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Management of exogenous threats to Antarctica and the sub-Antarctic Islands: balancing risks from TBT and non-indigenous marine organisms

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Abstract

The discovery of high levels of tributyltin compounds in Antarctic marine sediments has prompted managers to consider the banning of such substances in this region. We propose that the banning of antifouling coatings may result in an increase in the risk of non-indigenous species invasions. Our studies show that un-treated vessels carry a more diverse community of fouling organisms than treated hulls on which fouling is restricted to specific untreated niches. Up to 40% of the species recruited to the hulls of Southern Ocean vessels are species with invasive histories. Viable fouling assemblages can survive prolonged voyages to high-latitude coastlines, yet passage through sea-ice may remove fouling communities due to mechanical abrasion reducing the hazard of introductions to ice-bound coastlines. The banning of antifouling compounds may be of particular concern for the ice-free sub-Antarctic islands which represent a common anchorage point for vessels on-route to Antarctica.
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The discovery of high levels of tributyltin (TBT) and associated compounds in the marine sediments of the Antarctic shelf by Negri et al. (2004) raises some urgent questions for the management of shipping in this remote and relatively undisturbed environment. The impacts to marine communities associated with toxic antifouling compounds such as TBT have been well described (see review by Fent, 1996). Concern over their impacts has resulted in international agreement to ban the use of TBT under the International Convention on the Control of Harmful Anti-Fouling Systems on Ships (AFS, 2001). This convention will not enforce the ban on vessels owned by governments. Excluded are navy ships and other vessels owned and operated by governments, including the ice-breakers used to support many national Antarctic programs. Despite this exclusion, some governments have indicated they will voluntarily discontinue TBT antifouling paint use on government owned ships. Negri et al. (2004) question whether these measures are sufficient by asking if the use of antifoulant biocides on ships entering Antarctic waters should be addressed by the Antarctic Treaty system.

The purpose of this contribution is to consider some of the issues raised by Negri et al. (2004) and to broaden the discussion by suggesting additional factors for consideration when deciding on appropriate hull treatments for vessels operating in the Southern Ocean.

While a ban on biocidal agents in vessel coatings for high-latitude systems would reduce the impact of this particular exogenous threat to Antarctic and sub-Antarctic systems, such a ban is also likely to result in

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increased levels of hull fouling, which could increase the potential for transfer of non-indigenous species in hull fouling assemblages. Globally, invasive species are considered one of the primary threats to native biological diversity, equal to the threat posed by human mediated global climate change (Carlton, 2001; Hewitt, 2003). Although marine introductions have not yet been identified as a major issue in high-latitude waters, several species are suspected of being introduced to the Antarctic Peninsula region (Clayton et al., 1997; Tavares and De Melo, 2004) and to the New Zealand sub-Antarctic islands (Cranfield et al., 1998). In addition, we have demonstrated in a recent study that modern shipping activities to Antarctic waters can carry diverse fouling assemblages that may result in introductions to Southern Ocean coastlines (Lewis et al., 2003).

We have recently undertaken further investigations of the fouling assemblages on two vessels operating in the Southern Ocean; one with an antifouling paint (*R.V. Southern Supporter*) and one without (*R.V. Aurora Australis*). Divers surveyed the hulls of both vessels immediately before and after voyages of several weeks duration. Distribution of fouling communities was assessed through the use of 10 replicate 0.1 m^2 photo-quadrats at several depths. Due to a shallower draft, *R.V. Southern Supporter* communities were only sampled at 3 depths (1 m, 4 m, 6 m) while *R.V. Aurora Australis* communities were sampled at 4 depths (1 m, 4 m, 6 m, 8 m). Percentage cover data was calculated from the photo-quadrats using *Image J* software. Our results are relevant to the discussion on biocidal hull treatments because they illustrate the effects of passage through sea ice on hull fouling assemblages.

