

Oliver Floerl¹ & Graeme J. Inglis²

¹*School of Tropical Environment Studies and Geography, James Cook University, Townsville, QLD 4811, Australia [tel: +61 7 4781 6941, fax: +61 7 4781 4020, e-mail: oliver.floerl@jcu.edu.au].*

²*National Institute for Water and Atmospheric Research (NIWA), P.O. Box 8602, Christchurch, New Zealand [tel: +64 3 348 8987, fax: +64 3 348 5548, e-mail: g.inglis@niwa.cri.nz]*

MARINE BIOINVASIONS: QUANTIFYING THE POTENTIAL OF A TRANSFER VECTOR BY ANALYSING ITS RELATIONSHIP WITH THE DONOR REGION.

Abstract

Research on the spread of invasive marine organisms by hull fouling has neglected the potential for transfer of species by recreational boats. In this study, we examine relationships between the fouling assemblages of recreational boats and coastal boat marinas, which may act as potential sources of invasive organisms. Assemblages on vessels, pilings and floating jetties were surveyed in three marinas separated by 300–750 km of coastline in Queensland, Australia. Fouling assemblages varied widely among marinas. Vessels resident in each marina developed fouling assemblages that were characteristic of their homeport. Similarity between the vessel and marina fauna depended upon the age of the antifouling paint on the vessel's hull and how long the boat had been resident in the marina. Biota on the hulls of the vessels variously resembled assemblages on floating jetties or pilings, but the relative importance of each structure as a potential source of propagules varied from marina to marina. Our results show that recreational boat marinas may be an important source for the transfer and spread of hull-fouling organisms. The risk of species transfer depends, in part, on the vessels' antifouling history and on the amount of time they spend in home and destination ports.

Key-words: recreational vessels, marinas, post-invasion spread, marine fouling organisms, hull-fouling

Introduction

An understanding of the threat posed by invasive species requires information on the principle modes and rates of spread of organisms into new geographic areas (Grosholz 1996, Buchan & Padilla 1999). In marine environments, ocean-going vessels are recognised as the most important human vector for the introduction of exotic species (Carlton 1985 and 1996, Hewitt *et al.* 1999). Transport occurs principally through containment in the ballast water of ships (Williams *et al.* 1988, Pendick 1993, Smith *et al.* 1999) or by attachment of fouling organisms to ship's hulls. The latter is thought to have facilitated most historical introductions in marine environments (Hewitt & Campbell 1999, Thresher 1999) and continues to be a source of concern, despite the increasing efficiency of marine antifouling paints (Coultts 1999).

Research on the transport of marine species by hull fouling has focused predominantly on large commercial vessels and has overlooked the role that smaller, recreational craft may play in the spread of exotic species. Recreational vessels are known to be a significant vector for the spread of invasive species in freshwater environments (Johnstone *et al.* 1985, Buchan & Padilla 1999) and have been implicated in the arrival of at least one aggressive marine invader, the Blackstriped mussel, *Mytilopsis sallei* (Field 1999). The growing popularity of aquatic leisure activities means that recreational craft now account for

the majority of vessel movements in coastal waters and may facilitate the spread of hull-fouling species from one destination to the next.

The extent and composition of hull-fouling on commercial vessels depends primarily on the age of the antifouling paint (Visscher 1928, Coutts 1999) and on the travel history of the boat (Bishop *et al.* 1949). Recreational boating is far less economy-driven than commercial shipping. This means that the intervals between successive antifouling treatments are often more variable than commercial vessels and that the residency time in individual ports and marinas is, on average, much longer, providing greater opportunity for the settlement of species (Coutts 1999, Floerl unpubl. data).

The aim of our study was to establish the potential for recreational vessels to spread marine fouling organisms among coastal ports. For this to occur there must be recognisable differences in the pool of species available in different ports and these differences should be reflected in the assemblages present on the hulls of vessels resident within them. To test these predictions, we examined the influence of three factors - port of origin, length of residency, and antifoulant age - on fouling assemblages on the hulls of vessels located in three marinas on the North Queensland coastline, Australia. Assemblages on the vessels were compared to those on pontoons and pilings in each marina to determine their relative similarity with each potential source population. The findings provide a basis for assessing the relative risks associated with recreational vessels that have different patterns of maintenance and travel.

