corroborated in the biological samples, but clumps were targeted in the biological samples of the post-cleaning survey, so that a majority of the species remaining on the hull could be quantified. Thus, frequency of hard-shelled organisms appeared higher in biological samples than in underwater images.

A



B.

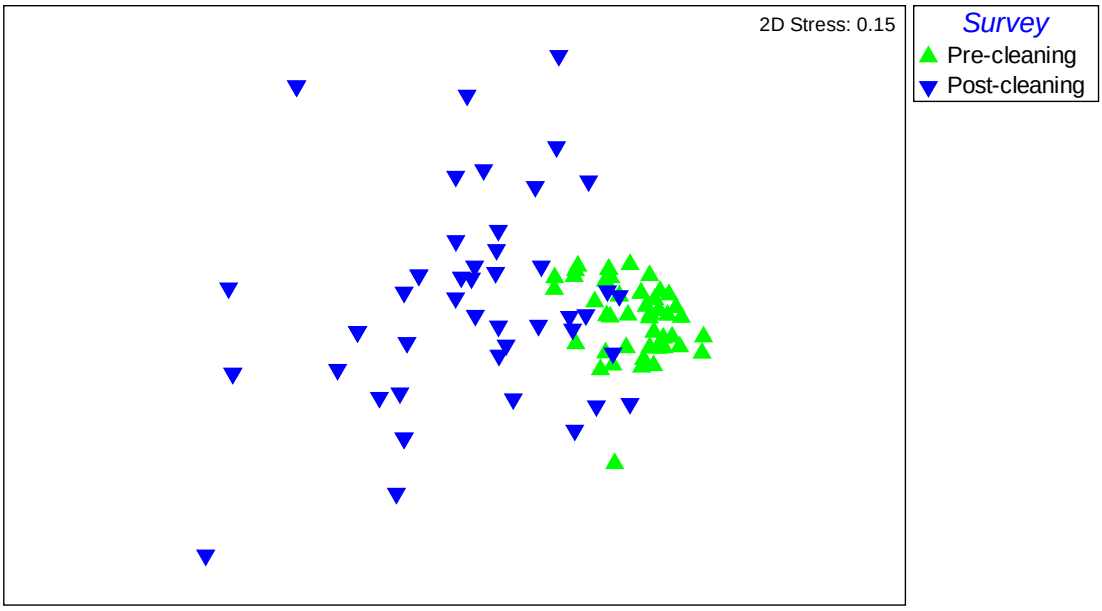


Figure 3-4. MDS for species abundance and composition (A) and presence-absence of species (B). Pre-cleaning and post-cleaning samples formed distinct groups in the diagram, indicating differences in species assemblages that were due to overall lower abundance and frequency of species in the post-cleaning samples, but not to differences in the total number of species. The same species recorded from the pre-cleaning samples were present in the post-cleaning samples.

Figure 3-5. Photographs of samples taken from the post-cleaning survey of the MISSISSINEWA showing the range of biota remaining on the hull. The sample on the left, collected from Transect 4 near the waterline, contained only a few barnacles. The sample on the right, collected from the bottom of Transect 3, contained a large clump of mussels with barnacles and hydroids.

