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NOTE

Polar pedunculate barnacles piggy-back on pycnogona, penguins, pinniped seals and plastics

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ABSTRACT: There is much concern about the potential for invasive species to enter the only marine region left with no known exotics — the Southern Ocean. Attention has focused on planktonic larval travel, shipping (ballast water and hull fouling) and marine debris as transport mechanisms. There is, however, another source of transport for biota across the Polar Frontal Zone — hitchhiking on megafauna, such as seals. In this study we report the frequency and burden of barnacles *Lepas australis* attached to Antarctic fur seals *Arctocephalus gazella* coming ashore to breed at Bird Island, South Georgia. In the austral summers of 2001/2002, 2002/2003 and 2003/2004, female fur seals with barnacles attached arrived at Bird Island in late November/early December and peaked in mid-December. About 4% of female fur seals carried barnacles, with the mean burden being ~10 barnacles. Pedunculate barnacles seem, therefore, to be entering the Southern Ocean in large numbers every year in the South Georgia region and probably elsewhere. We also found adult barnacles attached to a macaroni penguin and (perhaps the furthest and fastest travelling marine larvae) young stages (cyprids) on the leg ring of a wandering albatross. Barnacle plates provide a hard substratum to which other fouling marine organisms can attach, and thus travel as secondary hitch-hikers. We found polychaete worms (Spirorbidae) and a bryozoan colony (*Celleporella antarctica*) encrusting a stalked barnacle attached to a pycnogonan (*Collosendeis scotti*). We suggest that fouling hitch-hiking barnacles (on migrating megafauna) offer a considerable natural mechanism for potential colonisers of Antarctic waters. This is of particular importance at the current time given the context of strong regional warming in the Scotia Arc–Antarctic Peninsula region.

KEY WORDS: Antarctica · Species transport · Fur seals · Marine invasions · *Lepas*

INTRODUCTION

The Southern Ocean, demarked at its limit by the Polar Frontal Zone (PFZ), covers a large area from ~53° S to the coastline of the Antarctic continent at ~70° S. It is an exceptional region in terms of both oceanographic and biological features. The shelf region can display very high benthic taxonomic richness (Arntz et al. 1994, Brey et al. 1994, Clarke & Johnston 2003), and much of this fauna is endemic (Arntz et al. 1997). It is also the only marine region in which no nonindigenous species (NIS) has yet been reported as established. Given that there are large areas of the Southern Ocean (e.g. the Amundsen Sea) where the fauna is poorly known, it is possible that NIS have been transported, survived transportation and became established, but have not been recorded. Once established, terrestrial or lake invasions have proved hard to reverse, and no marine NIS has ever been removed. Thus there is much concern about the possibilities of species crossing the Polar Frontal Zone and invading a 'last frontier' (see Tavares & Melo 2004) that has been fairly isolated since the opening of the Drake's Passage 34 million years ago (Lawver & Gahagan 2003). This concern has been intensified by the rapid regional warming of air, land and lakes in parts of the polar regions, e.g. the Antarctic Peninsula (King & Harangozo 1998, Quayle et al. 2002).

There are a number of potential vectors for transport from ocean to ocean. (1) Long-lived larvae are capable

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of travelling large distances in the water column (Scheltema 1971). Nonindigenous (NI) decapod crustacean larvae, for example, have been found in the region of the South Shetland Islands, and may have travelled there as planktonic larvae (Thatje & Fuentes 2003). (2) Larvae or adults now travel across oceans and seas in the ballast water of ships (Carlton 1987, Carlton & Geller 1993). With increasing scientific, political and (particularly) touristic presence in Antarctic waters, shipping is widely considered as a major potential vector for NI invaders. (3) Organisms raft on floating marine algae, plant trunks, pods or other floating parts as well as on neustic animals or gas-filled shells of dead molluscs (Winston 1982, Jokiel 1990). Marine debris has been known to cross the PFZ in both directions (Barber et al. 1959, Coombs & Landis 1966). Heightened awareness of this potential source has arisen because of drastic increases of plastic debris in the marine environment (e.g. Ryan & Moloney 1993) and the high levels of colonising fauna it may carry (Barnes 2002). (4) Another way in which masses of marine invertebrates (particularly barnacles) cross oceans and the PFZ every year is by attachment to migrant megafauna, such as whales, pinniped seals or birds. Although this has been known for a number of decades (Laws 1953, Scheffer 1962, Bonner 1968) and is even likely to comprise the main mode of transport for some taxa, it has remained unquantified and largely ignored, perhaps because the major 'hitch-hiker' taxa (pedunculate [stalked] barnacles) are often neustonic and rarely include coastal species.