Materials & methods

Coastal marinas in Queensland are mostly small, sheltered harbours that are enclosed by a permanent breakwater. Boats within the marina basin are moored to pontoons (floating jetties) that are held in place by concrete or steel pilings. We surveyed fouling assemblages on pontoons, pilings, and the hulls of a total of 70 recreational vessels in marinas in Airlie Beach (Abel Point Marina, APM), Townsville (Breakwater Marina, BWM) and Cairns (Half Moon Bay Marina, HMBM). Each marina had been in operation since at least 1996 and contained moorings, refueling facilities, a dry-dock and a range of ancillary services. The marinas are separated by 300-750 km of coastline.

The surveys were carried out between the 22nd October and 3rd November 1999. All vessels present in the marina were initially inspected visually for signs of fouling and a subset of fouled vessels were subsequently chosen for quantitative surveys. Fouling assemblages were sampled using a remotely operated camera (ROC) that could be activated from above the surface of the water. This consisted of a Nikonos VTM underwater camera mounted on an adjustable mechanical "arm", that could be adjusted in length and angle. Release of the shutter was achieved by a pulley system connected to a trigger at the "top" of the arm. The camera was equipped with a 28mm lens that sampled an area of 0.15 x 0.22 m. Between 18 to 33 local vessels and all visiting vessels in each marina were sampled by taking eight images at haphazard locations around the hull of each vessel. Interviews with vessel owners and marina operators were used to establish the origin of each vessel, its date of arrival in the marina, and the age of boat's antifouling paint. Resident fouling assemblages were sampled by taking 10 images of each of six pilings (at a depth of 0.5 m to 1.5 m below LWS) and on the underside of six pontoons in each marina.

The percentage cover of fouling organisms in each image was determined by superimposing 60 randomly distributed dots on top of it. Both primary and secondary cover of organisms was estimated by counting the proportion of dots that overlay each organism. Where occupants of primary space could not be identified because of overgrowth, only the secondary cover was recorded. For all analyses, primary and secondary cover were summed, so that in some instances percentage cover was >100%. All fouling biota was categorized to the lowest possible taxonomic level and then by morphotype. Taxa that could not be identified reliably were summarized into broader groupings (e.g., barnacles and oysters). A digital image library was created for all identified "species".

Differences in the composition of resident assemblages in the marinas were tested for using a two-way crossed Analysis of Similarities (Clarke 1993) with marinas and structures (pontoons vs. pilings) as the two factors, and Bray-Curtis percentage similarities as the distance measure. Similarity Percentages

(SIMPER, Clarke 1993) were calculated to illustrate similarities between vessels with antifouling paint ages of >15 months and resident biotas of the different marinas. Differences in the taxonomic richness of hull fouling assemblages on vessels from different marinas were examined using linear models in which the age of antifoulant and residency time were covariates.

Results

Fig.1: Numbers of unfouled and fouled local and visiting vessels combined for all three marinas.

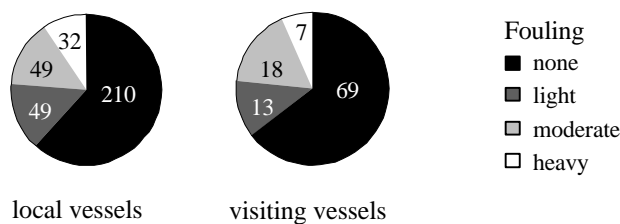


Table 1: (a) Two-way ANOSIM of the resident biotas of the three marinas. (b) Bray Curtis percentage similarities of vessels and marina resident biota of the three marinas.

(a)

Level	Global R-value	Significance
Marinas	1.000	p<0.0001
Structures	1.000	p<0.0001

(b)

	HMBM-R	BWM-R	APM-R
HMBM-V	41.64 (Pi) 67.94 (Po)	35.59 (Pi) 25.11 (Po)	35.91 (Pi) 25.92 (Po)
BWM-V	9.18 (Pi) 30.84 (Po)	41.55 (Pi) 26.92 (Po)	26.28 (Pi) 26.68 (Po)
APM-V	12.81 (Pi) 19.36 (Po)	24.31 (Pi) 12.68 (Po)	17.21 (Pi) 44.76 (Po)

V=vessels, R=resident biota, Pi=pilings, Po=pontoons

A total of 447 vessels were inspected in the three marinas. Although the majority of boats had comparatively clean hulls, a considerable proportion (~35%) of both local and visiting vessels carried light, moderate, or heavy fouling (Fig.1). Local vessels comprised a larger proportion of the overall sample ($n = 340$) than visiting vessels ($n = 107$), but the relative proportions of clean and fouled vessels were similar for both groups ($\chi^2 = 1.46$ at 3 d.f., $P > 0.05$, Fig.1).

