# Vessel biofouling as a vector for the introduction of non-indigenous marine species to New Zealand:
## Slow-moving barges and oil platforms

**Biosecurity New Zealand Project ZBS2005-02**

MAF Biosecurity New Zealand Technical Paper No: 2010/12

Prepared for Policy and Risk Directorate by the
Cawthron Institute

ISBN 978-0-478-37042-3 (online)
ISSN 1179-5840 (online)

**July 2010**

Ministry of Agriculture and Forestry
Te Manatū Ahuwhenua, Ngāherehere

# Disclaimer

While every effort has been made to ensure the information in this publication is accurate, the Ministry of Agriculture and Forestry does not accept any responsibility or liability for error or fact omission, interpretation or opinion which may be present, nor for the consequences of any decisions based on this information.

Any view or opinions expressed do not necessarily represent the official view of the Ministry of Agriculture and Forestry.

The information in this report and any accompanying documentation is accurate to the best of the knowledge and belief of the Cawthron Institute (Cawthron) acting on behalf of the Ministry of Agriculture and Forestry. While Cawthron has exercised all reasonable skill and care in preparation of information in this report, neither Cawthron nor the Ministry of Agriculture and Forestry accept any liability in contract, tort or otherwise for any loss, damage, injury, or expense, whether direct, indirect or consequential, arising out of the provision of information in this report.

Requests for further copies should be directed to:

Policy and Risk Directorate
MAF Biosecurity New Zealand
Pastoral House,
25 The Terrace
PO Box 2526
WELLINGTON

Tel: 04 894 4100
Fax: 04 894 4227

This publication is also available on the MAF website at www.maf.govt.nz/publications

## Contents

Page

# List of Figures

Page

## List of Tables

**Page**

# Executive Summary

Vessel traffic is the primary pathway for the introduction of non-indigenous marine species to New Zealand, with hull fouling now recognised as being the primary mechanism. In recognition of this, MAF Biosecurity New Zealand (MAFBNZ) commissioned a research project to investigate hull fouling on the range of vessel types arriving in New Zealand including: merchant ships, recreational yachts, fishing vessels, cruise ships and slow-movers. This study provides a snap-shot of hull fouling on eight slow-moving vessels (barges, tugs and a supply vessel) and an oil rig that arrived in New Zealand over a two year period (May 2006 to May 2008).

Slow-movers were sampled using a standardised sampling protocol developed by MAFBNZ that facilitates comparisons between other vessel types surveyed as part of the wider hull fouling project. Sampling included: (i) administering a vessel questionnaire, (ii) surface observations of fouling, (iii) sub-surface observations of paint condition and fouling, (iv) collection of photoquadrats from various sampling regions (bow, amidships, stern and niche areas) and sampling zones (surface, sub-surface and dry-docking support strips (DDSS)), and (v) collection and identification of fouling organisms within each photoquadrat.

A relatively diverse range of taxa was encountered on the barges and tugs surveyed (29 different taxa in total), representing four animal and four algal phyla. Samples from these vessels were numerically dominated by arthropods, molluscs and macroalgae. Approximately 24% of taxa were indigenous to New Zealand and 17% non-indigenous, while a high proportion of taxa (59%) were allocated “unknown” status due to insufficient taxonomic resolution. Non-indigenous taxa were found on both barges and tugs; however no first records for New Zealand were present in the samples taken and no cryptogenic (unknown origin) taxa were recorded.

Thirty taxa representing 10 phyla were sampled from the supply vessel *Far Grip*, with arthropods (7 species), annelids (6), bryozoans (4) and molluscs (4) the most numerically dominant groups of taxa. Non-indigenous taxa included the cosmopolitan foulers *Watersipora subtorquata* and *Hydroides elegans*, as well as two species of hydroids, *Coryne pusilla* and *Ectopleura crocea*, and the bryozoan *Cryptosula pallasiana*. The cryptogenic yellow/green alga *Feldmannia* aff *paradoxa* (Ochrophyta) was a first record of this species in New Zealand.

A total of 78 taxa (9 phyla) were sampled from the jack-up rig *ENSCO 56*. The rig was dominated (in terms of the number of taxa) by bryozoans (22 taxa), annelids (20 taxa) and arthropods (18 taxa). Samples collected from the spud can (i.e. the feet attached to the legs of the rig; 69 taxa) were more diverse than those collected from the bow leg (32 taxa). There was a high proportion of indigenous taxa on the rig (75%), while the sponge *Dactylia palmata* (a first record of this species in New Zealand) was the only non-indigenous species recorded.

In general, fouling assemblages encountered on barges and tugs were two-dimensional in structure rather than well-developed, three-dimensional late successional stages. Fouling cover ranged from 0-100% (overall mean = 17%), with higher levels observed on tugs compared with barges. Fouling cover did not vary greatly along the vessel regions (bow, amidships, stern and niche areas) for either vessel type. However, fouling cover on vertical sampling zones (i.e. surface, painted and DDSS) was more variable, with higher levels on the DDSS (where paint condition was poor) compared with painted areas of the hull. Taxon richness per photoquadrat on barges and tugs was very low (mean = 0.89 and 0.8 taxa,

respectively). Overall vessel taxon richness ranged between 3-10 taxa for barges (mean = 8.5), and 6-12 for tugs (mean = 7.0). Fouling biomass ranged between 0-4.4 $kg.m^{-2}$ (overall mean = 0.13 $kg.m^{-2}$), with highest levels observed on DDSS (mean = 0.3 $kg.m^{-2}$) and on niche areas (mean = 0.3 $kg.m^{-2}$) of the vessels.

On the supply vessel, fouling cover (overall mean = 21%), biomass (0.3 $kg.m^{-2}$) and taxa richness (2.3 taxa per photoquadrat) was, on average, highest at the bow and in niche areas. Lower fouling levels were observed in the amidships and stern regions. When pooled across vessel sampling regions, fouling extent within DDSS was more than twice that determined for painted areas of the hull. Lowest fouling levels were found at the surface and on painted zones at the amidships region of the vessel.

Fouling on the jack-up rig was rich and extensive, with 100% of the leg areas sampled covered in biofouling, and similarly high levels (93.4%) observed in the spud can. Average taxa richness per photoquadrat was higher within the spud can (mean = 19.1,) compared with the leg (mean = 10.0), however fouling biomass on the bow leg (mean = 1127 g) was more than twice as high as that observed within the spud can (mean = 523 g).

Strong positive linear relationships were evident between categorical level of fouling (LoF) scores assigned by divers and quantitative measures of fouling cover (and taxon richness) measured on the barges and tugs surveyed. Fouling biomass also increased with increasing LoF, however this relationship was non-linear (exponential), with a marked increase in biomass at LoF scores $\geq$3. There was no significant difference between LoF values assigned at the surface by non-divers and by divers. However, surface observations of fouling were unable to reliably predict fouling levels on painted areas of the vessel below the waterline, on DDSS or on niche areas of the hull.

Several factors appear to make slow-movers a high risk pathway for non-indigenous species (NIS) introduction by comparison to other vessel types. Specifically, slow movers: (1) often ply non-traditional shipping routes, potentially exposing New Zealand to NIS from bioregions not frequently encountered; (2) may spend extended periods of time idle between voyages, thus have the potential to accumulate high levels of fouling biomass and diversity; and (3) they travel at low speed, thus potentially increasing the likelihood of fouling survivorship. Survival on some slow movers may be enhanced by niche areas, such as sea chests and cross beams in the case of oil rigs, because such areas give protection from hydrodynamic forces and provide other habitat requirements.

Vector management is considered the primary tool to prevent NIS transfers and the ecological, economic, social and cultural consequences of invasion. For most vessel types, the application of anti-fouling paints within recommended timeframes and routine vessel hull maintenance are effective in reducing biofouling transfers. By contrast, the large size of oil rigs and lack of suitable dry-dock facilities globally make management of fouling relatively difficult. Hence, oil rigs are maintained on a less formal schedule than vessels, and in fact may go decades between dry-docking events. Nonetheless rig operators have some feasible options for managing fouling including: (i) where available facilities exist, dry-docking of rigs to remove fouling and re-apply anti-fouling paints, (ii) transportation of rigs onboard heavy lift vessels (HLV), and (iii) physical removal of fouling, either in-water or while being transported by HLV.

Reliance upon detecting high-risk slow-movers upon arrival in port (or other recipient areas) is clearly not desirable, particularly given the limited options available to treat heavily fouled vessels or vessels fouled with NIS under relatively short notice. In recognition of this, MAFBNZ is currently working toward the development of border standards for vessels entering New Zealand waters. Successful management requires, among other things, the ability to forecast potentially high risk situations. Given the low number of slow-mover arrivals each year, a logical approach may be to identify and assess vessel risks on a case-by-case basis prior to their entry into New Zealand waters.

*Keywords: biofouling; barges; hull fouling, oil rig, slow mover, supply vessel*

# 1 Introduction

## 1.1 BACKGROUND

Shipping is recognised as an important pathway for non-indigenous species (NIS) introductions globally (Hewitt et al. 1999; Gollasch 2002; Ruiz & Carlton 2003), and is likely to be the vector for close to 100% of the c. 200 known unintentional marine species introductions to New Zealand (Cranfield et al. 1998; Nelson 1999; Hayden et al. 2009). The most studied mechanisms of translocation associated with vessels are the uptake and subsequent discharge of organisms in ballast water (Carlton 1985; Olenin et al. 2000; Taylor et al. 2007) and the attachment to (or association with) the hull as fouling organisms (Carlton et al. 1995; Coutts et al. 2003; Lewis et al. 2003; Minchin & Gollasch 2003; Coutts & Taylor 2004). More recently, there has been increased evidence of the importance of hull niche areas, such as sea chests, as a transport mechanism for NIS (Coutts & Dodgshun 2007).

Managing biosecurity risks via the shipping pathway has proven difficult. Open-ocean ballast water exchange is a widespread and recent vector management strategy implemented to reduce risks posed by ballast water discharge (Taylor et al. 2007). Similarly, the application of anti-fouling paints and routine vessel hull maintenance are reasonably effective in reducing biofouling accumulation and preventing species translocations (Callow & Callow 2002; Coutts & Taylor 2004). However, despite the widespread use of anti-fouling coatings, fouled vessels continue to arrive at our border. Reasons for this include:

(1) Not all vessels undergo routine maintenance or have anti-fouling paints re-applied within recommended timeframes (e.g. obsolete vessels, oil rigs).
(2) Sub-standard paint application or inappropriate selection of paint for vessel type/operation.
(3) Biofouling can occur on non-hull areas of the vessel were anti-fouling paint condition is often poor; such as sea chests, gratings and intake pipes.
(4) Some taxa are resistant to anti-fouling biocides and are able to colonise recently anti-fouled surfaces.

Of the various international vessel types, ‘slow-movers’ (vessels with a cruising speed of c. 5 knots) have been identified as being high risk vectors of NIS (Lewis et al. 2006; Coutts & Forrest 2007; Coutts et al. 2010). Several factors make slow-movers distinct from other vessel types: (i) they often ply non-traditional shipping routes, potentially exposing New Zealand to non-indigenous taxa from bioregions not frequently encountered; (ii) they can spend extended periods of time idle between voyages, potentially accumulating fouling biomass and diversity (Lewis et al. 2006; Coutts & Forrest 2007); and (iii) they travel at low speed, increasing the likelihood of fouling being translocated (Lambert 2001; Coutts at al. 2010).

Slow-movers have been involved in several documented incursions to the marine environment (Table 1), with New Zealand examples including the discovery of South African brown mussels (*Perna perna*) on the semi-submersible oil rig *Ocean Patriot* during defouling in Tasman Bay (Hopkins et al. *in prep*), and the spread of the colonial ascidian *Didemnum vexillum* from Whangamata into the Marlborough Sounds on a barge (Coutts & Forrest 2007).

**Table 1: Documented examples of hull fouling on slow-moving vessels/structures.**

| Author(s) | Synopsis |
|---|---|
| Foster & Willan (1979) | Survival of 12 barnacle species on the hull of a Maui oil platform after it was towed from Japan to New Zealand in 1975. |
| DeFelice (1999) | Discovery of 20 exotic fouling organisms on the hull of the floating dry-dock *USS Machinist*, which was towed from Subic Bay (Philippines) to Pearl Harbour (Oahu) in May 1992. |
| Apte et al. (2000) | Successful translocation of the smooth-shelled blue mussel *Mytilus galloprovincialis* from the hull of the *USS Missouri* to a submarine ballast tank in Pearl Harbour after it was towed from Bremerton, Puget Sound. |
| Coutts (2002a) | Discovery of *Didemnum vexillum* on a barge that had been recently towed from Whangamata Harbour (North Island, NZ) to the Marlborough Sounds (South Island) in December 2001. |
| Lewis et al. (2006) | Discovery of 20 species on a barge being transported from a temperate estuarine system to Macquarie Island (sub-Antarctic); including an invasive amphipod (*Monocorophium acherusicum*). |
| Hopkins et al. (*in prep*) | Discovery of 10 non-indigenous taxa (6 first time records for New Zealand) on a semi-submersible drilling rig off the coast of New Zealand. |

## 1.2 INTERNATIONAL SLOW-MOVER TRAFFIC

In recent years, New Zealand has been visited by a diverse range of slow-movers, including: barges, tugs, oil rigs, drilling ships, pipe layers, dredgers, supply vessels and heavy lift vessels. Slow-movers typically comprise a small volume of the international vessel traffic arriving in New Zealand. In 2002, < 0.5% of the total number of international vessel arrivals in New Zealand (*n* = 3523) were slow-movers (of which half were repeat visits). The majority of vessel traffic was associated with merchant ships (73%) and pleasure craft (23%) (Campbell 2004). Over the period 2003-2007, slow-movers comprised 0.8% (± 0.2%) of all international arrivals (26 ± 7 vessels per annum). The amount of vessel traffic associated with slow-movers varies considerably each year (pers. comm., Liz Jones - MAFBNZ), and is difficult to predict due to fluctuations in market demand for exports (e.g. coal) and services (e.g. drilling contracts) that require the use of such vessel types.

Tugs and barges operated by Sea-Tow International Tug and Barge Operators (Sea-Tow) account for the majority of the international barge arrivals in New Zealand (pers. comm., Dick Mogridge - Marine superintendent, Sea-Tow). The main international trade routes are between Australia and New Zealand, and to a lesser extent the South Pacific Islands.

Various national and international companies manage the deployment of oil rigs in New Zealand, with Australia and Singapore being the most common source regions in recent years. Rigs are either dry-towed to New Zealand onboard a heavy lift vessel or towed in-water by supply vessels (Figure 1).

**Figure 1: The semi-submersible drilling rig *Kan Tan IV* onboard a heavy lift vessel (left), and the semi-submersible drilling rig *Ocean Patriot* being towed in-water (right).**

## 1.3 PROJECT OBJECTIVES

In January 2006, MAF Biosecurity New Zealand (MAFBNZ) commissioned the Cawthron Institute to undertake a study to examine hull fouling on slow-moving vessels. This study complemented a wider research programme (ZBS2004-03) that sampled the biofouling assemblages of international vessels arriving in New Zealand. While numerous studies have attempted to quantify fouling levels across vessel types (e.g. James & Hayden 2000; Coutts & Taylor 2004), comparisons between vessel types (and studies) are hampered due to inconsistent sampling techniques and the level of taxonomic resolution achieved in each study. To address this, the methods used to sample slow-movers were the same as those used in the wider MAFBNZ funded biofouling research programme.

The specific objectives of the present study were to:

1. Determine the identity, status and extent of biofouling occurrence on international slow-moving vessels visiting New Zealand, using a consistent sampling regime and methodology.