The hull of *R.V. Aurora Australis* was surveyed in Hobart on 2 September 2003 before it departed for the first voyage of the Antarctic season after a winter laid up in the Port of Hobart. The ship conducted marine scientific research in the sea-ice zone before moving to Australia's Casey Station (66°15′S) to transfer scientific and support staff. Both activities involved transit through sea-ice, with ice conditions (Table 1) to a maximum of 10/10 cover and up to 1.0 m deep first year ice with up to 0.4 m snow cover (Ian Allison, pers. comm., daily ship report). On return the hull was resurveyed in Hobart on 30 October 2003.

The pre-departure survey provided additional evidence of the diversity of fouling assemblages that can recruit to untreated hulls (see Table 2). Included in the 35 species recorded from the fouling assemblage were 13 species (40%) known to have invaded new coastal regions through an association with human transport vectors. Whilst fouling covered in excess of 80% of the hull surface in some locations prior to departure (Table 3), no fouling remained following the journey through sea-ice. This finding suggests that mechanical stress resulting from the passage through sea-ice cleaned the hull of fouling assemblages during the voyage and it is likely that the hull was clean prior to reaching Antarctic coastal waters.

The hull of the *R.V. Southern Supporter* was examined in the Port of Fremantle, Western Australia on 31 November 2003 before departing on a four week voyage to Heard Island (53°05′S). The voyage to Heard Island does not require transit through sea-ice but involves passage through some of the roughest seas in the world. On this occasion the ship experienced several days of very rough seas, heavy swells and winds up to 45 knots (Robb Clifton, pers. comm., daily ship report). On the return of the ship to Hobart on 30 December 2003 the hull was re-examined.

In contrast to the diverse assemblages recorded on the untreated hull of the *R.V. Aurora Australis,* the assemblage on the treated hull of the *R.V. Southern Supporter* before departure was much less diverse (18 spp.; Table 2). Consistent with other studies on the efficiency of antifouling treatments (Railkin, 2004) most of the

Table 1
Conditions during the two Southern Ocean voyages (from daily ship reports)

	R.V. Aurora Australis	*R.V. Southern Supporter*
Source Port	Hobart, Tasmania	Fremantle, Western Australia
Southern Ocean Destination	Casey Station, Antarctica	Heard Island, Sub-Antarctic
Recipient Port	Hobart, Tasmania	Hobart, Tasmania
Direct distance (Source Port/Destination/Recipient Port) (km)	6886	9510
Voyage duration (days)	52	28
Maximum ship speed (knots)	14.5	12.5
Maximum wind speed (knots)	44	40–45
Minimum water temperature (°C)	−1.8	1
Temperature range at point of departure (°C)[a]	Hobart: 9.0–20.1	Fremantle: 16.5–27.5
Maximum sea-ice	10/10 cover >1.0 m deep 0.4 m snow cover	None

[a] Temperature ranges at points of departure are based upon 1986–1999 Sea Surface temperatures from the IMCRA bioregions of the ports (A. Hobday, pers. comm.).

Table 2
Species diversity and distribution observed on the hulls of the vessels *R.V. Aurora Australis* and *R.V. Southern Supporter*. Species with a range in the Southern Ocean are identified, and those considered invasive in portions of their range are underlined and references marked to indicate whether they are introduced to Australia (*), cryptogenic in Australia (†), and considered invasive elsewhere in the world (§)

