Obsolete vessel biofouling and the effects of in-water cleaning: a case study of the vessel ORION at the James River Reserve Fleet, Virginia

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EXECUTIVE SUMMARY

As part of its obsolete vessel disposal program, the U. S. Maritime Administration (MARAD) oversees transfers of ships from reserve fleet locations to ship breaking facilities. These vessels may pose a high risk of hull-mediated invasions, because (a) their submerged surfaces are likely to be heavily fouled (colonized) by aquatic organisms and (b) movement of these ships has the potential to transfer dense and species-rich assemblages relative to other (operating) vessels. As one of the options to reduce organism density on a vessel's hull prior to departure from the reserve fleet, in-water cleaning has the potential to reduce the risk of bioinvasions. We conducted a pre- and post- cleaning survey of the vessel ORION at the James River Reserve Fleet, Virginia, to characterize biofouling of that vessel and assess the efficacy of in-water cleaning.

Biological surveys of the ORION's hull were carried out on two dates (June 27th and 30th, 2006), before and after in-water cleaning, just prior to the vessel's transfer to Baltimore, Maryland. The surveys were carried out using a standardized protocol of biological sample collection and photo-quadrats. The method of in-water cleaning was selected by MARAD and conducted by Seaward Marine Services Inc., using the SCAMP system (Submersible Cleaning and Maintenance Platform). A total of 64 samples, divided equally between both pre- and post-cleaning surveys, were taken.

Across the two surveys, 39 taxa (species or species groups) were recorded in the biological samples. The six dominant species from the pre-treatment survey included mobile organisms (amphipods, polychaetes) as well as sessile organisms (barnacles, bryozoans and bivalves), and these species remained in more than 50% of the samples taken during the post-treatment survey. Reductions in the percent occurrence of the 15 most common species within biological samples were quite variable (0-66%). Overall, across all taxa, there was a significant reduction in the number of species per sample between pre- and post-cleaning surveys, and biofouling assemblage organization did not differ between locations or depths on the vessel.

Photo-quadrats also revealed a significant and substantial reduction in biofouling extent brought about by in-water cleaning. Bare space increased from an average of 10.9% per sample prior to cleaning to 62.7% after cleaning. Not surprisingly, the assemblage organization pattern from image analysis revealed that hard-shelled organisms tended to persist after the vessel was cleaned, but that less robust organisms were removed. Overall, in-water cleaning had a significant effect, reducing the extent (both percent cover and frequency of occurrence) of biofouling organisms on the hull of the ORION. There was clearly an overall reduction in abundance of organisms, as measured by frequency of occurrence. However, our data also indicated that two-thirds of the original (pre-survey) species were detected in post-survey samples. The effect of 'in-water cleaning' on the biofouling of the ORION appears to be similar to the effect of 'voyage' on reducing biofouling on the vessels POINT LOMA and FLORENCE. In both studies, there was a significant reduction in biofouling extent (mainly evidenced from photo analysis) but persistence of numerous species across samples (mainly evidenced from the biological sample collections).

While our study demonstrates an effect of in-water cleaning on biofouling organisms, and this is likely to reduce the associated risk of invasions to some extent, there are several critical issues that remain unresolved and deserve further consideration. We outline these below:

1. **Only one method of in-water cleaning was considered and evaluated.** To our knowledge, this was not based upon a review of the current state of knowledge about available options (methods or equipment) and their relative performance. Such a review is worthwhile, as it would serve to (a) assess the general utility of in-water cleaning and (b) maximize its efficacy.

2. **We did not assess the effect of in-water cleaning on release of bottom paints or other toxic materials (or the fate of removed organisms).** The scope of our study focused solely on the effects of treatment on biofouling assemblages on the vessel.

3. **Our analysis was restricted to one vessel at one location and season, and thus results should not be considered general.** There is strong reason to expect significant variation by location and season, as the biological communities (species composition) will vary accordingly. Any management decisions would clearly benefit from analysis of each fleet by season, and some level of replication, to develop a robust understanding of treatment effects.

4. **The risk of invasion from residual biofouling communities (after in-water cleaning) has not been adequately addressed for reserve fleet vessels.** It is clear that in-water cleaning reduces organism numbers. It is also likely that cleaning followed by movement (towing) would cause a further reduction, but this has not yet been estimated. The combined effects of in-water cleaning and movements (replicated across sites and seasons, as above) would provide a clearer picture of human-aided dispersal, although it is not sufficient to estimate the associated risk of invasion. Specific analyses are still needed to estimate (a) the effect of propagule supply (number or organisms) on invasion success and (b) the physiological tolerance of those species present at reserve fleet locations to conditions present at destination ports (for ship-breaking) and en route.

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Introduction

Purpose

The U. S. Maritime Administration (MARAD) is mandated to dispose of obsolete vessels from its National Defense Reserve Fleets (NDRF). At the present time, the vessels are towed from the fleet to other geographic locations, where ship-breaking takes place. These vessels may act as vectors for the unintended transfer of organisms associated with the ships' hulls and underwater surfaces, creating a risk of biological invasion. The risk from these vessels is considered higher than for regular vessels because of their very long residence times, allowing accumulation of dense and diverse biofouling assemblages (for more details and discussion, see Davidson 2006a). This report is the 4th in a series that have documented the biofouling of obsolete vessels, the aspects of the ship disposal program relevant to vector activity and bioinvasions, and the consequences for biofouling of certain vector management options.