2. Determine the relationship between non-indigenous species presence on vessels and the extent of biofouling, measured both as biomass and according to categorical measures of 'Level of Fouling' currently used in project ZBS2004-03.

# 2 Methods

## 2.1 SAMPLING

Each vessel was sampled using a standardised methodology which comprised a questionnaire and physical sampling (Figure 2). The questionnaire was designed to collect information on the vessel, its maintenance history and voyage characteristics since it was last applied with anti-fouling paint. The questionnaire was administered prior to the physical sampling which consisted of five steps (Figure 2).

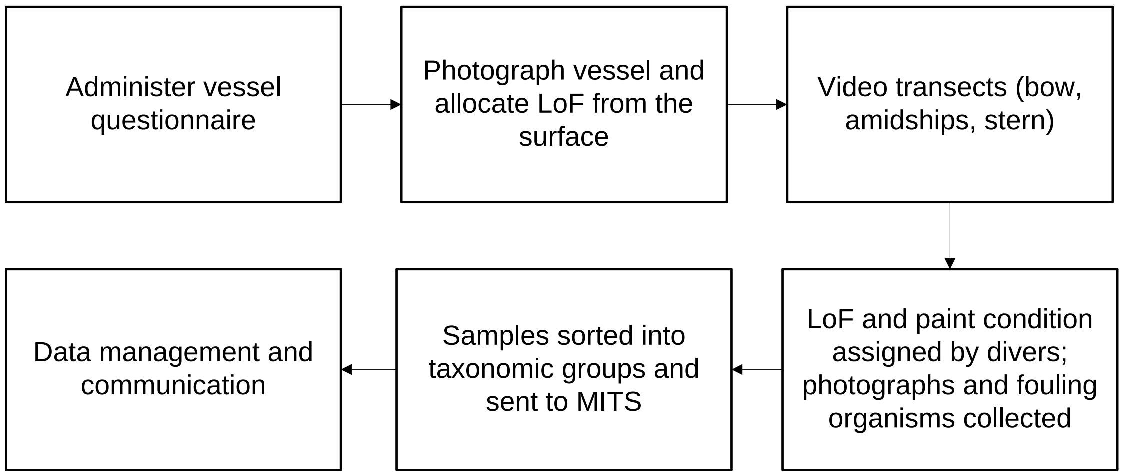


**Figure 2: Summary steps of the standardised vessel sampling protocol used in the MAFBNZ-funded hull fouling research programme.**

### 2.1.1 Surface observations

A LoF rank was assigned based on surface observations of the: (i) overall vessel, (ii) bow region, (iii) amidships-waterline, (iv) amidships-below waterline, and (v) stern/rudder.

### 2.1.2 Video transects

Divers undertook cross-sectional video transects at the bow, amidships and stern regions of the vessel (Figure 3). Each transect commenced at the waterline, and extended vertically down to the midpoint of the vessel.

### 2.1.3 Systematic photoquadrats

Divers collected photoquadrats (200 x 200 mm, $n$ = 3) at the three main vessel sampling regions (bow, amidships and stern) and from niche areas (e.g. gratings, propeller shaft, or areas of the hull) using a Canon EOS digital camera (8 megapixels). Bow and stern regions were sampled at least 1 m from the bow or stern. Sample areas within each region were taken from near surface (0.5 m), inside dry-docking support strips (DDSS) where feasible, and on sub-surface regions of the hull where anti-fouling paint was present. For each photoquadrat, a qualitative assessment of paint condition was made (i.e. good, average, poor). No criteria exist in the MAFBNZ sampling protocol for the allocation of paint condition scores. Therefore, Cawthron developed the following simple criteria for use by field staff to ensure consistency across sampling events: good = no imperfections present, average = minor chipping and visible paint wear to base layers, and poor = substantial areas of no paint and/or bare hull.

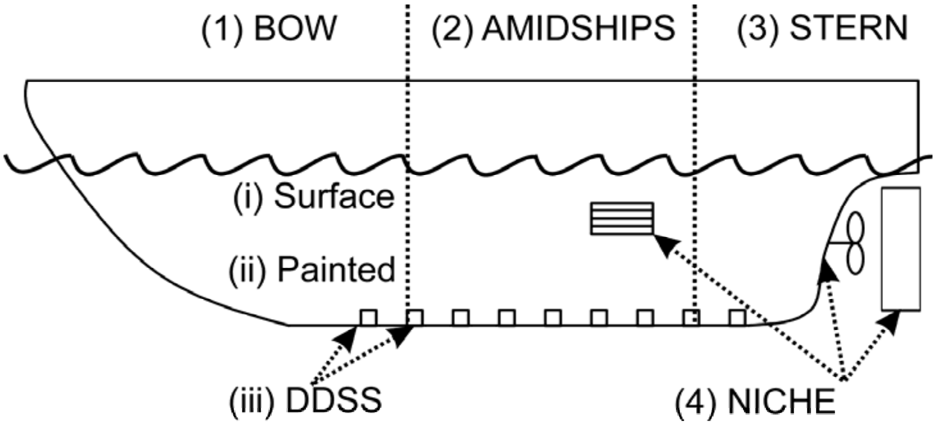


**Figure 3: Diagrammatic representation of a vessel hull identifying areas sampled (if present) using the MAFBNZ vessel sampling protocol. DDSS: dry-docking support strips.**

Level of fouling (LoF) was estimated based on a ranking scale developed by Floerl et al. (2005). Ranking ranged from 0 (no fouling present, not even a biofilm) to 5 (> 40% macrofouling cover) (refer Figure 4). Organisms within the quadrat were carefully scraped into labelled sample bags using metal handheld scrapers. Photographs and quantitative samples were also taken from niche areas of the vessel. The same dive team was used to sample all vessels to maintain consistency in assigning paint condition and fouling ranks.

#### 2.1.4 Sample processing

At the surface, samples were sieved (1 mm), blotted, weighed, sorted into broad taxonomic groups and preserved. Samples were then sent to NIWA's Marine Invasives Taxonomic Services (MITS) for formal identification.

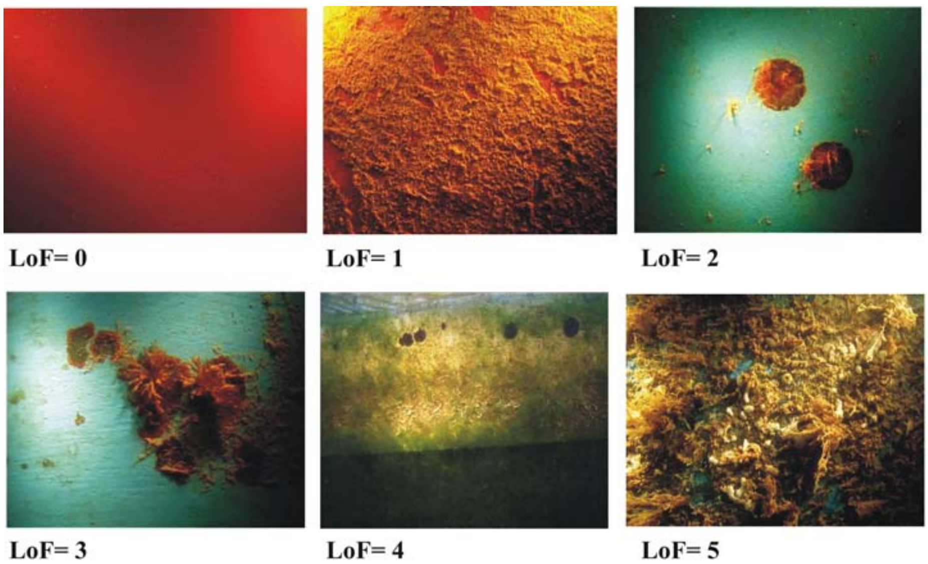


**Figure 4: Ranking scale developed for characterising levels of fouling (LoF) on vessels (Floerl et al. 2005). A LoF of 0 corresponds to no fouling present, 1: partial biofilm, 2: 1 - 5% of patchy macrofouling or filamentous algal cover, 3: 6 - 15% patchy cover, 4: 16 - 40% cover, and 5: > 40% fouling cover. Source: Oliver Floerl (NIWA).**

### 2.1.5 Jack-up rig

In May 2008, a jack-up rig (*ENSCO 56*) was sampled alongside a commercial wharf in Nelson. At the time of sampling, all three legs were jacked up, with the top surfaces of the spud cans (i.e. the feet attached to the legs of the rig) accessible from within the rig structure (Figure 5). It was not possible to apply the standard sampling protocol to the rig because: (1) there are a range of structures present on a rig that are not present on a vessel (e.g. spud cans), (2) there is no true bow, amidships or stern region to the vessel, and (3) accessibility to rig structures due to the height of the legs and other safety issues. Sampling on the jack-up rig was further complicated by the large-scale defouling that had occurred on the legs and 2 (out of 3) of the spud cans prior to arrival in port. As a consequence, a qualitative approach was used whereby representative photographs and samples of fouling communities (using the standard 0.04 m² photoquadrat) were collected from the most accessible regions of the rig.

A total of 9 samples were collected from a range of surface orientations and structures from one of the spud cans, such as evident in Figure 5. A total of 7 samples were collected from horizontal, vertical and diagonal girders on the bow leg, encompassing the range of orientations and surfaces fouled. Additional 'opportunistic' samples were also collected from within the spud can and leg areas.

**Figure 5:** ***ENSCO 56*** **berthed alongside a commercial wharf in Nelson Haven (left), and the bow 'spud can' sampled. The spud can is the foot of the leg that makes contact with the seafloor.**

## 2.2 DETERMINATION OF FOULING STATUS AND EXTENT

The MITS provided taxonomic identifications for the fouling samples submitted, which included a determination of the biosecurity status which classifies each specimen as indigenous (native), non-indigenous (alien), cryptogenic (origins uncertain), or unknown (i.e. insufficient taxonomic resolution to determine origin). A small number of samples (18 out of 613) were unidentifiable (sediments, debris and fragments) and consequently omitted from our analyses.

To determine the cover of biofouling, photoquadrats were rectified in ArcMap 9.2 (ESRI, Redlands, CA, USA). Fouling biota present within each 0.04 m² photoquadrat were traced to create a map from which percent cover of overall fouling could be calculated by dividing the total area of fouling taxa by the quadrat area.

## 2.3 STATISTICAL ANALYSES

Given the low vessel sample size, data analyses were restricted to descriptive statistics for the quantitative measures of fouling extent and qualitative assessments of paint condition, and categorical levels of fouling. However, differences between surface and diver observations of fouling were tested using the non-parametric Wilcoxon match pairs test. For these analyses, repeat sampling events of the same vessel and data collected from the supply vessel and jack-up rig were excluded.

A non-metric multi-dimensional scaling (nMDS) ordination procedure, based on the Bray-Curtis similarity measure of presence/absence data, was used to describe differences in taxa composition on vessels using PRIMER Version 5.2.2 (PRIMER-E Ltd, Lutton, Ivybridge, UK). The supply vessel and jack-up rig were omitted from these analyses given the one-off nature of these two sampling events and their strong influence on the plots. Similarity percentage analyses (SIMPER) in PRIMER were used to identify the species explaining trends evident in the nMDS plots (Clarke & Warwick 1994).

# 3 Results

## 3.1 SUMMARY OF VESSELS SAMPLED

A total of 9 different slow-movers, comprising 5 barges, 2 tugs, 1 supply vessel and a jack-up rig, were sampled at five ports within New Zealand between May 2006 and May 2008 (Table 2). Although tugs and the supply vessel can travel at speeds > 10 knots, they were included in the sampling as they travel at low speed when towing, visit the same ports/regions as barges, and can often remain idle with the barge or rig between projects. Sea-Tow often uses the same tug to tow different barges, and as such, the tug *Katea* was sampled on three separate occasions (May and August 2006, May 2007). Given the low vessel traffic during the sampling period, MAFBNZ also gave permission to sample the barge *Sea-Tow 60* on two separate occasions (September 2006 and May 2007). Therefore, while 9 discrete slow-movers were sampled, 12 sampling occasions are reported.

**Table 2: Summary of slow-moving vessels sampled.**

| Code | Vessel | Vessel type | Date sampled | Location sampled |
|---|---|---|---|---|
| CAW001A | *Katea* | Tug | 25/05/2006 | Auckland |
| CAW001B | *Soundcem II* | Barge | 25/05/2006 | Auckland |
| CAW001C | *Soundcem I* | Barge | 25/05/2006 | Auckland |
| CAW002A | *Sea-Tow 80* | Barge | 7/06/2006 | Tauranga |
| CAW002B | *Koranui* | Tug | 7/06/2006 | Tauranga |
| CAW003A | *Katea* | Tug | 29/08/2006 | Westport |
| CAW003B | *Sea-Tow 61* | Barge | 29/08/2006 | Westport |
| CAW004 | *Sea-Tow 60* | Barge | 28/09/2006 | Nelson |
| CAW005A | *Katea* | Tug | 10/05/2007 | Nelson |
| CAW005B | *Sea-Tow 60* | Barge | 10/05/2007 | Nelson |
| CAW006 | *Far Grip* | Supply vessel | 23/11/2007 | New Plymouth |
| CAW007 | *ENSCO 56* | Jack-up oil rig | 30/05/2008 | Nelson |

## 3.2 VESSEL QUESTIONNAIRE

All barges and tugs surveyed in this project had arrived from Australia and had been operating on New Zealand - Australian routes (Table 3). The supply vessel *Far Grip* had not left New Zealand since dry-docking in Auckland 7 months prior to sampling. The jack-up rig *ENSCO 56* arrived in New Zealand onboard a Heavy Lift Vessel (HLV) in 2005, and remained in New Zealand up until the time of sampling. The port of registration for the Sea-Tow vessels was either Singapore or Auckland; *ENSCO 56* was registered in Liberia, and the supply vessel was registered in Alesund (Norway).

Barges ranged in length from 47-97 m (beam range = 8.9-24.0 m), while tugs ranged from 29-34 m (beam range = 9.0-10.8 m). The largest slow-mover sampled was the jack-up rig *ENSCO 56*, which measured 53 x 53 m and had legs greater than 90 m long. Vessel speeds (while towing or being towed) ranged from 5.5-7.5 knots for barges and tugs, and c. 5 knots for the supply vessel and rig.

Time since last dry-docking varied between 1 month and 11 years across the vessel types sampled. The average time since dry-docking was 2 years (SE = 11 months) for barges and 15.8 months (SE = 2.5 months) for tugs. The time since dry-docking was 7 months for the supply vessel and 11 years for the rig (Table 4). All vessel types underwent high pressure water blasting prior to painting. Sea-Tow applied Altex Devoe paints to all of their barges and tugs, while the supply vessel used International Marine Coatings paints. Total Marine Services did not specify the type of anti-fouling paint applied to their two barges (*Soundcem I* and *II*). These vessels were towed from Fremantle within a month of dry-docking. The owners of the rig were also unable to specify the paint used when last dry-docked in April 1997. Except for when in dry-dock, treatment of fouling in sea chests was not routinely undertaken on any of the vessel types surveyed.