Taxa	Presence in Southern Ocean	Attached (A)/ Unattached (U)	*R.V. Aurora Australis*		*R.V. Southern Supporter*		Reference
			02.09.03	30.10.03	31.11.03	30.12.03	
PLANTAE							
Alga							
Bryopsis sp.		A			Y	Y	
Cladophoropsis sp.		A			Y	Y	
Ulva Enteromorpha compressa	Y	A	Y	–	Y	Y	† Lewis (1999)
Ulva Enteromorpha intestinalis	Y	A			Y	Y	† Lewis (1999)
Ulva rigida	Y	A	Y	–			† Lewis (1999)
Seagrass							
Ruppia magnacarpa		A	Y	–			
ANIMALIA							
Annelida							
Polychaeta							
Harmothoe sp.		U	Y	–			
Hydroides ezoensis		A			Y	Y	† Thorp et al. (1987) § AMBS (2002)
Polychaete sp. 1		A	Y	–			
Pomatocerus taenata		A	Y	–			
Arthropoda							
Amphipoda							
Caprellid sp. 1		U			Y	Y	
Corophidae sp. 1		U	Y	–			
Corophidae sp. 2		U	Y	–			
Monocorophium acherusicum		U	Y	–	Y	Y	* Poore and Storey (1999) § Hewitt et al. (2002)
Hyallidae sp. 1		U	Y	–			
Hyallidae sp. 2		U	Y	–			
Hyperrid sp.		U			Y		
Ischyroceridae sp.1		U	Y	–			
Jassa falcata		U			Y		
Jassa herdmani	Y	U				Y	
Jassa sp.		U	Y	–			
Cirripedia							
Balanus amphitrite		A			Y	Y	*§ Keough and Ross (1999)
Balanus variegatus		A			Y	Y	
Chonchoderma aurita	Y	A				Y	
Elminius modestus		A	Y	–			† Keough and Ross (1999) § Crisp (1958)
Lepas anitifera		A			Y	Y	
Decapoda							
Halicarcinus innominatus			Y	–			* Pollard and Hutchings (1990)
Machrobranchium sp.		U	Y	–			
Chordata							
Teleost							
Larval fish sp.		U	Y	–			
Cnidaria							
Fa. Plumulariidae		A				Y	
Fa. Campanulariidae		A	Y	–	Y		
Bougainvillia muscus		A	Y	–			*§ Watson (1999)
Clytia hemispherica		A			Y	Y	*§ Watson (1999)
Obelia dichotoma		A	Y	–			* Watson (1999) § Carlton (1979)
Obelia sp.		A	Y	–			
Ectopleura crocea		A	Y	–			* Watson (1999) § Carlton (1979); Hewitt et al. (2002)
Ectoprocta							
Bugula flabellata		A	Y	–			* Allen (1953); Pollard and Hutchings (1990) § Keough and Ross (1999)

(*continued on next page*)

Table 2 (*continued*)

Taxa	Presence in Southern Ocean	Attached (A)/ Unattached (U)	*R.V. Aurora Australis*		*R.V. Southern Supporter*		Reference
			02.09.03	30.10.03	31.11.03	30.12.03	
Bugula neritina		A			Y		* Bock (1982) § Hewitt et al. (2002)
Celleporina sp.		A			Y		
Electra sp.		A	Y	–			
Membranipora membranacea		A	Y	–			* Keough and Ross (1999) § Berman et al. (1992)
Tricellaria occidentalis		A	Y	–			* Keough and Ross (1999) § Gordon and Mawatari (1992); Dyryndra et al. (2000)
Watersiporia subtorquata		A	Y	–	Y	Y	* Keough and Ross (1999) § Carlton (1979); Gordon and Mawatari (1992)
UROCHORDATA							
Ascidian sp. 1		A	Y	–		Y	
Ascidian sp. 2		A	Y	–		Y	
Ascidian sp. 3		A	Y	–		Y	
Ascidian sp. 4		A	Y	–			
Ciona intestinalis		A	Y	–			*§ Kott (1985); Hewitt et al. (2002)
MOLLUSCA							
Mytilus galloprovincialis	Y[a]	A	Y	–	Y	Y	† McDonald et al. (1991); Hewitt et al. (2002) § Stewart et al. (1985); Hewitt et al. (2002)
Nudibranch sp. 1		U	Y	–			
Nudibranch sp. 2		U	Y	–			
Total			35	0	18	19	
% Non-indigenous			40	–	50	42.1	

[a] This species is known to occur in the Kerguelen Islands.

species were found on untreated parts of the hull such as the cathodic protection systems, which are deliberately left unpainted, and the areas covered by supporting chocks during re-painting in dry-docks, referred to as dry-dock support strips (DDSS; Coutts, 1999; Lewis et al., 2003).

