PLASTICS: ACCUMULATION, DISTRIBUTION, AND ENVIRONMENTAL EFFECTS OF MESO-, MACRO-, AND MEGALITTER IN SURFACE WATERS AND ON SHORES OF THE SOUTHWEST PACIFIC

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ABSTRACT

Plastic debris of all kinds and in all sizes is widespread in the southwest Pacific. Densities of virgin nibs exceed 1,000 km^{-2} in surface waters north of New Zealand and in nearshore waters adjacent to manufacturing centers. There is a latitudinal gradient of densities, with numbers falling to less than 20 km^{-2} south of New Zealand. On shorelines, greatest numbers (>>100,000 m^{-1} of beach length) are found near large cities, although a similar latitudinal gradient shows with very low numbers from around southern New Zealand (1-5 m^{-1}) and none from the subantarctic islands. In general, numbers of nibs on shores of eastern Australia are much less than they are on New Zealand shores. Significant numbers (>1,000 m^{-1}) have been found as local concentrations on some trade wind-facing beaches of all Pacific islands so far examined.

Distribution of these nibs, together with that of other plastic and persistent synthetic litter, is influenced by surface current patterns and prevailing wind regimes, with greatest concentrations being noted on windward and downdrift shores, in windrows, and (tentatively) along oceanic fronts.

Larger, fabricated plastic items have been seen on the shores of all isolated and unpopulated islands so far visited around the region. Where identifiable, sources frequently lie in distant water fishing activities. On populated islands, many of which lack adequate facilities for domestic waste and garbage disposal, there is a buildup of locally sourced litter along shores. Not only is this litter aesthetically distasteful, some materials (e.g., syringes) are hygienically unacceptable. The problem is an ever-growing one and needs addressing in appropriate forums. The environmental implications of this plastic pollution are many, with the most important involving entanglement and ingestion. The longer term significance of hazardous and persistent chemical residues, originally present in plastics as additives and released in minor amounts during degradation,

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In R. S. Shomura and M. L. Godfrey (editors), Proceedings of the Second International Conference on Marine Debris, 2-7 April 1989, Honolulu, Hawaii. U.S. Dep. Commer., NOAA Tech. Memo. NMFS, NOAA-TM-NMFS-SWFSC-154. 1990.

is difficult to assess. Pelagic plastics also provide an important hard substrate for an encrusting biota that includes a hermatypic coral, bryozoans, coralline and filamentous algae, hydroids, barnacles, and some foraminifers, and are a largely unrecognized vector in their wider distribution.

From surface crazing and other evidence of aging such as chalkiness and embrittlement, it is inferred that degradation rates decrease progressively from lower to higher latitudes.

INTRODUCTION

It is generally accepted that surface waters of the South Pacific Ocean (Fig. 1) are relatively free from man-made pollutants, other than in the nearshore zone of more heavily populated islands (Matos 1981). Recent reviews have tended to emphasize localized incidents involving point-sources of sewage and industrial effluents (e.g., Suva Harbor, Fiji: Brodie and Morrison 1984), and toxic chemicals and pesticides (Cook Islands: Hambuechen 1973; and Tonga: Brodie and Morrison 1984; Morrison and Brodie 1985), although wider political concern has been expressed over the prospect of seabed disposal and dumping or storage of nuclear waste in the expanses of the region (Branch 1984; Carew-Reid 1988). The area lies remote from tanker routes (Waldichuk 1977) and major shipping lanes, and pelagic tar balls so common to more frequently traversed waters are rarely encountered (Butler et al., 1973, p. 24; Bourne 1976; Gregory 1977, unpubl. data; Oostdam 1984; Lee pers. commun.). The problems of marine oil pollution become more evident passing westward into southeast Asian waters (Bilal 1985). However, the island countries of the southwest Pacific have a long and commonly expressed concern over contingency planning for pollution from oil spills (Hayes 1981; Dahl and Baumgart 1983; Hayes and Kay 1986).

Plastics and other persistent synthetic materials are today a significant contaminant of both open ocean and nearshore waters, particularly those adjacent to the industrial North. The sources and environmental problems they create are many and varied (Gregory 1978, 1983; Laist 1987; Pruter 1987). Plastic artifacts as well as casual litter and solid domestic wastes have long been an acknowledged, although seldom seriously addressed, problem on several Pacific islands (Anonymous 1976; Connor 1976; Efi 1976). On Tonga, for example, plastics and cigarette and candy wrappers have been identified as ". . .the second most common form of litter and the second largest waste item for disposal" (Chesher 1984, p. 38). In all instances known to this author, the importance of local sources has been noted, with little recognition that some material may have been adrift for a time before stranding. The observations of Sachet (1955) on the wide dispersal of exotic pumice on Pacific atolls, as well as those of Bligh (1792) on coconut husks, are evidence that, over the vastness of the Pacific, floating materials can drift far from their places of origin. Drift pumice, often with an encrusting biota, is common on beaches of eastern Australia (Table 1). Similarly, in the Southern Ocean there is evidence of floating debris such as logs, pumice, and man-made artifacts being rapidly dispersed in circumpolar fashion by the strong West Wind

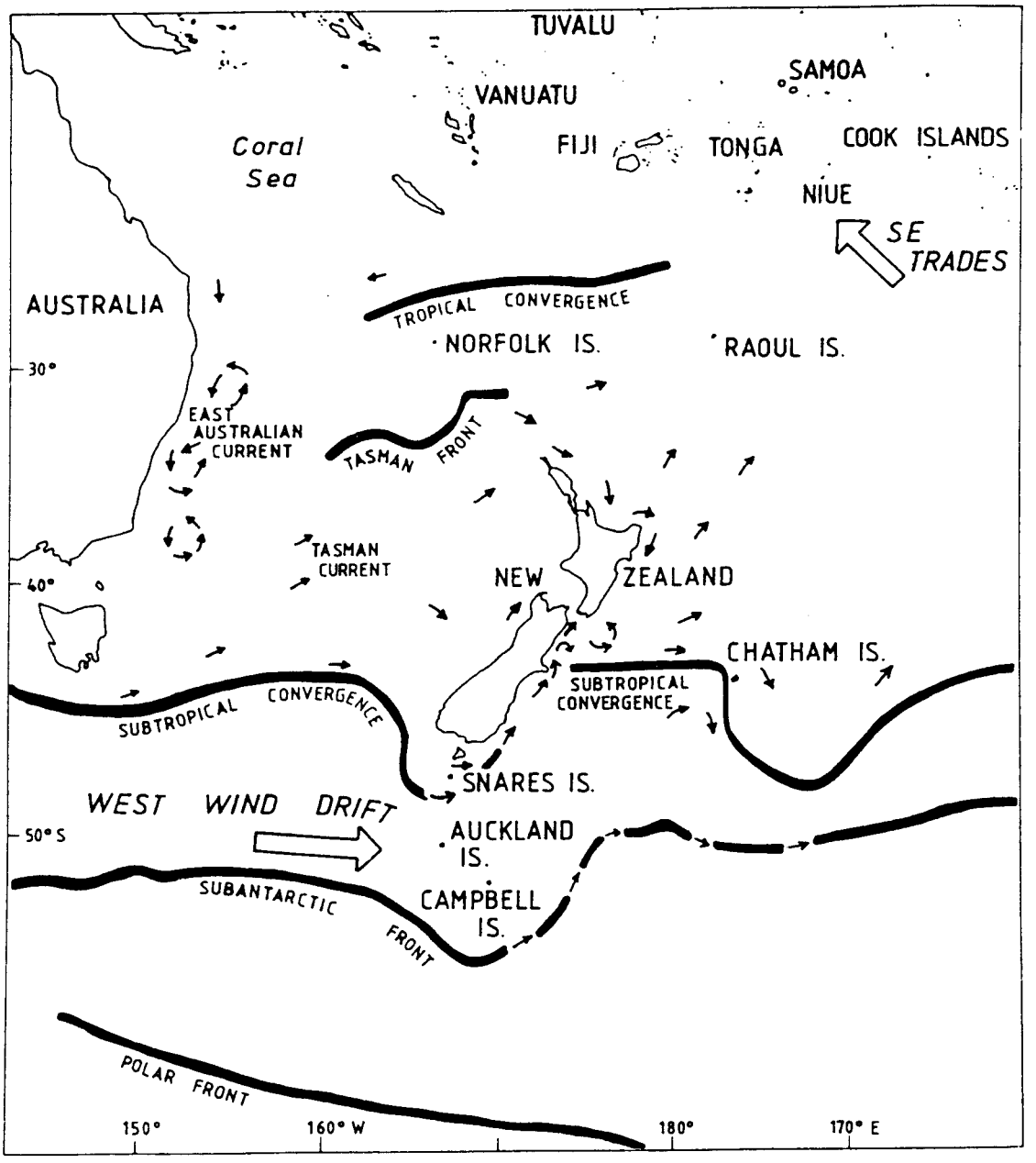


Figure 1.--Map of the southwest Pacific Ocean indicating principal places mentioned in text. Major oceanic features are also illustrated.

Drift Current and general oceanic circulation patterns (Barber et al. 1959; Gregory et al. 1984; Smith 1985; Gregory 1987, 1990; Lutjeharms et al. 1988).

Waters around New Zealand and its offshore islands are by any criteria relatively unpolluted, although semienclosed estuaries and harbors in the vicinity of larger urban centers give increasing cause for concern (Ridgway and Glasby 1984). Plastics and other persistent synthetic compounds,

Table 1.--Numbers of virgin plastic granules and drift pumice on selected beaches of eastern Australia (arranged from north to south). The quantities of granules are local maximums expressed in number per linear meter of shore, following the approach of Gregory (1978); p = present in low numbers (<1 m^{-1}). Drift pumice: * = abundant, + = present.

