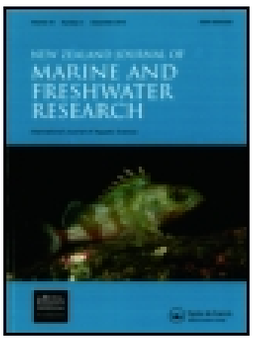

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Accumulation and distribution of virgin plastic granules on New Zealand beaches

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ABSTRACT

A 1972-76 survey of over 300 beaches showed that small plastic pellets and granules, of the kinds commonly being recorded on shores around the North Atlantic, are also widely distributed on the New Zealand foreshore. Most of the pellets are virgin polyolefins, the imported feedstock of the local plastics industry. The pellets find their way into the environment through accidental spillage during transport and handling; they are not litter or waste in the usual sense. The quantity of these virgin plastic pellets on New Zealand beaches today possibly exceeds 1000 t and has a value in excess of NZ$1 000 000. Virgin polystyrene pellets are rare: virgin polyvinyl chloride pellets were never seen.

Numbers of pellets are greatest near Auckland, Wellington, and Christchurch, which are the important source areas. However, pellets are also found on beaches remote from these cities, and some may have come from eastern Australia. Because they degrade slowly, plastics can be a significant contributor to coastal pollution, but the environmental hazards of their accumulation are uncertain.

INTRODUCTION

Discarded and waste plastics, with other man-made products, are increasingly found in all marine waters (e.g., Carpenter 1976). Because of relative inertness (Scott 1973, Staudinger 1972) and general resistance to degradation processes, plastics, once released, are particularly durable in all environments (Cooney *et al.* 1973, Ilgenfritz 1975, Rodriguez 1971) and they are often excessively conspicuous in beach litter (Evans 1974). The pollution potential of plastics is widely acknowledged (Hood & Kelley 1972).

Accumulation and concentration of plastic litter on beaches is widespread (e.g., Anon 1973; Cundell 1973, 1974; Scott 1972) and is often visually offensive. However, as well as aesthetically distasteful plastic litter, less conspicuous but significantly large quantities of small virgin plastic pellets and granules occur on beaches and in coastal as well as oceanic waters along the eastern seaboard of North America (Austin & Stoops-Glas 1977, Carpenter & Smith 1972, Carpenter *et al.* 1972, Colton *et al.* 1974, Cundell 1973, Hays & Cormons 1974) and also in the Bristol Channel and Severn Estuary, United Kingdom (Kartar *et al.* 1973, Kartar *et al.* 1976, Morris & Hamilton 1974). These pellets also occur in surface waters of the North Pacific (Wong *et al.* 1974) and recently I reported their widespread occurrence on New Zealand beaches (Gregory 1976). They are also found on the beaches of South Australia, Victoria, and New South Wales, as well as the Coral Coast of Fiji, and the Kermadec Islands (my unpublished data).

This report is based on observations made between November 1972 and December 1976 at over 300 beaches around New Zealand (Appendix 1) and is concerned solely with virgin material. No attempt was made to survey quantities of other plastics littering the foreshore.

METHODS

Seaborne plastic pellets wash up and accumulate on beaches, either concentrating along the drift line (Fig. 1) or spreading across the back beach and wash-over flat. They often become covered by drifting sand. Their abundance was recorded in terms of numbers per linear metre of beach (Appendix 1). Counts were easy to make where pellets were narrowly concentrated along the drift line. Where the pellets were broadcast over the back beach or wash-over flat, a value was obtained by counting the number in a transect 1 m wide normal to the general trend of the beach.

The intensity of sampling varied from place to place. In some, only a few metres or tens of metres of shoreline were examined, in others, several kilometres. Repeated visits to several beaches around Auckland showed that the number of pellets present varies irregularly from time to time. Three levels of pellet abundance in order of decreasing frequency were recorded at most localities (Appendix 1).

TYPES OF PLASTIC PELLETS

The several kinds of virgin plastic pellet recognised on New Zealand's beaches (Fig. 2a–f) are similar to those described from the North Atlantic (see Carpenter 1976, Colton *et al.* 1974).