In this study, we examined the hull of the vessel ORION at the James River Reserve Fleet (JRRF), in the James River, Virginia. This vessel was to be transferred from the JRRF to a ship breaking site near Baltimore, Maryland, also on the Chesapeake Bay. As such, this vessel transfer was an example of an intra-regional vector event because the vessel remained within the Chesapeake Bay watershed. Although intra-regional spread of species is also an important consideration in bioinvasions ecology, the biogeographical implications of this transfer are likely to be less significant than the inter-oceanic vector events previously studied (Davidson, 2006 a & b).

The main focus of this study was to measure the effect of in-water cleaning on the hull biofouling assemblage of the ORION. This is one option for vector management being considered by MARAD to reduce the risk of species transfers and introductions resulting from the obsolete vessel disposal program. This pilot study is the first ship-scale examination of biofouling and in-water cleaning of an obsolete vessel, in which we measured immediate changes in the extent and composition of fouling organisms associated with an in-water cleaning method selected by MARAD.

Objectives

The USS ORION was a submarine tender that served for 50 years between 1943 and 1993. Since decommissioning in 1993, it has been retained at the James River Reserve Fleet, Virginia. As part of the ship disposal program conducted by MARAD, the vessel was moved to Sparrows Point, Maryland (near Baltimore) shortly after July 27th, 2006. In an effort to reduce the amount of biofouling attached to its hull, thus reducing the risk of transferring species and possibly invasive species to the receiving port, MARAD contracted with a private company to conduct an in-water clean of the vessel. Both the method of cleaning and its application were defined by MARAD.

Our aim was to characterize the biofouling on the hull and underwater surfaces of the ORION, taking measurements before and after in-water cleaning, and begin to assess the efficacy of in-water cleaning (using one method, the SCAMP system) for biofouling removal. Our scope was restricted to immediate effects of cleaning on associated biota, and we did not examine (a) the subsequent effect of vessel movement or (b) any effects of the release of bottom coatings or chemical constituents. Two simple hypotheses were tested: 1) that there would be no significant difference in extent of biofouling before and after treatment and 2) that there would be no significant difference in assemblage composition between surveys.

Methods

Underwater sampling

The James River Reserve Fleet is situated at Fort Eustace, Virginia, approximately 39 kilometers upstream of where the James River reaches the Chesapeake Bay (fig. 1). The fleet consists of eleven rows of varying numbers of ships, and the ORION was situated centrally in a row of 14 ships. The vessel was sampled twice (27th and 30th of June, 2006), before and after an in-water cleaning. Water temperature varied between 27°C and 28.4°C and salinity varied between 4 and 10.4 ppt during surveys. In-water cleaning was conducted by technicians of Seaward Marine Services Inc., using the SCAMP system (Submersible Cleaning and Maintenance Platform). This is a diver operated method whereby multiple rotating scrubbers are used to clean the hull (see Seaward

Marine Services Inc website: www.seaward-marine.com). Three methods were used during the SCAMP of the ORION; vessel appendages were cleaned using a hand-held poly-brush and areas of the hull were cleaned using a machine with either poly- and steel brushes or poly-brushes only (fig. 2). The entire hull of the vessel was not cleaned during the interim period between sampling events, but areas sampled in the pre-cleaning survey were cleaned and then re-sampled. The remaining areas of the hull were reportedly cleaned prior to the vessels departure from the fleet in July, 2006.