Location	Plastic granules	Drift pumice
Tasmania		
Hobart to Bicheno	nil	nil
Victoria		
Portsea, Sorrento, Rosebud	p	nil
Mordialbo	>1,000	nil
St. Kilda	>500	nil
Altona	100	nil
New South Wales		
Narooma	nil	+
Batemans Bay	nil	*
Kioloa	nil	*
Jervois Bay	p	nil
Shoalhaven	>5	*
Stanwell Park	>50	*
Botany Bay	>>2,000	+
Bondi	>10	+
Manly	p	nil
Narrabeen	>20	nil
Port Macquarrie	p	*
Coffs Harbor	nil	*
Queensland		
Gold Coast	p	*
Brisbane (Red Cliffs)	nil	+
Bargara (Bundaberg)	5	*
Keppel Sands (Rockhampton)	5	*
Sarina	nil	*
Mackay	p	*
Townsville	nil	*

particularly those arising from packaging, are a significantly visible but minor part of the local waste stream (Ministry for the Environment 1987; Plastics Institute of New Zealand 1988). The environmental hazards and threats to local wildlife are varied and have been reviewed by a number of authors (Gregory 1977, 1978, 1987, 1990; Gregory et al. 1984; Cawthorn 1985, 1987; Mattlin and Cawthorn 1986; Dawson and Slooten 1987; Murray 1988).

Gregory (1977, 1978) initially recorded small virgin plastic resin granules and pellets in surprisingly high quantities on the New Zealand coast and mapped their distribution (Fig. 2). It was noted that greatest numbers occurred near metropolitan centers, suggesting that the distribution was caused by dispersal from local sources (Fig. 2), although some evidence indicated possible drift from eastern Australia waters (Gregory 1978). Changes in the composition of litter stranding on a remote northern New Zealand beach over an 8-year period have been recorded by Hayward (1984). Ever-increasing fishing activities add further to the seaborne litter load on even the most isolated shores (e.g., Auckland and Campbell Islands, Cawthorn 1985; Gregory 1987, 1990).

This paper reviews in detail the nature, characteristics, quantities, distribution and sources of pelagic plastics around the southwest Pacific region. It is based largely on the author's published studies from New Zealand and its offshore, subantarctic islands. However, the opportunity has been taken to include a corpus of previously unpublished data gathered from eastern Australia, several Pacific islands, and adjacent waters during opportunistic surveys over a number of years. The environmental consequences of this plastics pollution are evaluated and some conclusions reached on how they could be addressed.

PLASTIC MESOLITTER

In the category of plastic mesolitter I include the small, ovoidal-to-rounded and rod-shaped virgin plastic granules or nibs of polyethylene and polystyrene resins that are the raw materials or feedstock of plastic fabricators worldwide. The granules are mostly <5 mm across, are colorless to translucent or transparent, and have been described in detail previously (Gregory 1978, 1983). Intensely colored dye-carrying granules (yellow, blue, green, red, black, white) are never as common as the colorless ones. In addition, there are occasional sharply angular and jagged plastic chips of comparable size produced through granulation of larger items for recycling. These chips are variously colored but rarely transparent or translucent. Small, often flaky, fragments coming from the degradation and disintegration of larger plastic objects also fall into this category. The fragmenting and fracturing processes appear to be mostly embrittlement through oxidative aging and photodegradation rather than physical or mechanical weathering.

Gregory (1977, 1978) described the distribution of virgin plastic granules on New Zealand shores (Fig. 2). Large numbers, often >10,000 m^{-1} of beach length and in one instance >>100,000 m^{-1}, were recorded near some of the larger metropolitan and industrial areas where plastics fabricators are located (Fig. 2). Away from these regions numbers decreased, but they were persistently and surprisingly high at some remote localities (e.g., to >150 m^{-1} near North Cape; and to 50 m^{-1} near East Cape). Only around the southernmost part of South Island were they consistently very rare or absent. For the mid-1970's it was estimated that at least 1,000 metric tons of these granules were stranded on the shores of New Zealand (Gregory 1978).

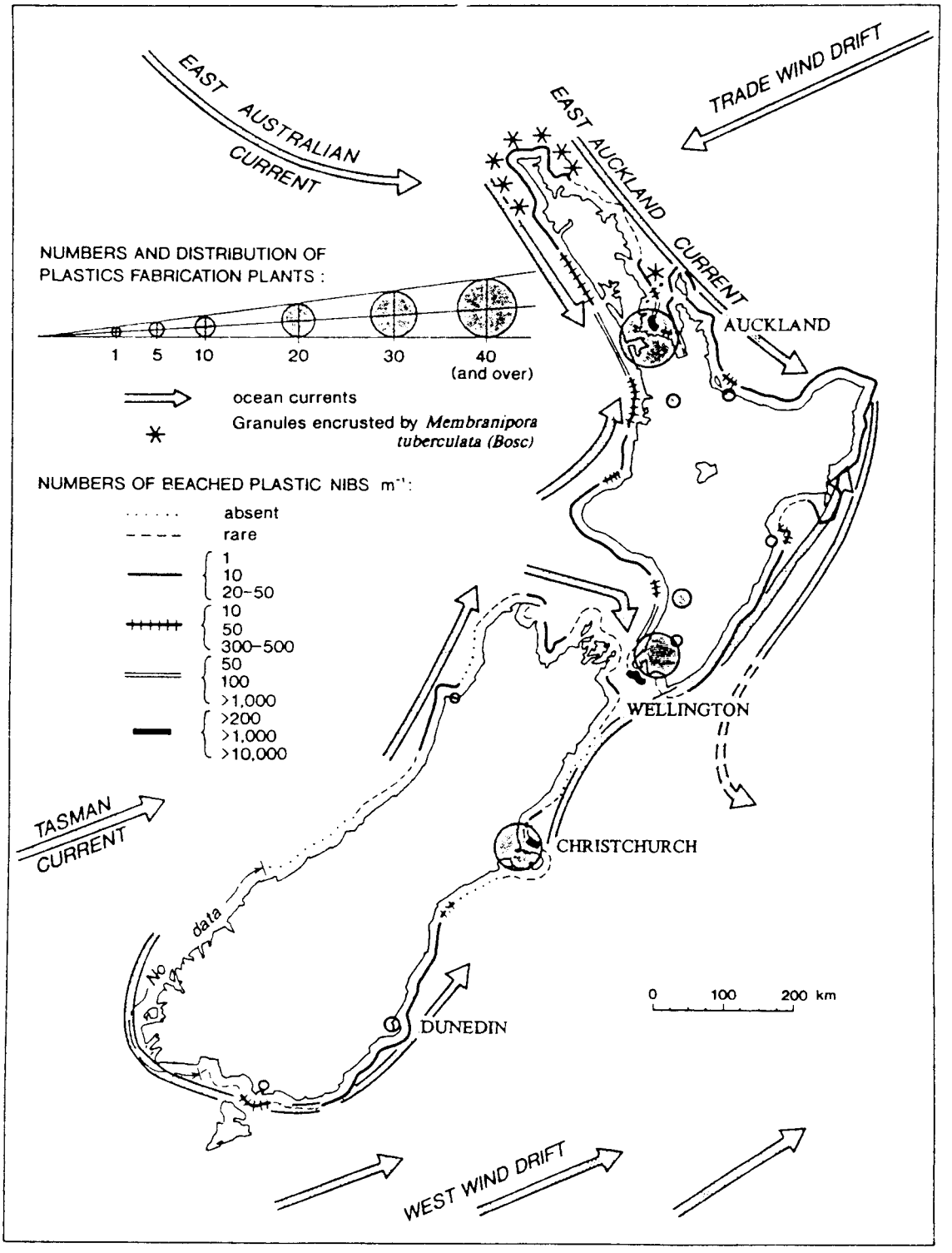


Figure 2.--Distribution of virgin plastic granules on New Zealand shores based on a 1972-78 survey. Three values given for each distribution line indicate abundance levels at which pellets were (i) reasonably consistent (lowest value, top of list), (ii) commonly encountered (middle value), and (iii) locally concentrated (greatest value). Data are from Gregory (1978). Local New Zealand sources of virgin plastic granules are after Bullen (1968); the surface currents and prevailing winds that spread them around and along the coast are after Brodie (1960).

Virgin plastic granules have been encountered on the shores of eastern Australia from Batemans Bay in New South Wales north to Townsville in Queensland (Table 1). They are also present around Melbourne and Adelaide. None have been noted on eastern Tasmanian shores northward from Hobart. Occurrences are sporadic, and numbers seldom reach those recorded from New Zealand. On remote beaches numbers are generally <1 m^{-1}, and in many instances a lengthy search is required to turn up any granules at all. It is only at a few isolated localities around Sydney (>2,000 m^{-1}) and Melbourne (>1,000 m^{-1}) that quantities ever approach those frequently recorded near Auckland.