There were distinct differences among the resident biotas of the three marinas, and between pilings and pontoons in each marina (Table 1a). Similarity percentage analysis (SIMPER) indicated that assemblages on fouled vessels were consistently most similar to the resident biota of the marina in which they resided (Table 1b). Moreover, the potential source of fouling organisms in each marina (indicated by the greatest overall similarity) appeared to vary among marinas. For example, hull-fouling assemblages in the Half Moon Bay Marina (HMBM) and Abel Point Marina (APM) were, on average, most similar to the resident biota on the pontoons, whereas those in Breakwater Marina (BWM) most closely resembled assemblages on the pilings (Table 2b).

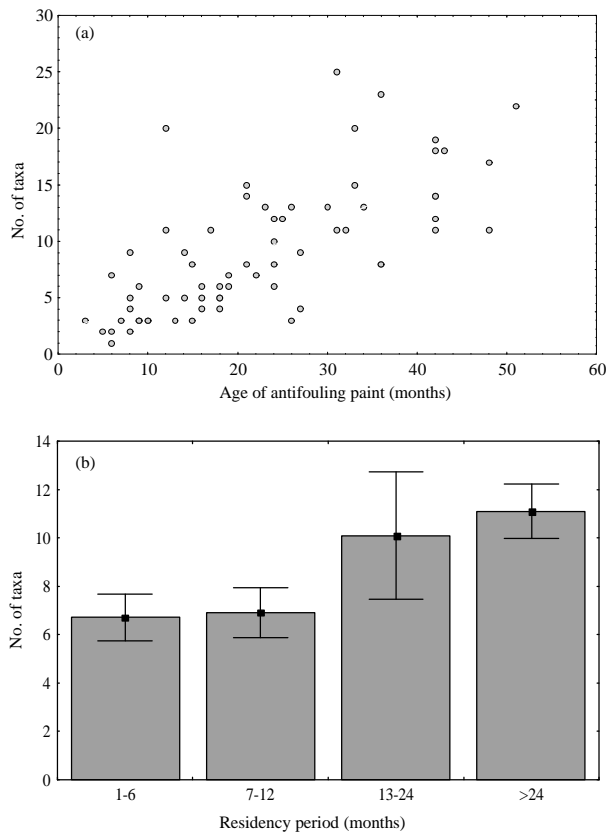
The number of taxa encountered on the vessel hulls increased linearly with the age of the antifouling treatment ($r = 0.71$, $P < 0.001$, Fig.2a). In general, fewer than five taxa were found within the first 15 months after repainting (Fig.2a). These mostly consisted of erect bryozoans (predominantly *Bugula* sp.), *Corophium*, serpulid polychaetes (mainly *Ficopomatus* and *Hydroides*), as well as some encrusting bryozoans and hydroids.

There was a trend of increasing diversity in the hull-fouling assemblages the longer each vessel spent in the marinas (Fig.2b, ANCOVA, $F_{3,55} = 3.85$, $P = 0.014$). Vessels that had resided in the marinas for longer than one year carried taxonomically richer assemblages than boats that had spent less than six months in the marinas (SNK test using the Generalized Studentized Range Statistic (Bryant & Paulson 1976), $p < 0.05$). There were also significant differences in taxonomic richness on vessel hulls between

marinas ($F_{2, 55} = 3.17$, $P = 0.049$); however, there was no significant interaction between marinas and residency period ($F_{6, 55} = 1.69$, 6 *d.f.*, $P = 0.14$).

Discussion

Fig.2: (a) Taxonomic richness of hull fouling assemblages with increasing antifouling paint age. (b) Taxonomic richness of hull fouling assemblages with increasing residency time in the marinas.