Despite the species and higher taxon richness described in many studies of Southern Ocean benthos, one of the features of the Antarctic marine fauna that has generated most interest is the near-absence of certain taxa. Here, reptant decapods, so prominent in all other oceans, are represented by just a few species of prawns, anomuran spider crabs and a lobster, and most of these are found only at >100 m depth. The other taxa that are also very under-represented are the barnacles (Cirripedia). Except as specific commensalists on cetaceans, balanamorph (acorn) barnacles, which encrust most other global shorelines, only occur as far as ~57° S (Foster 1978). Pedunculate barnacles have been found on a wide range of substrata (seals, marine debris and benthic organisms), but are not abundant or speciose. A number of species, and even genera, have been seen only on a couple of occasions (see Newman & Ross 1971). Apart from the Southern Ocean, barnacles occur only rarely north of 70° N. They dominate many littoral regions, and some of the spectacular invasions have been by balanomorphs, including the Australasian species *Elminius modestus*, which in the 1940s arrived at and subsequently dominated European shores (Bishop 1947), and *Chthamalus proteus* which colonised Hawaii (Southwood et al. 1998). Apart from being powerful invaders elsewhere, barnacles are of potential importance in the Southern Ocean because these hitch-hikers may carry their own hitch-hikers, as barnacle plates are an ideal substratum for encrusting taxa. This study describes Southern Ocean barnacle habitats, chiefly from observations at Bird Island, South Georgia. The study was part of a monitoring programme on behalf of the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) to monitor compliance with waste disposal under the convention for prevention of pollution from ships, MARPOL. We investigated the proportion of seals carrying epibiotic barnacles, and when and how many of these are carried onto Antarctic shores. We identified the barnacle species involved and examined their plates for encrustation by secondary hitch-hikers.

MATERIALS AND METHODS

Seals arriving to breed at Bird Island, South Georgia (54° S, 38° W; Fig. 1) were examined for attached barnacles in conjunction with a long-term population demographics study. Pedunculate barnacles are known to attach to female Antarctic fur seals *Arctocephalus gazella* during their winter at sea (Scheffer 1962, Bonner 1968) and are occasionally observed immediately after females come ashore to pup (early November to late December). Barnacles have not been observed on male Antarctic fur seals, presumably because males repeatedly haul-out on land during the winter and hence any attached larvae will be lost. The number, sex and

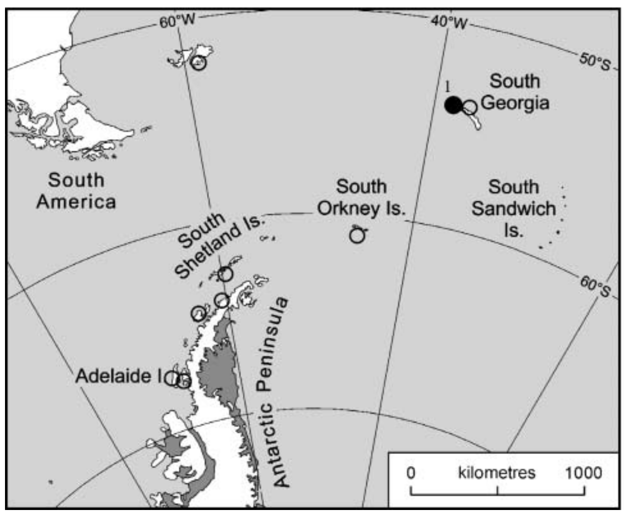

Fig. 1. Map of Scotia Arc study area on the margins of the South Atlantic and Southern Oceans. The main study site, Bird Island (●, 1); additional study localities (○)

timing of arrival of fur seals carrying pedunculate barnacles was monitored from 2001 to the present (2004). The study beach was monitored twice daily for newly hauled-out females, and the numbers of females with barnacle infestations were noted. Seals with infestations were caught and restrained using recognised techniques described in Gentry & Holt (1982) and in accordance with animal care directives. Samples of the barnacles were collected from 6 females for confirmation of identification. Other megafauna (seals and birds) were also checked opportunistically during the study period. All identifications of barnacles were made following the descriptions of Newman & Ross (1971).