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Ovoids and spheruloids, generally up to 5 mm in diameter (Fig. 2a) and occasionally much larger (Fig. 2c), as well as discs (Fig. 2b) and cylindrical rods of varying sizes (Fig. 2c & d) were the most common shapes. Clear to translucent, colourless pellets, often with included small air bubbles (Fig. 2c & d) are the more common, although opaque or whitish types are invariably present. Coloured discs and rods, mostly black and white, but also blue, yellow, and less often red and green were also found. Although most pellets are fresh and little abraded (Figs 2a & b) some degradation effects are apparent (see 'Degradation and Weathering').

These pellets float (density $<1.00\ g.cm^{-3}$) and have an average weight of 0.026 g (range <0.01–>0.08 g).

Through infrared absorption spectrophotometry, burning characteristics (Haslam *et al.* 1972, Staudinger 1970), and from informants in local industry, these pellets are identified as virgin polyethylene and polypropylene (= polyolefins) rather than polystyrene or polyvinyl chloride. Similar polyethylene 'nibs' are widespread around the North Atlantic (Carpenter 1976, Colton *et al.* 1974). Polyolefin pellets are *not* manufactured in New Zealand – they are the imported virgin material that is the feedstock of the local plastics industry.

Polystyrene 'suspension beads' like those common around the North Atlantic were never identified with certainty and rods of virgin polystyrene (Fig. 2f) were extremely rare. No virgin polyvinyl chloride granules were found.

As well as virgin material, embrittled and weathered, irregularly shaped and sized degradational chunks of plastic (Fig. 2d) were commonly present. Small pieces of coloured polyolefins, apparently chipped for recycling were occasionally found (Fig. 2g).

ABUNDANCE, DISTRIBUTION, SOURCES

Although sampling was uneven and abundance of plastic pellets highly variable, a map generalising their distribution around the New Zealand coast has been compiled (Fig. 3). Separate maps give details of pellet abundance in three regions where they are particularly common (Fig. 4 – Auckland; Fig. 5 – Wellington; Fig. 6 – Christchurch).

Colourless virgin plastic pellets were found on all sandy beaches examined except those of southern Westland and the northern Karamea Bight, and they were very rare around Golden Bay. Pellets were seldom seen on boulder, pebble, and shingle beaches; none were recovered from extensive stretches of the Kaikoura and South Canterbury coasts. This may reflect sampling bias. Loss through abrasion is improbable for wave action throws them high on to and beyond berm crests and out of reach of any grinding action. It is conceivable, although unlikely, that pellets are lost to view in the sieving effect of water filtering down through boulder and shingle beaches.

Consistently high pellet numbers were encountered on beaches near Auckland, where local concentrations often exceeded 10 000 per metre and once exceeded 100 000 per metre (Fig. 4). About Wellington numbers are generally a little lower, although at Petone and Oriental Bay local concentrations exceeded 40 000 per metre (Fig. 5). Auckland and Wellington harbours obviously act as effective traps for pellets released locally. Elsewhere around the North Island numbers are lower, although significant concentrations (often >1000 per metre) were found on the west coast from South Auckland to north of the Kaipara. Around the South Island fewer pellets were found and local concentrations exceeding 1000 per metre were found only near Christchurch (Fig. 6).

Coloured pellets and chips for recycling were never common and only became conspicuous on beaches near Auckland, Wellington, and Christchurch. Larger pellets (Fig. 2c) and flakes tended to be more abundant on South Island beaches.

These regional variations in pellet type are of minor significance and inadequate to permit identification of specific sources. However, the principle sources clearly lie in the cities where New Zealand's plastics industry is largely centred (Auckland, Wellington and Lower Hutt, Christchurch – see Bullen 1968). Numbers fall away rapidly with increasing

