Vol. 339: 307–310, 2007 | MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser | Published June 6

NOTE

Mytilus on the move: transport of an invasive bivalve to the Antarctic

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ABSTRACT: Increasing numbers of scientific and tourist vessels are entering the Antarctic region and have the potential to bring with them a range of organisms that are not currently found in the region. Little is known about the frequency of such introductions or the identity and survivorship of the species associated with them. In this study, we report the findings of an inspection of the sea chests of the South African National Antarctic Programme supply vessel, the SA 'Agulhas', while the vessel was in dry dock in June 2006. Large populations of a known invasive mussel, *Mytilus galloprovincialis* (Lamarck), were found. By extrapolating from shell length, the age of individuals was estimated, the results of which suggest that some specimens have survived transportation to the Antarctic region on multiple occasions. These findings are cause for concern and demonstrate that Antarctic research and supply vessels are important vectors for marine non-indigenous species into the region.

KEY WORDS: Antarctica · Gough Island · Invasive alien species · Marion Island · Propagule pressure

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INTRODUCTION

Biological invasions threaten nearly every major habitat type on earth (Millennium Ecosystem Assessment 2005), and the impacts of non-indigenous species (NIS) are significant even in remote regions such as the Antarctic (Frenot et al. 2005). While the study of NIS in the terrestrial realm is well developed, understanding of marine NIS and the extent to which they might become invasive in the Antarctic is less extensive (Barnes 2002, Lewis et al. 2003).

Countless vessels, including tourist ships, fishing vessels and scientific support vessels, enter the Antarctic region each year. The age, voyage schedule, antifouling regime and home ports of these vessels are diverse, presumably resulting in substantial variation in the diversity and abundance of NIS that are transported (Lewis et al. 2003). One notable feature of vessels entering the Antarctic is that few of them discharge ballast water at high latitudes. Instead, ballast water is more usually taken aboard in Antarctic waters, after cargo offloading, and subsequently discharged in temperate waters. Therefore, introductions via ballast water discharge are relatively unimportant in this region.

By contrast, good evidence exists that Antarctic supply vessels have the potential to introduce NIS to the region as hull fouling assemblages (Lewis et al. 2003, 2004, 2006). Large fouling assemblages accumulate when vessels are subject to long port layovers such as those experienced by Antarctic support vessels during the Austral winter. In this regard, sea chests, which are covered recesses in the hull from which water for the engines' cooling systems is drawn, are likely to be an important transport route for NIS to high latitudes. Fouling assemblages in sea chests are protected from the shearing forces found elsewhere on the hull, but they still experience a constant flow of nutrients. More-

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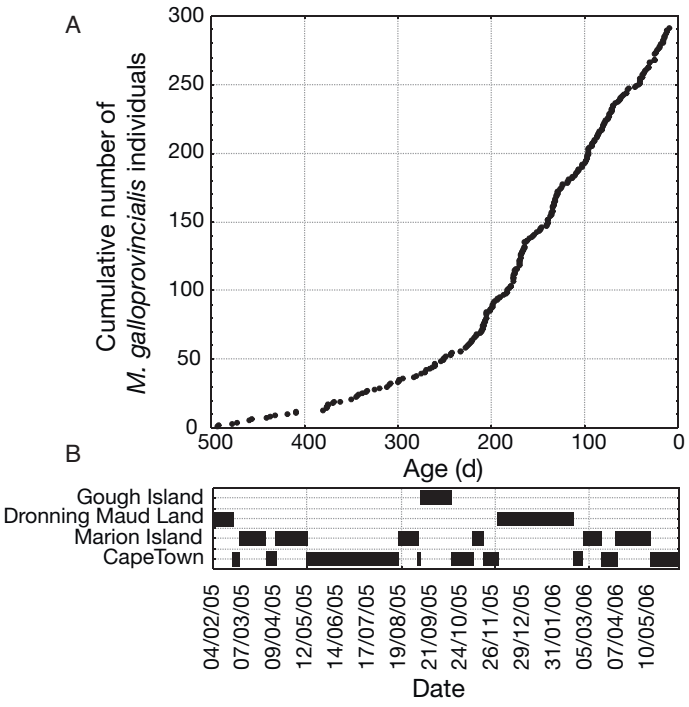

Fig 1. *Mytilus galloprovincialis*. (A) Cumulative frequency distribution of individuals collected from the sea chests of the SA 'Agulhas' and (B) the voyage schedule of the vessel. Dates given as dd/mm/yy. In (A), samples were taken from the sea chests on 10 June 2006, and ages were estimated from mussel size (see text). The frequency distribution indicates that only 50 of the sampled individuals were older than 250 d, whereas more than 90 individuals were younger than 100 d. The position of an individual in (A) also indicates, based on its age, the locations to which it has travelled as shown in (B), viz., an individual will have travelled to all locations to its right in (B)

over, in high latitude areas characterised by extensive sea ice, these assemblages are sheltered from the ice scour that typically removes the majority of fouling assemblages elsewhere on the hull (Lewis et al. 2004).