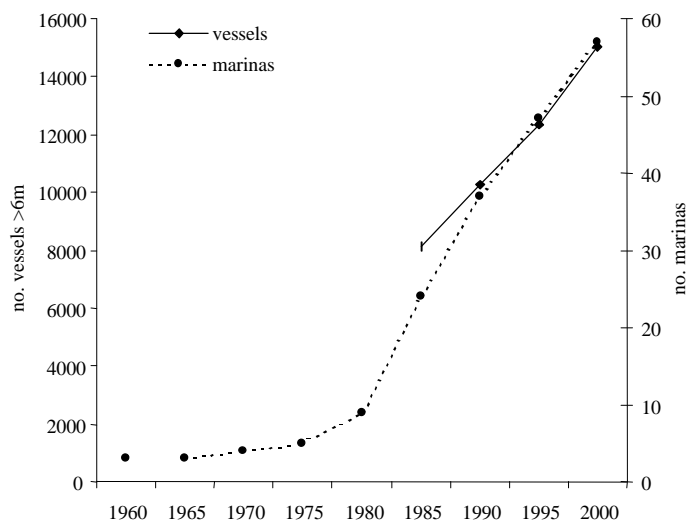


The results of our study indicate that the richness of hull-fouling assemblages on recreational vessel hulls is primarily governed by the age of the antifouling paint. When this effect is controlled for, the composition of the fouling assemblage is affected by the time a vessel has spent in a marina. Hull-fouling assemblages varied consistently among the three marinas that we sampled. Greatest differences were found among vessels that had resided for more than 12 months in any particular marina. Multivariate analyses showed that the assemblages of fouled vessels most closely resembled fouling communities on pilings or pontoons in the marina in which they resided, but that the relative similarity to each type of structure varied among marinas. Future surveys aimed at characterising potential source populations of invasive fouling species in ports and marinas must, therefore, incorporate both types of habitats in their sampling regime, as they often contain quite distinct assemblages (Connell 2000, Glasby 2000, this study).

Anecdotal accounts from the owners of recreational vessels suggest that the problem of hull-fouling varies in intensity among marinas. This was borne out in our analyses, which showed significant variation in the average richness of hull-fouling assemblages in the three marinas. Around 32% of all local vessels and 35% of visiting vessels in the marinas carried light to heavy fouling. Many of the visiting boats that we sampled subsequently left the marinas for other destinations, carrying examples of the local fouling assemblage on their hulls (unpubl. data). Frequent movement of vessels among marinas may facilitate the spread of invasive organisms from one port to the next.

Many introduced marine species have distinctly localised or disjunct distributions, around sheltered harbours and ports (Cranfield *et al.* 1998). Recent studies have shown that, for many of these species, range expansion may be limited by variable reproductive success (Johnson & Carlton 1996) and oceanic dispersal (Farrell *et al.* 1991, Roughgarden *et al.* 1986), and by the availability of suitable habitat (Groszholz 1996). In the last 15 years, the number of registered recreational vessels in Queensland > 6 m long has nearly doubled, from 8111 in 1985 to 15030 in 1999 (Fig. 3). This increase has been mirrored by a general increase in the number of marinas that have been developed to accommodate the growing number of boats (Fig.3). It appears from the number of marina facilities in Queensland that recreational boating

Fig.3: Numbers of vessel registrations (>6 meters) and marina facilities in Queensland, Australia, since 1960 (the oldest marina was established in 1958). Vessel registration data is only available from 1984.



has experienced a large and consistent increase in popularity particularly since the 1980s (Fig.3). As a consequence both the availability of artificial habitats and potential vectors for the spread of fouling organisms have increased. At the same time, the numbers of pleasure craft entering Australian waters have continued to increase, with a maximum of 922 recreational vessel arrivals in 1997 (Australian Customs Service, pers. comm.). Our results demonstrate the potential for recreational vessels to be an important vector for the transfer of fouling organisms among widely separated destinations. Vessels that have been resident in a port for > 12 months and which depart for other destinations without renewing their coat of antifoulant present the greatest risk of spread.

Acknowledgements

We thank managers and staff of the Abel Point Marina (Airlie Beach), the Breakwater Marina (Townsville), and the Half Moon Bay Marina (Yorkey's Knob, Cairns) for their help and permission to let us work in the marinas. We also thank Jo Harris, Tim Harvey, Tony Hill, and Chris "Fingers" Parker for their help with the fieldwork. This work was supported by a Supplementary Postgraduate Award from the Australian Quarantine and Inspection Service (AQIS Ballast Water Research and Management Program), as well as by internal funds from the School of Tropical Environment Studies and Geography (TESAG), James Cook University. OF was further supported by an Overseas Postgraduate Research Scholarship and a TESAG internal scholarship.