After the voyage to Heard Island a large proportion of the species in the original fouling assemblage remained (Table 2). Thirteen species or 72% of the original assemblage survived the journey, including eight species known to be invasive. All surviving species were restricted to the untreated areas of the DDSS and cathodic protection systems. The presence of these species at the beginning and end of the voyage shows that viable individuals were present on the hull when the vessel was in the waters adjacent to Heard Island. This is of particular concern because Heard Island is one of the few invasion-free environments remaining in the world—one of the values for which it was inscribed to the World Heritage List in 1997. In addition, not only did a significant portion of the original Fremantle assemblage survive the journey to Hobart via Heard Island intact, but at the end of the voyage an additional six species were detected, many native to the Southern Ocean.

The difference between fouling communities after the voyages to the Antarctic continent and Heard Island are strong evidence that passage through sea-ice is the cause of the loss of the fouling assemblage, probably due to abrasion. We believe that ice abrasion is the primary cause of the loss of the fouling community because of the strong sheer forces associated with pushing through sea-ice during ice-breaking operations. Alternative explanations such as faster traveling speeds, rougher seas or colder water were rejected because none of these factors differed greatly between the two voyages (Table 1).

Our results demonstrate that the benefits of using biocidal paints on external hull surfaces to reduce the risks of introductions may be largely negated for vessels operating in sea-ice. Negri et al. (2004) suggest that the introduction of TBT compounds to Antarctic sediments does not occur through slow leaching processes, but probably results from a similar process of abrasion of paints during passage through sea-ice; a process which may introduce flakes of paint directly into the waters adjacent to major shipping lanes. This process significantly reduces the effectiveness of the antifouling paint themselves, by leaving large chips and scrapes in the coating that allow the settlement of fouling organisms (pers. obs.).

Table 3
The distribution and dominant taxa observed at initial and final inspections of hull fouling communities for a) *R.V. Aurora Australis*, and b) *R.V. Southern Supporter*. Distribution was assessed through the use of 10 replicate 0.1 m^2 photo-quadrats at each depth. Note that large standard deviations recorded for the *R.V. Southern Supporter* communities correlate to the patchy distribution of barnacles at 1 m depth, the restriction of algal communities to cathodic protection installations at 4 m, and the restriction of fouling to DDSS at 6 m. Smaller standard deviations in the *R.V. Aurora Australis* community reflect a more uniform distribution of organisms

Depth (m)	Before 2.09.03		After 30.10.03		Notes
	% Fouling cover	Dominant taxa	% Fouling cover	Dominant taxa	
(a) R.V. Aurora Australis					
1	80.9 (10.3)	Algae	0	–	Species were evenly distributed at each depth of the hull surface. No species were observed from the hull of the *R.V. Aurora Australis* following the return of this voyage
4	71.7 (7.9)	Algae	0	–	
6	17.6 (6.4)	Ascidians, Polychaetes	0	–	
8	28.3 (14.3)	Ascidians	0	–	
	Before 31.11.03		After 30.12.03		
(b) R.V. Southern Supporter					
1	0.7 (1.5)	Cirripedes	0.6 (1.2)	Cirripedes	Few barnacles distributed on hull surface
4	1.8 (4.8)	Algae	2.6 (3.8)	Algae	Communities restricted to cathodic protection devices
6	9.7 (19.2)	Polychaetes, Cirripedes	12.1 (24.4)	Polychaetes, Cirripedes	Communities res tricted to DDSS

Epoxy coatings may be more durable and last longer than antifouling paints when used on the hulls of ice-breakers. Instead of biocidal paints, the *R.V. Aurora Australis* is coated with a durable epoxy (Hempadur Multistrength 4575), and biocidal agents (Hepadur Multistrength 4575—a self-polishing antifoulant with cuprious oxide, diuron and liquid hydrocarbon as the active agents) are restricted to the sea-chests and the bow- and stern thrusters which are not subject to ice abrasion. Lewis et al. (2003) demonstrate that due to the absence of antifouling compounds upon the *R.V. Aurora Australis* hull, diverse biological assemblages, including species with known invasive capabilities, settle on the hull during periods of inactivity over winter.

