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NATURAL AND PLASTIC FLOTSAM STRANDING IN THE INDIAN OCEAN

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ABSTRACT

Over long periods of geological time the island rich NE Indian Ocean region has developed to be a region of high marine species richness but in the last few decades it has also become a generator of anthropogenic flotsam. Plastic proved such a success, it was disposable, and is now transforming ocean surfaces and shorelines. Sea voyages, coastal conservation and remote island visits started raising awareness of the problems of rubbish at sea in the Atlantic and Pacific Oceans. Household plastic items are now chiefly made in SE Asia and their use in that area where there is a very large human population density in contact with a large coastline results in disposable plastic items entering the surrounding seas. Surveys from Negombo in West Sri Lanka, Ari Atoll in the Maldives, Pemba Island in North Tanzania, Christmas Island, Cocos Island, Quirimba Island in North Mozambique, Rodrigues Island, Nosy Ve in South-West Madagascar and Inhaca Island in South Mozambique are reported. The accumulation of durable rubbish reaching even remote mid Ocean islands such as Christmas and Cocos islands is high and much of what was found stranded on shores was colonized by animals. The vast amounts of waterborne debris is almost certainly drastically changing opportunities for many marine organisms to travel and thus for exotic invaders to spread. Supralittoral hermit crabs on such remote Indian Ocean shores are even starting to use debris instead of the more usual gastropod shells as debris is so abundant. As in other oceans awareness of the problem and periodic clean up operations have grown but dumping at sea continues.

INTRODUCTION

The large-scale use of plastics in manufacturing started almost 50 years ago, and its use has altered human society. Oceans and coastlines now provide evidence of plastics relative abundance, cheapness and durability. The accumulation of rubbish has not merely changed the aesthetics around urban areas but plastics have also now reached the most isolated mid-Atlantic (Carpenter and Smith 1972; Colton *et al.* 1974; Ryan 1987) and mid-Pacific (Benton, 1991; Gregory, 1999) islands. Furthermore it is not just changing aesthetics, it was soon realized our floating rubbish resulted in a number of impacts on wildlife that include starvation, poisoning and choking (Bonner and McCann, 1982; Van Franeker and Bell, 1988; Croxall *et al.* 1990; Bjorndal *et al.* 1994). Surveys of West Pacific, Southern Ocean and Atlantic shores showed oceanic rubbish was, in some places, increasing rapidly (Hayward, 1980; Gregory, 1987; Ryan and Moloney, 1993; Ryan and Swanepoel, 1996). Only on the really remote Southern Ocean islands and Antarctic continental coastline were plastics not apparent (Gregory *et al.* 1984). In the seas around Europe estimates of million items per day entering the oceans from ships were suggested (Horseman, 1982) and the proportion of persistent plastics keeps increasing (Franklin Associates, 1994). Organisms are now not only transported on floating seeds, wood, animal remains (such as *Nautilus* or *Spirula* shells) and gas-filled rock but also floating litter (Winston, 1982; Jokiel, 1990).

Plastics are a good surface for fouling organisms to attach to, demonstrable by the use of various plastic compounds as experimental settlement/recruitment panels by ecologists around the world. This is because it remains buoyant and it is extremely durable to the action of both UV and wave action. Such durablity makes plastic ideal as a surface transport and dispersal system of rafting organisms (Jokiel, 1990; Winston *et al.* 1997; Barnes, 2002a,b). This could have dramatic influences for neustic communities such as marine insects which lay their eggs of flotsam (Cheng, 1985) or for neustonic barnacles which hang off it (Minchin, 1996). It has the potential to carry non-native, invasive ‘pest’ species over long distances to a wide range of locations. The last few decades have not only enabled large-scale human transport around the globe but also drastically increased opportunities for fouling organisms. Comparatively little is known about sources, amounts, accumulation rates of flotsam and usage by organisms in the Indian Ocean, although to the north-east around Indonesia large amounts seem to be entering the water and stranding (Uneputty and Evans, 1997, 1998). It has been known for a number of decades that debris can cross the entire southern margin of the Indian Ocean (Barber *et al.* 1959; Coombs and Landis, 1966). Debris stranding on some south-eastern Indian shores even seems to be entering from the Southern Ocean (Gregory and Ryan, 1997). Here I discuss patterns of marine debris amounts, accumulation rates and organism use at sites across the Indian Ocean from Sri Lanka in the North to the Subantarctic islands.

