Marine Pollution Bulletin 56 (2008) 1538–1544

Contents lists available at ScienceDirect

Marine Pollution Bulletin

journal homepage: www.elsevier.com/locate/marpolbul

Interrupting a multi-species bioinvasion vector: The efficacy of in-water cleaning for removing biofouling on obsolete vessels

Ian C. Davidson [a,*], Linda D. McCann [b], Mark D. Sytsma [a], Gregory M. Ruiz [a,b]

[a] Aquatic Bioinvasion Research and Policy Institute, Portland State University, P.O. Box 751, Portland, OR 97207-0751, USA
[b] Marine Invasions Laboratory, Smithsonian Environmental Research Center, Edgewater, MD 21037, USA

ARTICLE INFO

Keywords:
Biofouling
Ships
Nonindigenous species
Transfer mechanism
Vector management
In-water cleaning

ABSTRACT

Vector management is the primary method for reducing and preventing nonindigenous species (NIS) invasions and their ecological and economic consequences. This study was the first to examine the efficacy of in-water scrubbing using a submersible cleaning and maintenance platform (SCAMP) to prevent invertebrate species transfers from a heavily fouled obsolete vessel. Initially, prior to treatment, 37 species were recorded in a biofouling matrix that reached 30 cm depth in some locations. The bryozoan *Conopeum chesapeakensis,* and bivalves *Mytilopsis leucophaeata* and *Ischadium recurvum*, were dominant sessile species that created structure, supporting mobile biota that included crabs and the associated parasitic barnacle *Loxothylacus panopae*. Scrubbing had the effect of significantly reducing organism extent and the number of species per sample, but a substantial and diverse (30 species) residual fouling community remained across the entire vessel. Further assessments of management options are needed to prevent potentially damaging NIS transfers. Additional measures taken within an integrated vector management (IVM) strategy may further improve invasion prevention measures.

1. Introduction

Preventing nonindigenous species (NIS) introductions through effective vector management is the leading tool available to agencies and managers concerned with impacts of invasive species (Ruiz and Carlton, 2003). Although rapid response, control, containment and eradication of species are desirable and sometimes unavoidable, these reactive measures can be labor intensive, time consuming and expensive, with limited opportunity for success unless timely detection, authorization, resources and expertise are put in place (Anderson, 2005). Moreover, the success of reactive measures is often contingent upon successfully preventing new incursions of NIS propagules during and after the eradication effort, highlighting the primacy of vector management.

For marine systems, shipping is a dominant transfer mechanism (vector) responsible for species transfers (Ruiz et al., 2000) and operates to transfer diverse biotic communities associated with ballast water and hulls (including a diverse array of surfaces). An effective interruption or management of the vector phase for these transfer mechanisms, therefore, will work to prevent a suite of species incursions. A recent and widespread vector management effort currently underway in marine systems is open-ocean ballast water exchange. By discharging coastal water (and associated organisms) from ballast tanks during ballast exchange and replacing it with oceanic water, the risk of species transfers from this vector can be reduced (e.g., IMO, 1991; Wonham et al., 2001; Minton et al., 2005; McCollin et al., 2007). Similarly, antifouling paints and hull husbandry reduce vessel biofouling transfers (Callow and Callow, 2002; Coutts and Taylor, 2004).

A subset of vessels, however, is not subjected to these hull maintenance practices and may pose a significant threat of species introductions (Foster and Willan, 1979; Brock et al., 1999; DeFelice, 1999; Godwin and Eldredge, 2001; Lewis et al., 2006). These vessels include inactive ships and barges, floating docks, oil platforms and other laid-up or unusual vessels. These vessels are dwarfed in number by active commercial and military vessels around the world, but account for a far higher risk of species introductions on a per-ship basis. Factors such as long lay-up times, slow speeds and lengthy durations at recipient ports, combined with a lack of hull maintenance, ensure that very dense and extensive assemblages of biofouling organisms get relocated and provided with an opportunity to establish in new areas (DeFelice, 1999; Davidson et al., 2008).

There is growing concern regarding these high-risk biofouling vectors (Godwin, 2005) and options for vector management are needed. Several strategies and tools exist and range from rudimentary and inexpensive to relatively complex and costly. They include beaching to cause desiccation, in-water cleaning, smothering with plastic, chlorine treatment (Coutts and Forrest, 2007), altering

* Corresponding author.
E-mail address: idavidso@pdx.edu (I.C. Davidson).

0025-326X/$ - see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.marpolbul.2008.05.024

salinity regimes (Brock et al., 1999), temperature or heat treatment (Wotton et al., 2004), and dry docking. The efficacy of these different approaches varies with differing conditions that are not well understood, however, and more studies are required to determine the merits and limitations of these strategies.

In this study, we used a stratified sampling protocol to measure the effectiveness of in-water scrubbing for reducing the number of organisms on the submerged surfaces of an obsolete vessel prior to its final voyage to a ship dismantling facility. The vessel ORION, one of the ghost fleet ships retained by the US Maritime Administration, was being transported to a ship breaking facility from the James River Reserve Fleet (JRRF) at Fort Eustace, Virginia, USA. After laying stationary at the JRRF for 13 years, allowing for substantial biofouling accumulation, we assessed biofouling extent, species richness and assemblage organization before and after in-water scrubbing at a variety of underwater vessel (hull) locations to determine the efficacy of in-water cleaning as a vector interruption tool. This was the first such analysis of vector management for obsolete vessels in the US.