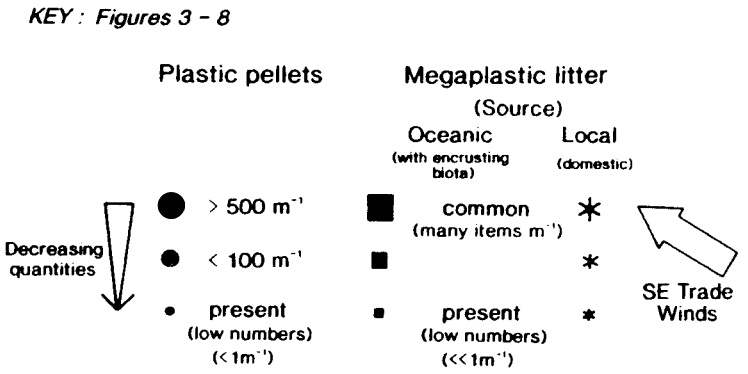
No virgin plastic granules have been found so far on any of New Zealand's subantarctic islands (e.g., Campbell, Auckland, Snares, Antipodes, and Bounty) (Gregory 1987), although they are not uncommon on Chatham Island (to >100 m^{-1}, Gregory 1978). The granules, however, have been found on all subtropical and tropical southwest Pacific islands that were systematically searched by this author during visits over the past few years (Table 2, Figs. 3-8). In several instances the numbers are unexpectedly high for such remote, nonindustrialized places (e.g., Tonga, >>1,000 m^{-1}).

The angular granules produced for recycling are never common away from the industrial centers of Australia and New Zealand, and have not been encountered on the shores of those Pacific islands so far examined.

The numbers of plastic granules and larger plastic items afloat in surface waters of the New Zealand sector of the Southern Ocean have been determined from over 50 neuston tow stations (Gregory et al. 1984; Gregory 1987, 1990). The numerous reports of Southern Ocean feeding seabirds ingesting plastic granules and other artifacts (Bourne and Imber 1982; Furness 1983; Randall et al. 1983; Brown et al. 1986; Skira 1986; Gregory 1987, 1990; Harper and Fowler 1987; Ryan 1987a) indicate these materials have circumpolar dispersal. Brief and sporadic surveys of pelagic plastic have been undertaken from research vessels on passage between New Plymouth and Norfolk Island, Tauranga and Raoul Island, and the Hauraki Gulf to Wellington by way of East Cape as well as around Auckland Harbor and its approaches. At this time data are inadequate to draw unequivocal conclusions. The data strongly suggest, however, that densities in surface waters to the north of New Zealand probably (and often substantially) exceed 1,000 km^{-2} (Fig. 9). Indeed, fresh granules stranding along the most recent swash line (by inference over one tidal cycle--February 1988) on Raoul Island at 5-10 m^{-1} suggest that densities approaching 10,000 km^{-2} may occur sporadically! Variation in numbers between stations is very large. There is apparently a strong latitudinal gradient in the areal density of floating granules (Fig. 9). In higher latitudes between the Subtropical Convergence and the Subantarctic Front, granules occur in numbers that may barely reach 20 km^{-2} (Gregory et al. 1984; Gregory 1987, 1990). Densities farther south and in the region of seasonal pack ice are negligible. In some nearshore waters much higher densities are commonplace (e.g., >10,000 km^{-2} in Hauraki Gulf; >20,000 km^{-2} in Auckland Harbor; >40,000 km^{-2} in Cook Strait approaches to Wellington Harbor) (Gregory 1990, unpubl. data). For comparison, densities elsewhere have been 1,500-3,600 km^{-2} for the Cape Basin region of the South Atlantic lying west of southern Africa (Morris 1980), and 3,640 km^{-2} from over 1,000 neuston trawl stations

Table 2.--Virgin plastic granule numbers on representative southwest Pacific island shores. Numbers given are local maximums expressed in number per linear meter of shore, following Gregory (1978); p = present in low numbers (<1 m^{-1}). For locations see Figures 3-8.

Location	Number
Norfolk Island	
Emily Bay	ca. 100
Raoul Island	
North Beach	>50
Denham Bay	nil
Fiji, Viti Levu	
Lautoka	p
Singatoka	p
Korolevu	<5
Deuba	>>100
Suva	>5(?)
Fiji, Vanua Mbalavu	
East	24
West	p
Tonga, Tongatapu	
Anahulu Beach	100
Laulea Beach	>>1,000
Oholei Beach	<50
Keleti Beach	nil
Fahina Beach	nil
Western Samoa, Upolu Island	
Apia	p
Vaiala Beach	nil
Malaeia Beach	20(?)
Cook Islands, Rarotonga	
Ngatangiia Harbor	>500
Raringaru Stream	>>10
Akapuao Stream	<10(?)
Totokoitu Stream	p
Papua Stream	10
Rarotongan Hotel	1-<10



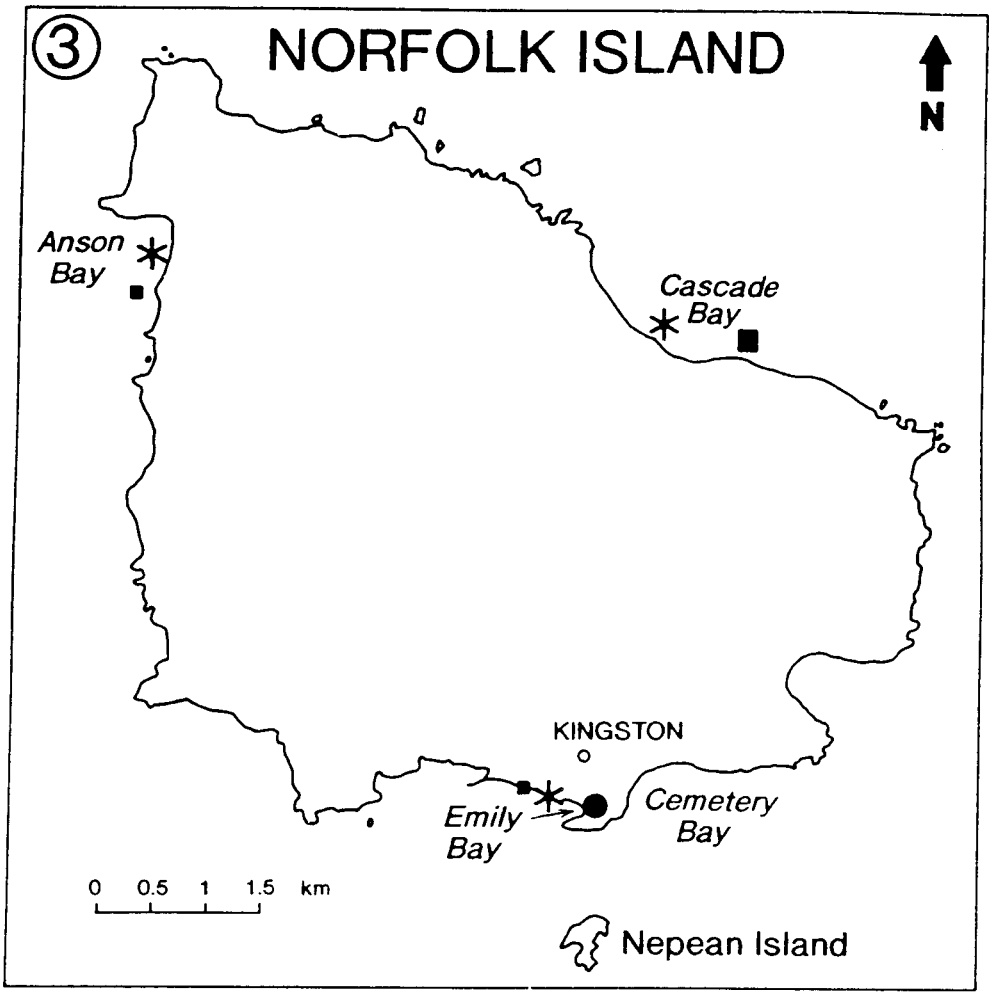
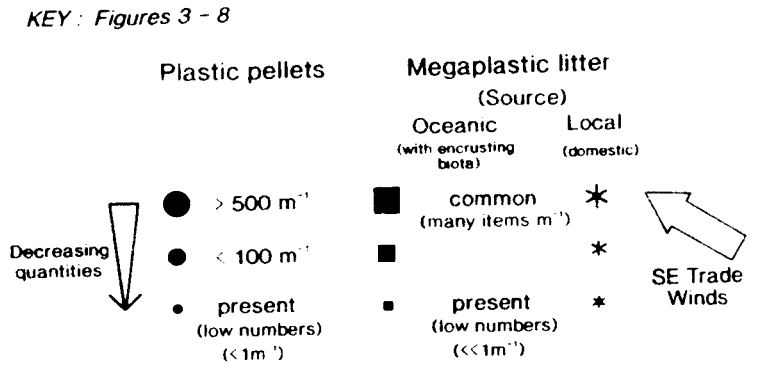


Figure 3.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Norfolk.



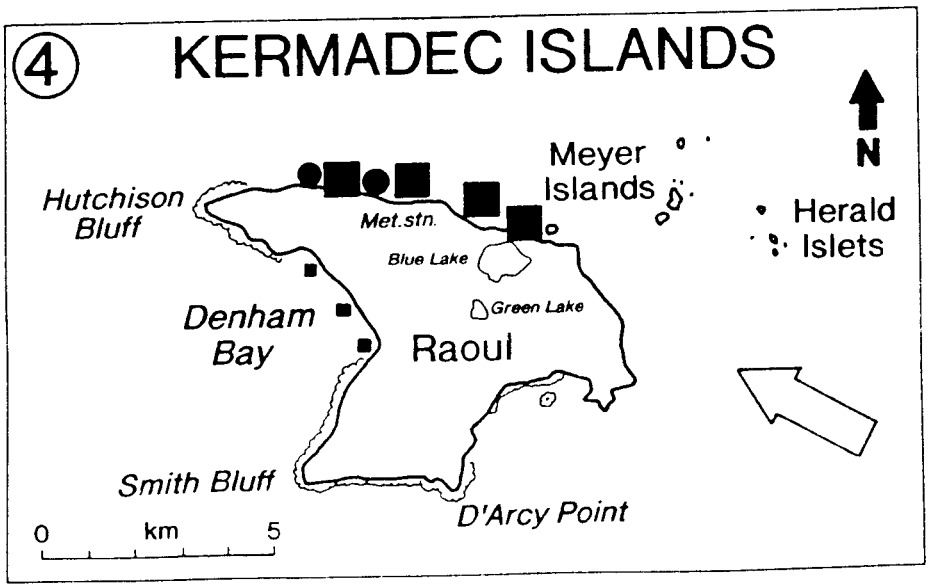


Figure 4.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Raoul.