**Table 3: Summary of the last 10 ports visited since last dry-docking for each vessel surveyed in the present study.**

| Vessel code | Vessel name | Date sampled | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CAW001A | *Katea* | 25/05/2006 | Fremantle* | Auckland** | Brisbane* | Onehunga** | Bluff** | Lyttelton** | Auckland** | Picton** | Westport** | Thevemard* |
| CAW001B | *Soundcem II* | 25/05/2006 | Fremantle* | | | | | | | | | |
| CAW001C | *Soundcem I* | 25/05/2006 | Fremantle* | | | | | | | | | |
| CAW002A | *Sea-Tow 80* | 7/06/2006 | Port Kembla* | Onehunga** | Westport** | Thevemard* | Melbourne* | Bell Bay* | Whyalla* | Westport** | Tarakohe** | Lyttelton** |
| CAW002B | *Koranui* | 7/06/2006 | Port Kembla* | Onehunga** | Westport** | Thevemard* | Melbourne* | Bell Bay* | Whyalla* | Westport** | Tarakohe** | Lyttelton** |
| CAW003A | *Katea* | 29/08/2006 | Thevemard* | Whyalla* | Westport** | Thevemard* | Whyalla* | Westport** | Auckland** | Fremantle* | Auckland** | Brisbane* |
| CAW003B | *Sea-Tow 61* | 29/08/2006 | Thevemard* | Whyalla* | Westport** | Thevemard* | Whyalla* | Westport** | Auckland** | Fremantle* | Auckland** | Brisbane* |
| CAW004 | *Sea-Tow 60* | 28/09/2006 | Whyalla* | Westport** | Nelson** | Lyttelton** | Greymouth** | New Plymouth** | Tarakohe** | Westport** | Lyttelton** | Tarakohe** |
| CAW005A | *Katea* | 10/05/2007 | Thevemard* | Whyalla* | Westport** | New Plymouth** | Westport** | Thevemard* | Whyalla* | Westport** | Tasmania* | Whyalla* |
| CAW005B | *Sea-Tow 60* | 10/05/2007 | Thevemard* | Whyalla* | Westport** | New Plymouth** | Westport** | Thevemard* | Whyalla* | Westport** | Tasmania* | Whyalla* |
| CAW006 | *Far Grip* | 23/11/2007 | New Plymouth** | | | | | | | | | |
| CAW007 | *ENSCO 56* | 30/05/2008 | Singapore | | | | | | | | | |

* Australian port
** New Zealand port

**Table 4: Summary information and maintenance history for each vessel surveyed. None of the slow-movers had been in-water cleaned or had sea chests treated since dry-docking.**

| Code | Vessel | Vessel type | Average speed (knots) | Time since last dry-dock | Dry-docking location | TWSA ($m^2$) |
|---|---|---|---|---|---|---|
| CAW001A | *Katea* | Tug | 6.0 | 11 months | Auckland, NZ | 331* |
| CAW001B | *Soundcem II* | Barge | 6.0 | 1 month | Fremantle, Australia | 673** |
| CAW001C | *Soundcem I* | Barge | 6.0 | 1 month | Fremantle, Australia | 673** |
| CAW002A | *Sea-Tow 80* | Barge | 7.5 | 6 years, 1 month | Brisbane, Australia | Unloaded- 1950*<br>Loaded- 2423* |
| CAW002B | *Koranui* | Tug | 7.5 | 1 year, 3 months | Nelson, NZ | 540* |
| CAW003A | *Katea* | Tug | 5.5 | 1 year, 2 months | Auckland, NZ | 331* |
| CAW003B | *Sea-Tow 61* | Barge | 5.5 | 1 year, 9 months | Batam, Indonesia | Unloaded- 1482*<br>Loaded- 2145* |
| CAW004A | *Sea-Tow 60* | Barge | 6.0 | 1 year, 10 months | Batam, Indonesia | Unloaded- 1482*<br>Loaded- 2145* |
| CAW005A | *Katea* | Tug | 6.5 | 1 year, 11 months | Auckland, NZ | 331* |
| CAW005B | *Sea-Tow 60* | Barge | 6.5 | 2 years, 6 months | Batam, Indonesia | Unloaded- 1482*<br>Loaded- 2145* |
| CAW006A | *Far Grip* | Supply vessel | 5-12 | 7 months | Auckland, NZ | 1020*** |
| CAW007A | ENSCO 56 | Jack-up rig | 5.0 | 11 years | Singapore | N/A |

* Provided by SEATOW
** Calculated as (length between perpendiculars x (beam + (2 x light load draft)) x 0.72
*** Calculated as (2 x length x draft) + (beam x draft)

## 3.3 ANTI-FOULING PAINT CONDITION

Anti-fouling paint condition varied across vessel sampling regions and sampling zones (Figure 6; Figure 7). Paint condition was consistently poor on niche areas (e.g. sea chests, gratings) and on the dry-docking support strips (DDSS) where paint could not be applied during the previous dry-docking event. All of the painted areas of the hull had ‘good’ paint condition on the tugs and supply vessel sampled; whereas barges typically had a higher proportion of poor and average paint condition. In particular, the barge *Sea-Tow 80* had poor paint condition present on all sub-surfaces inspected (> 6 years since last dry-dock). There was also a higher proportion of average and poor paint scores assigned to surface sampling zones (approx. 1 m below the waterline) for both barges and tugs. By contrast, DDSS was the only sampling zone on the supply vessel that had poor paint condition present.

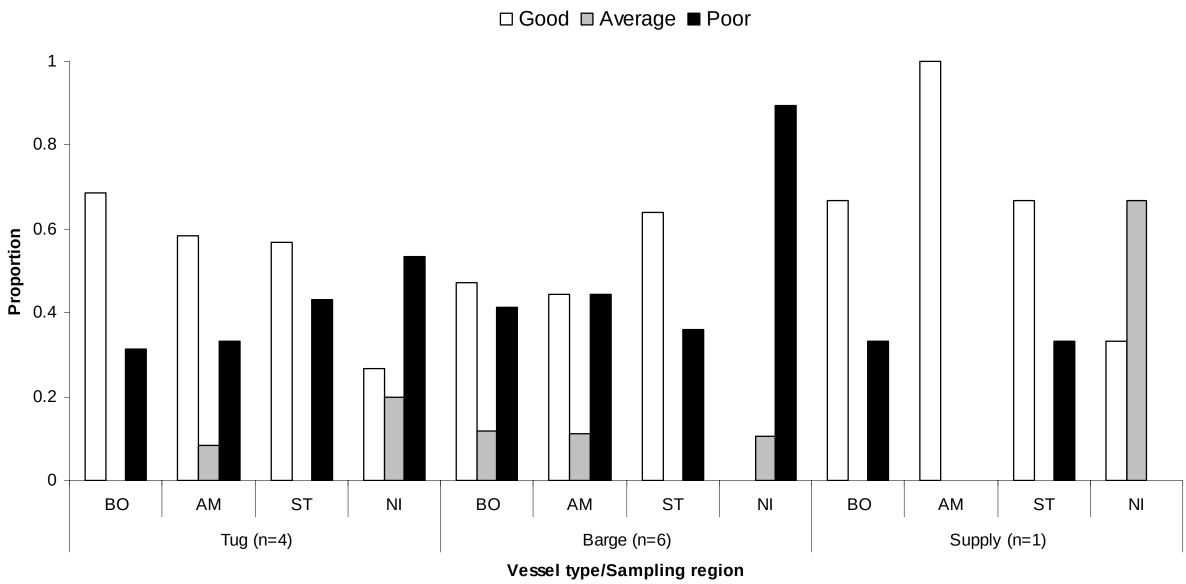


**Figure 6: Diver observations of anti-fouling paint condition across vessel sampling regions (BO: bow, AM: amidships, ST: stern, NI: niche areas).**

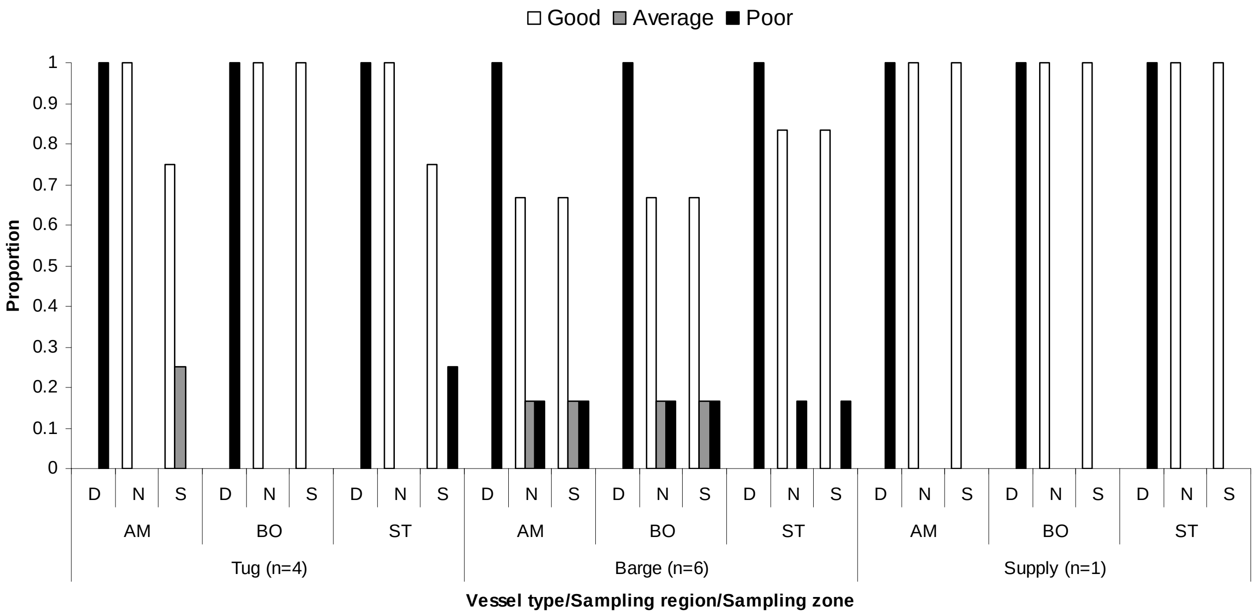


**Figure 7: Diver observations of paint condition across vessel sampling regions (excluding niche areas) and sampling zones (BO: bow, AM: amidships, ST: stern, D: dry-docking support strips, N: painted (below waterline) and S: surface).**

## 3.4 IDENTITY AND STATUS OF FOULING

### 3.4.1 Barges and tugs

Twenty nine taxa were identified in the 125 samples collected from the barges and tugs (Table 5). Of these, 41% were identified to species-level, 31% to genus-level and the remaining 28% to phylum. A relatively diverse range of taxa was encountered, representing four animal and four algal phyla (Figure 8). Samples were numerically dominated by arthropods (mainly crustaceans), molluscs and macroalgae. Approximately 24% of taxa were indigenous to New Zealand and 17% non-indigenous, and a high proportion of taxa (59%) had "unknown" status due to insufficient taxonomic resolution (i.e. as a result of partial/damaged specimens or lack of distinguishing features in juveniles). Non-indigenous taxa were found on both barges and tugs; however no first records for New Zealand were present in the samples taken (Table 5). No cryptogenic taxa were recorded.

**Table 5: Presence of taxa on vertical sampling zones and niche areas of barges and tugs, and their current biosecurity status in New Zealand. X = present.**

| | | | Barges (*n* = 6) | | | | Tugs (*n* = 4) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Taxon** | **Phylum** | **Biosecurity Status** | **Surface** | **Painted** | **DDSS** | **Niche** | **Surface** | **Painted** | **DDSS** | **Niche** |
| *Acryptolaria* sp. | Cnidaria | Unknown | | | X | | | | | |
| *Amphibalanus amphitrite* | Arthropoda | Non-indigenous | X | | | X | | X | | |
| *Amphibalanus variegatus* | Arthropoda | Indigenous | X | X | X | X | | X | X | X |
| *Anthozoa* | Cnidaria | Unknown | | X | | | | | | |
| *Austrominius modestus* | Arthropoda | Indigenous | X | X | X | X | X | | X | X |
| *Bangia* sp. | Rhodophyta | Unknown | | | | X | X | | | |
| *Bivalvia* | Mollusca | Unknown | | | | | | | X | |
| *Cladophora* sp. | Chlorophyta | Unknown | | | | X | X | | | |
| *Conchoderma auritum* | Arthropoda | Indigenous | | | | | | | X | X |
| *Coryne pusilla* | Cnidaria | Non-indigenous | | | X | X | | | | |
| *Crassostrea gigas* | Mollusca | Non-indigenous | | X | | | | | | X |
| *Crassostrea* sp. | Mollusca | Unknown | | | | | | | X | |
| *Cyanobacteria* | Cyanobacteria | Unknown | | | | X | | | | |
| *Ectocarpales* | Ochrophyta | Unknown | X | | | | X | | | |
| *Ectocarpus fasciculatus* | Ochrophyta | Indigenous | | X | | X | X | | | X |
| *Eudendrium* sp. | Cnidaria | Unknown | | | X | | | | | X |
| *Hydrozoa* | Cnidaria | Unknown | | X | X | X | | | X | |
| *Lepas anatifera* | Arthropoda | Indigenous | | | X | | X | X | | |
| *Maxillopoda* | Arthropoda | Unknown | X | | X | X | | | X | |
| *Mytilus galloprovincialis* | Mollusca | Indigenous | | | X | X | | | X | |
| *Obelia dichotoma* | Cnidaria | Non-indigenous | | | | X | | | | |
| *Obelia* sp. | Cnidaria | Unknown | | | X | X | | | | |
| *Ostreidae* | Mollusca | Unknown | | X | X | | | | | |
| *Paracerceis sculpta* | Arthropoda | Non-indigenous | | | | | X | | | |
| *Polysiphonia* sp. | Rhodophyta | Unknown | | | | | X | | | |
| *Rhizoclonium* sp. | Chlorophyta | Unknown | | | | | X | | | |
| *Serpulidae* | Annelida | Unknown | | | | X | | | | |
| *Stylonema alsidii* | Rhodophyta | Indigenous | | | | X | | | | |
| *Ulva* sp. | Chlorophyta | Unknown | X | | | X | X | | | X |

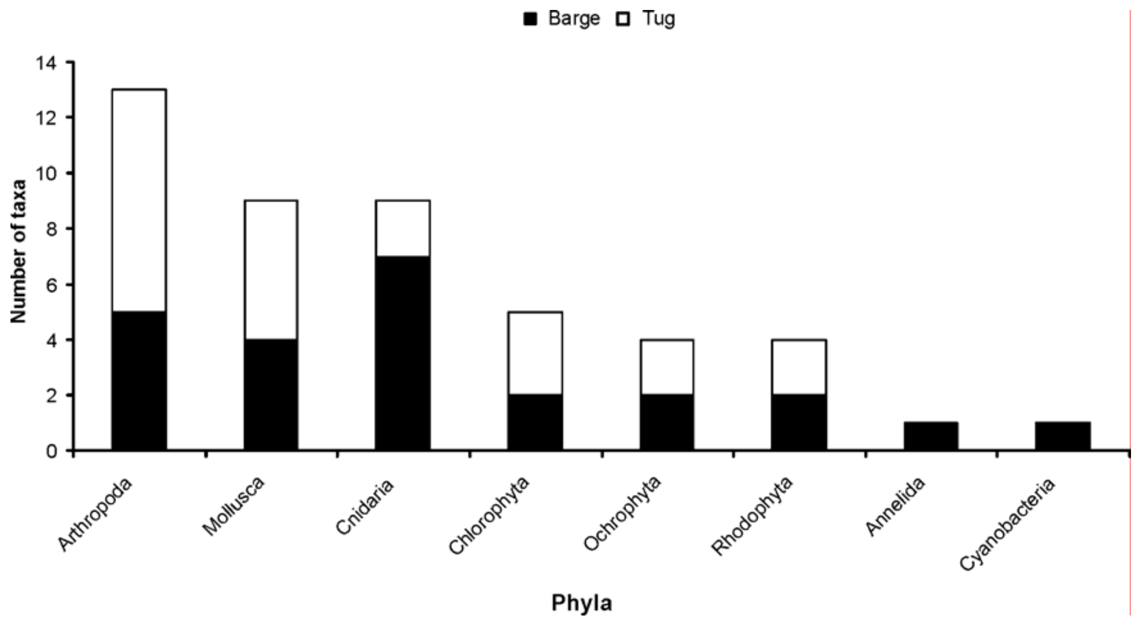


**Figure 8: Number of taxa (assigned to phyla) on barges and tugs surveyed.**

### 3.4.2 Supply vessel and jack-up rig

Thirty taxa representing 10 phyla were sampled from the supply vessel *Far Grip*, with arthropods (7 taxa), annelids (6), bryozoans (4) and molluscs (4) the most numerically dominant groups of taxa. Non-indigenous taxa included the cosmopolitan foulers *Watersipora subtorquata* and *Hydroides elegans*, as well as two species of hydroids, *Coryne pusilla* and *Ectopleura crocea*, and the bryozoan *Cryptosula pallasiana* (Table 6). The cryptogenic yellow/green alga *Feldmannia* aff *paradoxa* (Ochrophyta) was a first record of this species in New Zealand.