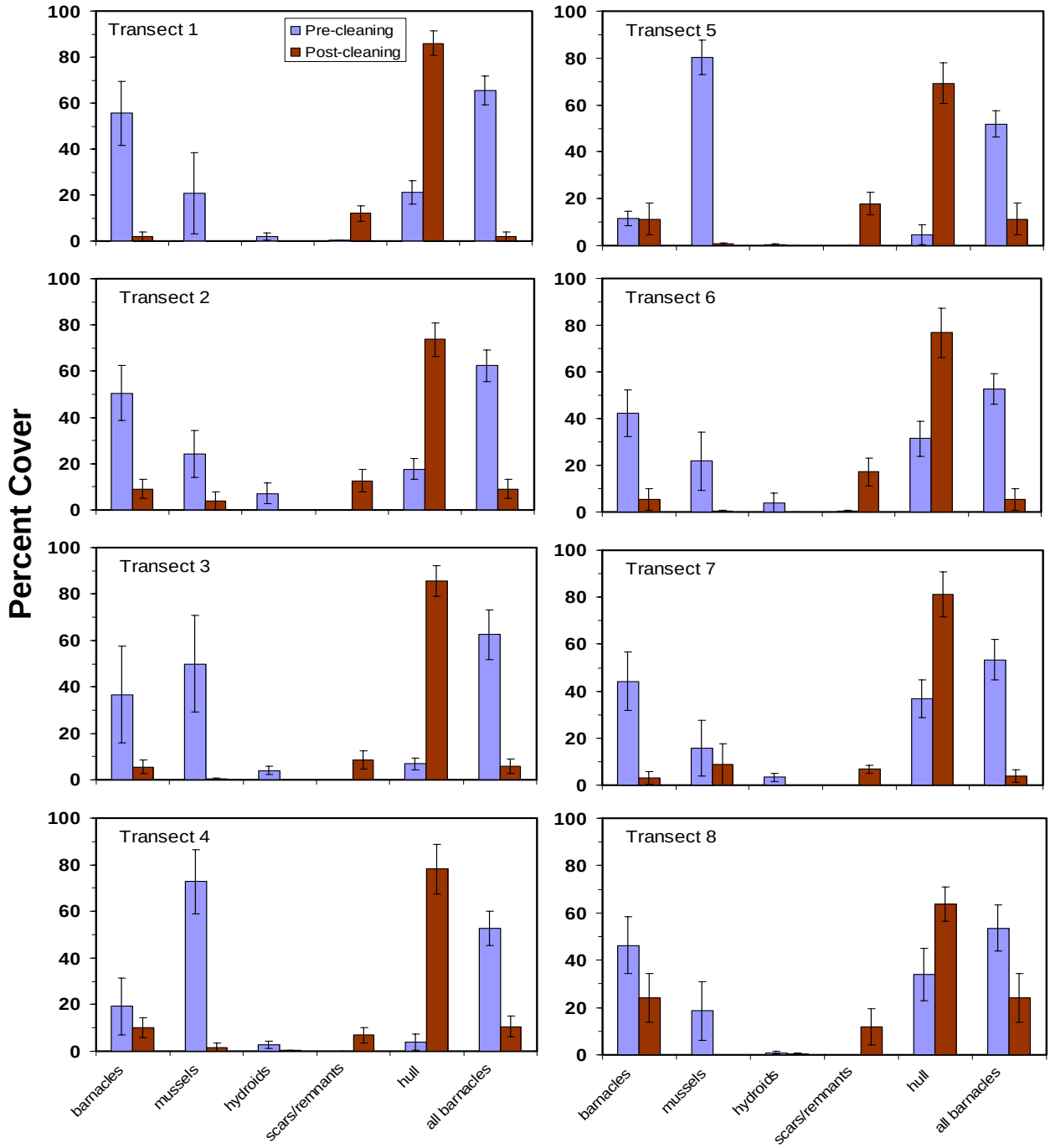


Figure 3-6. Differences in biofouling percent cover between the pre-cleaning and post-cleaning surveys. The mean +/- one standard error of the 6 most prominent categories of biofouling estimated from photo quadrats is plotted by transect (1-8) and position along the hull (waterline, mid-depth, and bottom). Transect 9 is the stern appendages. "Barnacles" is barnacles on hull. "All barnacles" is the sum of barnacles on hull, barnacles on mussels, and barnacles on oysters.

