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Competing financial interests: declared none.

Biodiversity

Invasions by marine life on plastic debris

Colonization by alien species poses one of the greatest threats to global biodiversity¹. Here I investigate the colonization by marine organisms of drift debris deposited on the shores of 30 remote islands from the Arctic to the Antarctic (across all oceans) and find that human litter more than doubles the rafting opportunities for biota, particularly at high latitudes. Although the poles may be protected from invasion by freezing sea surface temperatures, these may be under threat as the fastest-warming areas anywhere² are at these latitudes.

Like humans, marine organisms are now experiencing unparalleled availability, distribution and duration of transport. Floating debris is the most common sea-going transport system^{3–5} and is responsible for the widespread distribution of many marine animals that use it to hitch a ride. Natural debris such as volcanic rock, or pumice, and wood have always carried

organism propagules. But there has recently been an explosive increase in anthropogenic debris as a result of massive amounts of plastic entering the oceans — for example, the amount of debris doubled from 1994 to 1998 around the coastline of the United Kingdom⁶, and in parts of the Southern Ocean it increased 100-fold during the early 1990s⁷.

I examined about 200 items of debris washed ashore on each of 30 islands (Fig. 1), which were scattered over a geographical range extending from Spitsbergen in the Arctic to Signy Island in the Antarctic. I found that 20–80% of this debris was anthropogenic (man-made) in origin (Fig. 2a), of which the highest proportion was in the Southern Ocean (as land there has no forests, there is scarcely any local natural debris). There was generally less anthropogenic debris at low latitudes in the Southern Hemisphere than at equivalent northern latitudes, presumably because there are fewer people there and more ocean.

Many types of animal use marine debris as a mobile home, particularly bryozoans, barnacles, polychaete worms, hydroids and

molluscs (in order of abundance), and I found that among the most numerous were animals with cosmopolitan distributions. The successful natural dispersal of species with longer-lived planktonic larvae, such as the bryozoan *Membranipora*, is unsurprising, but most of the other colonizing animals, such as the hydroid *Halecium*, have brooded or brief-duration larvae and no obvious means of dispersal. Oceanic debris therefore offers a major opportunity for dispersal of such species.

Another opportunity for invasion of new habitats by alien organisms is presented by their adherence to ships' hulls. Compared with boats, however, man-made debris is longer lasting, more pervasive and travels more slowly, factors that could favour the survival of colonists.

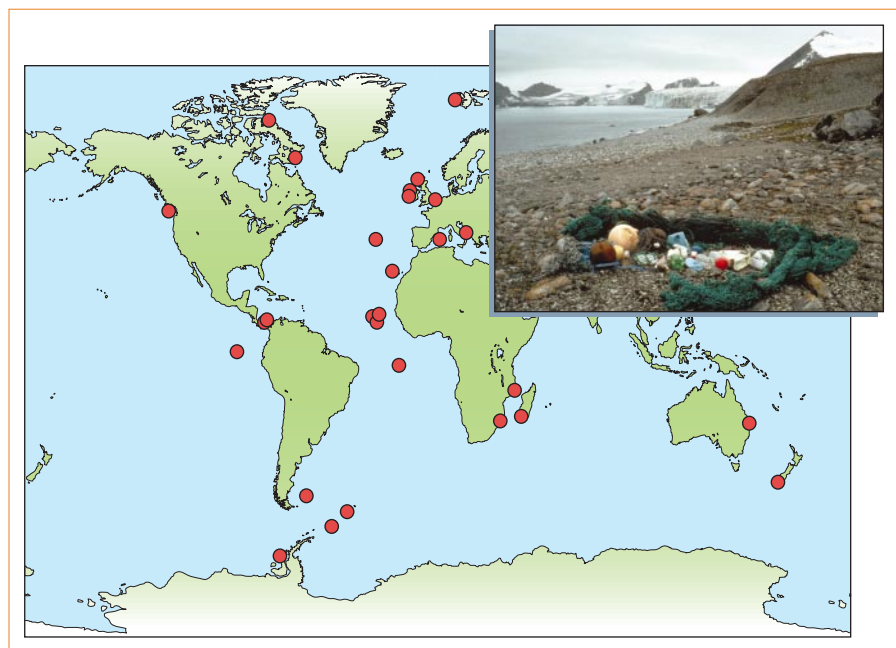


Figure 1 A global picture of shore debris. Dots show the locations of the sampling sites. Inset, typical examples of raft debris washed ashore. The movement of such debris has increased the propagation of colonizing fauna, threatening biodiversity in many regions.