STUDY AREAS AND METHODS

Surveys and resurveys of windward beaches at various Indian Ocean localities were carried out between 1996 and 2002 (Fig. 1). The sites were, from north to south: [1] Negombo in West Sri Lanka; [2] Ari Atoll, Maldives; [3] Pemba Island in North Tanzania; [4] Diego Garcia; [5] Christmas Island; [6] Cocos Island; [7] Quirimba Island in North Mozambique; [8] Rodrigues Island; [9] Nosy Ve in South-West Madagascar and [10]

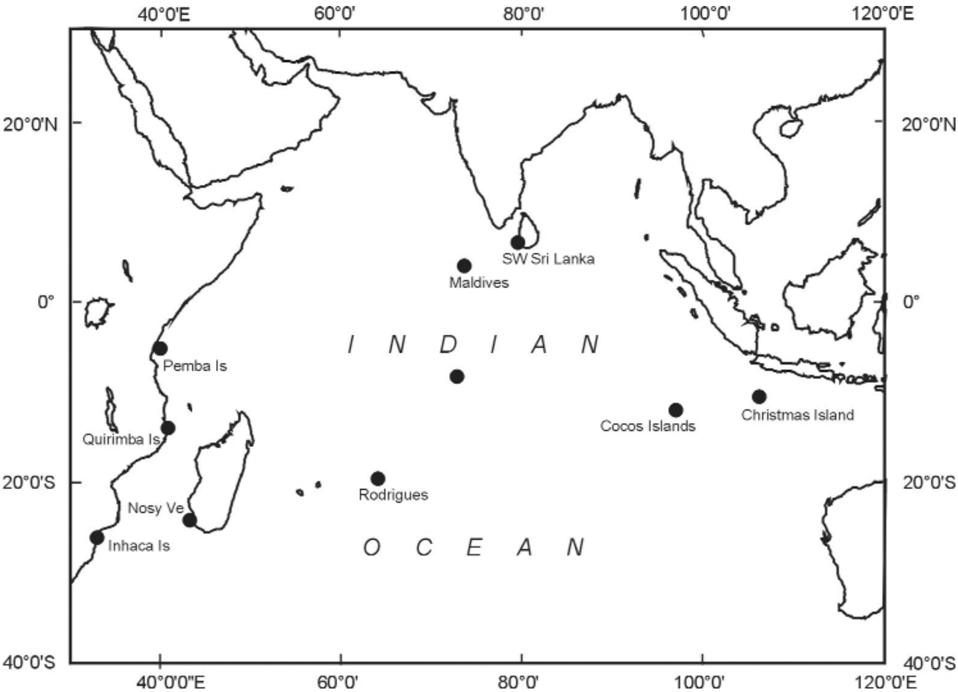

Fig. 1. Beach debris sample locations.

Inhaca Island in South Mozambique. At each locality a study beach, which was windward to prevailing winds, was selected. The beach lengths varied from hundreds of metres to tens of km. At each a 200 m strip parallel to the low water mark was first cleared and then searched again after 1 year periods and all macro-items ($>1cm^2$) were removed and recorded. This included part buried material but beaches were not excavated to search for completely buried material. No volumes or weights of flotsam were measured. Whether or not the item was anthropogenic in origin and what is was made of was noted as was whether each item was colonized by biota. Where the item was part of a plant (e.g. seed) or animal (e.g. shell), they were identified to species where possible. If biota were attached, these were identified to class or order level only. Three separate beach surveys were made in Sri Lanka, Maldives, north and south Mozambique and South-west Madagascar. The data from these surveys is shown as mean ±SE. At Greta Beach, Christmas Island, additional data was collected by resurvey 1 day and 6 months after clearance. These surveys were carried out with otherwise identical methodology to the yearly sampling elsewhere.

Debris accumulation patterns on southernmost island shores fringing the Indian Ocean was obtained from Gregory *et al.* (1984), Ryan and Watkins (1988), Slip and Burton (1991), Gregory and Ryan (1997); Burton and Schulz (2001); Eriksson and Burton (2001). The data in the literature was sampled in approximately similar ways to those undertaken as part of this study.

RESULTS

Patterns in space

The highest levels of accumulation in this study were from the Christmas and Cocos Islands and the lowest values from SW Madagascar and S Mozambique. Although there would appear to be a trend in decreasing accumulation with increasing latitude (Fig. 2, top graph), a similar plot with distance from the NE Indian Ocean also had a similar trend. Total variability in accumulation of debris in the Indian Ocean including literature reports was almost four orders of magnitude. The lowest values were on islands on the margins of the Southern Ocean. There was no obvious effect of isolation, indeed two of the highest and the four lowest values were from mid ocean islands. There is a large gap in our data in terms of latitudes covered from about 30–45°S.