2. Methods

2.1. Underwater sampling

Vessel sampling was conducted at the JRRF, which is situated approximately 39 kilometers upstream of where the James River reaches the Chesapeake Bay. There are several rows of vessels tied side-by-side at the JRRF, and the ORION was situated centrally in a row of 14 ships. The vessel was sampled on two occasions (27th and 30th of June, 2006) at this location, before and after 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 a submersible cleaning and maintenance platform (SCAMP) on the hull and hand-held brushes on vessel appendages. A SCAMP is a self-propelled vehicle, usually accompanied by a diver, of approximately 1.8 m diameter with multiple rotating/oscillating circular brushes that scrub surfaces as they move across vessel hulls. The brushes used for cleaning the ORION had bristles of polypropylene with steel inserts and also just polypropylene alone. The hand-held brushes were used on the rudder, propeller, stern tube, and struts (vessel appendages) because the SCAMP cannot access heterogeneous, confined or concave surfaces.

Pre- and post-scrubbing surveys were conducted *in situ* using divers connected by real-time audio and visual communications to a surface support team. Divers sampled the vessel by collecting photographic images and biological samples in a sampling scheme stratified by vessel location. The four levels of stratification included hull sampling at three depths (bottom, mid depth and just below the waterline) and vessel appendages. Images were collected using an underwater camera that captured photo-quadrats of 15 cm × 15 cm area (225 cm^2). A total of 64 pre-scrubbing and 58 post-scrubbing images were collected and used in analyses. Replicate biological sample collections were made using the same stratification scheme, consisting of 32 biological samples collected for each pre- and post- cleaning survey (64 in total). Collections were made by removing all macro-organisms from areas measuring 231 cm^2 (six square inches) and placing them into individually labeled re-sealable (zipped) bags. Preliminary sorting of biological samples was done in the field, as soon as possible after collection (less than 90 min), to determine whether organisms were 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 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 board the research vessel. Samples were preserved in 95% ethanol and returned to the laboratory, where detailed processing took place to estimate the number and identity of species in each replicate sample. Specimens were sent to expert taxonomists for identification and verification and organisms were identified to the lowest possible taxonomic level.

2.2. Data analyses

Photo-quadrats were analyzed using the point count method to determine percentage cover of different fouling groups by superimposing a grid of 100 random dots over each photo-quadrat. Fouling groups consisted of eight coarse categories that were readily identifiable from the images: barnacles, mussels, oysters, encrusting species, filamentous species (mainly hydroids and erect bryozoans), mobile crustaceans, organism scars and hull surface. A data matrix consisting of percentages of each of the eight fouling categories per sample was used for assessing biofouling extent. The biological samples data, a presence/absence matrix of species per sample, was used to examine variation in biofouling species richness and assemblage composition among samples.

The two data matrices were used separately for univariate analyses, multivariate analyses and graphical presentation. A two-factor ANOVA was used to test for differences in species richness and biofouling percent cover using scrub (2 levels: before and after) and hull location (4 levels: appendages, bottom, mid depth and waterline) as factors. Ordinations were carried out using the multidimensional scaling (MDS) technique in PRIMER (PRIMER-E Ltd., Plymouth, UK), which produces a plot revealing sample similarity from Bray-Curtis similarity measures: points close together in the plot represent samples that are compositionally similar while those far apart are dissimilar. The analysis of similarities (ANOSIM) test was used to test for significant differences between factors. The test statistic (R) is usually a value between zero and one, with values close to one revealing that groups of samples are clearly distinguishable and dissimilar in terms of species composition whereas values close to zero mean that groups of samples are similar in composition (Clarke and Gorley, 2001).

3. Results

3.1. Biofouling samples: species richness

There were 39 distinct taxa (species and species groups, the latter including unique species that were not identifiable to species level as well as invertebrate juvenile stages, damaged specimens, fish eggs and larvae) recorded from the 64 biological samples collected from both surveys (Table 1). These 39 unique taxa are referred to as species from this point forward. Twenty-eight species were recorded in both pre- and post-treatment surveys, 9 were recorded from the pre-treatment survey only, and two were encountered during the post-treatment survey only (Table 1). Four species, *Conopeum chesapeakensis* (bryozoan), *Balanus improvisus* (barnacle), *Neanthes succinea* (polychaete) and *Apicorophium lacustre* (amphipod), were recorded in 100% of pre-scrub samples. Live specimens of all abundant or common species (occurring in >50% of samples) were collected. Although complete specimens of other rarer species were observed, no determination of live versus dead was possible for these species because they were not encountered alive during preliminary sorting. Of the 26 species that were recorded alive during pre-scrub surveys, only three were not recorded alive during post-scrub sampling. Two of these three species were not recorded in post-scrub samples at all, while *Polydora* sp. was only recorded (post-scrub) after sample preservation.