A total of 78 taxa (9 phyla) were sampled from the jack-up rig *ENSCO 56*. The rig was dominated (in terms of the number of taxa) by bryozoans (22 taxa), annelids (20) and arthropods (18). Samples collected from the spud can (a total of 69 taxa) were more diverse than those collected from the bow leg (32 taxa). There was a high proportion of indigenous taxa on the rig (75%), and the sponge *Dactylia palmata* (a first record of this species in New Zealand) was the only non-indigenous species recorded (Table 7). A relatively high proportion of taxa was identified to species (81%). Sampling on the jack-up rig was complicated by the large-scale defouling that had occurred on the legs and 2 (out of 3) of the spud cans prior to arrival in port. Thus, despite targeting areas that had fouling communities intact, it is possible that the number of taxa that had colonised the structure is under-reported in this study.

**Table 6: Presence of taxa on vertical sampling zones and niche areas of the supply vessel, and their current biosecurity status in New Zealand. X = present.**

| Taxon | Phylum | Biosecurity Status | Surface | Painted | DDSS | Niche |
|---|---|---|---|---|---|---|
| *Austrominius modestus* | Arthropoda | Indigenous | X | X | X | |
| *Balanidae* | Arthropoda | Unknown | | | X | |
| *Bangia* sp. | Rhodophyta | Unknown | X | | | |
| *Celleporaria* sp. | Bryozoa | Unknown | | | X | |
| *Chrysopetalum sp.* | Annelida | Unknown | | | X | |
| *Clytia hemisphaerica* | Cnidaria | Indigenous | | | X | |
| *Coryne pusilla* | Cnidaria | Non-indigenous | | | X | X |
| *Crassimarginatella fossa* | Bryozoa | Indigenous | | | X | |
| *Cryptosula pallasiana* | Bryozoa | Non-indigenous | | | X | |
| *Cyanobacteria* | Cyanobacteria | Unknown | X | | | |
| *Doto* sp. | Mollusca | Unknown | | | | X |
| *Ectopleura crocea* | Cnidaria | Non-indigenous | | | | X |
| *Feldmannia aff paradoxa* | Ochrophyta | Cryptogenic | X | X | X | X |
| *Halicarcinus innominatus* | Arthropoda | Indigenous | | | | X |
| *Hydroides elegans* | Annelida | Non-indigenous | | | X | |
| *Jassa marmorata* | Arthropoda | Cryptogenic | | | X | X |
| *Maxillopoda* | Arthropoda | Unknown | | | X | X |
| *Mytilus* sp. | Mollusca | Unknown | | X | | X |
| *Neanthes kerguelensis* | Annelida | Indigenous | | | | X |
| *Nemertea* | Nemertea | Unknown | | | | X |
| *Notomegabalanus decorus* | Arthropoda | Indigenous | | X | | |
| *Perna* sp. | Mollusca | Unknown | | X | X | X |
| *Plagusia chabrus* | Arthropoda | Indigenous | | | X | |
| *Saccoglossa* | Mollusca | Unknown | | | | X |
| *Scytosiphon lomentaria* | Ochrophyta | Indigenous | X | X | X | |
| *Serpula* sp. | Annelida | Unknown | | | X | |
| *Serpulidae* | Annelida | Unknown | | X | X | |
| *Spirobranchus* sp. -A | Annelida | Unknown | | | X | |
| *Ulva* sp. | Chlorophyta | Unknown | X | X | X | |
| *Watersipora subtorquata* | Bryozoa | Non-indigenous | | | X | |

**Table 7: Presence of taxa on the jack-up rig *ENSCO 56*. X = present.**

| Taxon | Phylum | Biosecurity Status | Leg | Spud can |
|---|---|---|---|---|
| *Achelia assimilis* | Arthropoda | Indigenous | X | X |
| *Aetea australis* | Bryozoa | Indigenous | | X |
| *Aetea truncata* | Bryozoa | Indigenous | | X |
| *Alpheus socialis* | Arthropoda | Indigenous | X | X |
| *Arachnopusia unicornis* | Bryozoa | Indigenous | | X |
| *Balanus trigonus* | Arthropoda | Indigenous | | X |
| *Bitectipora rostrata* | Bryozoa | Indigenous | | X |
| *Caberea rostrata* | Bryozoa | Indigenous | | X |
| *Cellaria immersa* | Bryozoa | Indigenous | | X |
| *Celleporina sinuata* | Bryozoa | Indigenous | X | X |
| *Chaetopterus* sp. (*Chaetopterus* -A ) | Annelida | Cryptogenic | | X |
| Chrysopetalidae | Annelida | Unknown | | X |
| Cirolanidae | Arthropoda | Unknown | | X |
| *Cnemidocarpa nisiotis* | Chordata | Indigenous | | X |
| *Cnemidocarpa otagoensis* | Chordata | Indigenous | | X |
| *Coscinasterias muricata* | Echinodermata | Indigenous | | X |
| *Dactylia palmata* | Porifera | Non-indigenous | | X |
| *Dicathais orbita* | Mollusca | Indigenous | X | X |
| *Disporella pristis* | Bryozoa | Indigenous | | X |
| *Dorvillea australiensis* | Annelida | Indigenous | | X |
| *Dromina wilsoni* | Arthropoda | Indigenous | | X |
| *Eunice australis* | Annelida | Indigenous | X | X |
| *Eurynolambrus australis* | Arthropoda | Indigenous | X | |
| Fasciculipora | Bryozoa | Unknown | X | |
| Favosipora | Bryozoa | Unknown | | X |
| *Favosipora tincta* | Bryozoa | Indigenous | | X |
| *Galeolaria hystrix* | Annelida | Indigenous | | X |
| *Galeopsis polyporus* | Bryozoa | Indigenous | X | X |
| *Galeopsis porcellanicus* | Bryozoa | Indigenous | X | X |
| *Halicarcinus innominatus* | Arthropoda | Indigenous | X | |
| *Haplocheira barbimana* | Arthropoda | Indigenous | | X |
| *Hiatella arctica* | Mollusca | Indigenous | X | X |
| Hydroides | Annelida | Unknown | | X |
| Idmidronea | Bryozoa | Unknown | | X |
| *Jassa slatteryi* | Arthropoda | Cryptogenic | X | |
| *Lepidastheniella comma* | Annelida | Indigenous | X | |
| *Lepidonotus jacksoni* | Annelida | Indigenous | X | X |
| *Lepidonotus polychromus* | Annelida | Indigenous | | X |
| *Lophopagurus cookii* | Arthropoda | Indigenous | | X |
| *Lumbrineris sphaerocephala* | Annelida | Indigenous | X | X |
| *Maxillopoda* | Arthropoda | Unknown | | X |
| *Metavermilia acanthophora* | Annelida | Indigenous | | X |
| *Modiolarca impacta* | Mollusca | Indigenous | X | X |
| *Neanthes kerguelensis* | Annelida | Indigenous | X | X |
| *Neovermilia sphaeropomatus* | Annelida | Indigenous | | X |
| *Notomegabalanus decorus* | Arthropoda | Indigenous | X | X |
| *Notomithrax minor* | Arthropoda | Indigenous | X | X |
| *Oenone fulgida* | Annelida | Cryptogenic | | X |
| *Opaeophora lepida* | Bryozoa | Indigenous | | X |
| *Ophiactis resiliens* | Echinodermata | Indigenous | X | |
| *Ophiopteris antipodum* | Echinodermata | Indigenous | X | X |
| *Ostrea chilensis* | Mollusca | Indigenous | | X |
| *Parawaldeckia vesca* | Arthropoda | Indigenous | | X |
| *Perna canaliculus* | Mollusca | Indigenous | X | X |
| *Petrolisthes elongatus* | Arthropoda | Indigenous | X | |
| *Petrolisthes novaezelandiae* | Arthropoda | Indigenous | X | X |
| *Pherusa parmata* | Annelida | Indigenous | X | X |

**Table 7 (continued): Presence of taxa on the jack-up rig *ENSCO 56*. X = present.**

| Taxon | Phylum | Biosecurity Status | Leg | Spud can |
|---|---|---|---|---|
| *Phorbas fulva* | Porifera | Indigenous | X | |
| *Phyllodocidae* | Annelida | Unknown | | X |
| *Pinnotheres novaezelandiae* | Arthropoda | Indigenous | | X |
| *Plagusia chabrus* | Arthropoda | Indigenous | X | X |
| *Pododesmus zelandicus* | Mollusca | Indigenous | X | X |
| *Polychaeta* | Annelida | Unknown | | X |
| *Schizosmittina cinctipora* | Bryozoa | Indigenous | | X |
| *Schizosmittina conjuncta* | Bryozoa | Indigenous | X | |
| *Scruparia ambigua* | Bryozoa | Cryptogenic | | X |
| *Serpula* | Annelida | Unknown | | X |
| *Smittina palisada* | Bryozoa | Indigenous | | X |
| *Smittina purpurea* | Bryozoa | Indigenous | | X |
| *Smittoidea maunganuiensis* | Bryozoa | Indigenous | X | X |
| *Spirobranchus* (*S. polytrema* complex) | Annelida | Cryptogenic | | X |
| *Syllidae* | Annelida | Unknown | | X |
| *Talochlamys zelandiae* | Mollusca | Indigenous | X | X |
| *Terebratella sanguinea* | Brachiopoda | Indigenous | | X |
| *Tsengia laingii* | Rhodophyta | Indigenous | X | X |
| Tubulipora | Bryozoa | Unknown | | X |
| *Xymene* sp. | Mollusca | Unknown | | X |
| *Xymene traversi* | Mollusca | Indigenous | | X |

## 3.5 PATTERNS AND EXTENT OF FOULING

### 3.5.1 Barges and tugs

Fouling assemblages encountered on the vessels were two-dimensional in structure rather than well-developed, three-dimensional late successional stages. Fouling cover ranged from 0-100% (overall mean = 17%), with generally higher levels observed on tugs compared with barges (Figure 9a; Table 8). Fouling cover did not vary greatly along the vessel regions (bow, amidships, stern and niche areas) for either vessel type. However, fouling cover on vertical sampling zones (i.e. surface, painted and DDSS) was more variable, with higher levels on the DDSS (where paint condition was poor) compared with painted areas of the hull (Figure 9b; Figure 10). Taxon richness per photoquadrat on barges and tugs was very low (mean = 0.89 and 0.8 taxa, respectively) (Figure 11). Overall vessel taxon richness ranged between 3-10 taxa for barges (mean = 8.5, SE = 1.3), and 6-12 for tugs (mean = 7.0, SE = 1.2). Fouling biomass ranged between 0-4.4 $kg.m^{-2}$ (overall mean = 0.13 $kg.m^{-2}$, SE = 0.03 $kg.m^{-2}$), with highest levels observed on DDSS (mean = 0.3 $kg.m^{-2}$, SE = 0.1 $kg.m^{-2}$) and niche areas (mean = 0.3 $kg.m^{-2}$, SE = 0.05 $kg.m^{-2}$) of the vessels surveyed (Figure 12).

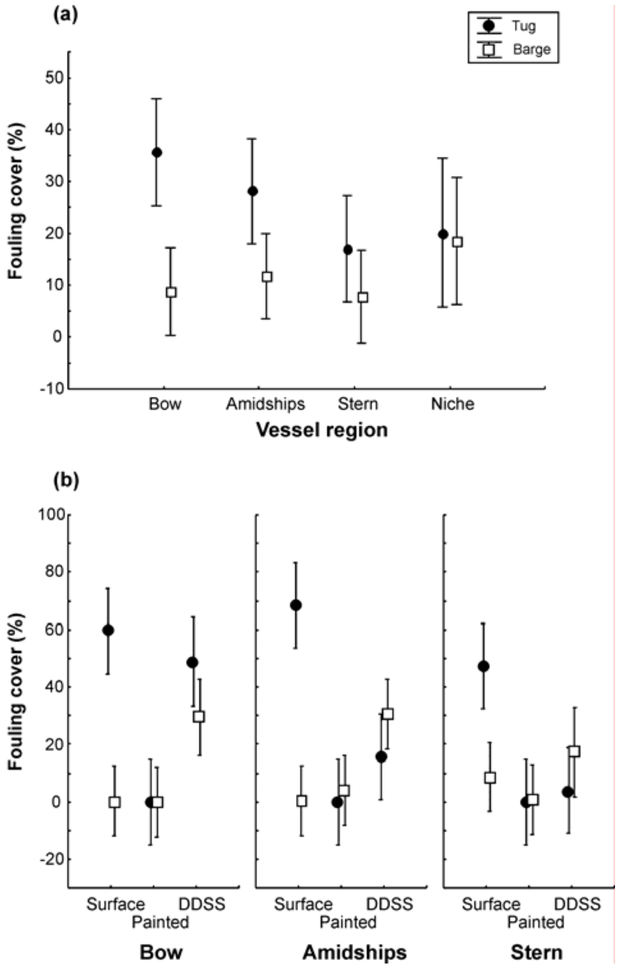


**Figure 9: Mean fouling cover (%) per photoquadrat (0.04 m²) within the four vessel regions (a), and within the three vertical sampling zones sampled at the bow, amidships and stern (b). Error bars denote 95% confidence intervals.**

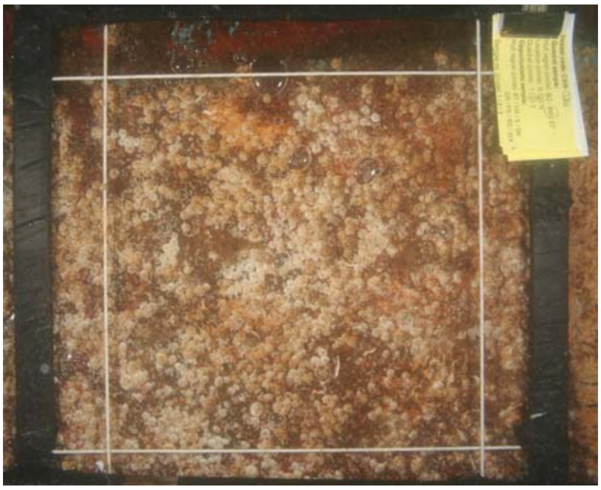

**Figure 10: Photoquadrat of the hull of a barge showing the dry-docking support strip with a high level of fouling (LoF = 5).**