Some species, such as the Australian native hydroid *Ralpharia magnifica*, have been shown to settle in substantial assemblages only two weeks after passage through sea-ice (Lewis et al., 2003). As a consequence, antifouling coatings may still both reduce the risk of transfer of invasive marine species and increase the operational efficiency of vessels due to the reduced tendency of vessel hulls to accumulate fouling organisms during periods of inactivity in temperate ports.

Whether or not the application of antifouling treatments would confer an operational or economic benefit depends entirely on how the ship is used. There is little value in treating those ice-breakers that are based in southern hemisphere ports and are only used to support activities on the Antarctic continent. The reduction in maximum speed and fuel efficiency caused by a heavily fouled hull only lasts until sea-ice is first encountered during the first voyage of the Antarctic season. The cost of antifouling treatments is unlikely to be off-set by increased fuel efficiency during this brief period. However, for ships based in the northern hemisphere or involved in Antarctic voyages for only part of the year, such as many ice-breakers used for tourism, the operational benefits of antifouling treatments may be much greater. A fouling layer of only 1mm thickness can cause a 15% loss in ship speed, and fouling may result in a 36% increase in fuel consumption (Walters, 1996). This increased efficiency could generate a substantial cost saving during a relocation voyage from the northern hemisphere.

Similarly, the environmental benefits of either using or not using an antifouling treatment will also depend on how the ship is operated. While antifouling paints may cause toxic impacts to benthic communities in the near-shore Antarctic marine environment, they also reduce the chance of transfer of non-indigenous species under certain circumstances. For those ships based in southern hemisphere ports and only traveling to the Antarctic continent there appears to be no environmental benefit to the use of antifoulants and there is the potential risk of toxicants entering the environment. However, shipping activities in the Southern Ocean often involve multiple shore approaches which may include anchoring in nearshore waters of sub-Antarctic islands. Both tourism operators and scientific research and re-supply vessels routinely visit sub-Antarctic islands en route to Antarctic coastal waters. For ships that are used in this way the environmental benefits of not using biocidal antifoulants must be balanced against the increased hazard of marine introductions, particularly to sub-Antarctic islands.

The introduction of toxic substances to the pristine waters of the Antarctic continental shelf is manifestly undesirable, yet the introduction of invasive marine organisms may have a far more profound and long-lasting influence upon high latitude marine communities (Grosholz, 2002). While pollution by TBT and other biocidal compounds are localized and will decrease with time, invasive populations of marine organisms are capable of maintaining, and subsequently increasing their density and impacts following establishment. Furthermore, upon introduction in areas adjacent to shipping activity, populations of invasive organisms are capable of spreading laterally away from the site of initial infection and affecting communities remote from any human disturbance (Orensanz et al., 2002; Wasson et al., 2001). As an extreme example of lateral spread, populations established at one sub-Antarctic island could be capable of spreading to down-stream islands through an association with kelp rafts (Edgar, 1987; Smith, 2002) or floating plastic debris (Barnes, 2002; Barnes and Fraser, 2003), both of which have been shown to be capable of dispersing coastal organisms between sub-Antarctic islands in association with the circum-Antarctic currents.

Due to a combination of rapid climate change and an increase in the intensity of human operations in the Southern Ocean, the risk of marine introductions in this region will increase in the future (Chown et al., 1998; Chown and Gaston, 2000; Convey, 2001; Stachowics et al., 2002; Frenot et al., submitted for publication). While we consider that the exogenous threat of TBT compounds and other toxic agents used in antifouling paints needs to be addressed in high latitude systems, we also urge caution in consideration of any measures aimed to limit the use of antifouling agents in Southern Ocean waters. Any move to do so must carefully weigh the potential side-effects, and should consider the secondary impacts to the sub-Antarctic islands which are connected to the Antarctic coastal waters through common shipping pathways.

References

AFS, 2001. International Convention on the Control of Harmful Anti-Fouling Systems on Ships, adopted 5 October 2001. Available from: <http://www.imo.org>, accessed 1 June 2004.

Allen, F.E., 1953. Distribution of marine invertebrates by ships. Australian Journal of Marine and Freshwater Research 4, 307–316.

AMBS—Australian Museum Business Service, 2002. Port Survey for Introduced Marine Species—Sydney Harbour Final Report, report prepared for Sydney Ports Corporation, 7 May, 2002.