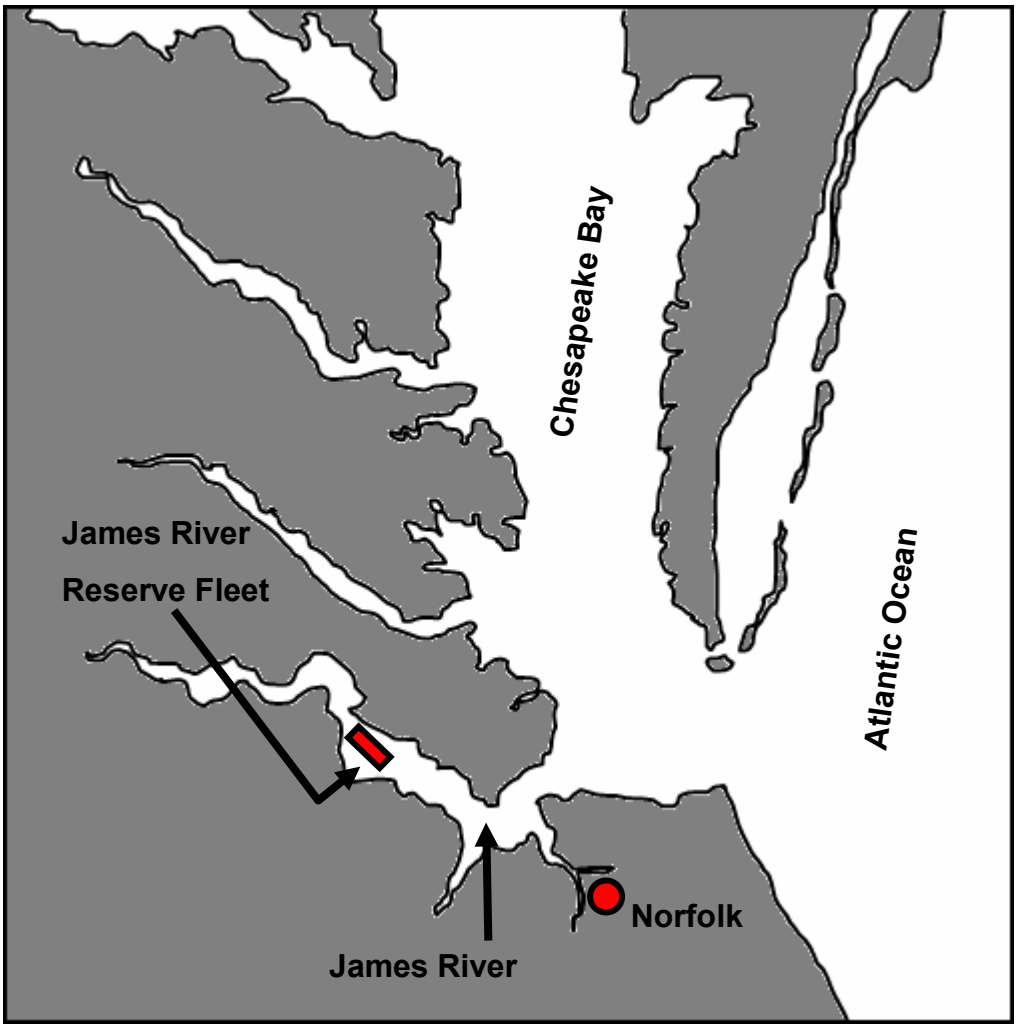

Figure 1. James River Reserve Fleet. The JRRF is located approximately 39 km upstream of where the James River enters the Chesapeake Bay.

Surveys were conducted using our standard sampling protocol (see Davidson et al., 2006). Briefly, divers sampled the vessel by collecting photographic images and biological samples in a stratified sampling scheme by hull location. Stratification was based upon depths (bottom, mid depth and just below the waterline) and location (hull transects and vessel running gear). Photo-quadrats were taken using an underwater camera rather than a video camera and a clear water box was not required (compared to previous surveys at sites with higher turbidity, Davidson et al., 2006 a & b). Replicate biological samples were collected by removing all macro-organisms from areas measuring six square inches (231 cm^2) and placing them into individually labeled zip-lock bags. There were a total of 32 biological samples collected for pre- and post-cleaning surveys. Photographs were taken within a meter of these sample locations, but additional photo-surveys were conducted such that a total of 122 images were used in analysis (58 pre-clean and 64 post-clean). As in previous studies, the running gear appendages (propeller, rudder, propeller shafts, and struts) were sampled as part of both surveys (Davidson et al., 2006). The sample collection and photo-quadrats were all carried out by the same technicians involved in the in-water cleaning.

Figure 2. Brushes used in the SCAMP system for in-water cleaning. These machine operated brushes rotate back-and-forth to remove biofouling on vessel hulls while the SCAMP machine is held in position by divers. Brushes can be used with (right) or without (left) steel attachments.

Data analyses: biological samples and photo-quadrats

We used a stepwise process of analysis for the biological samples. Preliminary sorting was done in the field, as soon as possible (within minutes to hours) after collection, to determine whether organisms were either alive or dead. Our goal was to assess quickly whether living specimens of each species were present, as this cannot be easily or reliably determined from preserved samples. This first step was accomplished by coarsely sorting through material in the samples and vouchering specimens of each morpho-species that were alive. Detailed note taking, labeling and sample preservation were also carried out on dockside. As the next step, samples were preserved in 95% ethanol and returned to SERC's laboratories in Maryland and California, where detailed processing took place using a standardized protocol (see Davidson et al. [2006] for further description). Sorting of preserved material was used to estimate the number (and identity) of species in each replicate sample. Voucher specimens were sent to expert taxonomists for each major group for identification.

Based upon analysis of the survey data, a data matrix was constructed for the biological samples and photo-quadrat data collected on each vessel. The biological samples data, a presence/absence matrix of species or species groups, was used for univariate and multivariate analysis to characterize the associated species richness and biofouling community. For the photo-quadrat data, the matrix consisted of the percent cover (as estimated by point count methods described in Davidson et al., 2006) per quadrat for each of nine distinguishable categories: barnacles, mussels, oysters, mobile crustaceans, encrusting spp, branching spp (vertically growing bryozoans and hydroids), paint/hull, biofilm, organism scars/remnants.