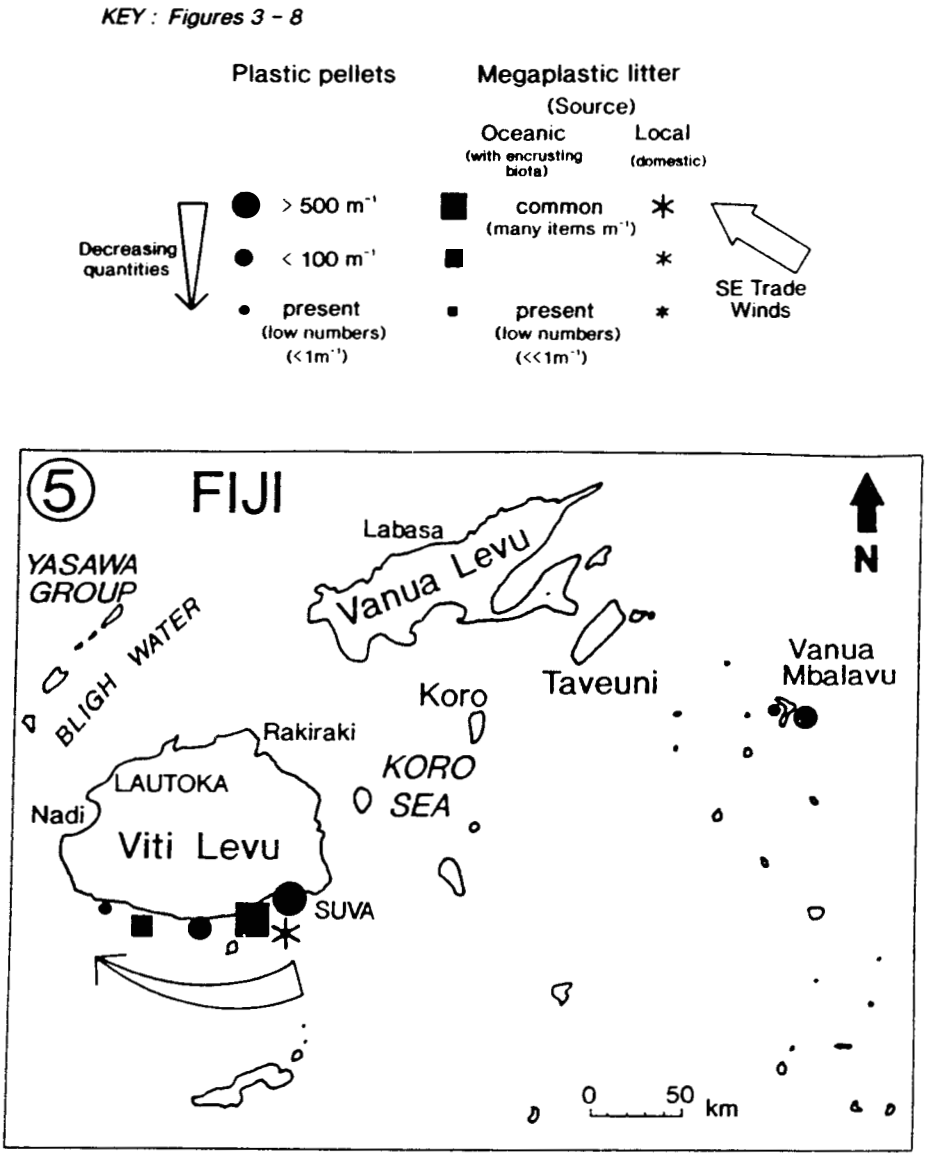


Figure 5.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Fiji.

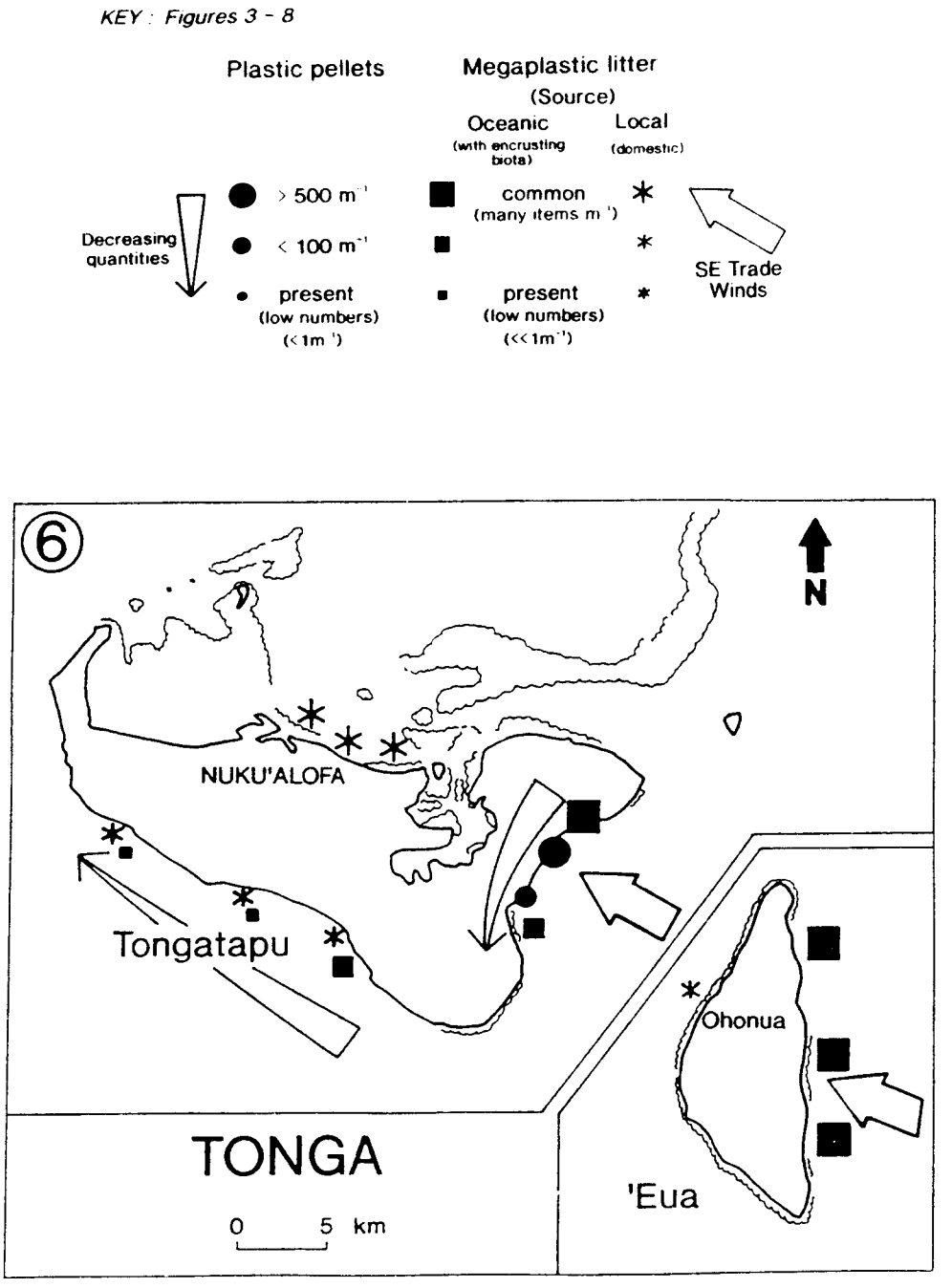


Figure 6.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Tonga.

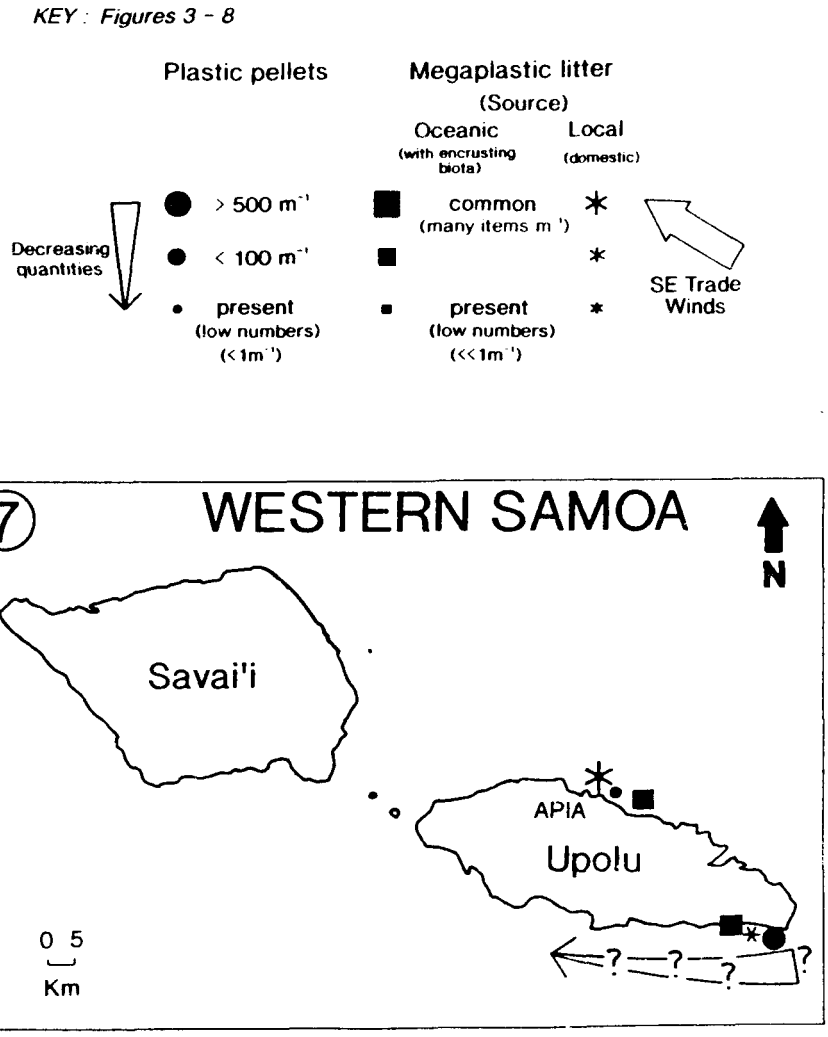


Figure 7.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Western Samoa.