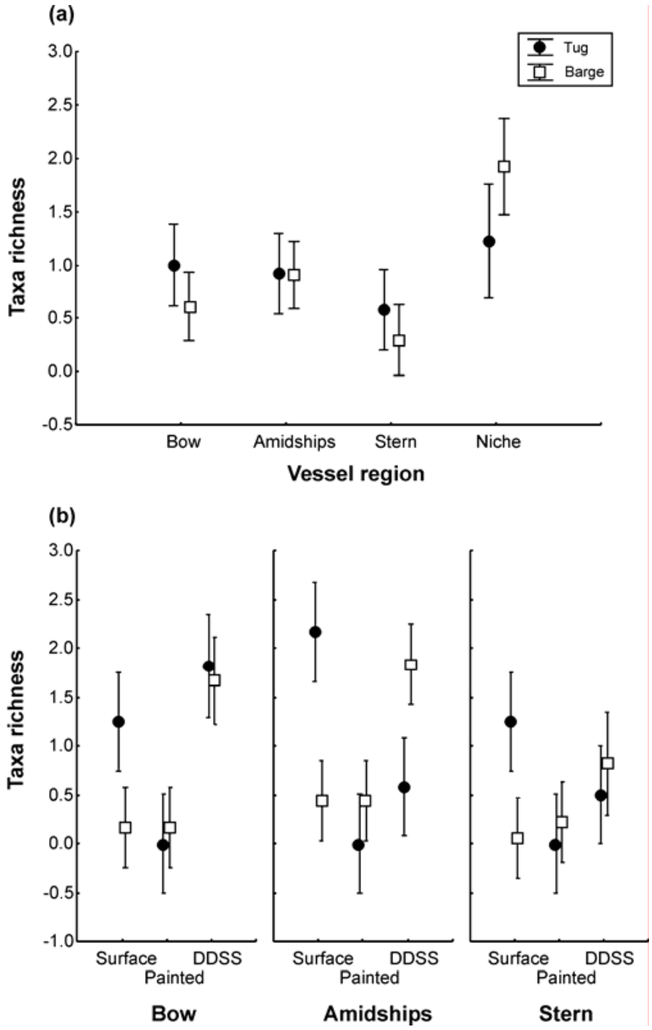


**Figure 11: Mean taxa richness per photoquadrat (0.04 m²) within the four vessel regions (a), and within the three vertical sampling zones sampled at the bow, amidships and stern (b). Error bars denote 95% confidence intervals.**

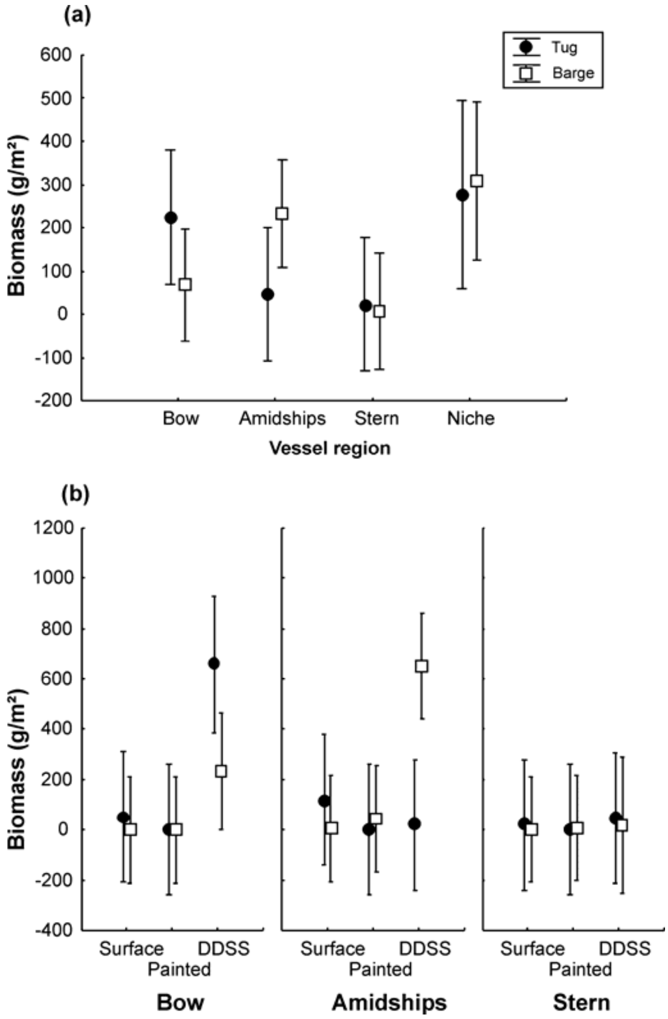


**Figure 12: Mean fouling biomass (g.m$^{-2}$) within the four vessel regions (a), and within the three vertical sampling zones sampled at the bow, amidships and stern (b). Error bars denote 95% confidence intervals.**

**Table 8: Mean fouling cover (%) and richness per photoquadrat (0.04 m²) taken within vertical sampling zones (Surface, Painted, DDSS) across the vessel sampling regions (refer Figure 1). Associated standard error (bracketed values) is shown.**

| Vessels | | Bow | | | Amidships | | | Stern | | | Niche |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Surface | Painted | DDSS | Surface | Painted | DDSS | Surface | Painted | DDSS | |
| **Cover (%)** | | | | | | | | | | | |
| **Tugs** | | | | | | | | | | | |
| | *Katea* (1) | 100 (0) | 0 | 7.9 (3.3) | 100 (0) | 0 | 0.2 (0.2) | 0 | 0 | 0 | 0.2 (0.1) |
| | *Koranui* | 0 | 0 | 64.9 (20.4) | 0 | 0 | 60.1 (14.1) | 0 | 0 | 4 (0.18) | 31.6 (11.8) |
| | *Katea* (2) | 100 (0) | 0 | 39.0 (13.5) | 100 (0) | 0 | 0.2 (0.1) | 100 (0) | 0 | 0 | 44.7 (20.1) |
| | *Katea* (3) | 38.1 (7.6) | 0 | 100 (0) | 74.5 (9.6) | 0 | 3.1 (2.2) | 89.0 (4.7) | 0 | 14.9 (6.7) | 29.8 (15.5) |
| **Barges** | | | | | | | | | | | |
| | *Soundcem II* | 0 | 0 | 0 | 0 | 0 | 2.2 (1.5) | 0 | 0 | 0.2 (0.1) | 8.8 (5.1) |
| | *Soundcem I* | 0 | 0 | 0 | 0 | 0 | 2.8 (1.4) | 0 | 0 | 0 | 81.5 (0) |
| | *Sea-Tow 80* | 1.5 (0.4) | 0.4 (0.1) | 1.0 (0.2) | 3.3 (2.9) | 24.9 (7.1) | 8.7 (3.6) | 0.02 (0.02) | 5.0 (0.7) | 0 | 11.5 (3.3) |
| | *Sea-Tow 61* | 0 | 0 | 2.6 (0.7) | 0 | 0 | 2.8 (0.6) | 0 | 0 | 0.1 (0.1) | 6.1 (0.1) |
| | *Sea-Tow 60* (1) | 0 | 0 | 65.1 (16.9) | 0 | 0 | 82.9 (17.1) | 52.5 (20.1) | 0 | 63.8 (7.8) | 36.6 (12.3) |
| | *Sea-Tow 60* (2) | 0 | 0 | 79.7 (6.1) | 0 | 0 | 84.7 (15.4) | 0 | 0 | 0 | 24.7(0.1) |
| **Richness** | | | | | | | | | | | |
| **Tugs** | | | | | | | | | | | |
| | *Katea* (1) | 0 | 0 | 1 (0) | 2.3 (1.2) | 0 | 0.7 (0.7) | 0 | 0 | 0 | 0.5 (0.4) |
| | *Koranui* | 0 | 0 | 1.3 (0.3) | 0 | 0 | 1.0 (0) | 0 | 0 | 1.0 (0) | 2.0 (1) |
| | *Katea* (2) | 3.0 (0.6) | 0 | 2.0 (0.6) | 4.3 (0.3) | 0 | 0 | 3.0 (0) | 0 | 0 | 1.0 (0.4) |
| | *Katea* (3) | 2.0 (0) | 0 | 3.5 (0.5) | 2.0 (0) | 0 | 0.7 (0.3) | 2.0 (0) | 0 | 1.0 (0) | 2.5 (0.5) |
| **Barges** | | | | | | | | | | | |
| | *Soundcem II* | 0 | 0 | 0 | 0 | 0 | 1.0 (0.6) | 0 | 0 | 0.7 (0.3) | 1.7 (0.3) |
| | *Soundcem I* | 0 | 0 | 0 | 0 | 0 | 1.7 (0.3) | 0 | 0 | 0 | 1.0 (0) |
| | *Sea-Tow 80* | 1.0 (0) | 1 (0) | 1.0 (0) | 2.7 (0.9) | 2.7 (0.3) | 2.7 (0.3) | 0.3 (0.3) | 1.3 (0.3) | 0 | 1.0 (0.2) |
| | *Sea-Tow 61* | 0 | 0 | 3.0 (0) | 0 | 0 | 1.0 (0) | 0 | 0 | 0.3 (0.3) | 1.0 (0) |
| | *Sea-Tow 60* (1) | 0 | 0 | 2.0 (0) | 0 | 0 | 2.0 (0) | 0 | 0 | 2.0 (0) | 3.8 (1.2) |
| | *Sea-Tow 60* (2) | 0 | 0 | 2.3 (0.3) | 0 | 0 | 2.6 (0.3) | 0 | 0 | 0 | 3.0 (0) |

Overall, the composition of the fouling assemblages among the barges and tugs surveyed was quite dissimilar (Figure 13a). There was no distinction between vessel type, with three of the four groups formed at c. 40% Bray-Curtis similarity comprising both barges and tugs (Figure 13b). In fact, barges and the tugs that tow them were often more similar to each other in fouling composition (up to 80% Bray-Curtis similarity) than to their respective vessel types. SIMPER analyses revealed several taxa responsible for the patterns observed in the nMDS plot: Cluster A (comprising two repeat samples of the tug *Katea* and the barge *Sea-Tow 60*) was characterised by the presence of several algal taxa (*Ectocarpus fasciculatus*, *Cladophora* sp. and *Ulva* sp.), while cluster B (comprising two barges that had been anti-fouled 1 month prior to sampling, and a barge anti-fouled 21 months prior to sampling) had mainly early stages of fouling present (e.g. hydroids, *Ulva* sp.). Clusters C and D (comprising barges and the tugs that tow them) were characterised by fouling associated with the later stages of fouling (e.g. oysters, mussels and barnacles). Although changes in fouling assemblages over time (on the two vessels that were repeat sampled) are not strongly evident in the nMDS, in the case of the tug *Katea* there was nonetheless a greater dissimilarity in composition in the sampling occasions 12 months apart (70% dissimilar) than between the first two sampling events (40% dissimilar). For the barge *Sea-Tow 60*, there was also high (70%) dissimilarity between the two sampling occasions 8 months apart.

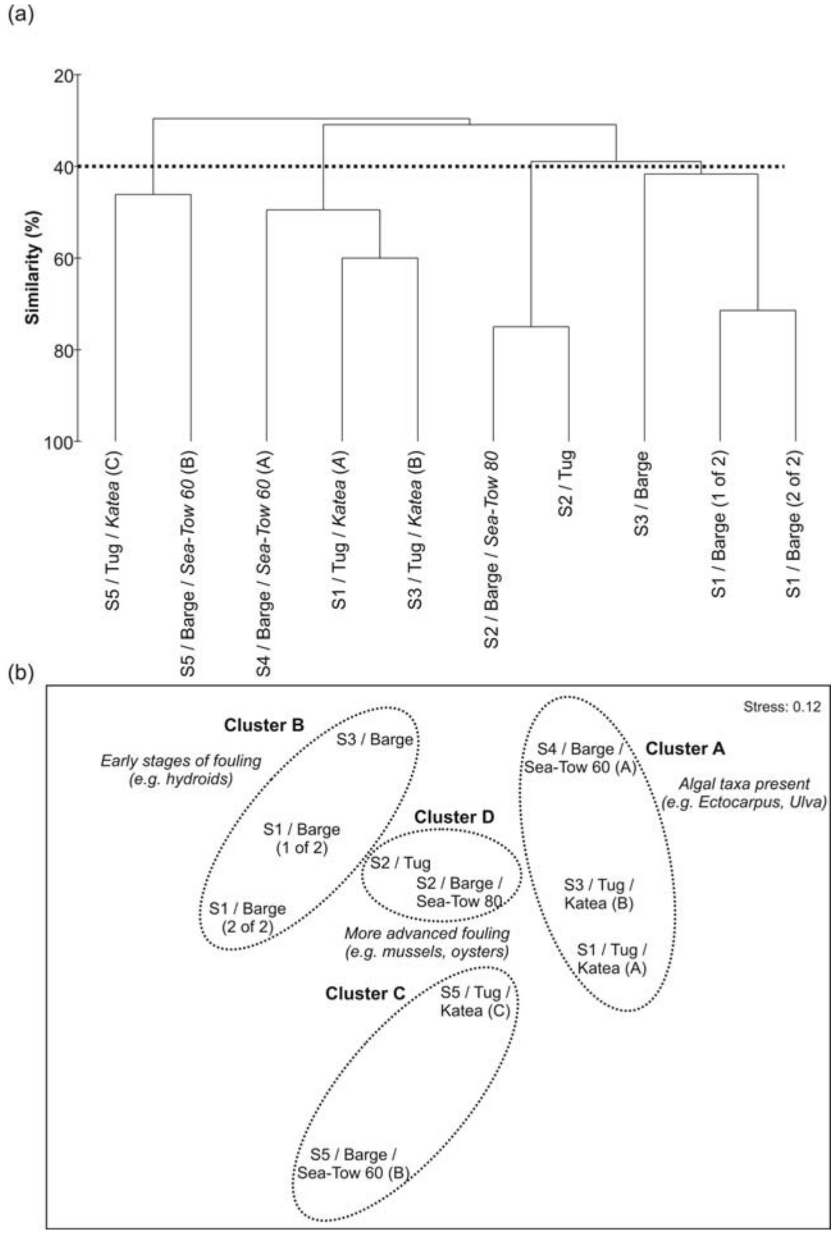


**Figure 13: Similarity dendrogram (a) and nMDS plot (b) of the composition of fouling on tugs and barges. S1 to S5 correspond to sampling event; however, note that during the first sampling event (S1), one tug towed two barges, and no tug was sampled during the fourth sampling event (S4). (A) to (C) refer to repeat sampling events of the tug *Katea* (S1 (A), S3 (B) and S5 (C)) and the barge *Sea-Tow 60* (S4 (A) and S5 (B)). Dotted lines in the nMDS plot represent ≥ 40% Bray-Curtis similarity.**

The similarity in fouling composition was greater for samples collected from within vertical sampling zones than across vessel regions (Figure 14), indicating that factors that vary with water depth and anti-fouling paint condition play an important role in structuring fouling communities on slow-moving vessels. Samples collected from niche areas of the vessels where paint condition was often poor were characterised by high taxa richness; including fouling taxa typically associated with later stages of fouling (e.g. bivalves). By contrast, painted areas of the vessel hulls had low richness with mainly barnacles and hydroids present. Surface zones were characterised by a high incidence of macroalgae. DDSS (i.e. where anti-fouling paint was absent) had a diverse range of taxa present (e.g. barnacles, bivalves and hydroids), with macroalgae noticeably absent within this zone.