Univariate analysis was carried out on species occurrences and percent cover per photo-quadrat. Multivariate analysis, using the PRIMER program (Primer-E Ltd., 2002), was used to assess how assemblage organization differed between survey, depth and locations. Ordinations were carried out using the multi-dimensional scaling (MDS) technique, which produces a plot revealing sample similarity from Bray-Curtis similarity

measures: points close together in the plot are compositionally similar while those far apart are dissimilar. The analysis of similarities (ANOSIM) test was used to test if significant differences existed between factors (e.g. before vs after). The test statistic (R) is usually a value between 0 and 1 with greater than 0.6 showing groups of samples are clearly distinguishable and dissimilar in terms of assemblage composition whereas values less than 0.3 mean that groups of samples are similar in composition (Clarke & Gorley, 2001).

Results and Discussion

1. Biological samples

There were 39 distinct taxa (species and species groups) recorded from the 64 biological samples collected from both surveys (table 1). Live specimens of all abundant or common species (occurring in > 50% of samples) were collected; with no determination possible for rarer species that were only encountered during laboratory based sample processing after the samples had been preserved. Of the 39 species, 28 were recorded in both pre- and post- treatment surveys, 9 were recorded from pre-treatment the survey only, and two were only encountered during the post-treatment survey (table 1). The seven most common distinct species (fig. 3) during the pre-treatment survey, each occurring in 30+ samples of the 32 taken, were : *Apicorophium lacustre* (amphipod), *Balanus improvisus* (barnacle), *Conopeum chesapeakensis* (bryozoan), *Neanthes succinea* (polychaete worm), *Mytilopsis leucophaeata* (mussel), *Ischadium recurvum* (mussel), and *Garveia franciscana* (hydroid). With the exception of *G. franciscana*, each of these species occurred in more than 50% of the samples collected during the post-treatment survey. Amphipods (other than Apicorophium) were also ranked highly, but proved difficult to differentiate. For the top 15 ranked species from the pre-treatment survey, the percent reduction after cleaning ranged from zero to 66%.

Table 1. Taxa (species and species groups) recorded on submerged surfaces of the vessel ORION. The species, higher taxonomic group and status in pre- and post- clean surveys (L=live, P=present, A=absent) are listed. A total of 39 species were collected from the hull and underwater appendages of the ORION.

species	taxonomic group	status	
		pre	post
red alga	alga	L	L
green alga	alga	L	L
alga C	alga	P	A
Apicorophium lacustre	amphipod	L	L
Stenopluestes sp	amphipod	L	L
Gammarus cf tigrinus	amphipod	P	A
Melita planaterga	amphipod	L	L
Melita sp	amphipod	L	L
Synidotea laticauda	isopod	L	L
Balanus improvisus	barnacle	L	L
cyprid	barnacle (juvenile stage)	L	A
Mytilopsis leucophaeata	mussel	L	L
Ischadium recurvum	mussel	L	L
Crassostrea virginica	oyster	L	L
Conopeum chesapeakensis	bryozoan	L	L
Bowerbankia sp	bryozoan	L	L
Victorella pavida	bryozoan	L	L
calanoid copepod	copepod	A	L
harpacticoid copepod	copepod	L	L
Eurypanopeus depressus	decapod (crab)	L	L
Rhithropanopeus harrisii	decapod (crab)	L	L
Callinectes sapidus	decapod (crab)	L	L
unidentified decapod	decapod (crab)	L	A
crab parasite	crustacean	P	A
crab zoea	crab (juvenile stage)	A	P
egg (fish)	egg	P	P
fish/fish larvae	fish	P	P
Stylochus ellipticus	platyhleminthes (flat worm)	L	L
Euplana ?	platyhleminthes (flat worm)	L	L
Garveia franciscana	hydroid	L	L
Campanulinid sp	hydroid	L	L
hydroid B	hydroid	P	A
nematode A	nematode	P	P
small gastropod	mollusc	P	A
Neanthes succinea	polychaete	L	L
Polydora sp	polychaete	L	P
Polychaete A	polychaete	P	P
Polychaete B	polychaete	P	A
Polychaete C	polychaete	P	A

There were significantly fewer species per sample after the vessel had been cleaned and this was consistent across different depths on the hull and on running gear surfaces (ANOVA, d.f.=1, F=85.62, p<0.001; fig. 4). The greatest reduction was observed for the running gear surfaces where the mean species density per sample dropped from 17.75 to 7.6, although the difference between locations was not significant due to high variation among samples. These surfaces were not cleaned with the large SCAMP machine but with hand-held brushes. A clear pattern emerged from the MDS plot of presence/absence in biological samples (fig. 5A) whereby no differences in assemblage composition were evident between depths or locations, but there was a difference between pre- and post-cleaning (ANOSIM, R=0.473, p<0.01). The significant reduction in mean number of species per sample played a role in this observed pattern (fig. 5B) because a gradient in species density per sample is evident between the two clusters (pre- vs post- cleaning; fig 5A and B) of samples.