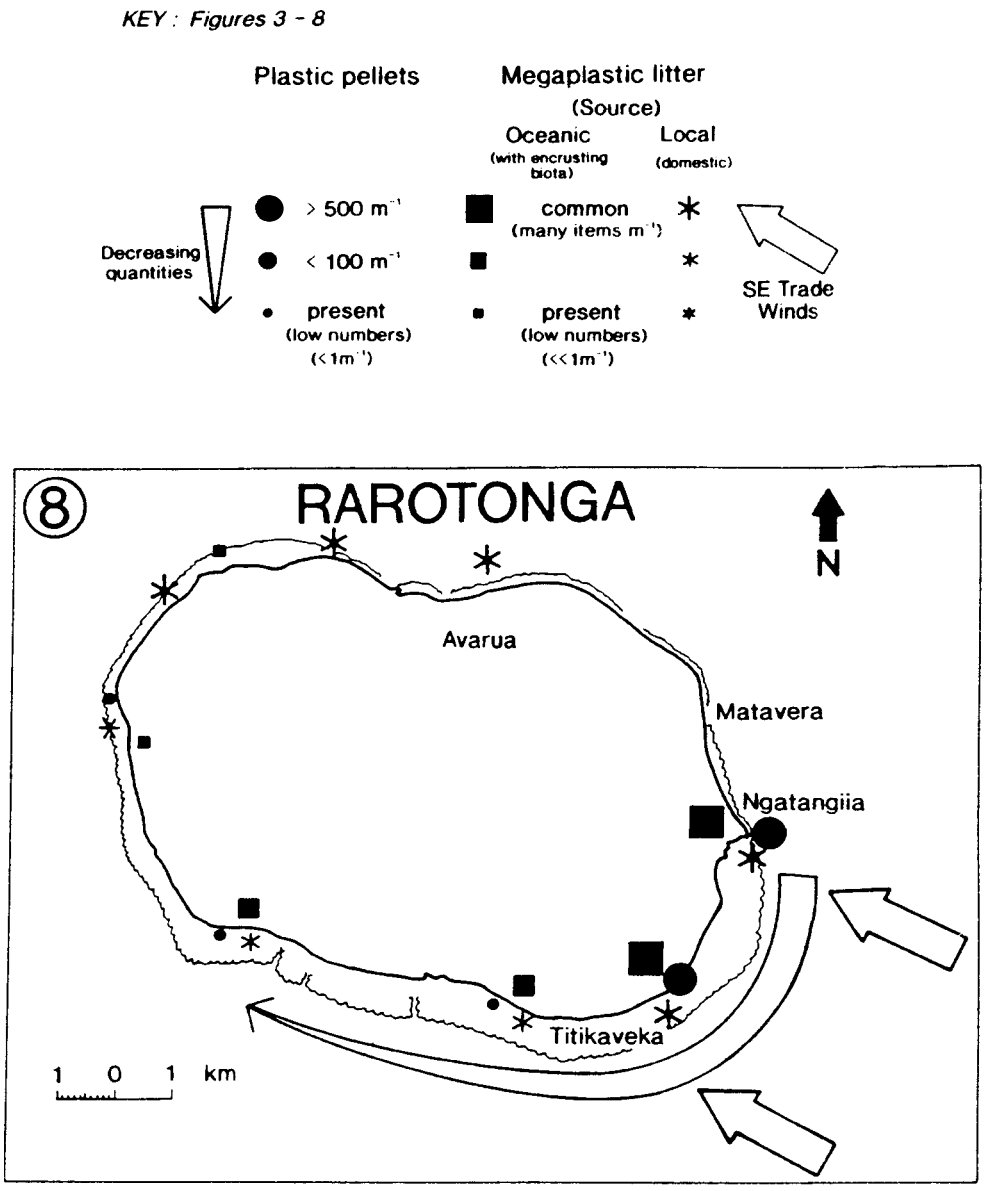


Figure 8.--Virgin plastic granules, oceanic and locally generated megalitter on southwest Pacific island shores: Rarotonga.

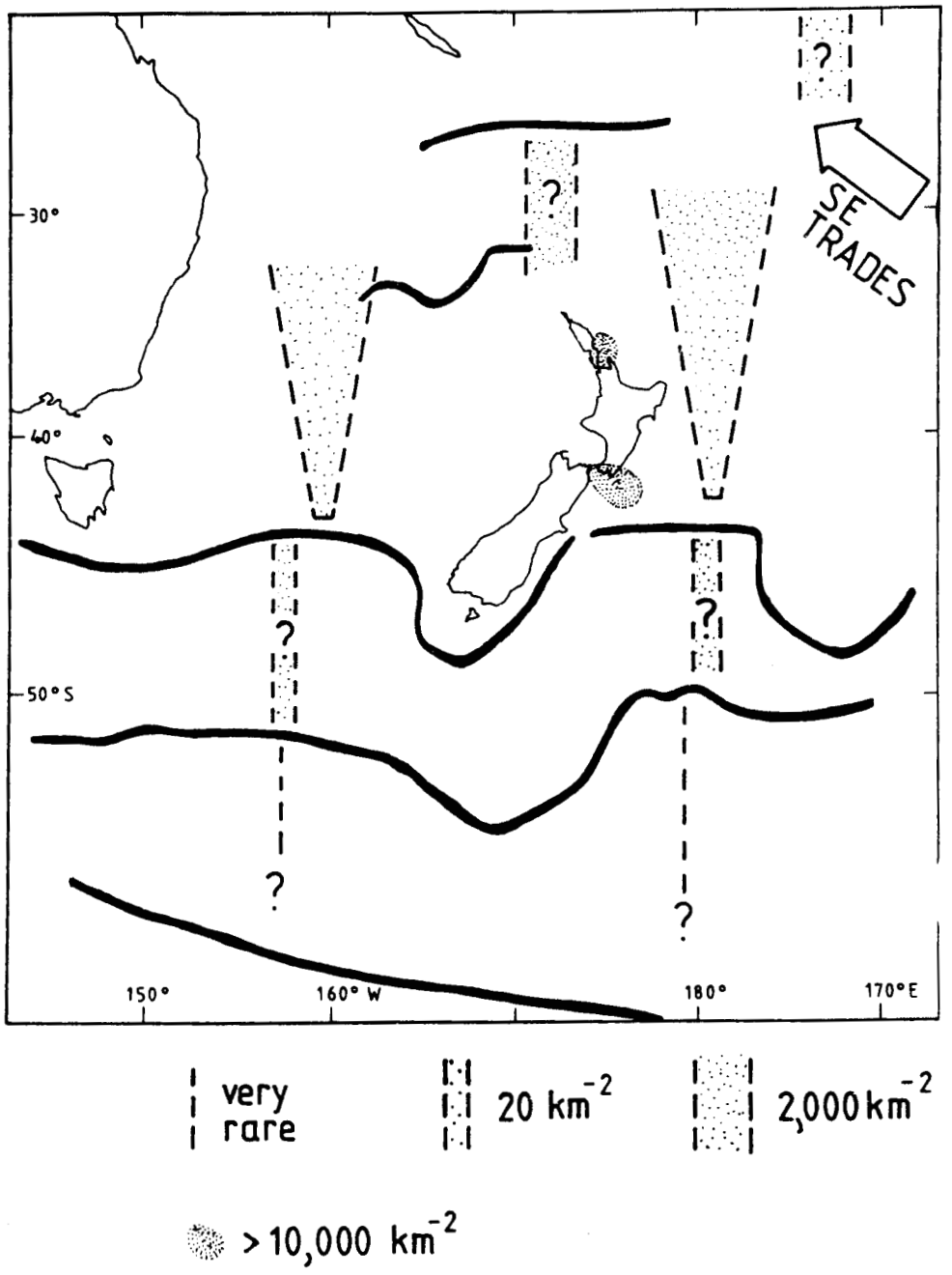


Figure 9.--Regional distribution of pelagic plastic granules across the southwest Pacific is influenced by oceanic fronts and wind and surface current patterns. Based on Gregory et al. (1984); Gregory (1987, 1990), and unpublished data.

for waters in the Agulhas Current up to 100 nmi offshore from Cape Province (Ryan 1988). On the other hand, densities in surface waters of the northern Sargasso Sea include >10,000 pieces of plastic and 1,500 pellets km^{-2} (Wilber 1987). Elsewhere around the eastern North Atlantic, densities of polluting plastic are lower, with only 700 pieces km^{-2} and 80 pellets km^{-2} being reported from waters north of the Gulf Stream (Wilber 1987).