There was a very high proportion of items of anthropogenic origin (Fig. 2 middle plot)–especially in the tropics considering that at this latitude, natural floating objects (seeds, fruits, wood, etc) are most numerous. Three seeds were found in the Cocos Islands, two *Terminalia catapa* and one *Entada* sp., and three seeds were also found at Christmas Island, one *Callophyllum* sp., one *Ipomoea* sp. and one *Pandanus* sp. Six coconuts and one unidentified seed were present in our North Mozambique samples, a further two coconuts were found amongst Sri Lankan samples. Mollusc shells were also abundant, including one *Nautilus* shell and five *Spirula* shells in North Mozambique (also present in the South Mozambique, Madagascar, Maldives and Sri Lanka samples). Finally, one *Sepia* bone was found in each of the Tanzania, Madagascar and North Mozambique samples. No natural (non-anthropogenic) debris is reported in the literature (Ryan and Watkins, 1988; Slip and Burton, 1991; Gregory and Ryan, 1997; Burton and Schulz, 2001; Eriksson and Burton, 2001) for the southern most sites considered here but it may have not been considered to comprise debris. Antarctica has no known plants or animals, which would leave floating macro-seeds or shells etc., other than sporadic rock (e.g. pumice) from volcanic emissions. Input of natural flotsam at low southern latitudes is, therefore, likely to have reduced total amounts and natural debris stranding. Other comparable studies (e.g. Barnes, 2002a,b; Convey *et al.* 2002) have found only very small proportions of natural debris in Subantarctic debris elsewhere. Most of the anthropogenic items were persistent plastic type materials thus these values were also very high (Fig. 2 middle plot).

As found by Barnes (2002a) the proportion of debris, which was colonized by macrofauna declined with distance from the equator (Fig. 2 lower plot). Although subAntarctic sites for which there are data have zero colonization rates, Burton and Schulz (2001) did find *Lepas* sp. barnacles on stranded plastics at Macquarie island (54°S). The most common organisms colonizing debris were cheilostome bryozoans (dominant in Madagscar, Mozambique and Tanzania), boring animals (probably bivalves – typically 5–12 mm bore diameters) and lepadomorph and balanomorph barnacles (common at most sites). Polychaete annelid worms (spirorbidae), hydroids, corals and sponges were also present.