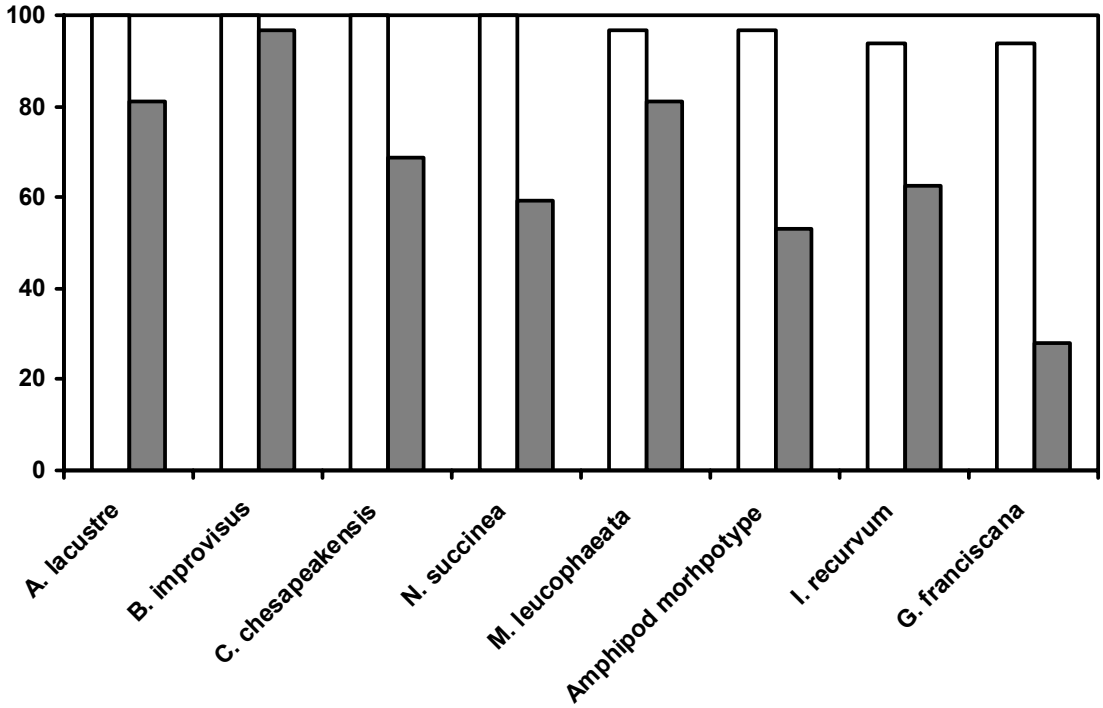

Figure 3. Differences in occurrence of common species between surveys. Before- (white) and after- (grey) cleaning comparisons for all species that occurred in ≥ 30 of 32 samples from the pre-treatment survey are plotted. Percent reductions of the top 15 ranked species from pre-treatment surveys ranged from 0% to 66%.

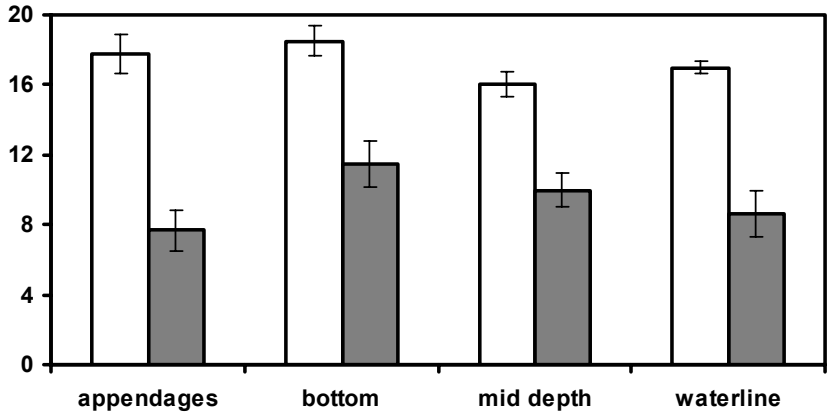

Figure 4. Differences in mean number of species before and after cleaning. The mean species density per sample (+/- S.E.) is plotted for three depths and the vessel running gear (appendages) for pre-cleaning (white) and post-cleaning (grey). There was no significant difference between depths but there was a significant decrease in mean species richness after cleaning at each location.