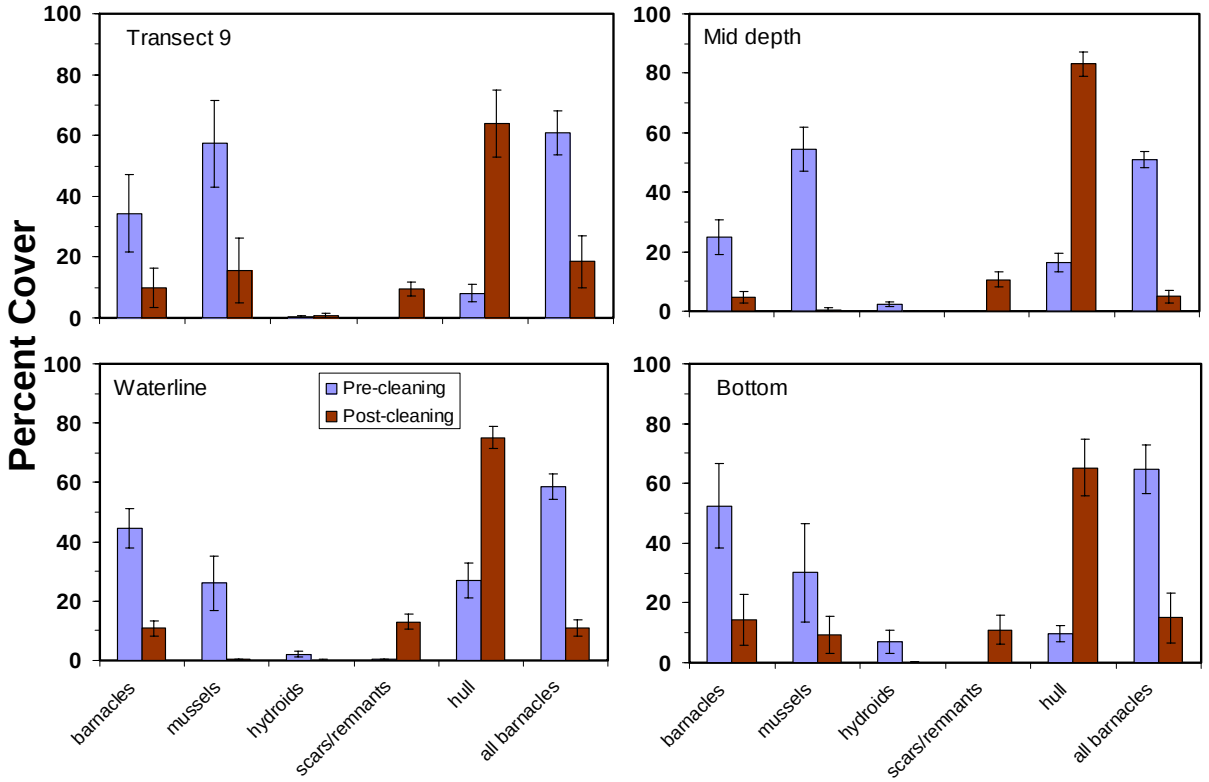


Figure 3-6. Continued.

Differences in percent cover between the pre-cleaning and post-cleaning surveys were also revealed in the MDS of photo-quadrats (Figure 3-7). The two groups of underwater images were distinct in the plot, but there was overlap between groups. The areas of overlap had photo-quadrats that showed abundant hard-shelled species in both the pre-cleaning and post-cleaning surveys (100% cover in two images).

3.5 RISK OF SPECIES INTRODUCTIONS

The cleaning of the hull was successful at removing on average 85% of the biofouling cover of the MISSISSINEWA. However, hard-shelled organisms were not entirely removed. In some sections of the ship, photo-quadrats revealed 40% to 100% cover of mussels and barnacles after cleaning. A majority of the species recorded in the pre-cleaning biological samples were present in the post-cleaning samples. Two of the species, the encrusting bryozoan *Conopeum chesapeakensis* and the amphipod *Gammarus daiberi* are not known to be established in the Gulf of Mexico. Therefore, there was a risk for the introduction of these two species, although they do not seem to have the characteristics that would make them potentially invasive. Because mussels and barnacles provide three-dimensional structure in which many species hide, the potential for transfer of species was high given that hull cleaning did not achieve a more thorough removal of the base layer of these organisms.