PLASTIC MACRO- AND MEGALITTER

In the categories of plastic macro- and megalitter I include large manufactured items and artifacts fabricated from plastics and other persistent synthetic materials and the products of their fragmentation and disintegration, following the approach of McCoy (1988). Megalitter is of a size enabling visual identification of floating items by a shipboard observer (generally decimeters or larger), while macrolitter is mostly smaller items and fragmented material, larger than the previously described granules and readily seen with the naked eye during shoreline surveys. Typical examples of the former are fishing floats, containers, crates, bottles and their tops, netting, lines, hawsers, strapping bands, plastic sheeting and bags, foamed items, and confectionery wrappings. Only some of these items are readily degradable.

Significant quantities of macro- and megalitter have been seen on all shores examined to date (Tables 2 and 3, Figs. 3-8, 10-13). The amounts are highly variable, but even on uninhabited islands and the otherwise remotest of places discarded plastic is present. In a survey of New Zealand's subantarctic islands, Gregory (1987, Appendix 1) itemized a great diversity of plastic material and noted that the quantity of macrolitter was surprisingly small considering the abundance of megalitter items (Fig. 10). A similar diversity of seaborne megalitter becomes stranded on islands of the southwest Pacific. As an example, Raoul Island in the Kermadec Group some 500 km northeast of New Zealand (Fig. 1), has <10 permanent residents at a weather station, and yet large quantities of macro- and megalitter are stranded on the beaches (Table 3).

In late 1988 New Zealand's Department of Conservation, with cooperation from the Wildtrack Programme produced by the Natural History Unit of TVNZ (Television New Zealand), initiated a nationwide survey of plastic litter on beaches. Most participants are students who complete a standard record card (Fig. 14). Preliminary reviews of some 50 returns coming from widely separated places, both remote and near population centers of the North and South Islands, confirm casual observations that considerable quantities of plastic macro- and megalitter accumulate on these shores. It is surprising to note that few returns identified the small resin granules, even at places where they are reasonably common. Those items most frequently recorded were fragments of foamed and hard plastic, plastic bags and sheeting, strapping bands, bottles, and bottle tops. The following selected examples illustrate the magnitude of contamination:

74 bottles on 860 m of beach--Ohope, Bay of Plenty

426 bottles and 82 bags on 2 km of beach--Mohaka, Hawkes Bay

32 bags on 500 m of beach--Petone, Wellington Harbor

2,817 bottle tops (from repeated surveys: 4 August, 14 and 19 September 1988)--Oreti, Southland

200 packing straps on <200 m of beach--Mokomoko Inlet, Southland

Table 3.--Simplified catalogue of plastic megalitter and other artifacts found on a 3-km stretch of beach on the northern coast of Raoul Island, southwest Pacific.

Type of litter	Number
Fish boxes and crates	10
Fishery floats	26
Bottles and containers (detergent, cosmetics, etc).	40
Hawser, rope	
Long (ca. ±10 m)	10
Short (<10 m)	5
Netting (trawl) and rigid mesh	5
Foamed material (Styrofoam)	
Small (<2 cm)	>30
Moderate (>2 to <15 cm)	>10
Large (>15 cm)	>20
Sheeting	10
Strapping bands	>20
Footware (jandals/thongs)	20
Miscellaneous	>10

Repeated surveys (1974, 1978, 1981, and 1982) at Kawerua, a remote beach on the exposed west coast of Northland, showed a gradual decrease in numbers of plastic bags and an increase in bottles and total plastic items, probably reflecting changes in types of packaging over that period (Hayward 1984). Comparable trends in plastic megalitter accompanying changing patterns in offshore fishing activities have been noted for the subantarctic islands and mainland New Zealand shores (Cawthorn 1985).

SOURCES AND DISTRIBUTION

From the approach of Ryan (1987b), it is appropriate to identify three categories of plastic debris on shores throughout the region.

1. Material having a local onshore source.

2. Material originating from nearby fishing and shipping activities.

3. Material that has drifted from afar and that can be considered oceanic.

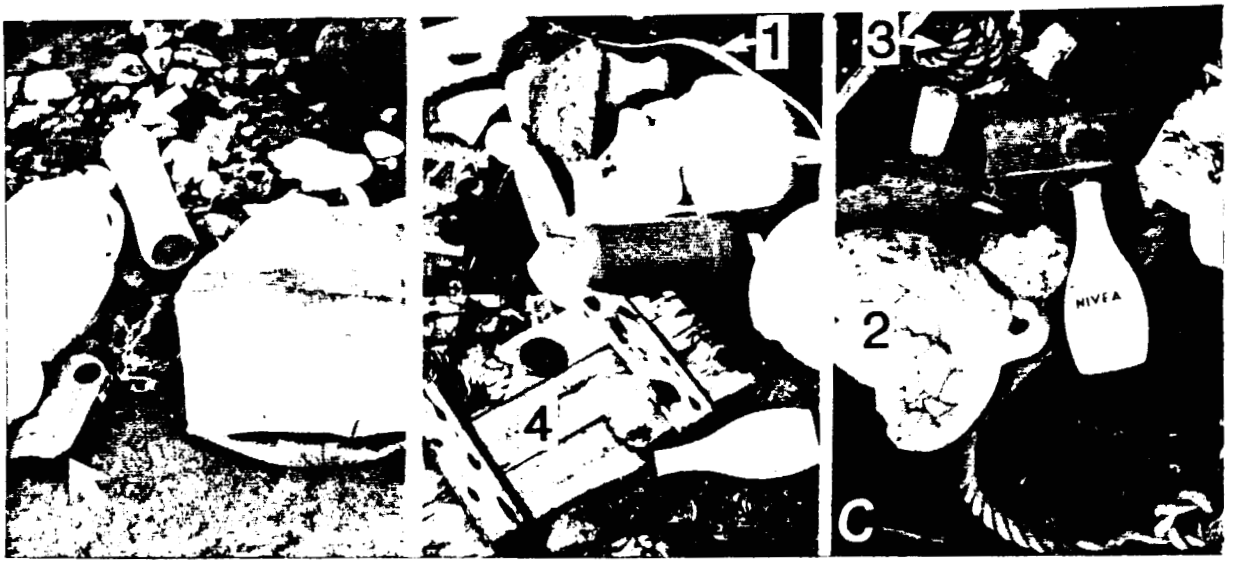


Figure 10.--Representative plastic items washed up on New Zealand's subantarctic islands: North West Bay, Campbell Island (A) and Derry Castle Reef, Auckland Islands (B and C). The large crushed container in (A) is of French origin and the two smaller items (arrow) are of United Kingdom manufacture. Note the polypropylene strapping (1), incipient crazing on the inside of broken high-density plastic fishing floats (2), cordage (3), and parts of wooden packing crates (4) in B and C.

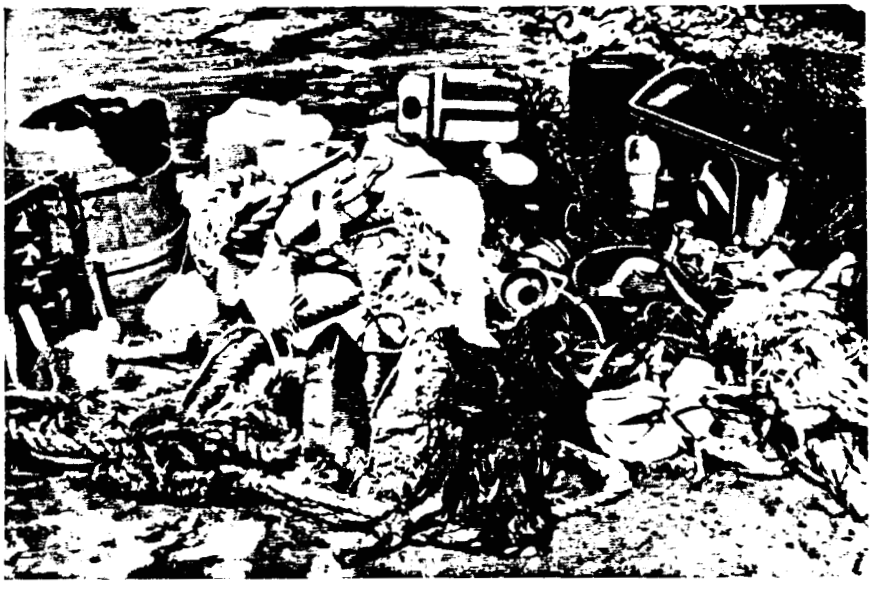


Figure 11.--Representative locally generated and oceanic plastic litter assembled from combing 100 m of beach at Makara, west coast near Wellington, New Zealand. Some of this collection has clearly come from fishing activities. (Photograph taken by M. Cochrane.)