Pedunculate barnacles were also surveyed on what is often considered their major habitat, marine flotsam. The nature and levels of marine debris arriving at Bird Island, South Georgia, was monitored by monthly collections from March to September, each year. The survey was part of a programme on behalf of CCAMLR to monitor compliance with waste disposal under MARPOL and the effectiveness of additional regulations to reduce the entanglement of marine mammals and birds in fishing nets (Walker et al. 1997). Because of the high breeding density of Antarctic fur seals at Bird Island, the monitoring of stranded debris on beaches during October to March was not possible; therefore all summer debris was collected in March, and subsequent collections were made monthly. Also, marine debris was surveyed for barnacle (and other) colonists at Signy Island (1990 to 1993), Husvik, South Georgia (April 1993), Stewart Island, New Zealand (February 1995), the Falkland Islands, and various localities along the Antarctic Peninsula: Adelaide and Trump (68° S, 67° W), Wienke (63° S, 63° W), Thorgersen (64° S, 63° W) and King George (62° S, 60° W) islands (2001 to 2003).

The composition of 23 Agassiz trawls at 50 to 300 m depth around Signy Island (Fig. 1) between 1991 and 1993 was examined, as were several organisms from a trawl at 150 to 500 m in Dallman Bay, north of Anvers Island and a trawl at the same depth in Bransfield Strait near King George Island in June 2001. In March 2002, D.K.A.B. discovered that 1 of the pycnogonans collected by the Dallman bay trawl as a by-catch of a fish survey, bore 3 similar pedunculate barnacles, 1 of which was removed from the pycnogonan, photographed and preserved in 60% alcohol for subsequent identification. The critical piece of morphological evidence used for generic identification was the reduction of the capitella plates characteristic of *Litoscalpellum* (separating the morphologically similar genera *Litoscalpellum* and *Arcoscalpellum*), while the shape of the carino-lateral, infra-median-lateral plates and distal part of the tergum were the key morphological characteristics for identification to species. However, identification was uncertain because of degradation of the internal organs.

RESULTS

We found 2 pedunculate barnacle species in the 3 environments surveyed (marine megafauna [fur seals], marine debris and benthos). About 4% of females (0% males) arriving at Bird Island during the study period had barnacles attached (Fig. 2A), with infestations mostly concentrated in the rump area (62 to 70% in the study period). Apart from the rump, barnacles were seen on the shoulders, back and flippers. In all cases, the barnacles dropped off within a few days of the seal staying on land. The levels of infestation showed little obvious pattern, varying from 1 to >50 but typically comprising ~10 barnacles (Fig. 3). In all 3 summers studied, the number of seals (at Bird Island) with attached barnacles peaked in early December (Fig. 3), coincident with the peak in number of fur seals arriving to breed. The barnacles collected were identified as *Lepas australis* (although *L. anatifera* is similar, and these are hard to distinguish when internal body parts are missing, as in our specimens). No plates of any specimen bore epibiotic colonists.

Lepas australis was also found on driftline plastic debris and wood at Stewart Island, the Falkland Islands and Bird Island. Of these, the record at Bird Island is significant, for although this barnacle species has been recorded on natural debris such as pumice within the PFZ (the boundary of the Southern Ocean), ours is the first record of it (or any barnacle that we know of) on man-made debris south of the PFZ (Newman & Ross 1971). There were 2 other instances of pedunculate barnacles attached to megafauna that travel long distances: adults were seen attached to a macaroni penguin (*Eudyptes chrysolophus*) and cyprid larvae were found on a metal identification ring on the leg of a wandering albatross (*Diomedea exulans*) (Fig. 2B). The barnacles found attached to fur seals, the macaroni penguin and the wandering albatross had very probably crossed the PFZ (from Atlantic to Southern Ocean waters).