Most of the species found in this study are euryhaline, meaning that they are physiologically capable of surviving in a wide range of salinities and temperatures (See Appendix A). Therefore, they may be viable and reproductive active at the destination regions, even though the receiving waters of those regions are of much higher salinity than those of the oligohaline James River. Post-cleaning densities, frequency, and diversity of species are expected to increase invasion success (Davidson et al. 2008), and therefore a compelling case should exist for additional management options that may help maximize the efficacy of in-water hull cleaning.

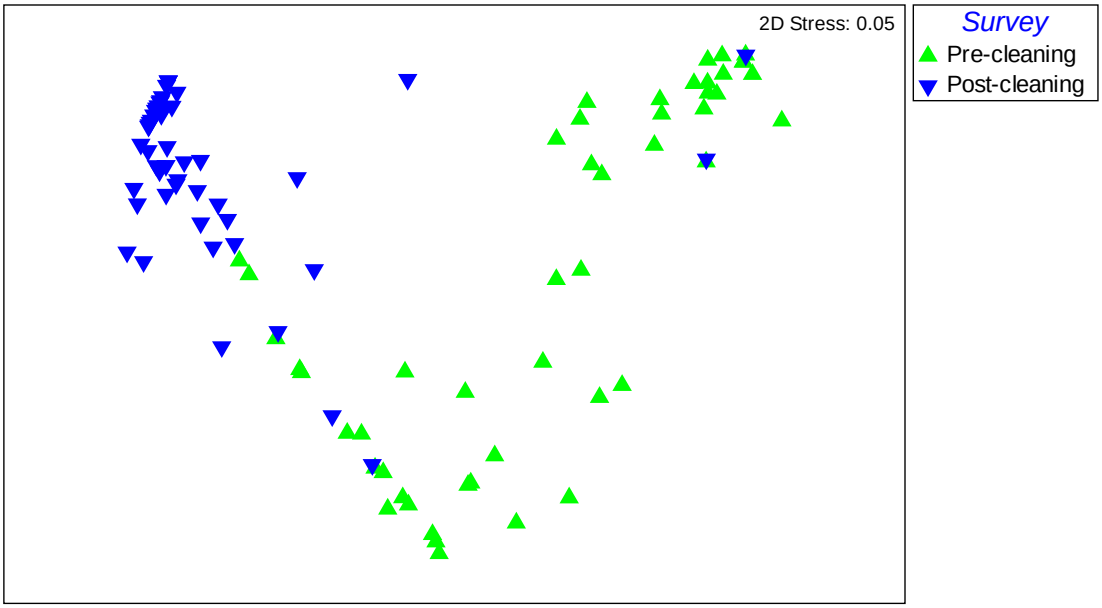


Figure 3-7. MDS of photo-quadrat data. Percent cover differed between the pre-cleaning and post-cleaning surveys, but areas of overlap in the plot indicated high abundance of hard-shelled organisms (mussels and barnacles) in both the pre-cleaning and post-cleaning surveys.

4.0 SUMMARY AND CONCLUSIONS

1. Pre-cleaning and post-cleaning surveys of biofouling were conducted on the JRRF vessel MISSISSINEWA. The surveys yielded a total of 23 taxa, 17 of which could be identified to species level. Only one nonindigenous species was recorded, the hydroid *Garveia franciscana*. Two species were not known to be established in the Gulf of Mexico. All the other species recorded in the samples are known to occur in Gulf of Mexico waters, and none are invasive in those waters.

2. Species densities and frequency of occurrence differed between surveys; however, the same assemblage of organisms was present in the biological samples before and after cleaning.

3. The biofouling community prior to hull cleaning was dominated by mussels and barnacles, which formed a thick layer over most of the hull. However, in mid-sections of the ship, about 35% of the hull was visible in photo quadrats. There were no concentrations of organisms in sheltered areas of the hull, such as the rudder or other appendages. The analysis of photo-quadrats did reveal a tendency for hard-shelled organisms to cover a greater area of the hull at mid-depth than near the waterline or bottom of the hull.