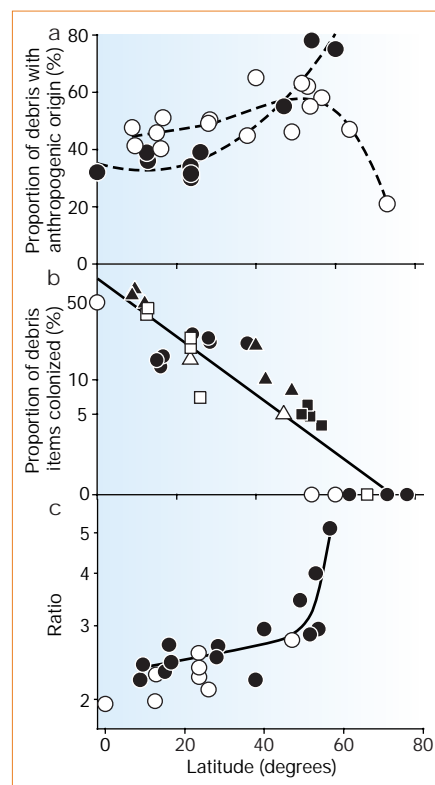


Figure 2 Colonization of man-made and natural debris by marine organisms at different latitudes. **a**, Proportion of man-made debris found offshore at 30 remote islands (Fig. 1); debris is classed as either anthropogenic (mainly plastic) or natural (mostly wood, but not lumber); $n \approx 200$ for each point. Open symbols, islands in the Northern Hemisphere; filled symbols, islands in the Southern Hemisphere. **b**, Variation with latitude, hemisphere and remoteness of island shorelines in the proportion of marine debris of each type that was colonized by fauna. Symbols represent the distance of each island from the continental mainland: circles, hundreds of kilometres; triangles, tens of kilometres; squares, less than 10 km. Fitted regression line has associated $r^2 = 72.7$, and significance by ANOVA: $F = 85$, $P \leq 0.001$. **c**, Variation with latitude and hemisphere in the ratio of propagules on non-anthropogenic to those on anthropogenic debris on island shores. Data are calculated from the proportional colonization by different types of debris shown in **a** at the latitudes given in **b**. The best-fit curve is exponential and has associated $r^2 = 0.74$ and significance by ANOVA: d.f. = 4, $F = 10.25$, $P = 0.002$.

It has been proposed⁸ that floating debris might be colonized by marine organisms in a cline from the poles to the tropics, and that the density and type of recruit might also vary with latitude. The global data set that I collected from surveying marine debris on 30 island shores not only shows a striking increase with latitude in the proportion of debris that is man-made (Fig. 2a), but also in the potential for transporting organisms (Fig. 2b). Although this survey leaves many unknowns, including time spent at sea, drift path, route, proximity of larval supply sources and even point of origin, a strong latitudinal trend still emerges (Fig. 2b). The strength of this pattern, the hemisphere symmetry and the agreement with other results⁹ suggests that the relationship is robust.

Surprisingly, the distance from the mainland to each island does not seem to influence the proportion of debris colonized. Latitude is a good predictor of debris colonization up to about 60°, beyond which no samples were found to carry fauna. Possible explanations include increased agitation of the raft by wave action or ice scour, the lack of pole-bound currents (in Antarctica) or increased ultraviolet radiation mediated by decreased stratospheric ozone, but persistently low temperatures are the most likely.

If freezing temperatures are the main barrier to invasion by marine-borne organisms, then polar warming (a recent model predicts a temperature rise of more than 2 °C over the next 100 years in the Southern Ocean¹⁰) could alleviate this constraint. Whereas the geologically young Arctic Ocean is still being invaded by new species¹¹, the Antarctic Southern Ocean, which has been isolated by the circumpolar current for at least 25 million years, is largely populated by endemic species. Invasion from rafting biota could therefore be ecologically more significant in the Southern Ocean, where the highest proportion of man-made debris is found, making Antarctic waters relatively (not absolutely) more susceptible.

I estimate that rubbish of human origin in the sea has roughly doubled the propagation of fauna in the subtropics and more than tripled it at high (>50°) latitudes (Fig. 2c), increasing the potential for alien invasion and adding to the problems already created by sea-borne plastic materials in the form of injuries and mortality among marine mammals and birds^{7,12,13}.

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COMMUNICATIONS ARISING

Spintronics

Spin accumulation in mesoscopic systems

In spintronics, in which use is made of the spin degree of freedom of the electron, issues concerning electrical spin injection and detection of electron spin diffusion are fundamentally important. Jedema *et al.* describe a magneto-resistance study in which they claim to have observed spin accumulation in a mesoscopic copper wire¹, but their one-dimensional model ignores two-dimensional spin-diffusion effects, which casts doubt on their analysis. A two-dimensional vector formalism of spin transport^{2,3} is called for to model spin-injection experiments, and the identification of spurious background resistance effects is crucial.