We found pedunculate barnacles on a recently trawled pycnogonan (*Collosendeis scotti*) (Fig. 2), now in the Palmer Research station aquarium. This epibiotic barnacle had its own epibiota of *Spirobis* spp. polychaetes and a cheilostomatid bryozoan, *Cellepora antarctica* (Fig. 2D). We consider this pycnogonan colonist to be a fully grown (final stage) *Litoscalpellum convexum* of the family Scalpellidae. This species has rarely been seen and never collected from such shallow depths. The only reports we know of this species are the type description from 1901 to 1903 from Cumberland Bay, South Georgia, and a later report by Newman & Ross (1971) for the same region. The finding of this species in shallow waters of the Antarctic Peninsula thus expands the bathymetric range of *L.*

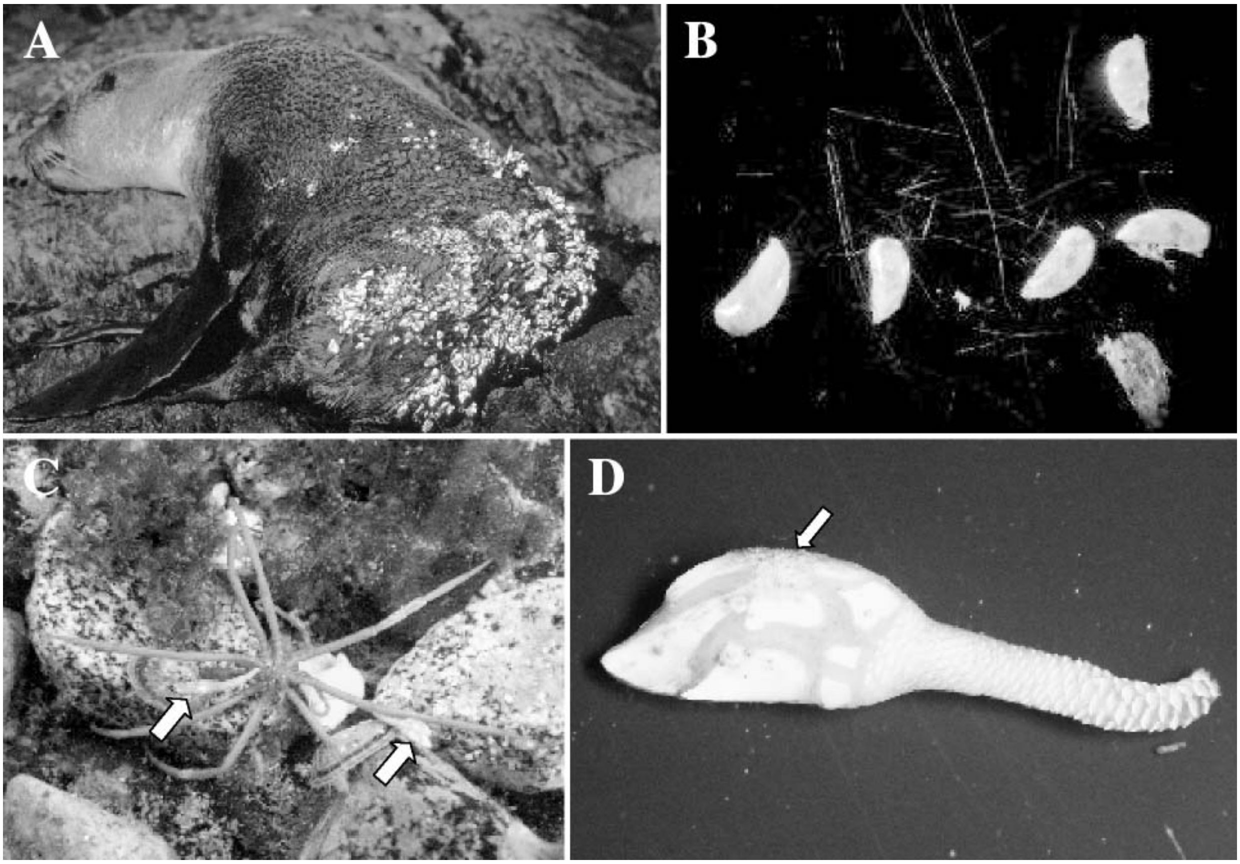

Fig. 2. Pedunculate barnacles in the Southern Ocean. (A) Heavy infestation of *Lepas australis* on fur seal *Arctocephalus gazella*; (B) cyprids attached to leg ring of a wandering albatross *Diomedea exulans*; (C) pycnogonid *Collosendeis scotti* with 2 attached *Litoscalpellum convexum* (arrows); (D) detail of *L. convexum* with epibiotic polychaetes and bryozoan colony (arrow)

convexum, and its occurrence to the Antarctic as well as the Subantarctic. The plates of 1 *L. convexum* specimen were colonised by spirorbid polychaete worms and colonies of the cheilstome bryozoan *C. antarctica*.

DISCUSSION

The massive increase in shipping during the last century, and drift plastic in the last half-century, has created an expanding niche for 'hitch-hikers' (Winston 1982), particularly for taxa such as barnacles (Bishop 1951, Minchin 1996). Pedunculate barnacles, probably like many epibiota (Key et al 1995), attach to almost anything that floats, including tar balls (Minchin 1996). Marine pollution such as tar balls, plastic debris and other artefacts are now common at sea and appear