4. In-water hull cleaning was successful at removing on average 85% of the biofouling cover, substantially reducing the thick cover of mussels and barnacles. However, hard-shelled organisms were not entirely removed, and provided ample coverage for amphipods, crabs, and worms. Hooked mussels occurred in 74% of the post-cleaning samples, barnacles occurred in 82%, and encrusting bryozoans in 100%.

5. Mussels and barnacles provide three-dimensional structure in which many species hide; thus, the potential for transfer of species to destination ports was high given that hull cleaning did not achieve a more thorough removal of the base layer of these organisms.

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APPENDIX

SPECIES BIOGEOGRAPHY AND LIFE HISTORY INFORMATION

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Phylum	Class	Species/Taxon Name	Common Name	Chesapeake Bay Invasion Status	Status in Texas	Geographical Distribution		Salinity (psu)		Temperature (°C)		Substrate Preference-adults	Developmental Mode	Feeding Mode	Reference
						Native Range	Invaded Range	Range	Optimum	Range	Optimum				
Chlorophyta		Algae sp. A	algae	?	?										
Chlorophyta		Algae sp. B	algae	?	?										
Crustacea	Amphipoda	Apocorophium lacustre	tube-building amphipod	native	cryptogenic	Northwest Atlantic	Northeast Atlantic					epibenthic tube-building	brooder	detritus feeder; suspension feeder	Bousfield 1973, USGS Nonindigenous Aquatic Species database: http://nas.er.usgs.gov/
Crustacea	Cirripedia	Balanus improvisus	Bay barnacle	native	native	Western Atlantic Ocean, Gulf of Mexico	Northeast Atlantic, Caspian Sea, North Pacific Ocean	0-?	5-25	-2-38	14-30	epibenthic	planktonic larvae	suspension feeder	Davidson et al. 2006
Annelida	Polychaeta	Boccardiella ligerica	polychaete or bristle worm	cryptogenic	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	demersal eggs laid in strings in burrows; planktonic larvae	interface feeder	NEMESIS database: http://invasions.si.edu/nemesis/chesapeake .html
Chaetognatha		Chaetognatha	arrow worm	native species present	native species present										
Ectoprocta		Conopeum chesapeakensis	bryozoan or moss animal	native	no record/not present	Chesapeake Bay	San Francisco Bay, CA					epibenthic	brooder, planktonic larvae (inferred)	suspension feeder	Banta et al. 1995, Davidson et al. 2008
Mollusca	Bivalvia	Crassostrea virginica	Eastern oyster	native	native	Northwest Atlantic, Gulf of Mexico	NE Pacific (British Columbia), Hawaii	5-40	14-28	-2-36	15-30	epibenthic	planktonic larvae	suspension feeder	Kennedy et al. 1996
Platyhelminthes	Turbellaria	Euplana gracilis	flatworm	native	cryptogenic	Northwest Atlantic	Northeast Atlantic (The Netherlands)						demersal eggs, planktonic larvae	carnivore	Hyman 1940, Wolff 2005
Crustacea	Decapoda	Eurypanopeus depressus	Flatback mud crab	native	native	Western Atlantic Ocean, Gulf of Mexico		4.5-20				epibenthic, among oysters	brooder, planktonic and benthic larvae	omnivore	Williams 1984
Crustacea	Copepoda	Eurytemora affinis	calanoid copepod	native	native	North Atlantic, Gulf of Mexico, Caspian Sea, Baltic Sea, North Pacific	Inland waters in Eastern and Southeastern North America, Great Lakes	0-40	5-15		10-15	planktonic	brooder	filter feeder	Balcer et al. 1984, Saunders 1993, USGS Nonindigenous Aquatic Species database :http://nas.er.usgs.gov/