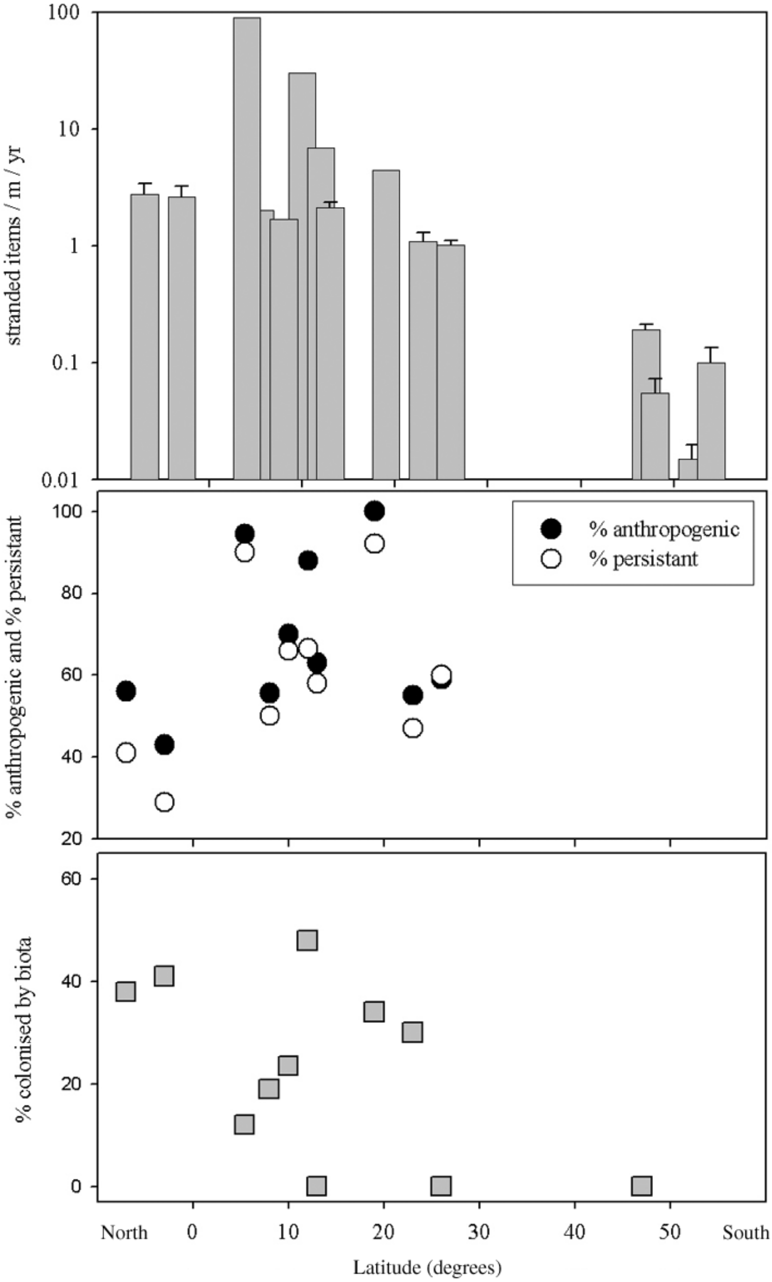

Fig. 2. Nature of stranded flotsam on Indian Ocean shores with latitude. Upper plot shows accumulation rates of stranded items per meter per year, data sources as in Table 1. Data are presented as either single surveys or mean of surveys of three different beaches with SE. Middle plot shows proportions of anthropogenic and persistent debris, data from this study only. Lower plot shows proportion of debris colonised by encrusting biota, data from this study plus information from Ryan (1987).

Table 1.—Site locations, data collected and sources. The sources are Uneputty and Evans 1998 (1), Ryan 1987 (2), and Slip and Burton 1991 (3).

Location	Items/ km/yr	% man made	% colonised by biota	Source
Sri Lanka	2.77	56	38	This study
Maldives	2.6	43	41	This study
Pulau, Indonesia	~90	ND	ND	1
N Tanzania	2.00	94.5	12	This study
Diego Garcia	1.60	55.6	ND	This study
Christmas Is	30.0	70	19	This study
Cocos Is	6.87	88	23.5	This study
N Mozambique	2.12	63	48	This study
Rodriques Is	4.41	100	0	This study
SW Madagascar	1.085	55	34	This study
S Mozambique	1.01	59	30	This study
Prince Edward Is	0.19	ND	0	2
Marion Is	0.055	ND	0	2
Heard Is	0.015	ND	ND	3
Macquarie Is.	0.1	ND	ND	3

Patterns in time

Long term data sets, such as have been maintained in the Arctic (Merrell, 1980) or in the South Atlantic (Ryan and Moloney, 1993 – Atlantic Inaccessible Island shown for comparison in Fig. 3) are present at only few sites and in the Indian Ocean these are restricted to the Subantarctic, largely due to the CCAMLR requirement to collect the data. Temporal patterns are not straight forward though there is a suggestion of increasing accumulation rates at a number of localities (Fig. 3). What is clear is what a striking change must have occurred in just a few decades. In many places large-scale operations to clean up the coastline take place regularly as a necessity. For four decades the effort and cost of this has drastically increased in South Africa (Ryan and Swanepoel, 1996). Yet after just one day the new strandline is evident (Plate 1.1). Six months after the beach clear up on Christmas Island the beach is piled with marine debris – mostly plastics (Plate 1.2). Daily rates of accumulation vary from >200 plastic items /km/day in Indonesia through >50 plastic items/km/day at Christmas Island to <1 plastic item /km /day in some localities South of the Polar Frontal Zone (Gregory *et al.* 1984), but values as high as 11.6 plastic items /km/day have been reported from subantarctic Macquarie Island (Burton and Schulz, 2001). With baseline values established here, albeit after there has clearly been substantial (but surprisingly unquantified) global increases over the proceeding decades, small time scale increases should, in future, be easy to establish.