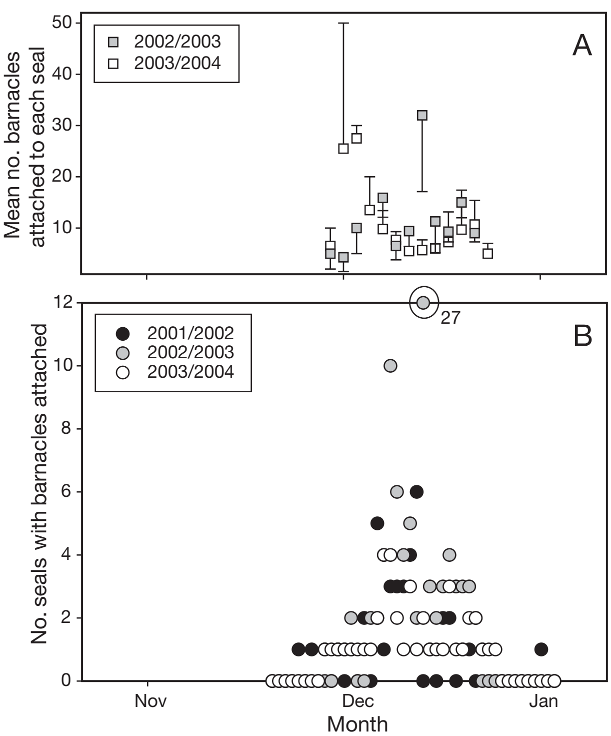

Fig. 3. Pedunculate barnacle loading on seals and frequency of attachment to seals. (A) Number of barnacles attached to seals (squares) are shown as mean ± SE. (B) Number of seals with barnacles attached (circles) are shown as daily totals

Table 1. Pedunculate barnacle species found on southern austral seals

Location	Host species	Barnacle species	Source
South Africa	*Mirounga leonina*	*Conchoderma auritum*	Best (1971)
Amsterdam Island	*Mirounga leonina*	*Lepas* sp.	Arnaud (1973)
St. Paul Island	*Arctocephalus gazella*	*Lepas hillii*	Scheffer (1962)
South Georgia	*Mirounga leonina*	*Lepas australis*	Laws (1953), Arnbom & Lundberg (1995)
South Georgia	*Arctocephalus gazella*	*Lepas australis*	Bonner (1968), King (1983)

on remote island shores across the globe (Ryan & Moloney 1993, Barnes 2002), even in the Southern Ocean (Gregory et al. 1984, Walker et al. 1997). In warm-waters, floating debris is often colonised by fauna (Winston 1982, Barnes 2002), and this may also occur at the margins of, or south of, the PFZ (MacIntyre 1966, Barnes & Fraser 2003 respectively). Pedunculate barnacles can be so numerous on artefacts washed ashore that they temporarily become a valuable source of food for coastal birds (Slip & Burton 1991). Our data and observations in the literature suggest that seals, which spend some of their time north of the PFZ, carry barnacles and maybe other secondary hitch-hikers regularly and for a long time.