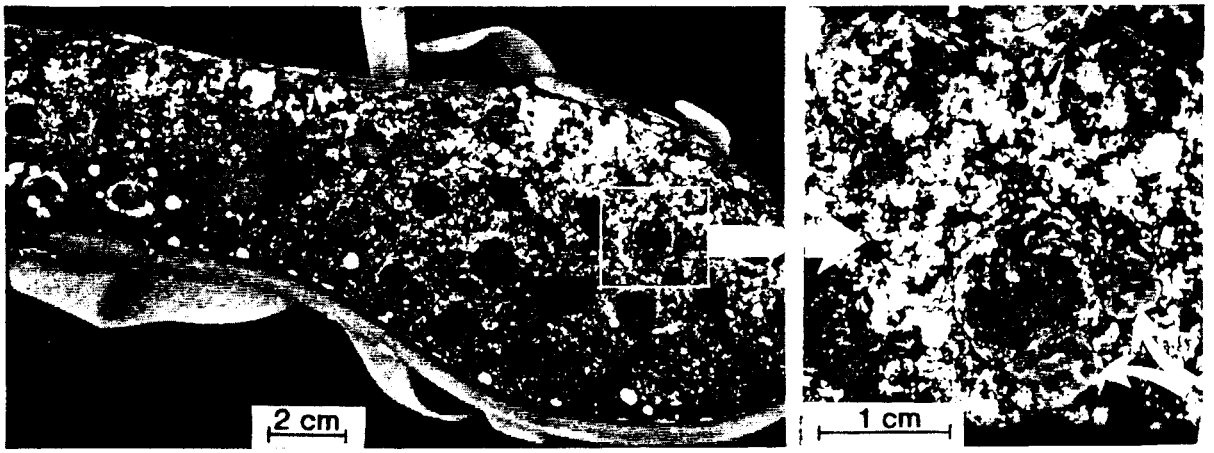


Figure 12.--Plastic sandal heavily encrusted with bryozoans, coralline algae, and clumps of the pink foraminiferan, *Homotrema rubra* (arrow). (Collected by K. A. Rodgers on Tuvalu.)

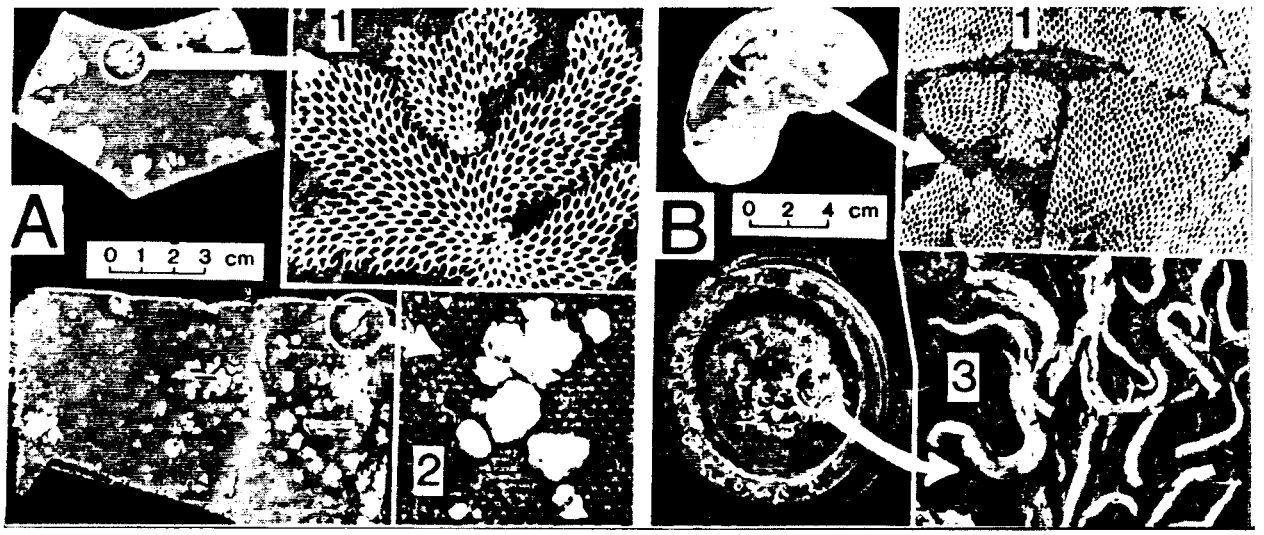


Figure 13.--Encrusted oceanic plastic items from Rarotonga (A) and Raoul Island (B). Note the bryozoans (1), coralline algae (2), and calcareous annelid tubes (3).

For the New Zealand coast and inshore waters, Gregory (1978) identified industrial centers as the principal sources (Fig. 2) of plastic mesolitter (mostly granules). This litter was material that was accidentally spilled in wharf and other cargo handling areas and at processing plants, and reached the sea through sewage and storm drainage systems as well as natural waterways. Subsequent dispersal was effected by coastal currents (Fig. 2). On populated islands (e.g., Tonga, Rarotonga), as on New Zealand shores, it is possible to separate plastic megalitter into two populations. One is probably of local (or domestic) origin, and the other comes from offshore sources and may have been adrift for some time. Casual visitors as well as indiscriminate and uncontrolled garbage dumping are responsible

BEACH CLEAN UP & SURVEY RECORD CARD

Date:____General Location: _____

Exact Site on beach _____

Approx. size of area:___metres long by ___metres wide

Character of survey area _____

Name of surveyor or organisation: _____

Contact address and tel. no: _____

An easy way to record the material you pick up is by counting in groups of five like this:
Bottles ~~IIII~~ II Total 7

HARD PLASTICS	Total	GLASS	Total
Bottles, containers		Bottles	
Tops		Light bulbs and tubes	
6-pack yokes		Broken fragments	
Buckets		ALUMINIUM	
Toys/combs		Cans, cartons	
Fragments		Foil/trays/wrapping	
Other		Other	
FOAM PLASTICS		TIN/STEEL	
Trays/cups/packaging		Tins/cans	
Fishing floats		Drums	
Foam fragments		Wire	
Other		Bottle tops	
PLASTIC SHEET AND FIBRES		Other	
Plastic sheets		PAPER	
Plastic & cellophane bags		CARDBOARD	
Fishing nets		TIMBER (leave driftwood on beach)	
Fishing lines (approx. length in metres)		CLOTH ITEMS	
Other rope/cord (approx length in metres))		RUBBER ITEMS	
Packing tape/strapping - cut		FOREIGN DEBRIS (describe overleaf)	
Packing tape/strapping - uncut		ENTANGLED/STRANDED ANIMALS (describe overleaf)	

ESTIMATE OF TOTAL VOLUME OF RUBBISH COLLECTED FROM YOUR AREA _____

THANK YOU FOR COMPLETING THIS SURVEY CARD. PLEASE RETURN IT TO YOUR BEACH CO-ORDINATOR, OR YOUR LOCAL DEPARTMENT OF CONSERVATION OFFICE, OR POST TO ANNIE WHEELER, MARINE DEBRIS NETWORK, C/O DEPARTMENT OF CONSERVATION, P O BOX 8 NEWTON, AUCKLAND.

DETAILS OF ENTANGLED/STRANDED ANIMALS

Identify bird or animal _____

Cause of injury or death _____ If the creature is still alive seek help from your beach co-ordinator, or local RSPCA, DOC office or Forest and Bird. Take photographs.

DETAILS OF FOREIGN DEBRIS

Describe item and the country you think it is from _____

WHERE DO YOU THINK MOST OF THE RUBBISH YOU HAVE COLLECTED HAS COME FROM? (ie fishing boats, picnickers, household rubbish, foreign boats etc)

_____

The NZ Marine Debris Network is a coalition of conservation groups who are concerned about the issue of marine debris and coastal pollution and its effect on wildlife. The Network includes representatives from the Department of Conservation, Greenpeace, Royal Forest and Bird Protection Society, University of Auckland, RSPCA, and the World Society for the Protection of Animals.

One of the aims of the Network is to co-ordinate the efforts of the many groups and individuals thoughout the country who are involved in beach clean ups and to carry out a survey of the debris collected off New Zealand beaches. This information can then be used to determine the main types and sources of the debris that litters our beaches. It will contribute to a national marine debris data base, and will help develop solutions to marine debris pollution.

Your participation in this beach clean up is an important contribution to an on-going nationwide effort.

GUIDELINES FOR COLLECTORS

1. Carry out your beach clean-up and survey at low tide.
2. Make sure you have warm clothing, and sun protection if necessary.
3. Wearing rubber or gardening gloves can be a good idea.
4. Before you start: make sure you've got your record card and board, pen and rubbish collection bags.
5. Take something to drink and perhaps a snack.
6. Work in small groups, so some of you can be picking up and sorting the rubbish into categories for recycling (see below) while one person is recording the details on the survey record card.
7. Know who your beach co-ordinator is and where to find them. Be clear about what area you are meant to be surveying.
8. Know where the rubbish collection point is.
9. Report any entangled animals to your co-ordinator and take photos if possible.
10. Give your record card back to your co-ordinator or post to the address on the other side of this form.
11. MAKE SURE YOU SEPARATE YOUR RUBBISH INTO DIFFERENT BAGS WITH 1. PLASTICS, 2. GLASS, 3. PAPER, 4. ALUMINIUM CANS, 5. TINS; AS ALL THIS MATERIAL IS GOING TO BE RECYCLED.

Figure 14.--Standard record card used in New Zealand coastal plastic pollution surveys.

for much of the former; some must also come from vessels operating in local waters. The most unsavory items found during the course of these surveys were soiled (disposable) baby diapers, syringes, and discarded pesticide or agricultural chemical containers. Litter coming from distant offshore sources is considered oceanic. It is characteristically embrittled and sports an encrusting biota (see below).