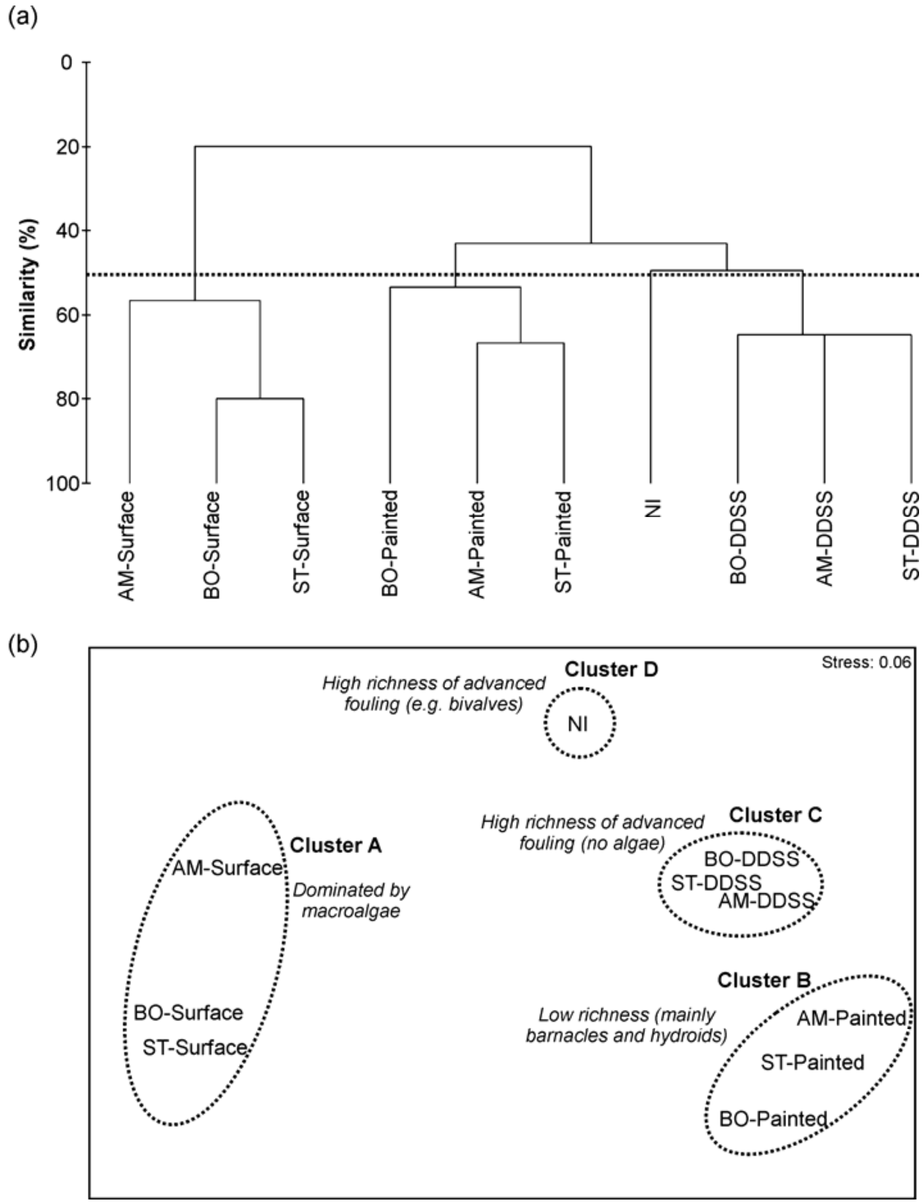


**Figure 14: Similarity dendrogram (a) and nMDS plot (b) of fouling on vertical sampling zones (surface, painted, DSSS) within vessel regions (BO = bow, AM = amidships, ST = stern and NI = niche areas pooled across vessel). Dotted lines in the nMDS plot represent $\geq$ 50% Bray-Curtis similarity.**

### 3.5.2 Supply vessel and jack-up rig

Fouling cover on the supply vessel ranged between 0-100% (mean = 20.9%, SE = 5.6%), while biomass and richness ranged between 0-4.8 $kg.m^{-2}$ (mean = 0.26 $kg.m^{-2}$, SE = 0.16 $kg.m^{-2}$) and 0-11 taxa per photoquadrat (mean = 2.3, SE = 0.6), respectively. Lowest levels of fouling were found at the surface and on painted zones at the amidships region of the vessel, and when data were pooled across vessel sampling regions, fouling extent within DDSSs was more than twice that determined for painted areas of the hull.

Fouling on the jack-up rig was rich and extensive (Figure 15; Figure 16). The bow leg had 100% fouling coverage dominated (in terms of biomass) by the indigenous green-lipped mussel (*Perna canaliculus*). The spud can had a similarly high level of fouling cover present

(93.4%, SE = 6.6%); however there was higher taxa diversity and less dominance by *P. canaliculus* on this area of the rig. In fact, average taxa richness per photoquadrat was much higher within the spud can (mean = 19.1, SE = 2.6) compared with the leg (mean = 10.0, SE = 1.4). However fouling biomass on the rig leg (mean = 1127 g, SE = 92 g) was more than twice that found within the spud can (mean = 523 g, SE = 83 g).

## 3.6 UTILITY OF LOF AS A MEASURE OF FOULING

Strong positive linear relationships were evident between categorical level of fouling (LoF) scores assigned by divers and quantitative measures of fouling cover and taxon richness measured on the barges and tugs surveyed. Fouling biomass also increased with increasing LoF; however this relationship was non-linear (exponential), with a marked increase in biomass at LoF scores $\geq 3$ (Figure 17).

Given the relative ease in which surface scores for LoF can be assigned, it was of interest to determine whether they corresponded to the LoF below the surface of the vessel. As expected, there was no significant difference between LoF values assigned at the surface by non-divers and by divers (Wilcoxon Match Pairs Test, $Z = < 0.01$, df = 63, $P = 1.00$). However, surface observations of fouling were unable to reliably predict fouling levels on painted areas of the vessel below the waterline ($Z = 4.29$, df = 63, $P < 0.001$), on DDSS ($Z = 5.18$, df = 56, $P < 0.001$) or on niche areas of the hull ($Z = 4.22$, df = 34, $P < 0.001$).

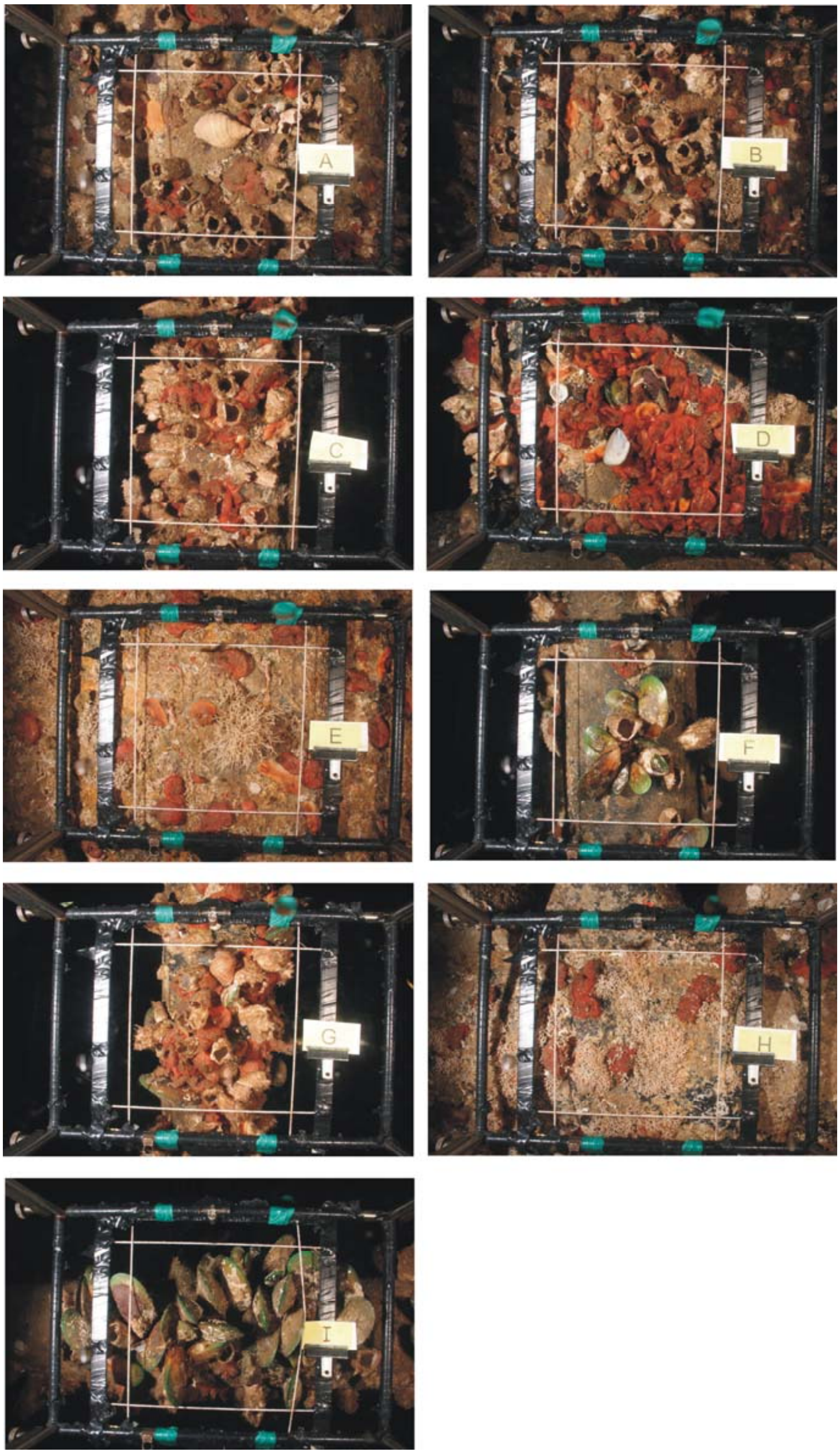


**Figure 15: Photoquadrats from within the bow spud can of the rig. A: vertical column, B: vertical column, C: diagonal girder, D: base of a vertical/diagonal girder, E: vertical base of the jack-up mechanism, F: base of a diagonal girder, G: underside of a horizontal strut, H: main vertical column, I: topside of a horizontal girder.**

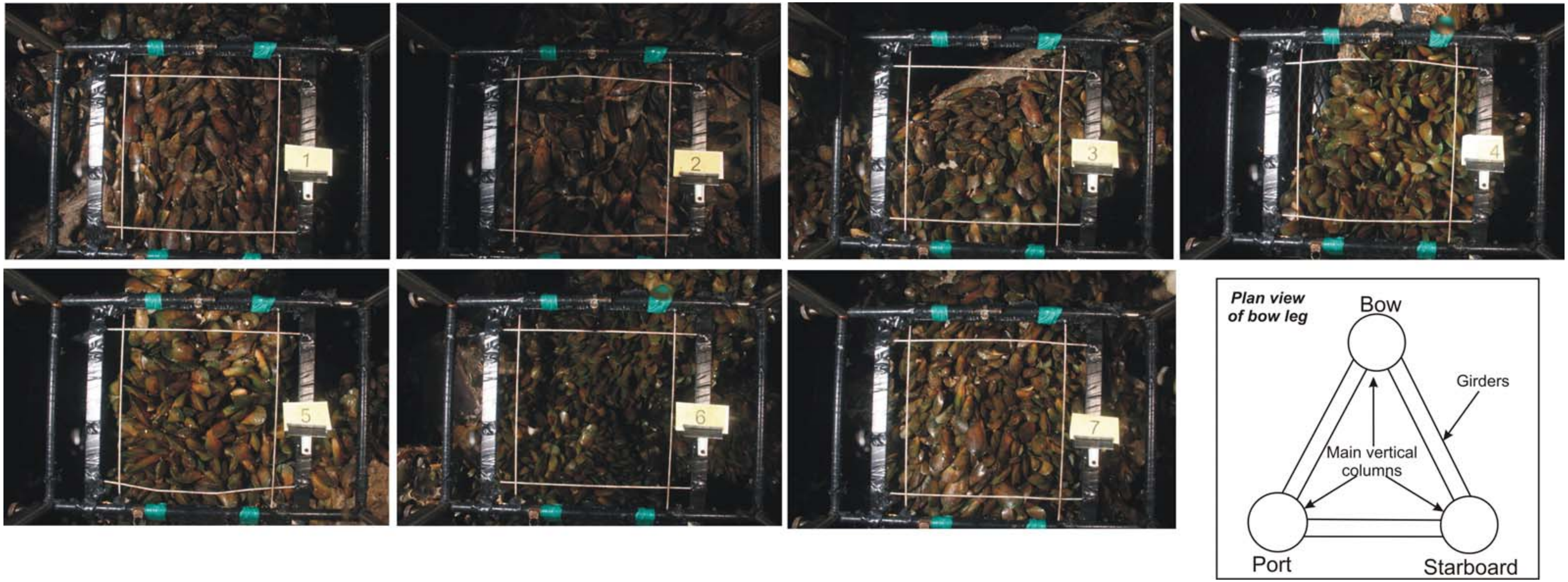


**Figure 16: Photoquadrats from the bow leg of the rig. 1: main vertical column on starboard side (33 m from bottom of leg), 2: vertical column on port side (33 m), 3: intersection of diagonal, vertical and horizontal girders on port side (25 m), 4: underside of horizontal girder (25 m), 5: top of diagonal/horizontal girders (22 m), 6: intersection of diagonal, vertical and horizontal girders on bow side (25 m), 7: vertical column on bow side (27 m).**

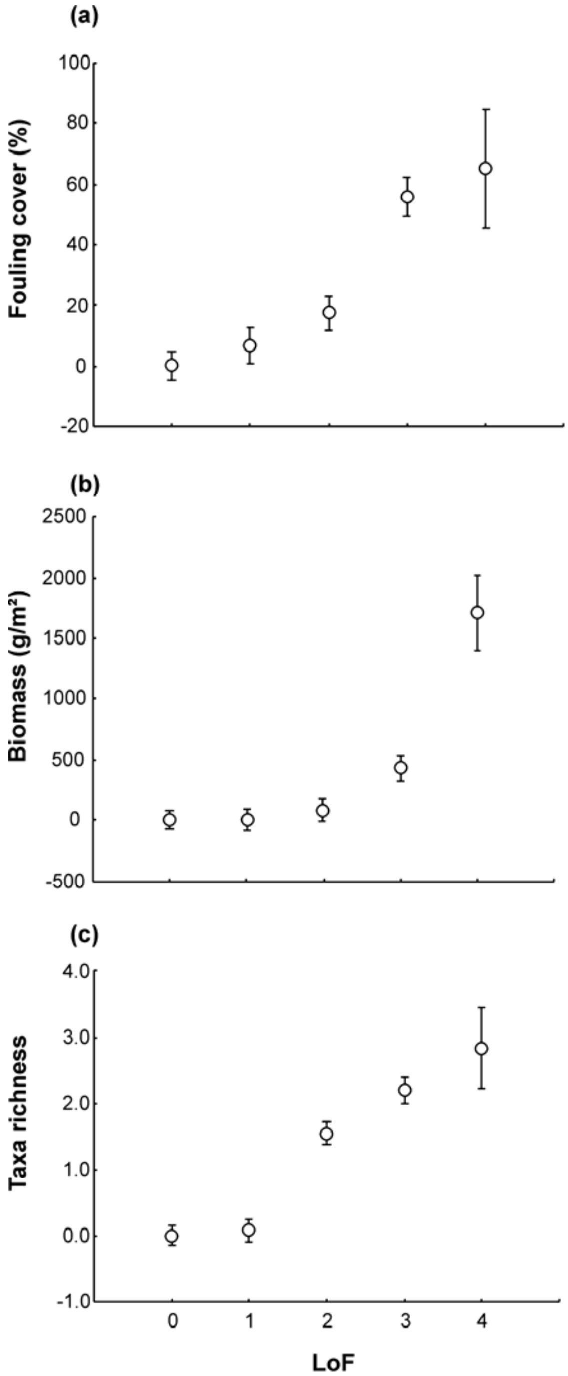


**Figure 17: Categorical levels of fouling (LoF) and corresponding (a) fouling cover, (b) biomass, and (c) taxa richness determined from sampling undertaken on barges and tugs. Error bars denote 95% confidence intervals.**

# 4 Discussion

## 4.1 FOULING COMPOSITION AND PATTERNS ON SLOW-MOVERS

A diverse range of fouling taxa was sampled from the slow movers, including: seaweeds, bryozoans, hydroids, barnacles, mussels, oysters, calcareous tubeworms, crustaceans, brittle stars and sea spiders. Approximately 55% of taxa collected were indigenous, 7% non-indigenous, 6% cryptogenic, and 32% were assigned 'unknown' biosecurity status. The fact that one-third of taxa were assigned 'unknown' biosecurity status reinforces the view held among New Zealand's marine science community that the current state of knowledge regarding our marine biota is poor (Hewitt 2004). As such, the proportion of non-indigenous and/or cryptogenic taxa may be under-reported in this study.