Barnes, D.K.A., 2002. Invasions by marine life on plastic debris. Nature 416, 808–809.

Barnes, D.K.A., Fraser, K.P.P., 2003. Rafting by five phyla on man-made flotsam in the Southern Ocean. Marine Ecology Progress Series 262, 289–291.

Berman, J., Hamis, L., Lambert, W., Buttrick, M., Defrense, M., 1992. Recent invasions of the Gulf of Maine: three contrasting ecological histories. Conservation Biology 6 (3), 435–441.

Bock, P.E., 1982. Bryozoans (Phylum Bryozoa or Ectoprocta), pp. 319–394. In: Shephard, S.A., Thomas, I.M. (Eds.), Marine Invertebrates of Southern Australia. Part 1. South Australian Government Printer, Adelaide, South Australia, Australia.

Carlton, J.T., 1979. History, biogeography, and ecology of the introduced marine and estuarine invertebrates of the Pacific coast of North America. Ph.D. dissertation, University of California, Davis, 904 pp.

Carlton, J.T., 2001. Introduced species in US coastal waters: environmental impacts and management priorities. Pew Oceans Commission, Virginia, USA, 28 pp.

Chown, S.L., Gremmen, N.J.M., Gaston, K.J., 1998. Ecological biogeography of Southern Ocean islands: species-area relationships, human impacts and conservation. American Naturalist 152, 562–575.

Chown, S.L., Gaston, K.J., 2000. Island hopping invaders hitch a ride with tourists in the Southern Ocean. Nature 408, 637.

Clayton, M.N., Wiencke, C., Kloser, H., 1997. New records of temperate and sub-Antarctic marine benthic macroalgae from Antarctica. Polar Biology 17, 141–149.

Convey, P., 2001. Terrestrial ecosystem response to climate changes in the Antarctic. In: Walther, G.R., Burga, C.A., Edwards, P.J. (Eds.), "Fingerprints" of Climate Change—Adapted Behaviour and Shifting Species Ranges. Kluwer, New York, pp. 17–42.

Coutts, A.D.M., 1999, Hull fouling as a modern vector for marine biological invasions: investigation of merchant vessels visiting northern Tasmania. Masters Thesis, Australian Maritime College, Launceston, unpublished.

Cranfield, H.J., Gordon, D.P., Willan, R.C., Marchall, 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, Wellington, NZ.

Crisp, D.J., 1958. The spread of *Elminius modestus* Darwin in north-west Europe. Journal of the Marine Biological Association of the United Kingdom 37, 483–520.

Dyryndra, P.E.J., Fairall, V.R., Occhipinti-Ambrogi, A., d'Hondt, J.L., 2000. The distribution, origins and taxonomy of Tricellaria inopinata d'Hondt and Occhipinti Ambrogi, 1985, an invasive bryozoan new to the Atlantic. Journal of Natural History 34, 1993–2006.

Edgar, G.J., 1987. Dispersal of faunal and floral propagules associated with drifting *Macrocystis pyrifera* plants. Marine Biology 95, 599–610.

Fent, K., 1996. Ecotoxicology of organotin compounds. Critical Reviews in Toxicology 26, 1–117.

Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P.M., Convey, P., Skotnicki, M., Bergestrom, D.M., submitted for publication. Biological Invasions in the Antarctic: extent, impacts and implications. Biological Reviews.

Gordon, D.P., Mawatari, S.F., 1992. Atlas of marine-fouling Bryozoa of New Zealand ports and harbours. Miscellaneous Publications of the New Zealand Oceanographic Institute 107, 1–52.

Grosholz, E.D., 2002. Ecological and evolutionary consequences of coastal invasions. Trends in Ecology and Evolution 17, 22–27.

Hewitt, C.L., Martin, R.B., Sliwa, C., McEnnulty, F.R., Murphy, N.E., Jones, T., Cooper, S. (Eds.), 2002. National Introduced Marine Pest Information System. Available from: <http://crimp.marine.csiro.au/nimpis>.