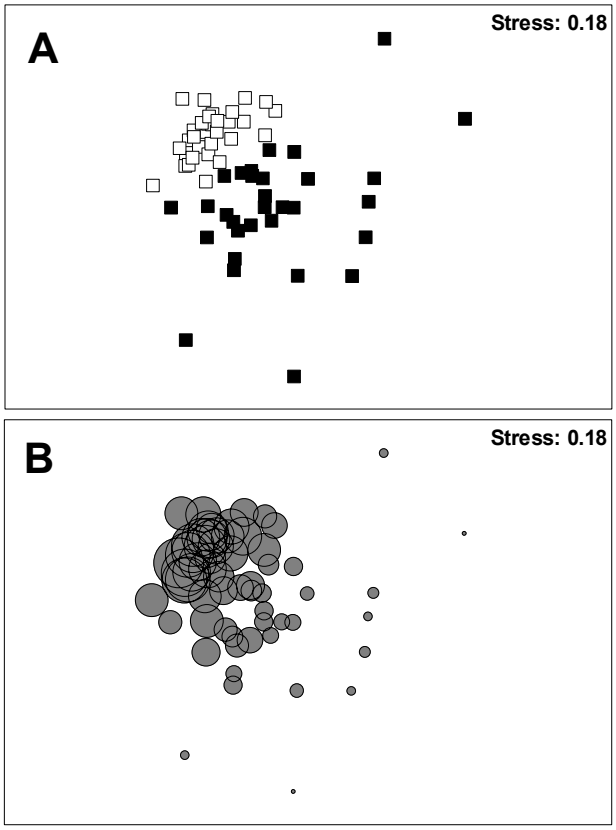

Figure 5. Biofouling organization based on presence/absence data from samples. (A) Using data from biological sampling, the samples between pre-cleaning (white squares)and post- pre-cleaning (black squares) cluster together (ANOSIM, R= 0.473, p<0.01). (B) A gradient in number of species per sample appears to explain much of the variation for biofouling organization.

2. Photo Analysis

Photo-quadrat analysis revealed differences in assemblage organization between pre- and post- treatment surveys (fig. 6) similar to that of the biological samples analysis but with different underlying reasons for the pattern. There were no differences in assemblage organization between depths or locations on the hull for both surveys but there was a significant difference between pre- and post- treatment groups of samples (ANOSIM, R=0.504, p<0.01). There was some overlap between the sample groups and two distinct clusters of samples did not emerge, as may have been predicted. Differences in the response between organisms (or morpho-types/categories) to the impact of in-water cleaning help to explain this observation (fig. 7). A clear contrasting pattern was observed for branching and encrusting species versus bare space and organism scars/remnants (fig. 7 A & B). The former were clearly prevalent prior to treatment (fig 7 A) and the latter pattern was the result of the removal of the organisms that contributed to this biofouling matrix (fig 7 B). Organisms with hard-shells, however, were not removed to the same degree and played an important role in ensuring a lesser distinction in biofouling extent between pre- and post- cleaning surveys. This is similar to the observation from the biological samples (fig. 3) that showed robust hard-shelled species as well as abundant species from the pre-treatment survey were observed in the post-cleaning survey as well.

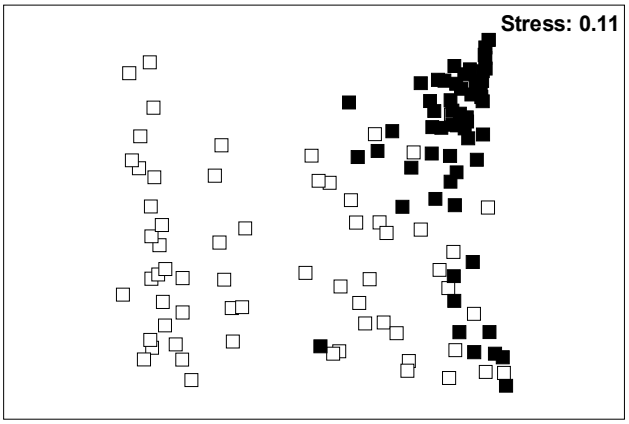

Figure 6. Biofouling organization based on photo-quadrat data. Biofouling organization differed between pre-cleaning (white squares) and post-cleaning (black squares) (ANOSIM, R = 0.501, p < 0.01). Although a clear pattern emerged from left to right on the plot, a gradient from left to right rather than distinct clustering of samples occurred.

Overall, in-water cleaning was effective at significantly increasing the organism-free space observed on the hull. A substantial and significant increase (ANOVA, $F=159$, $p<0.001$) in bare space was the most dominant feature of the photo-quadrat comparisons over both surveys, which had a mean of 10.9% per sample prior to cleaning and 62.7% after cleaning. A large increase in bare space (a combination of paint/rust and scars/remnants categories) was consistent across all depths of the hull and on the surfaces of the vessel's running gear (fig. 8). This appears to have been brought about by removal of the softer matrix-forming biofouling organisms (branching and encrusting species). The hard-shelled barnacles and bivalves were also reduced significantly by in-water cleaning, but they tended to persist nonetheless and were visible in the photo-quadrats. The more cryptic branching bryozoans, hydroids and encrusting species were not detected in the photo-quadrats but the biological samples data suggested they remained to a certain degree as well.