None of MAFBNZ's designated marine 'Unwanted Organisms' were encountered, despite Australia (the main source region for the slow movers sampled) having established populations of four of the seven marine taxa present on the current unwanted list: *Asterias amurensis*, *Sabella spalanzanii*, *Caulerpa taxifolia* and *Carcinus maenas* (Hewitt et al. 2004b). However, a number of other well-known NIS were recorded, including the bryozoan *Watersipora subtorquata*, the Pacific oyster *Crassostrea gigas*, and the serpulid worm *Hydroides elegans*. These species are regarded as cosmopolitan and are already found throughout New Zealand.

### 4.1.1 Barges and tugs

Observations of low fouling extent in the present study were most likely due to the fact that most vessels were sampled within two years of their most recent anti-fouling coating (average of c. 2 years for barges and c. 16 months for tugs). Furthermore, vessels typically spent short periods of time idle between voyages (i.e. 85% of port visits were < 5 days), thus the window of opportunity for colonisation and growth by local taxa was considerably less than that of vessels with long residency periods (e.g. obsolete vessels, Davidson et al. 2008b). Trends of fouling composition revealed that barges and the tugs that tow them are more similar to each other than they are to other vessel types. This is not unexpected, given that their voyage histories are in most cases identical, and that they travel at the same speed when in tow.

It appears that differences in fouling due to location are likely to be less pronounced for slow-moving vessels than observed on faster moving vessels such as merchant ships (speeds > 20 knots), for which fouling is greater in hydrodynamically protected areas (Coutts et al. 2003; Coutts & Taylor 2004). Conceivably, the forces on a vessel moving at slow speeds (c. 5 knots) are not sufficient to adversely affect (e.g. dislodge, damage) fouling assemblages, such that patterns of fouling across the hull are independent of location. However, our observation of higher fouling on DDSS and niche areas is consistent with most other vessel hull fouling studies (e.g. Godwin & Eldredge 2001; Coutts & Taylor 2004; Coutts & Dodgshun 2007; Davidson et al. 2009), and is intuitive given that anti-fouling paint was generally in poor condition and was unlikely to contain/release sufficient active biocides to prevent colonisation by the planktonic propagules of fouling biota (Coutts & Taylor 2004). As these vessel regions are prone to accumulating fouling and have been shown to have the greatest number of taxa present, they pose the greatest biosecurity risk (Coutts & Taylor 2004; Davidson et al. 2009).

### 4.1.2 Supply vessel and jack-up rig

Several crab species were found on the supply vessel *Far Grip*, including: *Plagusia chabrus* (the red bait crab) among fouling on a DDSS (LoF = 3). The supply vessel travels at c. 12 knots when not towing. While such observations suggest that the crabs may have survived transit on the external hull at this speed, it is also possible that they originated from an adjacent sea chest or colonised the hull while the vessel was in port. Nonetheless, the transit of mobile species with external hull fouling assemblages is not without precedent. Previous studies have documented survival from hull fouling transport of larger macrofauna, such as crabs (Carlton & Hodder 1995) and small crustacean epibiota (Davidson et al. 2008a,b).

Fouling on the rig was extensive (up to 40 $kg.m^{-2}$), diverse (77 taxa) and dominated by indigenous green-lipped mussels, *Perna canaliculus*. This is consistent with the fact that it had not been dry-docked for 11 years, nor the sampled regions defouled in any way in the intervening period. Oil rigs are not typically anti-fouled on a frequent basis and fouling removal (e.g. during dry-docking or by in-water methods) occurs less frequently than on other commercial vessels. As such, high diversity and biomass are a common feature of fouling communities on rigs. For example, a 2007 survey of the semi-submersible drilling rig *Ocean Patriot*, moored off the coast of Taranaki, revealed a high biomass and diverse range of taxa (including several non-indigenous species) on the submerged pontoons (Hopkins et al. *in prep*). Similarly, a recent study of an oil platform in the Beibu Gulf of China found multi-layered fouling assemblages (largely dominated by oysters and acorn barnacles) comprising 105 taxa, with biomass levels ranging from approximately 16-29 $kg.m^{-2}$ (Yan et al. 2006). Community composition on offshore structures has been found to vary with depth, with structures being more algal-dominated near the surface (0-15 m), and characterised by mussels, hydroids, bryozoans, ascidians and tubeworms at greater depths (e.g. Forteath et al. 1982; University of Auckland 1982). Mussels can be particularly dominant on some rigs, exemplified by *Perna canaliculus* on New Zealand rigs (University of Auckland 1982; Hopkins et al. *in prep*), and blue mussels (*Mytilus* spp.) on rigs overseas (Southgate & Myers 1985; Relini et al. 1998). In the Adriatic Sea, for example, optimal growing conditions led to mussel biomass reaching in excess of 150 $kg.m^{-2}$on an oil platform off the coast of Ravenna (Relini et al. 1998).

Mobile taxa, such as crabs and brittle stars, were observed on the legs of the jack-up rig. As such organisms may be considered as surrogates for recognised pests (e.g. the seastar *Asterias amurensis*, and green crab *Carcinus maenas*), it is important to ascertain whether they could survive in-water towing. Unfortunately, as the *ENSCO56* was towed to Nelson from Taranaki with its legs raised out of the water this could not be accomplished. However, in the case of the *Ocean Patriot*, several indigenous crabs (*Plagusia chabrus*) were sampled from the main pontoons after it had been towed several tens of kilometres from the offshore to nearshore coast of Taranaki (Figure 18). From these observations, it is suggested that high levels of fouling may afford protection from hydrodynamic drag. Further, it is conceivable that extensive fouling and niche areas provide other habitat requirements (e.g. a food source) during species translocation.

Despite the presence of extensive fouling assemblages on rigs (e.g. Wanless et al. 2009; Yeo et al. 2010), documented cases of NIS are not common. This is most likely due to the fact that there have been few studies undertaken that specifically consider NIS associated with such structures. The fouling assemblage on the *ENSCO 56* included five cryptogenic species (the polychaete worms *Chaetopterus* sp., *Spirobranchus* sp. and *Oenone fulgida*, the erect bryozoan *Scruparia ambigua*, and the amphipod *Jassa slatteryi*) and a non-indigenous sponge (*Dactylia palmata*). The presence of the latter is unexpected, given that the rig arrived onboard a heavy-lift vessel (HLV) in 2005 and had not left New Zealand since. However, the species may be a recent invader, or an indigenous sponge not previously described. Alternatively, this species may have survived the out-of-water journey to New Zealand (a duration of several weeks). This ability has been described for invasive macroalgae in the presence of high humidity (Sant et al. 1996; Schaffelke & Deane 2005; Forrest & Blakemore 2006).

**Figure 18: Sessile and mobile fouling organisms collected from the hull of the semi-submersible drilling rig *Ocean Patriot* during an inspection off the Taranaki coast (G. Hopkins, unpublished data).**

The discovery of the South African brown mussel (*Perna perna*) on the *Ocean Patriot* is a recent example of an oil rig transporting NIS. Taxonomic verification of the presence of *P. perna* occurred while the rig was being defouled in Tasman Bay, prior to relocation to Australia. Concerns regarding the effects of *P. perna* on New Zealand's green-lipped mussel industry and on the environment led to a major campaign to remove the defouled material from the seabed (Hopkins et al. *in prep*). NIS colonisation of platforms in transit to New Zealand have also been described. Foster & Willan (1979) found six species of barnacle that had not previously been recorded in New Zealand on parts of the *Maui A* platform that were constructed in Osaka, Japan. A further six species of tropical barnacle that likely settled while the platform was in transit via New Caledonia and the Solomon Islands were also documented. However, a later investigation of the platform found only dead barnacle tests of the tropical species, suggesting they had not survived in the cooler temperate waters off the Taranaki coast (University of Auckland 1982).

Observations made during the present study highlight the possibility that vessels associated with offshore drilling rigs have the potential to act as stepping-stones for NIS to coastal environments. Juvenile mussels (spat) were collected from areas on the supply vessel *Far Grip* where anti-fouling paint condition was poor or absent. These spat were thought to be either the brown mussel *Perna perna* or *Perna canaliculus* (differentiation requires molecular taxonomy which was not undertaken). Both mussel species were present on the drilling rig *Ocean Patriot*, which the supply vessel had serviced since last dry-docking. Hence, it is possible that larvae released from fouling on the rig led to colonisation of the supply vessel. Further, in the present study we noted the similarities in hull fouling assemblage composition between barges and their tugs. However, the authors note that many factors must be taken into consideration before such a possibility can be confirmed, including the voyage history of the supply/towing vessel and the fouling assemblages present in the surrounding medium during periods of lay-up.

## 4.2 PREDICTORS OF FOULING

The small sample size ($n$ = 11) of vessels and the absence of vessel movements other than trans-Tasman journeys, prevented the application of robust analyses to test for differences in fouling extent (i.e. fouling cover, biomass and richness) in relation to risk factors such as time since dry-docking, bioregions visited and anti-fouling paint types used. Nonetheless, increased fouling was consistently observed where paint was old (DDSS) or absent (many of the niche areas). An exception was the barge *Sea-Tow 80*, which hadn't been dry-docked (and re-painted) for > 6 years. Although poor paint condition and elevated fouling levels were observed, the composition of the fouling assemblage on *Sea-Tow 80* was not appreciably dissimilar to the other barges (time since dry-docking < 2.5 years), and comparable to its tug (*Koranui*) which had been dry-docked only 15 months earlier.

Surface observations of vessel fouling are quick and easy to obtain (compared to diver observations and sample collection), and as such, their relationships to observed fouling levels are of interest. In the present study, surface observations of fouling appeared to be a useful predictor of sub-surface fouling levels for the main laminar surface of the hull; however they did not reliably predict fouling levels on non-painted surfaces (DDSS) or niche areas of the hull (e.g. gratings, intake pipes, anode straps, etc). These findings are in agreement with other vessel types (e.g. recreational vessels, merchant vessels) surveyed as part of the wider MAFBNZ hull fouling programme. In terms of understanding biosecurity risk, the niche areas may be of most significance. As such, a thorough assessment of risk will generally need to be based on in-water inspection rather than surface observation alone. Despite the high likelihood that risk profiling (e.g. based on vessel questionnaires) and surface inspections will pick up the truly 'rogue' vessels, it cannot be assured that such approaches will fully characterise the biosecurity risks of fouling.

## 4.3 ARE SLOW-MOVERS HIGH RISK?

Despite our general findings of minimal fouling of slow moving vessels during the two year sampling window, it is nonetheless evident from previous studies that the potential for significant biosecurity risk arises from movements of barges (Coutts 2002a; Lewis et al. 2006; Coutts & Forrest 2007), oil rigs (Foster & Willan 1979; Hopkins et al. *in prep*) and other towed structures (DeFelice 1999; Apte et al. 2000). For example, in 2001 a heavily fouled barge (the *Steel Mariner*) was discovered in the Marlborough Sounds, New Zealand's foremost mussel aquaculture region. The estimated fouling biomass on the hull of the barge was 25,941 kg, comprising 6 algal and 70 animal taxa (Coutts 2002b). Among this assemblage was an estimated 1,397 kg of the 'sea squirt' (*Didemnum vexillum*), which has subsequently become a fouling pest to aquaculture (Forrest 2007). Despite these types of unforeseen and unmanaged events being low likelihood, they can have such significant consequences that a consideration of management options is clearly important. Given that there are numerous domestic vectors that facilitate the spread of invasive marine species after their initial incursion (Hewitt et al. 2004a; Dodgshun et al. 2007), managing domestic barge movements is also desirable. The management programme for *Didemnum* that was implemented following the Marlborough Sounds incursion highlights the significant fouling that can occur on such craft (Coutts & Forrest 2007). In this instance, 5 domestic barges both within and outside of the initial incursion area were found to be fouled with *Didemnum* and were subsequently treated (3 barges were beached for 3 weeks and 2 were wrapped in plastic) to prevent further spread in the region.

Several factors appear to make slow-movers a high risk pathway for NIS by comparison to other vessel types. Specifically, slow movers often ply non-traditional shipping routes, potentially exposing New Zealand to NIS from bioregions not frequently encountered; they can spend extended periods of time (months) idle between voyages (pers. comm., Dick

Mogridge, Sea-Tow), thus have the potential to accumulate high levels of fouling biomass and diversity (Lewis et al. 2006; Coutts & Forrest 2007); and they travel at low speed, potentially increasing the likelihood of fouling survivorship (Lambert 2001; Coutts at al. 2010). Survival on some slow movers may be enhanced by niche areas such as sea chests (Coutts & Dodgshun 2007) and cross beams in the case of oil rigs (Hopkins & Forrest 2009), because such areas give protection from hydrodynamic forces and provide other habitat requirements.

A further characteristic of slow-movers, which theoretically enhances their biosecurity risk, is that they can spend extended periods in a recipient environment. Biosecurity risks from hull fouling on slow-movers will primarily arise when competent invasive NIS are released into a recipient region in the form of adult life-stages, planktonic propagules, or fragments in the case of some macroalgae and colonial invertebrates (Valentine et al. 2007; Hopkins & Forrest 2008; Hopkins et al. 2008). For planktonic propagules, it is well recognised that factors such as increased density or frequency of release are related to invasion success (Lonsdale 1999; Ruiz et al. 2000; Drake et al. 2005), and the same concept of "propagule pressure" applies to adult organisms or fragments (Lockwood et al. 2005). Hence, biosecurity risk is likely to be enhanced with residence time in a recipient location because there are more opportunities for a suitable invasion 'window' to arise. There is also a greater likelihood that high risk species transported as juvenile life-stages (e.g. recently recruited larvae) will grow to reproductive maturity (Hopkins & Forrest 2009).

## 4.4 CONCLUDING REMARKS AND FUTURE RESEARCH

Vector management is considered the primary tool to prevent NIS transfers and the consequences of invasion. For most vessel types, the application of anti-fouling paints within recommended timeframes and routine hull maintenance are effective in reducing biofouling transfers. By contrast, the large size of oil rigs and lack of suitable dry-dock facilities globally make management of fouling relatively difficult. Hence, oil rigs are maintained on a less formal schedule than vessels, and in fact may go decades between dry-docking events. Nonetheless rig operators have some feasible options for managing fouling including: (i) where available facilities exist, dry-docking of rigs to remove fouling and re-apply anti-fouling paints, (ii) transportation of rigs onboard heavy lift vessels (HLV), and (iii) physical removal of fouling, either in-water or while being transported by HLV.

Reliance upon detecting high-risk slow-movers upon arrival in port (or other recipient areas) is clearly not desirable; particularly given the limited options available to treat heavily fouled vessels or vessels fouled with NIS under relatively short notice. In recognition of this, MAFBNZ is currently working toward the development of border standards for vessels entering New Zealand waters. Successful management requires, among other things, the ability to forecast potentially high risk situations. Given the low number of slow-mover arrivals each year, a logical approach may be to identify and assess vessel risks on a case-by-case basis prior to their entry into New Zealand waters.