DISCUSSION

It has been known for a long time that natural materials, such as gas-filled rock and animal shells, tree trunks and disseminules have dispersed widely across seas. Many types

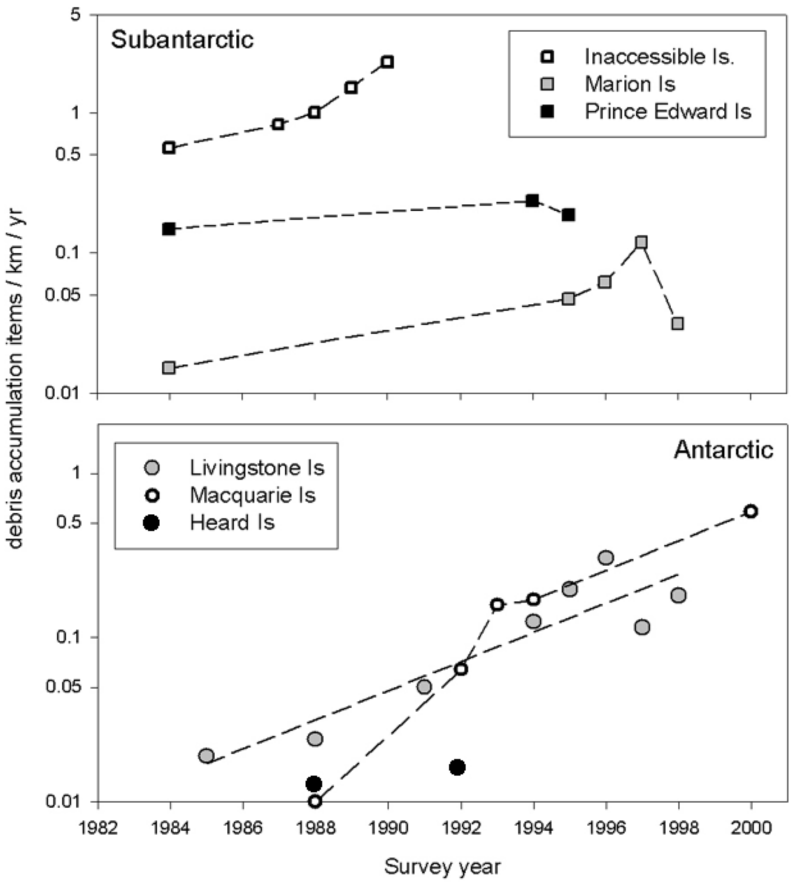

Fig. 3. Marine debris accumulation on Subantarctic and Antarctic island shores. Data for Inaccessible Is. (Atlantic Ocean) from Ryan and Moloney (1993) and for Marion and Prince Edward islands (Indian Ocean) from Ryan and Watkins (1988). Data for Livingstone Is. from Torres and Gajardo (1985) and Torres and Jorquera (1996), for Macquarie and Heard islands from unpublished reports, Burton and Schulz (2001) and Eriksson and Burton (2001).

of disseminules have now been found to cross oceans and strand on remote shores (Gunn and Dennis 1999). Recently these seem to comprise the minority of marine flotsam (Barnes 2002a,b). The Indian Ocean has been, to our knowledge, poorly sampled with respect to flotsam and even more so for organism foulers of such debris. Our data may establish points for future comparison but are too restricted for hard statistical comparisons of factors such as site geography e.g. isolation or latitude. Nevertheless it seems very likely the very high values around Indonesia (Uneputty and Evans, 1997, 1998) is spreading and drifting out from this hotspot and our nearest study localities are the Christmas and Cocos islands. The levels of plastic debris on some Java and Bali shores in 1988 were at least an order of magnitude lower than at present (pers obs). There are a couple of very remote

Plate 1. Marine debris accumulation at Greta beach, Christmas Island 2002

1.1 After one day. Credit: Sven Sewell

1.2 After six months. Credit: Sven Sewell islands, Amsterdam and St Paul, in this region and information on marine debris accumulation is collected there (as required by the Committee for the Conservation of Antarctic Marine Living Resources). This data is currently being worked up by other authors.