As predicted⁴, spin-polarized electrons injected from a ferromagnetic film, F1, into

a non-magnetic metal, N, (Fig. 1a) accumulate in N when the injection rate, I_M , is greater than the spin-relaxation rate, $1/T_2$. Spin accumulation (equivalent to the non-equilibrium magnetization, \vec{M}) in the volume of N near F1 is proportional to the difference of up- and down-spin sub-band electrochemical potentials, $\vec{M} = I_M T_2 / \text{vol}$, which is proportional to $\mu_{\text{up}} - \mu_{\text{down}}$, and decays exponentially in N on the length scale of the classical spin depth, δ_N (refs 2,3). The spin-coupled voltage, V_S , detected at a film F2 (for sample dimensions $< \delta_N$) is

$$V_S / I = R_S = (\eta^2 \rho_N \delta_N^2) / \text{vol} \quad (1)$$

where ρ_N is the resistivity of N, and η is the polarization injection efficiency⁵. Spin accumulation can be detected as a resistance change $\Delta R = 2R_S$ when magnetic fields in the x - y plane change the magnetization orientations \vec{M}_1 and \vec{M}_2 from parallel to antiparallel^{5,6}.

In the geometry and model described by Jedema *et al.*, permalloy films Py1 and Py2 are located on the vertical arms of a copper (van der Pauw) cross and have edges at $y = \pm L/2$. Spins are injected at the Py1–Cu edge, diffuse into the copper, and may be detected at Py2. For the device with $L = 250$ nm at $T = 4$ K, the expected magnitude of ΔR is found from equation (1) by using¹: $\text{vol} = d_N \times W_N \times L$, $d_N = 50$ nm, $W_N = 100$ nm, $\rho = 1.5 \times 10^{-6}$ Ω-cm, $\eta = 40\%$ (ref. 7) and (from $\tau/T_2 = 0.001$; refs 5, 6) $\delta_N = \lambda_N = 1.0$ μm. The estimate $\Delta R = 1.9$ Ω is 10^3 times greater than the measured value¹, $\Delta R = 1.5 \times 10^{-3}$ Ω.

To account for this discrepancy, Jedema *et al.* claim that a ‘resistance mismatch’ at the F–N interface diminishes the polarization in proportion to

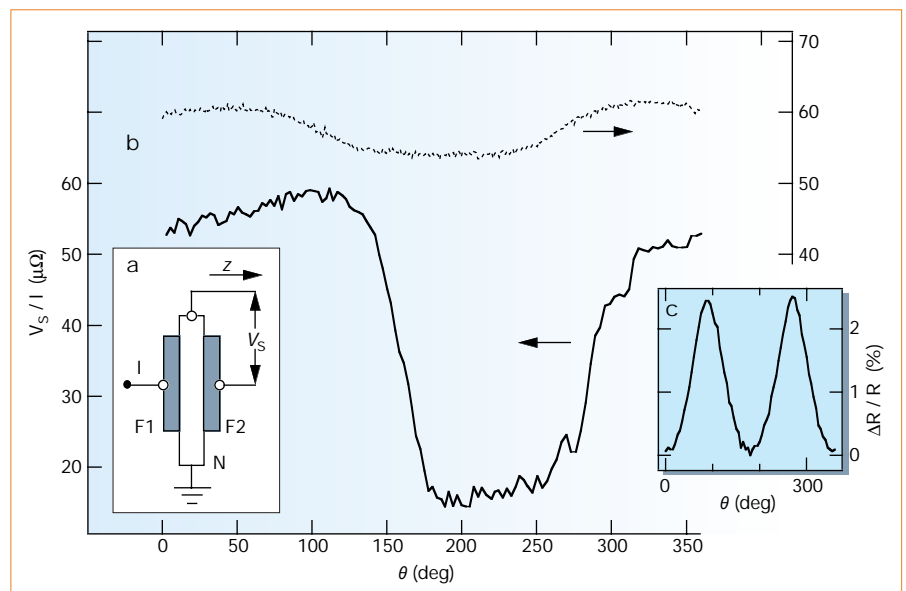


Figure 1 Background resistance and electron spin-diffusion effects in an all-metal mesoscopic spin valve. **a**, Cross-section of pedagogical spin-injection device. **b**, $\cos\theta$ angular symmetry of spin accumulation. Field \vec{H} is rotated in the x - y plane (see **a**). **c**, $\cos 2\theta$ angular symmetry of anisotropic magneto-resistance, measured in a 100-nm-thick permalloy film at 76 K.