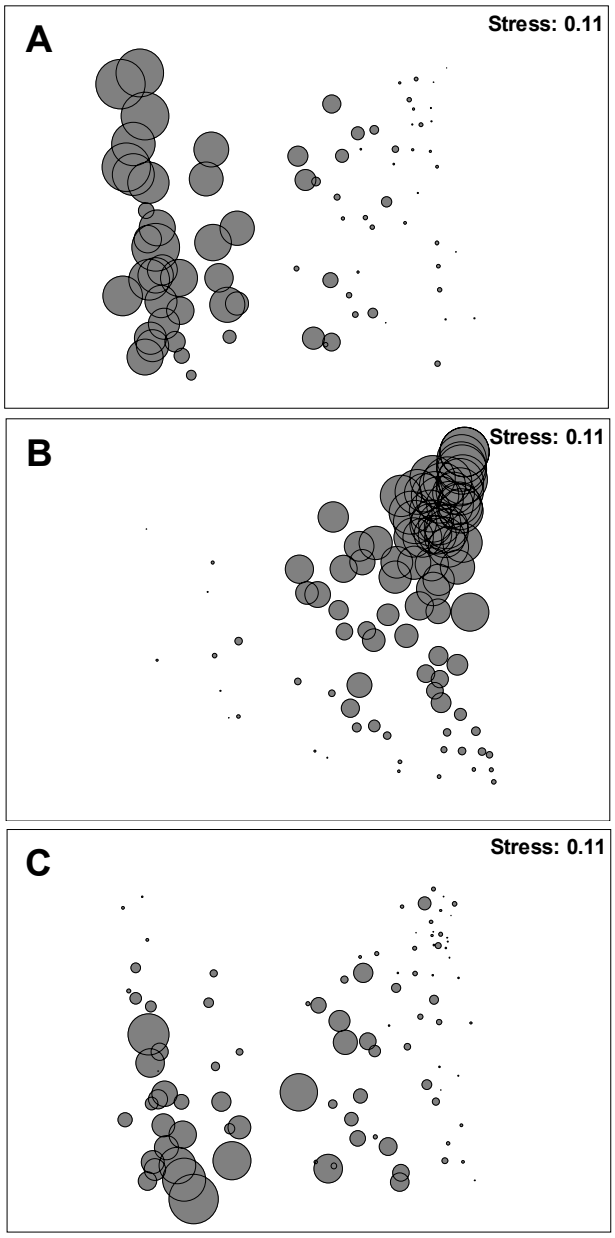

Figure 7. Biofouling organization by morpho-types. These MDS plots of biofouling organization are the same plot as figure 6, but with bubble sizes representing the prevalence of branching & encrusting species (A), bare space & organism scars/remnants (B), and barnacles & mussels & oysters (C). Each plot shows how different categories contributed to the pattern of biofouling organization. Plots (A) and (B) show a clear impact of in-water cleaning with distinct clusters grouped according to pre- and post- treatment. Plot (C) is less distinct, revealing that hard-shelled organisms were less impacted.