We do not know the source of the barnacles we found, but Newman & Ross (1971) described *Lepas australis* as distributed around the Subantarctic Front and southern parts of Atlantic, Pacific and Indian Oceans. The wintering range of female Antarctic fur seals that breed at South Georgia includes areas to the north of the PFZ particularly in the region of the Patagonian shelf (Boyd et al. 2002). This area coincids with the distribution of *L. australis* described by Newman & Ross (1971). Future studies need to determine whether this is indeed the area from which the barnacle hitch-hikers originate. This could be done by comparing their DNA profile with those of Patagonian Shelf populations. Knowing their locality of growth would also enable workers to age the hitch-hikers: this was not possible with our study specimens as their size would depend on food availability in the local area where each host seal overwintered. Crucial information also lacking is whether *L. australis* or other hitch-hiking barnacles release viable larvae and what the adult and cyprid thermal tolerances are. We did, however, find cyprids (Fig. 2B) in addition to adults.

The large size of many of our study barnacles makes it very unlikely that any *Lepas australis* had attached within Southern Ocean waters during the previous winter, where there would have been very little food available (and where suspension feeders are typically slow-growing: see Arntz et al. 1994). This, in conjunction with the known distribution of *L. australis* predominantly north of the PFZ, suggests that pedunculate barnacles may be entering the Southern Ocean in large numbers every year in the South Georgia region, and it seems likely that this would be the case elsewhere (for example at Bouvet or Heard Islands).

Although only observed as recently as the 1950s (Table 1) (Laws 1953, Scheffer 1962), it seems that mass crossings of the PFZ by marine invertebrates is a natural event that has been occurring for some considerable period of time. The patterns of barnacle arrival (Fig. 3) indicate that, each December, many *Lepas australis* barnacles are imported into the Southern Ocean by fur seals. The few barnacle plates taken from seals that we examined carried no other epibiotic hitch-hikers, but clearly the huge numbers of barnacles which must be regularly crossing the PFZ represent a considerable opportunity for transfer of epibiota to the Southern Ocean. The pedunculate barnacle *Litoscalpellum convexum*, which we found attached to a pycnogonan, did bear epibiota. However, this barnacle would have always been immersed and the fauna it bore was Antarctic in origin. Nevertheless, it is highly likely that some barnacles travelling into the Southern Ocean do occasionally carry fouling fauna. The freezing winter temperatures of the Southern Ocean and perhaps thermal shock on first arrival, probably make current chances of viability low. However, only a small change in sea surface temperatures would be required to elevate Southern Ocean waters above zero degrees (generally accepted predictions suggest a ~2°C rise in the Southern Ocean in <100 yr: see Murphy & Mitchell 1995). Kolar & Lodge (2001) identified 3 phases of NIS invasion: transport, establishment and spread. Climate change would be unlikely to alter the transport phase (or survival of adult barnacles), but would be likely to influence the establishment (and ultimate spread) of larvae or secondary hitch-hikers, as has already occurred with new colonists/invaders in the Antarctic terrestrial environment (Walther et al. 2002).

Introductions are causing massive ecological changes in terrestrial, freshwater and marine environments across the globe. There can be little doubt that anthropogenic influences on the transport and establishment of NIS has been, and is, considerable. Our study suggests that a long-known (but little considered) method of natural transport by adults and larvae — hitch-hiking on migrating megafauna — could also be important. At least 1 species of pedunculate barnacle makes major migrations from southern temperate to Subantarctic/

Antarctic coasts as a hitch-hiker on seals and occasionally on penguins. Even this potential for travel may be surpassed by cyprids that hitch-hike on wandering albatross rings (Fig. 2B). When Scheltema (1971) suggested that marine larvae might be able to travel thousands of kilometres, it is unlikely he envisaged this as occurring within a matter of a few weeks and by air.

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