Hewitt, C.L., 2003. Marine biosecurity issues in the world oceans: global activities and Australian directions. Ocean Yearbook 17, 193–212.

Keough, M.J., Ross, D.J., 1999. Introduced fouling species in Port Phillip Bay, pp. 193–226. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), The Introduced Species of

Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests Technical Report No. 20, CSIRO Marine Research, Hobart.

Kott, P., 1985. The Australian Ascidiacea part 1, Phlebobranchia and Stolidobranchia. Memoirs of the Queensland Museum 23, 1–440.

Lewis, J.A., 1999. A review of the occurrence of exotic macroalgae in Southern Australia, with emphasis on Port Phillip Bay, Victoria, pp. 61–87. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), The Introduced Species of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests Technical Report No. 20, CSIRO Marine Research, Hobart.

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

McDonald, J.H., Seed, R., Koehn, R.K., 1991. Allozymes and morphometric characters of three species of *Mytilus* in the northern and southern hemispheres. Marine Biology 111, 323–333.

Negri, A.P., Hales, L.T., Battershill, C., Wolff, C., Webster, N.S., 2004. TBT contamination identified in Antarctic marine sediments. Marine Pollution Bulletin 48, 1142–1144.

Orensanz, J.M., Schwindt, E., Pastorino, G., Bortolus, A., Casas, G., Darrigran, G., El'ýas, R., Grappa, J.L.L., Obenat, S., Pascual, M., Penchaszadeh, P., Piriz, M.L., Scarabino, F., Spivak, E.D., Vallarino, E.A., 2002. No longer the pristine confines of the world ocean: a survey of exotic marine species in the southwestern Atlantic. Biological Invasions 4, 115–143.

Pollard, D.A., Hutchings, P.A., 1990. A review of exotic marine organisms introduced to the Australian Region. II. Invertebrates and Algae. Asian Fisheries Science 3, 223–250.

Poore, G.C.B., Storey, M., 1999. Soft sediment Crustacea of Port Phillip Bay, pp. 150–170. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), The Introduced Species of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests Technical Report No. 20, CSIRO Marine Research, Hobart.

Railkin, A.I., 2004. Marine Biofouling: Colonization Processes and Defenses. CRC Press, Florida 303pp.

Smith, S.D.A., 2002. Kelp rafts in the Southern Ocean. Global Ecology and Biogeography 11, 67–69.

Stachowics, J.J., Terwin, J.R., Whitlatch, R.B., Osman, R.W., 2002. Linking climate change and biological invasions: ocean warming facilitates nonindigenous species invasions. Proceedings of the National Academy of Sciences of the United States of America 99 (24), 15497–15500.

Stewart, Grant, W., Cherry, M.I., 1985. *Mytilus galloprovincialis* Lmk. in Southern Africa. Journal of Experimental Biology and Ecology 90 (2), 179–191.

Tavares, M., De Melo, G.A.S., 2004. Discovery of the first known benthic invasive species in the Southern Ocean: the North Atlantic spider crab *Hyas araneus* found in the Antarctic Peninsula. Antarctic Science 16 (2), 129–131.

Thorp, C.H., Pyne, S., West, S.A., 1987. *Hydroides ezoensis* Okuda, a fouling serpulid new to British coastal waters. Journal of Natural History 21, 863–877.

Walters, S., 1996. Ballast Water, Hull Fouling and Exotic Marine Organism Introductions via Ships—A Victorian Study. Environmental Protection Authority, State Government of Victoria, Melbourne.

Wasson, K., Zabin, C.J., Bedinger, L., Diaz, M.C., Pearse, J.S., 2001. Biological invasions of estuaries without international shipping: the importance of intraregional transport. Biological Conservation 102, 143–153.

Watson, J.E., 1999. Review of hydroids introduced to Victorian waters, pp. 88–107. In: Hewitt, C.L., Campbell, M.L., Thresher, R.E., Martin, R.B. (Eds.), The Introduced Species of Port Phillip Bay, Victoria. Centre for Research on Introduced Marine Pests Technical Report No. 20, CSIRO Marine Research, Hobart.