Here we provide a first assessment of the dominant organism dwelling in the sea chests of the supply vessel used by the South African National Antarctic Programme (SANAP), the SA 'Agulhas'. The vessel is based in Cape Town harbour, which is home to several highly invasive species, including the Mediterranean mussel *Mytilus galloprovincialis* and the European green crab *Carcinus maenas* (Robinson et al. 2005). *M. galloprovincialis* probably entered the harbour by ship(s) (Branch & Steffani 2004), and it seems equally likely that this species can leave by the same means. We show that *M. galloprovincialis* predominates in the sea chests of the SA 'Agulhas', and based on an estimate of the age-structure of the population, we demonstrate that at least some individuals in this population have survived multiple voyages to the Antarctic region.

METHODS

The SA 'Agulhas' undertakes several voyages into the Antarctic region each year (Fig. 1). The hull and sea chests of the vessel are painted with Interspeed 340 (International Paints), a controlled depletion, self-polishing anti-fouling paint containing a gum rosin polymer system and copper oxide and zinc oxide biocides. The vessel is also fitted with a cathodic protection system. The anti-fouling paint and the cathodic protection system were last replenished in June 2003. Although the sea chests have a volume of only 6 m^3, they contain several baffles and have a complex internal structure, and so have a surface area of ca. 42 m^2, thus providing a substantial potential habitat area.

In June 2006, within 24 h of the vessel entering the dry dock, the sea chests were inspected. During the inspections, ten 0.1 m^2 quadrats were randomly placed within each of the vessel's 2 main sea chests. Fouling cover was recorded and representative samples of all organisms were collected for later identification in the laboratory. Fouling cover ranged from 100% cover on exposed surfaces subject to high water flow to 10% in more sheltered areas of the sea chests, giving a mean (± SD) cover of 59.5 (± 43.03)% for the port sea chest and 64.5 (± 33.37)% for the starboard sea chest. Assemblages were dominated by *Mytilus galloprovincialis* (Fig. 2), although individuals of *Aulacomya ater* (Mollusca, Bivalvia), *Notomegabalanus algicola* (Crustacea, Cirripedia) and *Ciona intestinalis* (Chordata, Ascidiacea) were also found. *M. galloprovincialis* specimens were stimulated with a sharp tap to elicit valve closure, and individuals that did not respond (20 of a total of 311) were considered dead and excluded from subsequent analyses. Mitutoyo digital callipers were used to measure the maximum shell length of all live specimens to the nearest µm. Individuals <1 mm were not included, because accurate identification of these individuals was not possible. The mean shell length was 23.12 ± (13.17) mm and the maximum was 55.9 mm.

Mytilus galloprovincialis has variable growth rates that are strongly influenced by temperature, air exposure and water flow (van Erkom Schurink & Griffiths 1993). Although sea chests are permanently flooded, both temperature and water flow within the sea chests of the SA 'Agulhas' are highly variable. When the ship is in port, there is almost no water flow through the sea chests, whereas it can rise to 1000 $m^3\ h^{-1}$ when the ship is at sea (J. Klopper pers. comm.). Similarly, water temperatures range from a mean of –1.6°C when the ship is stationed off Dronning Maud Land to a mean of 15.5°C when it is berthed in Cape Town harbour (33° 55′ S, 18° 26′ E; temperatures obtained from Advanced Very High Resolution Radiometer remotely sensed data, available on request from