The point of convergence of the Indian and Pacific Ocean basins (the Indo-West Pacific region) has long been regarded as a biologically rich region (Stehli *et al.* 1967; Stehli and Wells, 1971; Crame, 2000). It seems that in a short period of time it has also become a hotspot for anthropogenically produced flotsam. This may largely be a consequence of the combination of high human population density and large coastline. Such densities of plastic or other artefacts may not yet be, on average, as high as in the seas around industrialized Europe (Dixon and Dixon, 1981; Horsman, 1982) but very large amounts of durable rubbish is clearly reaching remote mid Ocean islands such as Christmas, Cocos and Diego Garcia islands (Plate 1.2). Hermit crabs on such remote Indian Ocean shores are even starting to use debris instead of the more usual gastropod shells as the debris is so abundant. At both Christmas and Cocos islands, as at so many other places around the globe, both an awareness of the problem and periodic clean up operations have grown. This does, however, merely temporarily relieve a symptom rather than any underlying cause. The extent and seriousness of the environmental and economic implications of debris both at sea and collecting is in the process of being realized. We have little idea about how much debris enters the sea, where it enters, how long it spends in the sea, where it goes and what its major effects are. If rafting by biota on anthropogenic flotsam is as widespread as our preliminary surveys suggest we need to know what species are being carried – is the phenomena simply increasing opportunities for the existing neustic community or is it spreading coastal species? For example, even animals as large as Iguanas are noted to have rafted to new islands (Censky *et al.* 1998). If coastal species are on the move can they maintain themselves on route or are their larvae viable on arrival to those regions with different environmental characteristics? The answers to these questions will dictate whether the Indian Ocean faces an acceleration of an already serious problem and possibly extinctions and monopolization of coast by alien invaders. NW Europe is currently in the process of experiencing this through the spread of a number of species (Leppakoski *et al.* 2002) some of the more obvious of which are the Australasian barnacle *Elminius modestus* on the shore and the alga *Caulerpa taxifola* in the Mediterranean Sea. So why are known modern extinctions in the sea rare, despite the fossil record being dominated by them? There are probably many reasons, such as the paucity of knowledge of marine species, their status and long term data bases as well difficulty of resurvey in anything but shallow water. Even when an invasion of exotic barnacles accumulated on a shore close to a marine laboratory it went unnoticed (Carlton pers. com.). It seems, even less likely therefore, that changes, which can't be seen from above water, would be well recorded. James Carlton, an expert in modern marine invasions and extinctions, recently commented that fewer biologists seem to know their local fauna and that this is widely seen as of lesser importance. Finally whilst biologists are continually emphasizing the importance of long-term data sets, they also acknowledge most available grants are structured in such a way as to make their maintenance very difficult.

The colonization of continents and islands by man brought a wave of extinctions on land but the transport involved in doing this and moving long distance more frequently is moving huge numbers of species around. Loss of global biodiversity is a problem and invasive exotic species are considered to a major cause and threat. It may have taken time and effort but non-native pest plants and animals are beginning to be removed from islands (albeit small islands and large animals such as mammals). Removing marine invaders is an altogether more difficult task. No marine exotics, to the author's knowledge, have been successful removed from anywhere they have invaded yet. There is already thought to be considerable movement of species via ship hulls and ballast water (Carlton and Geller, 1993). Plastic packaging debris has provided a new travel service for fouling species, which leaves from anywhere and goes almost anywhere. Marine debris may be blown by wind or taken by surface currents but the Indian Ocean currents reverse in Monsoon and alter inter-annually with El Nino Southern Oscillation. There are, therefore, very few potential paths that durable plastics could not take. The high levels of colonization of tropical debris by organisms suggest much species movement is taking place at low latitude. At a more limited scale, though, such movement has been taking place for a very long period (Barnes, 2002a). Since the fragmentation of Gondwana, polar migration and subsequent cooling of Antarctica, there has been little transport opportunity in the Southern Indian Ocean or the Southern Ocean. Thus the proportional change at the southern latitudes (Barnes, 2002a), coupled with the high levels of endemism in southern polar waters (Arntz *et al.* 1994; Clarke and Johnston, 2003), make this a likely point to be most drastically influenced by raft carried introductions.

CONCLUSIONS

This preliminary baseline study of Indian Ocean debris accumulation rates, nature and colonization reflects patterns suggested by other authors for parts of the Atlantic and Pacific Oceans. The restricted number, geography and identification of associated biota of this study poses strong limits on conclusions especially as even the sources of debris are many and unknown. For certain though four decades ago plastics were virtually unreported and insignificant on Indian Ocean shores. This study shows that even on mid-ocean islands, far from their sources, accumulation levels are high enough to be visible on a daily basis. Much of this debris is highly persistent and is carrying biota. The Indian Ocean has already become a major source of export of marine organisms to the Mediterranean Sea via the Suez Canal. Debris and ship carried invaders now seem likely to pose a serious threat to the Southern Ocean around Antarctica, the only marine realm from which exotic invaders are unknown.

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