Crustacea	Amphipoda	Gammarus daiberi	amphipod	native	no record/not present	Northwest Atlantic (South of Delaware)	San Francisco Bay, Hudson River estuary	1-15	1-5	?-32		epibenthic, pelagic	brooder	detritus feeder; omnivore	Bousfield 1973, Cohen and Carlton 1995, USGS Nonindigenous Aquatic Species database: http://nas.er.usgs.gov/
Cnidaria	Hydrozoa	Garveia franciscana	Rope Grass hydroid	introduced	introduced	Unknown, possibly Indian Ocean	Atlantic Ocean, Gulf of Mexico, NE Pacific, SW Pacific, Black Sea, Caspian Sea	1-35	5-25	0-37.5	9-34	epibenthic	brooder, planktonic larvae	suspension feeder	Cohen and Carlton 1995, NEMESIS database: http://invasions.si.edu/nemesis/chesapeake .html
Crustacea	Copepoda	Halicyclops sp.	cyclopoid copepod	native species present	native species present	Cosmopolitan		brackish to salt				epibenthic and planktonic	brooder	herbivore; detritus feeder; suspension feeder	
Mollusca	Bivalvia	Ischadium recurvum	Hooked mussel	cryptogenic	native	Northwest Atlantic south of Chesapeake Bay, Gulf of Mexico	Barnegat Bay, NJ, and northwards, with transplanted oysters	4.5-36	8-36		11.6-24.5	epibenthic, among oysters	planktonic larvae	suspension feeder	NEMESIS database: http://invasions.si.edu/nemesis/chesapeake.html
Crustacea	Amphipoda	Melita nitida	amphipod	native	native	Northwest Altantic, Caribbean, Gulf of Mexico	Northeast Pacific, Northeast Altlantic	0-30	3-20			epibiont	brooder	herbivore; detritus feeder; omnivore	Davidson et al. 2006, Cohen and Carlton 1995
Mollusca	Bivalvia	Mytilopsis leucophaeata	Dark False mussel	native	native	Chesapeake Bay to Gulf of Mexico	Hudson River, Europe, Baltic Sea, Black Sea	0.1-31	3-22	5-30	10-30	epibenthic	planktonic larvae	suspension feeder	Mills et al. 1996, Verween et al. 2007 and references herein
Annelida	Polychaeta	Neanthes succinea	pile worm	native	native	Atlantic Ocean, Gulf of Mexico	Northeast Pacific, Southwest Pacific	2.5-65	5-50	-2-34		Infaunal and epibenthic	planktonic eggs; planktonic larvae	carnivore; detritus feeder; omnivore	Davidson et al. 2006, Cohen and Carlton 1995
Nematoda		Nematode sp.	roundworms	native species present	native species present										
Annelida	Polychaeta	Polydora cornuta	mud worm	native	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, 0-30		0-25		epibenthic tube-building, epibiont	brooder, planktonic larvae	interface feeder	Cohen and Carlton 1995 (as Polydora ligni), Zajac and Whitlatch 1982
Crustacea	Decapoda	Rhithropanopeus harrisii	White-fingered mud crab	native	native	Northwest Atlantic, Gulf of Mexico	Oregon, Northern California coast, San Francisco Bay, Northeast Atlantic, Black Sea, Caspian Sea; Inland lakes of Texas	0-40	0-20		20-31	epibenthic, among oysters	brooder, planktonic and benthic larvae	omnivore	Williams 1984, Carlton 1979, Cohen and Carlton 1995, CA Fish & Game 2002, USGS Nonindigenous Aquatic Species database: http://nas.er.usgs.gov/
Platyhelminthes	Turbellaria	Stylochus ellipticus	flatworm	native	native	Northwest Atlantic, Gulf of Mexico, Caribbean	Northeast Atlantic	2.5-27	<20			epibenthic, commensal	demersal eggs, planktonic larvae	carnivore	Hyman 1940, Kennedy et al. 1996
Crustacea	Decapoda	Xanthidae (juv.)	mud crab	native species present	native species present										