References

- Bishop M.W.H., Pyefinch K.A., Spooner M.F. (1949). The interpretation of fouling samples from ships. *Journal of the Iron and Steel Institute*. **161**:35-40.
- Bryant J.L. & Paulson A.S. (1976). An extension of Tukey's method of multiple comparisons to experimental designs with random concomitant variables. *Biometrika*. **63**:631-38.
- Buchan L.A. & Padilla D.K. (1999). Estimating the probability of long-distance overland dispersal of invading aquatic species. *Ecol.Applic.* **9**(1):254-65.
- Carlton J.T. (1985). Transoceanic and interoceanic dispersal of coastal marine organisms: the biology of ballast water. *Oceanogr.Mar.Biol.Ann.Rev.* **23**:313-71.

- Carlton J.T. (1996). Pattern, process, and prediction in marine invasion ecology. *Biol.Cons.* **78**:97-106.
- Clarke K.R. (1993). Non-parametric multivariate analyses of changes in community structure. *Aus.J.Ecol.* **18**:117-43.
- Connell S.D. (2000). Floating pontoons create novel habitats for subtidal epibiota. *J.exp.mar.Biol.Ecol.* **247**:183-94.
- Coutts A.D.M. (1999). *Hull fouling as a modern vector for marine biological invasions: investigation of merchant vessels visiting north Tasmania*. MSc thesis, Australian Maritime College. 252pp.
- 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* (Eds.). NIWA Technical Report 34, Wellington. 48pp.
- Farrell T.M., Bracher D., Roughgarden J. (1991). Cross-shelf transport causes recruitment to intertidal populations in central California. *Limnol. Oceanogr.* **36**(2):279-88.
- Field D. (1999). Disaster averted? Black striped mussel outbreak in northern Australia. *Fish Farming International.* **26**:30-31.
- Glasby T.M. (2000). Surface composition and orientation interact to affect subtidal epibiota. *J.exp.mar.Biol.Ecol.* **248**:177-90.
- Grosholz E.D. (1996). Contrasting rates of spread for introduced species in terrestrial and marine systems. *Ecol.* **77**(6):1680-86.
- Hewitt C.L. & Campbell M.L. (1999). Vectors, shipping and trade. In: Hewitt C.L., Campbell M.L., Thresher R.E., Martin R.B. (Eds.) *Marine Biological Invasions of Port Phillip Bay, Victoria*. Centre for Research on Introduced Marine Pests. Technical Report No.20. CSIRO Marine Research, Hobart. pp. 45-60.
- Hewitt C.L., Campbell M.L., Thresher R.E., Martin R.B. (1999). *Marine Biological Invasions of Port Philip Bay, Victoria* (Eds.). Centre for Research on Introduced Marine Pests. Technical Report No.20. CSIRO Marine Research, Hobart. 344pp.
- Johnson L.E. & Carlton J.T. (1996). Post-establishment in large-scale invasions: dispersal mechanisms of the zebra mussel *Dreissena polymorpha*. *Ecol.* **77**(6):1686-89.
- Johnstone I.M., Coffey B.T., Howard-Williams C. (1985). The role of recreational boat traffic in interlake dispersal of macrophytes: a New Zealand case study. *J.Environ.Man.* **20**:263-79.
- Pendick D. (1993). Ballast-water invaders pose ecological risk. *Science.* **144**(2):20.
- Roughgarden J., Gaines S.D., Pacala S.W. (1986). Supply side ecology: the role of physical transport processes. In: Gee J.H.R. & Giller G.H. (Eds.) *Organization of communities: past and present*. Blackwell Scientific Publications, London. pp. 491-518.
- Smith L.D., Wonham M.J., McCann L.D., Ruiz G.M., Hines A.H., Carlton J.T. (1999). Invasion pressure to a ballast-flooded estuary and an assessment of inoculant survival. *Biological Invasions.* **1**:67-87.

Thresher R.E. (1999). Diversity, impacts and options for managing invasive marine species in Australian waters. *J. Environ. Man.* **6**:137-48.

Visscher J.P. (1928). Nature and extent of fouling of ships' bottoms. *Bull. Bur. Fish.* **43**(2):193-252.

Williams R.J., Griffiths F.B., van der Wal E.J., Kelly J. (1988). Cargo vessel ballast water as a vector for the transport of non-indigenous marine species. *Est. Coast. Shelf Sc.* **26**:409-20.