The results of this study suggest that niche areas on slow-moving vessels (such as sea chest gratings, anodes) likely pose the greatest biosecurity risk, as they had the highest biomass and number of taxa present. Cawthron are currently investigating the use of steam/hot water to treat sea chests *in-situ* as part of the NIWA/Cawthron outcome based investment (OBI) research programme, with the aim of redirecting steam generated by the vessel to treat sea chests as part of their normal operating procedure. Other niche areas, such as propeller shafts, bow thrusters, and intake gratings will require alternative approaches. There is also a need for the further development of encapsulation techniques to broaden their application to treat large structures such as oil rigs, as their efficacy in mitigating biosecurity risks at this scale is currently unproven.

# 5 Summary

## 5.1 BARGES AND TUGS

(1) The majority of barges and tugs entering New Zealand come from Australia, but anecdotal evidence suggests that the Pacific Islands can also be another common source region.
(2) Anti-fouling paint condition on barges and tugs was generally good, although poor paint condition was observed on dry-docking support strips (DDSS) and niche areas, as well as on vessels that had not been dry-docked for >5 years.
(3) A relatively diverse range of fouling organisms was found on barges and tugs; including non-indigenous and cryptogenic species.
(4) Fouling on DDSS and niche areas is generally higher than areas of the hull with good paint condition.
(5) Fouling composition on barges and the tugs that tow them was similar.
(6) Observations of fouling made from the surface were unable to reliably predict the majority of sub-surface fouling levels.
(7) While a highly fouled vessel was not sampled in the present study, there are several documented examples of heavily fouled vessels entering New Zealand and overseas ports. Unfortunately these types of events can be difficult to predict.

## 5.2 SUPPLY VESSEL

(1) One supply vessel was sampled during this study, and as such little can be concluded about the biosecurity risks posed by this vessel type.
(2) Anti-fouling paint on the supply vessel was in good condition, with advanced fouling limited to DDSS and niche areas.

## 5.3 OIL RIG

(1) Rigs contain many structures that provide a settlement substrate for a broad range of taxa; as well as refugia for mobile taxa (e.g. crustaceans).
(2) Based on the present study and documented accounts in the published literature, fouling biomass and taxa diversity on jack-up and semi-submersible rigs are likely to be high unless they have been recently dry-docked or defouled.
(3) There are limited methods available to mitigate biosecurity risks posed by rigs due to their large size and the current lack of suitable maintenance facilities globally.

# Acknowledgements

The authors wish to acknowledge the assistance of Rod Asher (Cawthron), Dick Mogridge (Sea-Tow Ltd) and Bruce Lines (Diving Services New Zealand Ltd). We also thank Andrew Bell, Daniel Kluza and Eugene Georgiades (MAF Biosecurity New Zealand) for their input throughout the project.

# 6 References

Apte, S., Holland, B.S., Godwin, L.S., Gardner, J.P.A., 2000. Jumping ship: a stepping stone event mediating transfer of non-indigenous species via a potentially unsuitable environment. *Biological Invasions*, 2: 75-79.

Callow, M.E., Callow, J.A., 2002. Marine Biofouling: a sticky problem. Biologist, 49: 1-5.

Campbell, M.L., 2004. *Analysis of vessel entries into New Zealand between 1998 and 2003*. Unpublished report, Ministry of Fisheries, Wellington.

Carlton, J.T., 1985. Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. *Oceanography and Marine Biology Annual Review*, 23: 313-374.

Carlton, J.T., Hodder, J., 1995. Biogeography and dispersal of coastal marine organisms: experimental studies on a replica of a 16th-century sailing vessel. *Marine Biology*, 121: 721-730.

Carlton, J.T., Reid, D.M., van Leeuwen, H., 1995. *Shipping study: the role of shipping in the introduction of non-indigenous aquatic organisms to the coastal waters of the United States (other than the Great Lakes) and an analysis of control options*. US Coast Guard, Connecticut, Department of Transportation, Washington, DC. pp. 1–213.

Clarke, K.R., Warwick, R.M., 1994. *Changes in marine communities: an approach to statistical analysis and interpretation*. Natural Environment Research Council, UK, 144 p.

Coutts, A.D.M., 2002a. *A biosecurity investigation of a barge in the Marlborough Sounds*. Cawthron Report 744, Cawthron Institute, Nelson, New Zealand. 59 p.

Coutts, A.D.M., 2002b. *The development of incursion response tools – underwater vacuum and filter system trials*. Cawthron Report No. 755, Cawthron Institute, Nelson, New Zealand. 27 p.

Coutts, A.D.M., Dodgshun, T.J., 2007. The nature and extent of fouling in vessel sea-chests: a protected mechanism for marine bioinvasions. *Marine Pollution Bulletin*, 54: 875-886.

Coutts, A.D.M., Taylor, M.D., 2004. A preliminary investigation of biosecurity risks associated with biofouling of merchant vessels in New Zealand. *New Zealand Journal of Marine and Freshwater Research*, 38: 215–229.

Coutts, A.D.M., Forrest, B.M., 2007. Development and application of tools for incursion response: lessons learned from the management of the fouling pest *Didemnum vexillum*. *Journal of Experimental Marine Biology and Ecology*, 342: 154-162.

Coutts, A.D.M., Moore, K.M., Hewitt, C.L., 2003. Ships' sea-chests: an overlooked transfer mechanism for non-indigenous marine species? *Marine Pollution Bulletin*, 46: 1510–1513.

Coutts, A.D.M., Piola, R.F., Hewitt, C.L., Connell, S.D., Gardner, J.P.A., 2010. Effect of vessel voyage speed on the survival and translocation of biofouling organisms. *Biofouling*, 26: 1-13.

Cranfield, H.J., Gordon, D.P., Willan, R.C., Marshall, B.A., Battershill, C.N., Francis, M.P., Nelson, W.A., Glasby, C.J., Read, G.B., 1998. *Adventive marine species in New Zealand*. NIWA Technical Report 34. 48 p.

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

Davidson, I.C., McCann, L.D., Sytsma, M.D., Ruiz, G.M., 2008b. Interrupting multi-species bioinvasion vector: the efficacy of in-water cleaning for removing biofouling on obsolete vessels. *Marine Pollution Bulletin*, 56: 1538-1544.

Davidson, I.C., Brown, C.W., Sytsma, M.D., Ruiz, G.M., 2009. The role of containerships as transfer mechanisms of marine biofouling species. *Biofouling*, 25: 645-655.

DeFelice, R.C., 1999. *Fouling marine invertebrates on the floating dry dock USS Machinist in Pearl Harbour to its move to Apra Harbour, Guam*. Hawai'I Biological Survey, Bernice P. Bishop Museum Honolulu, Hawaii. Contribution No. 1999-013 to the Hawaii Biological Survey.

Dodgshun, T.J., Taylor, M.D., Forrest, B.M., 2007. *Human-mediated pathways of spread for non-indigenous marine species in New Zealand*. DOC Research and Development Series 266. Science & Technical Publishing, Department of Conservation, Wellington, New Zealand. 44 p.

Drake, J.M., Baggenstos, P., Lodge, D.M., 2005. Propagule pressure and persistence in experimental populations. *Biology Letters*, 1: 480-483.

Floerl, O., Inglis, G.J., Hayden, B.J., 2005. A risk-based predictive tool to prevent accidental introductions of nonindigenous marine species. *Environmental Management*, 35: 765-778.

Forrest, B.M., 2007. Fouling pests in aquaculture: issues and management options. *New Zealand Aquaculture*, 17: 12-13.

Forrest, B.M., Blakemore, K.A., 2006. Evaluation of treatments to reduce the spread of a marine plant pest with aquaculture transfers. *Aquaculture*, 257: 333-345.

Foster, B. A., Willan, R. C., 1979. Foreign barnacles transported to New Zealand on an oil platform. *New Zealand Journal Marine Freshwater Research*, 13: 143-149.

Forteath, G.N.R., Picken, G.B., Ralph, R., Williams J., 1982. Marine growth studies on the North Sea oil platform Montrose Alpha. *Marine Ecology Progress Series*, 8: 61-68.

Godwin, L.S., Eldredge, L.G., 2001. South Oahu marine invasions shipping study (SOMISS). Technical Report No. 20. Hawaii Biological Survey, Bishop Museum. 104 p.

Gollasch, S., 2002. The importance of ship hull fouling as a vector of species introductions into the North Sea. *Biofouling*, 18: 105-121.

Hayden, B.J., Inglis, G.J., Schiel, D.R., 2009. Marine invasions in New Zealand: a history of complex supply-side dynamics. *In*: Rilov, G., Crooks, J.A. (Eds.), Invasions in Marine Ecosystems. Chapter 24, pp. 409-423. *Ecological Studies* 204, Springer-Verlag Berlin Heideberg.

Hewitt, C.L., 2004. New Zealand marine biosecurity research directions to underpin management. *New Zealand Science Review*, 61:73-77.

Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B., 1999. *Marine biological invasions of Port Phillip Bay, Victoria*. Technical Report No. 20. CSIRO Marine Research. Centre for Research on Introduced Marine Pests, Hobart, 344 p.

Hewitt, C.L., Willing, J., Bauckham, A., Cassidy, A.M., Cox, C.M.S., Jones, L., Wotton, D.M., 2004a. New Zealand marine biosecurity: delivering outcomes in a fluid environment. *New Zealand Journal of Marine and Freshwater Research*, 38: 429-438.

Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B., Mays, N., Ross, D.J., Boyd, S., Gomon, M.F., Lockett, M.M., O'Hara, T.D., Poore, G.C.B., Storey, M.J., Wilson, R.S., Cohen, B.F., Currie, D.R., McArthur, M.A., Keough, M.J., Lewis, J.A., Watson, J.E., 2004b. Introduced and cryptogenic species in Port Phillip Bay, Victoria, Australia. *Marine Biology*, 144:183-202.

Hopkins, G.A., Forrest, B.M., 2008. Management options for vessel hull fouling: an overview of risks posed by in-water cleaning. ICES *Journal of Marine Science*, 65: 811–815.

Hopkins, G.A., Forrest, B.M., 2009. *Biosecurity management plan and risk assessment for the drilling rig Kan Tan IV*. Draft report prepared for the Kan Tan IV Consortium. Cawthron Report No. 1597, Cawthron Institute, Nelson, New Zealand. 50 p.

Hopkins, G.H., Forrest, B.M., Coutts, A.D.M., 2008. *Determining the efficacy of incursion response tools: rotating brush technology (coupled with suction capability).* MAF Biosecurity New Zealand Project ZBS2005-21. 66 p.

Hopkins, G.A., Forrest, B.M., Jiang, W., *In prep*. *Successful eradication of a marine pest in a soft sediment environment*.

James, P., Hayden, B., 2000. *The potential for the introduction of exotic species by vessel hull fouling: a preliminary study*. NIWA Technical Report No. 16. National Institute of Water and Atmospheric Research, Wellington. 15 p.

Lambert, G., 2001. A global overview of ascidian introductions and their possible impact on the endemic fauna. *In*: Sawada, H.; Yokosawa, H.; Lambert, C.C. (Eds) *The Biology of Ascidians*. Springer-Verlag, Hong Kong. 249-257.

Lewis, P.N., Bergstrom, D.M., Whinam, J., 2006. Barging in: a temperate marine community travels to the subantarctic. *Biological Invasions*, 8: 787-795.

Lewis, P.N., Hewitt, C.L., Riddle, M., McMinn, A., 2003. Marine introductions in the Southern Ocean: an unrecognised hazard to biodiversity. *Marine Pollution Bulletin*, 46: 213-223.

Lockwood, J.L., Cassey, P., Blackburn, T., 2005. The role of propagule pressure in explaining species invasions. Trends in ecological evolution, 20: 223-228.

Lonsdale, W.M., 1999. Global patterns of plant invasions and the concept of invisibility. *Ecology*, 80: 1522-1537.

Minchin, D., Gollasch, S., 2003. Fouling and ships' hulls: how changing circumstances and spawning events may result in the spread of exotic species. Biofouling, 19: 111-122.

Nelson, W.A., 1999. A revised checklist of marine algae naturalised in New Zealand. *New Zealand Journal of Botany*, 37: 355-359.

Olenin, S., Gollasch, S., Jonusas, S., Rimkute, I., 2000. *En-route* investigation of plankton in ballast water in ship's voyage from the Baltic Sea to the open Atlantic coast of Europe. *International Review of Hydrobiology*, 85: 577-596.

Relini, G., Tixi, F., Relini, M., Torchia, G., 1998. The macrofouling on offshore platforms at Ravenna. *International Biodeterioration and Biodegredation*, 41: 41-55.

Ruiz, G.M., Carlton, J.T., 2003. Invasion vectors: a conceptual framework for management. *In*: Ruiz, G.M., Carlton, J.T. (Eds.) *Invasive species: vectors and management strategies*. Island Press, pp. 459-504.

Ruiz, G.M., Fofonoff, P.W., Carlton, J.T., Wonhom, M.J., Hines, A.H., 2000. Invasion of coastal marine communities in North America: apparent patterns, processes and biases. *Annual Review of Ecology and Systematics*, 31: 481–531.

Sant, N., Delgado, O., Rodriguez-Prieto, C., Ballesteros, E., 1996. The spreading of the introduced seaweed *Caulerpa taxifolia* (Vahl) C. Agardh in the Mediterranean Sea: testing the boat transportation hypothesis. *Botanica Marina*, 39: 427-430.

Schaffelke, B., Deane, D., 2005. Desiccation tolerance of the introduced marine green alga *Codium fragile* ssp. tomentosoides – clues for likely transport vectors. *Biological Invasions*, 7: 557-565.

Schultz, M., Swain, G.W., 2000. The influence of biofilms on skin friction drag. *Biofouling*, 15: 129–139.

Southgate T., Myers A.A., 1985. Mussel fouling on the Celtic Sea Kinsale field gas platforms. *Estuarine and Coastal Shelf Science*, 20: 651-659.

Taylor, M.D., MacKenzie, L.M., Dodgshun, T.J., Hopkins, G.A., de Zwart, E.J., Hunt, C.D., 2007. Trans-Pacific shipboard trials on planktonic communities as indicators of open ocean ballast water exchange. *Marine Ecology Progress Series*, 350: 41-54.

University of Auckland, 1982. Chapter 8: Platform Fouling by Foster B.A. *In*: Kibblewhite A. C., Berquist P. R., Foster B. A., Gregory M. R. and Miller M. C. *Maui development environmental study: Report on Phase Two 1977-1981*.

Valentine, P.C., Carman, M.R., Blackwood, D.S., Heffron, E.J., 2007. Ecological observations on the colonial ascidian *Didemnum* sp. in a New England tide pool habitat. *Journal of Experimental Marine Biology and Ecology*, 342: 109–121.

Wanless, R.M., Scott, S., Sauer, W.H.H., Andrew, T.G., Glass, J.P., Godfrey, B., Griffiths, C., Yeld, E., 2009. Semi-submersible rigs: a vector transporting entire marine communities around the world. *Biological Invasions* (published online in November 2009; DOI: 10.1007/s10530-009-9666-2).

Yan T., Yan W., Don Y., Wang H., Yan Y. Liang, G., 2006. Marine fouling of offshore installations in the northern Beibu Gulf of China. *International Biodeterioration and Biodegradation*, 58: 99-105.

Yeo, D.C.J., Ahyong, S.T., Lodge, D.M., Ng, P.K.L., Naruse, T., Lane, D.J.W., 2010. Semisubmersible oil platforms: understudies and potentially major vectors of biofouling-mediated invasions. *Biofouling*, 26: 179-186.