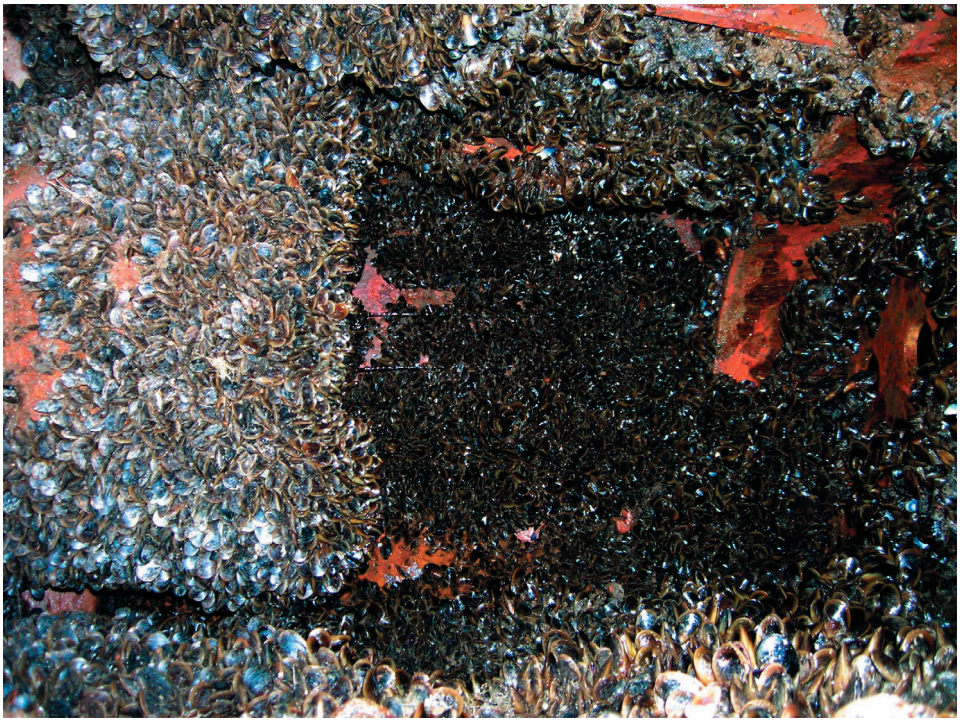

Fig. 2. *Mytilus galloprovincialis* dominating fouling assemblages in the sea chests of the SA 'Agulhas'

http://satori.gso.uri.edu). No growth rate estimations for these conditions are available. However, a conservative estimate of *M. galloprovincialis* growth rate was obtained from data provided for a colony of *M. galloprovincialis* grown at approximately 15°C with high water circulation and zero aerial exposure at Saldanha Bay, 110 km north of Cape Town (van Erkom Schurink & Griffiths 1993). The age of specimens found in the sea chests of the SA 'Agulhas' at a given length was estimated using the equations provided by van Erkom Schurink & Griffiths (1993):

$$l(t) = a + bt - ct^2 \quad (1)$$

$$t(l) = \frac{b - \sqrt{b^2 - 4cl}}{2c} \quad (2)$$

where l is length in mm, t is age in months, and a, b and c are constants. According to van Erkom Schurink & Griffiths (1993), b = 5.197 and c = 0.108. Although van Erkom Schurink & Griffiths (1993) set a = 20.25 and measured the growth of individuals above this size, we set a = 0 because many individuals in our study were less than 20.25 mm in length. Using these values, individuals collected from the SA 'Agulhas' were estimated to range from 0.31 to 16.23 mo in age. These age estimates are conservative, because growth rates are slower at lower temperatures (Seed 1976, van Erkom Schurink & Griffiths 1993).

Therefore, *Mytilus galloprovincialis* has been transported to the Antarctic region in the sea chests of the SA 'Agulhas' on multiple occasions (Fig. 1). *M. galloprovincialis* reaches maturity at approximately 25 mm in length (C. Griffiths pers. comm.). In consequence, larvae could have been released at any of the locations visited by the vessel. The minimum survival temperature of *M. galloprovincialis* is 0°C (Braby & Somero 2006), and some individuals of the SA 'Agulhas' population have clearly survived at least –1.6°C. Growth in this species has been recorded at a minimum temperature of 3°C (Seed 1976). Given that sea surface temperature varies annually between 5 and 8°C at Marion Island and between 10 and 16°C at Gough Island (Mélice et al. 2003), establishment of larvae or of displaced adults or immatures could have taken place at these islands. Long-term survival and growth under Antarctic conditions seems less likely, but it is clear that other marine NIS can survive in the region (Clayton et al. 1997, Tavares & De Melo 2004).

IMPLICATIONS

The transport of *Mytilus galloprovincialis* from Cape Town harbour to various locations throughout the broader Antarctic region and its survival in these conditions demonstrate that temperate species are capa-

ble of short-term survival under polar conditions. They also show that Antarctic supply vessels are important vectors for NIS and that the antifouling technology employed by such vessels has limited effectiveness. Given the provisions of the Antarctic Treaty and its associated protocols, as well as the management plans of many Southern Ocean islands, the confirmed transport and survival of a known invasive species (Branch & Steffani 2004) to the Antarctic is cause for concern. Further research is now needed to determine if *M. galloprovincialis* is capable of reproduction in Antarctic waters, to assess the extent to which research vessels based in other locations carry similar fouling loads, and to determine best practises for addressing these problems given the unique operating conditions of these vessels. Moreover, inspection of the intertidal areas of both Gough and Marion Islands for populations of this invasive species should be undertaken.

Acknowledgements. Thanks to J. Klopper (Smit Marine) for technical information on sea chests and voyage schedules of the SA 'Agulhas' and for considerable assistance; to J. Fergus (International Paint Ltd.) for information on the anti-fouling paint; to S. Oosthuizen of the South African Department of Environmental Affairs and Tourism (DEA&T) for assistance, to C. Griffiths of the University of Cape Town for confirmation of species identifications; to 2 anonymous referees for their helpful comments; and to DEA&T for logistic support.

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Editorial responsibility: Howard Browman (Associate Editor-in-Chief), Storebø, Norway

Submitted: September 7, 2006; Accepted: November 30, 2006
Proofs received from author(s): May 17, 2007