Around the subantarctic islands, plastic macro- and megalitter concentrate on west-facing (i.e., windward) shores, whereas little reaches their eastern (leeward) coasts (Gregory 1987). The dominating influence here is the strong West Wind Drift Current of the Southern Ocean (Lutjeharms et al. 1988). The same pattern is repeated on southwest Pacific island shores. Here, however, it is the eastern shores--those facing into the southeasterly trade winds--onto which plastic meso-, macro-, and megalitter are herded (Figs. 3-8). Further, in several instances, it is possible to identify crude decreases in quantities of plastics in the downdrift direction (e.g., Viti Levu, Tongatapu, and Rarotonga; Figs. 5, 6, and 8). The encrusting biota (see below) of many megalitter items suggest they have been afloat for some time. These are part of the global oceanic population of pelagic litter. Plastic granules on Australian, New Zealand, and Fiji shores can have their major origins in local suppliers and manufacturers.

Norfolk, Raoul, Vanua Mbalavu, Tongatapu, and Rarotonga have no local sources for virgin plastic granules, and lie upwind from regional ones. Nibs on these shores must have come from the same global oceanic population of pelagic plastics and are dispersed by the southeast trade winds. A possible source exists in French Polynesia, which lies upwind, but I have no data for this region.

Although plastic macro- and megalitter on eastern Australian shores have not been surveyed, quantities of this litter and the resin granules appear to be much lower than at equivalent sites in New Zealand. This difference probably reflects coastal current and broad oceanic circulation patterns as well as persistent winds that blow offshore or parallel to the coast over this region. On the other hand, drift pumice is quite common on these shores, as it is on the shores of many Pacific islands (Sachet 1955). Much of the plastic litter on popular recreational beaches of Australia, New Zealand, and larger southwest Pacific islands comes from casual visitors and day trippers; it is dominated by food and confectionery wrappings and drink bottles. This material is seldom conspicuous on isolated shores. From these remote places, there is evidence that much plastic debris comes from fishing-related or other shipping activities (Cawthorn 1985, 1987; Mattlin and Cawthorn 1986; Gregory 1987, 1990).

Attention has already been drawn to the accumulation of plastic debris on the windward shores of several southwest Pacific islands. The materials involved are mostly of oceanic origin and also from fisheries-related and shipping activities, and their quantities on west- and north-facing (leeward) shores are minimal. The principal urban population centers of Tongatapu, Rarotonga, and Upolu (Western Samoa) are all situated on north-facing coasts along which much locally generated plastic has spread.

Plastic items, categorized by country of origin (when possible), are summarized in Table 4 for New Zealand's subantarctic islands and for subtropical Raoul Island. Some items are truly oceanic (e.g., an Argentinian fishing float reaching the Snares), but most appear related to regional fishing activities. South Korean, Taiwanese, and Japanese vessels are common in these waters, so the dominance of Asian-sourced artifacts is not unexpected. The Russians also have a considerable presence, but one that is not reflected in the seaborne litter. Personal experience on a Russian research vessel reveals that they generate very little plastic, and discarded paper and cardboard packaging are incinerated.

The regional distribution of dispersed pelagic or oceanic plastics is schematically summarized in Figure 9. It has been inferred (Gregory et al. 1984; Gregory 1990) that major oceanic fronts such as the Polar, Subantarctic, Subtropical, and Tropical Fronts, and eddies from the East Australian Current have important influences on the distribution and abundance of litter. They act as barriers arresting the spread of material, and along these barriers the material is also concentrated and carried. For example, Bourne and Clarke (1984) noted an accumulation of garbage in the Humbolt Front off Valparaiso, Chile. Observations in the Hauraki Gulf, northern New Zealand, show that densities of plastic granules taken in tows made along windrows may exceed 10,000 km^{-2}, whereas densities in tows transverse to the windrows may be as few as 1,000 km^{-2} (Gregory, unpubl. data).

Table 4.--Summary of numbers of plastic items having identifiable countries of origin.

Country of origin	Subantarctic islands	Raoul Island
Asia	11	5
United Kingdom	5	1
New Zealand	4	6
Australia	3	2
Spain	2	--
Bulgaria	1	--
France	1	--
Norway	1	--
U.S.S.R.	1	1
Argentina	1	--

ENCRUSTING BIOTA

Plastics and other synthetic litter afloat on surface waters of the ocean are an important and expanding, although little studied, ecological niche for a pseudoplanktic biota of the kind commonly present on *Sargassum* (Winston 1982; Butler et al. 1983). Gregory (1978) noted that granules from beaches of northernmost New Zealand were sometimes encrusted by the bryozoan *Membranipora tuberculata*. This is a tropical species and has also been found on drift plastics from Australia, Norfolk and Raoul Islands, and Fiji, Rarotonga, and Tongatapu. It was inferred that there had been eastward dispersal across the north Tasman Sea by way of eddies in the East Australian Current (Gregory 1978). Other encrusting taxa identified during past and present studies include further bryozoan species awaiting identification, coralline algae, calcareous annelids, barnacles, a hermatypic coral, and the pink foraminiferan *Homotrema rubra* (Figs. 12, 13). Encrusters are less common on artifacts from the subantarctic, where only goose barnacles (*Lepas* spp.) and the annelid *Spirorbis* have been recognized.

It is evident that pelagic plastic litter may be an important vector in the transoceanic and regional dispersal of a varied biota and may increase the chances of migration to distant shores, including isolated islands, as contemplated by Ryan (1987b).

DISCUSSION

The general environmental problems of the southwest Pacific region, with its limited financial and natural resources, have received wide attention (e.g., Chan 1973; Salvat 1979; Izrael et al. 1981; Dahl and Carew-Reid 1985; Carew-Reid 1988). Plastics are an unnecessary additional contaminant to the region, and the environmental implications to be drawn are those that have been identified elsewhere (Laist 1987) and need no further elaboration. For animals these implications include death or

debilitation through entanglement; blockage of the intestinal tract through ingestion, leading to starvation and death; ulceration of delicate tissues by jagged plastic fragments; and reduction in quality of life and reproductive performance. In addition, large items can be hazards to shipping. The aesthetic concerns expressed about plastic pollution also must be acknowledged. Unsightly accumulations of locally generated or oceanic plastics on beaches could be to the detriment of tourism (Prasad 1987). Soiled diapers, used syringes, and medicinal and pesticide containers stranded or abandoned on beaches will discourage even the most hardy of tourists.

The oceanic problem can be addressed through MARPOL and the London Dumping Convention. The local problem needs to be approached with cultural delicacy, for traditional practice and attitudes towards refuse disposal are in many ways rather casual (Anonymous 1976). Educational efforts, directed primarily at the young (Bryant 1988), will need to draw on and develop from traditional Pacific ways.

The very attributes that mankind finds desirable in plastics--lightness, strength, manufacturing adaptability, flexibility, inertness, resistance to degradational processes, transparency, and prolonged shelf life in packaging--are also the reasons they are today a globally important marine pollutant (Andrady 1988; Johnson 1988).

It is difficult to estimate the rate at which plastics disappear or are adsorbed into the environment (Gerrodette 1985). And while the breakdown of plastic compounds in itself may create few problems, the effects of released additives such as antioxidants, retardants, and biocides have never been assessed, only speculated about (Gregory 1978). Locally generated litter is likely to be fresh in appearance, while much of the oceanic and offshore-generated plastic litter stranding on these tropical and subtropical Pacific shores is chalky, crazed, and embrittled, all evidence of oxidative aging and photodegradation. Whether this occurs while it is afloat or after it is stranded on the shore has not been established. Circumstantial evidence suggests that aging is more rapid once artifacts are stranded high and dry on a beach (Gregory 1983). On the New Zealand coast, the extent of degradation apparently decreases southwards, although a detailed survey to confirm this claim has not been undertaken. Similarly, the proportion of degraded virgin granules is much greater on the tropical shores than it is on temperate ones (Table 5) (Gregory 1983, table 1). On high-latitude subantarctic shores, crazing is less evident and much breakdown occurs through mechanical abrasion and battering (Gregory 1987).

The extent of crazing and embrittlement of plastic granules (Table 5) and megalitter items observed on Raoul, Rarotonga, and Tonga suggest that a survival time of 5 years (Gregory 1983) may be overly generous. Evidence indicates that plastics degrade more rapidly in the Australian and New Zealand region than they do in equivalent Northern Hemisphere latitudes, although contrary to popular belief, the reason is not necessarily related to higher ultraviolet values (Sharman 1987). Controlled experiments and observations on rates of plastic degradation around the world are needed if we are to understand adequately the population dynamics of pelagic plastics

Table 5.--Relative numbers (in percentages) of fresh, slightly degraded, and highly degraded plastic granules from selected localities.

Locality	Number	Increasing degradation ——> Fresh	Slightly degraded	Highly degraded
Fiji	163	18	45	37
Raoul	25	24	52	24
Rarotonga	70	19	41	40
Tonga	60	20	30	50
Auckland, New Zealand	216	79	13	8
Botany Bay, Australia	73	53	40	7

and to establish whether an equilibrium state between accumulation (strandings) and losses in environmental sinks (disappearance from view) has been already reached.

CONCLUSIONS

Although pollution by plastics of the southwest Pacific marine environment has not yet reached the magnitude evident in waters adjacent to more heavily populated, industrialized, and fished regions of the Northern Hemisphere, it is a developing problem and cause for concern.

Increased fishing activities across the region, and in particular drift gillnetting, are likely to escalate presently identified problems.

Regional distribution and dispersal are influenced by proximity to sources, oceanic current and circulation patterns, and prevailing winds. Oceanic fronts may have a key role in defining boundaries to zones with broadly similar areal densities of pelagic plastics.

Population dynamics of pelagic plastics across the southwest Pacific as well as globally are not well understood, and more information is needed on the "sinks" of this material.

There is need to educate the public about the environmental problems arising from the indiscriminate disposal of plastics and other persistent synthetic compounds.

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