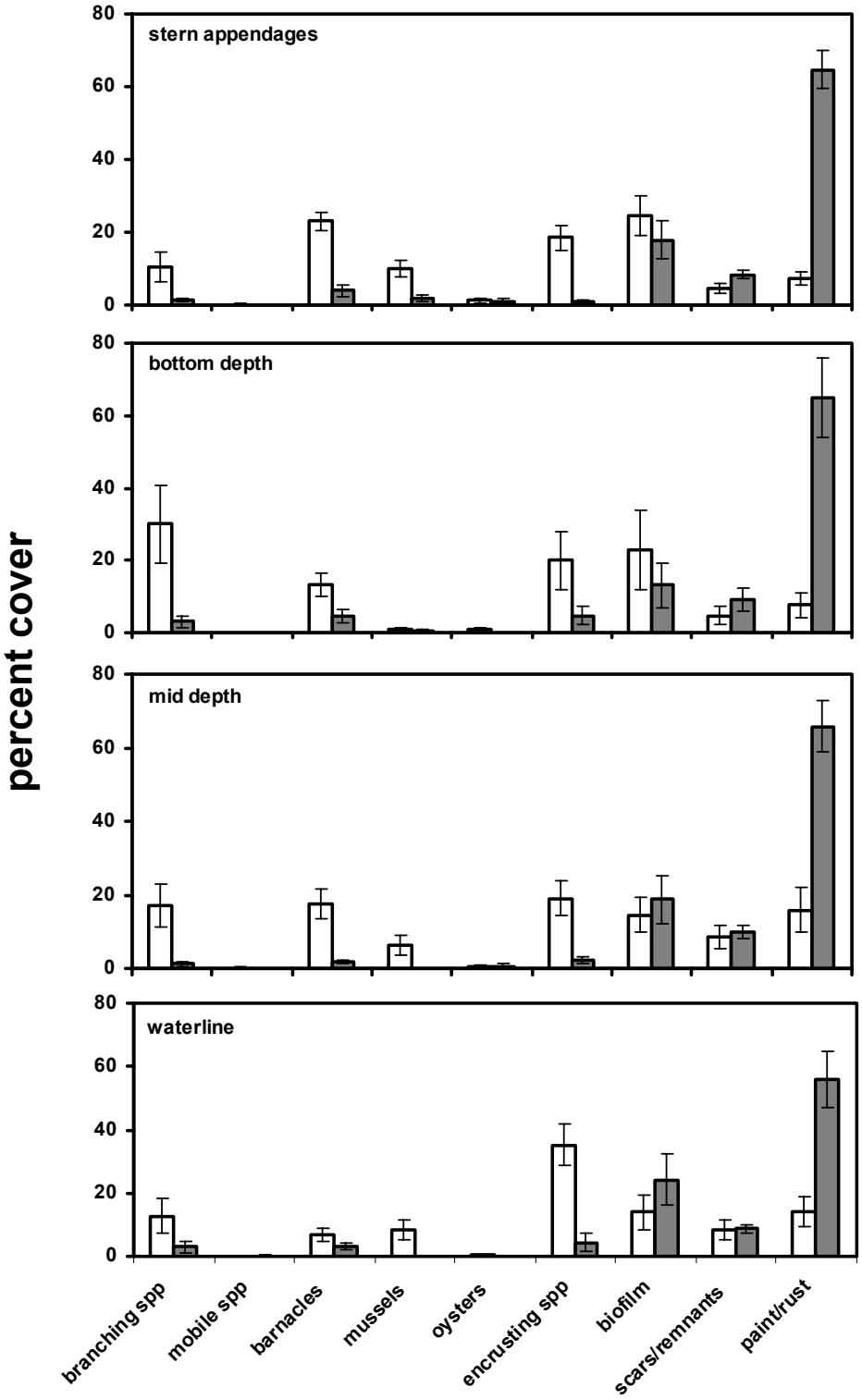

Figure 8. Differences in biofouling percent cover between pre- and post- cleaning. The mean (+/- S.E.) percent cover of nine categories of biofouling estimated from photo-quadrats is plotted for pre-cleaning (white) and post-cleaning (dark grey) for three depths and stern appendages (rudder, propeller, shafts, struts).

Summary & Conclusions

- The obsolete vessel ORION was surveyed at the James River Reserve Fleet, Virginia prior to its removal from the fleet for dismantling. Pre- and post- cleaning surveys were carried out with the aim of characterizing biofouling on its hull and assessing the efficacy of in-water cleaning as a risk reduction option to prevent hull-mediated species introductions.
- Analyses of biological samples revealed that 40 different taxa (species and species groups) were recorded over both surveys. 65% of these were encountered during both surveys, 30% were not sampled during the second survey and two taxa were only recorded during the post-treatment survey. For the 15 most prevalent species, the percent reduction in occurrence across samples ranged from zero to 66%.
- There were significantly fewer species recorded from the post-cleaning survey and this had a strong influence on the pattern of biofouling assemblage organization. Overall, the biological samples data revealed that although species removal was achieved across different depths and locations to a significant degree, numerous organisms persisted across most samples and were alive. Cleaning of vessel appendages (rudder, propeller, shafts, and struts) was at least as effective at removing species as the SCAMP system used on the hull.
- Photo-quadrat analysis revealed a very clear reduction in biofouling extent (percent cover and biomass) across all locations sampled. The removal of branching and encrusting biota was significant, leading to a substantial increase in the amount of bare space recorded in the post-cleaning samples. There was also a reduction in the percent cover of barnacles and bivalves, although the distinction was not as clear for these more robust species and this was reflected in the ordination plots. This was expected prior to cleaning because the option of rigorously removing ‘hard fouling’ was not taken given concerns over the age and condition of obsolete vessels.
- Based upon the results, the hypotheses of no change in biofouling extent and no change in composition between pre- and post- cleaning surveys are rejected. There was a clear reduction in the number of species per sample recorded after the SCAMP machine had been used and there was also a significant reduction in percent cover of

biofouling. Clearly, in-water cleaning reduces the total number of organisms associated with vessel hulls prior to movement, and we would expect a further reduction to result from the movement itself, although the cumulative effect is not quantified here. Further evaluation (of this and other cleaning methods) is required, however, as numerous species remained on the hulls and live specimens were recorded for many of these, suggesting an invasion risk.

- The effect of 'in-water cleaning' on the biofouling of the ORION appears to be similar to the effect of 'voyage' on reducing biofouling on the vessels POINT LOMA and FLORENCE. In both studies, there was a significant reduction in biofouling extent (mainly evidenced from photo analysis) but persistence of numerous species across samples (mainly evidenced from the biological sample collections).
- While we expect in-water cleaning to result in some reduction of invasion risk, simply based upon the observed numerical response, there remain several critical gaps.
    1. Only one method of in-water cleaning was considered and evaluated. To our knowledge, this was not based upon a review of the current state of knowledge about available options (methods or equipment) and their relative performance. Such a review is worthwhile, as it would serve to (a) assess the general utility of in-water cleaning and (b) maximize its efficacy.
    2. We did not assess the effect of in-water cleaning on release of bottom paints or other toxic materials. The scope of our study focused solely on the effects of treatment on biofouling assemblages.
    3. Our analysis was restricted to one vessel at one location and season, and thus results should not be considered general. There is strong reason to expect significant variation by location and season, as the biological communities (species composition) will vary accordingly. Any management decisions would clearly benefit from analysis of each fleet by season, and some level of replication, to develop a robust understanding of treatment effects.
    4. The risk of invasion from residual biofouling communities (after in-water cleaning) has not been adequately addressed for reserve fleet vessels. It is clear that in-water cleaning reduces organism numbers. It is also likely that cleaning

followed by movement (towing) would cause a further reduction, but this has not yet been estimated. The combined effects of in-water cleaning and movements (replicated across sites and seasons, as above) would provide a clearer picture of human-aided dispersal, although it is not sufficient to estimate the associated risk of invasion. Specific analyses are still needed to estimate (a) the effect of propagule supply (number or organisms) on invasion success and (b) the physiological tolerance of those species present at reserve fleet locations to conditions present at destination ports (for ship-breaking) and en route.

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