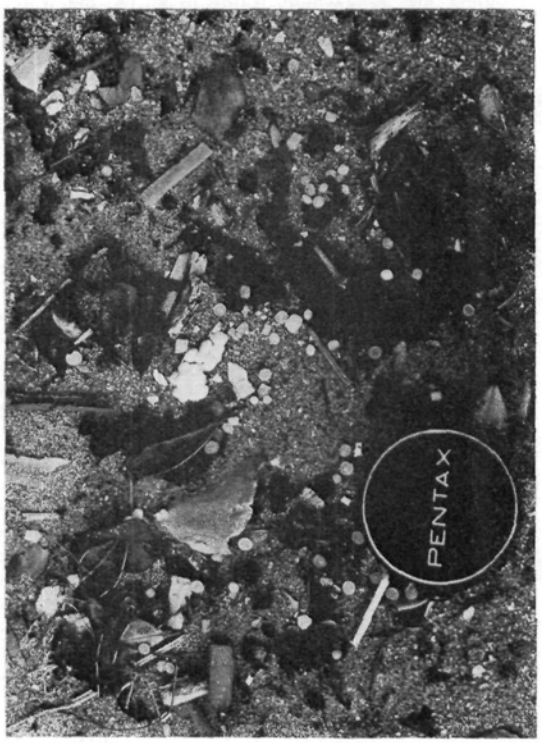


FIG. 1—Virgin plastic pellets in beach litter at Takapuna Beach, Auckland, March 1977; abundance level >1000 per metre.

distance from these source regions (Figs 4–6). Secondary sources are apparent where numbers rise above ambient levels (e.g., Tauranga, Timaru, and Westport). Pellet distribution (Figs 3–6) reflects dispersion from these source regions and is in general accord with the coastal currents illustrated by Brodie (1960).

Pellet numbers on the west coast of the North Island from Taharoa northwards to Kaipara Harbour and beyond appear anomalously high. If the main source was Auckland *via* the Manukau Harbour, high numbers would be expected around that harbour, and in particular on Cornwallis Peninsula, which lies athwart the main tidal stream; however, numbers here are rather low. Similarly, numbers near the Waikato River mouth are not sufficiently high to make Hamilton an attractive alternative source, although some contribution must come by this route. Some pellets along this coast may have come from Australia.

These virgin polyolefin pellets are imported raw materials that have yet to enter the fabrication process; they are not indiscriminate litter. Likely sources are accidental spillages during handling on wharves. Pellets may also make their way into coastal waters through rivers, streams, and storm water drains following spills at inland processors, or during transport there. Large numbers of fresh pellets are often to be seen on streets and in gutters near the Auckland wharves. I have also followed trucks leaving trails of pellets cascading like sugar from splits in paper sacks stacked on pallets, and which have probably been accidently punctured by fork hoists during handling. Some spillage may also occur at sea.

DEGRADATION AND WEATHERING

Most of the virgin plastic pellets found on New Zealand beaches are fresh (Figs 2a & b), but some show degradation effects. Many pellets are 'crazed' (Figs 2c & 7e) and others are distinctly chalky and embrittled (Fig. 2e). ('Crazing' is very fine cracks and fissures developing from the surface of a material; in plastics associated with progressive embrittlement.) 'Yellowing' sometimes occurs. These are all well-known weathering degradation phenomena in plastics (Baum 1974, Chottiner & Bowden 1965, Ives *et al.* 1971, Rugger 1968). The progressive nature of this deterioration is illustrated in Figs 7a–f. Ultimately, it leads to the complete distintegration of pellets.

The durability of unprotected virgin polyolefin pellets in beach environments is difficult to assess. It may well be less than 3 y (Estevez 1965, Fergusson 1974, Rugger 1968), although unconfirmed local sources suggest 5–10 y is a more realistic estimate. Additives can extend this time, and then periods exceeding 30–50 y do not seem unreasonable (Fergusson 1974, Kamal & Saxon 1967).

BIOLOGICAL AND OTHER ENVIRONMENTAL FACTORS

Diatoms, hydroids, and bacteria grow on plastic spherules in waters of the northwest Atlantic and Sargasso Sea (Carpenter & Smith 1972, Carpenter **et al.** 1972). Diatoms, possible hydroids, and filamentous algae, and dried-out unidentifiable mucoid and other organic materials were occasionally recognised on pellets from New Zealand. In rare instances pellets were encrusted by coralline algae.

Pellets from beaches about northernmost New Zealand were sometimes encrusted by the bryozoan *Membranipora tuberculata* (Bosc) (Fig. 8). This species is characteristic of the tropical and subtropical Indo-Pacific and Atlantic and commonly encrusts algal fronds. Other than an isolated observation in the mid 1960s at Goat Island Bay, Leigh (D. Gordon, Auckland University Leigh Marine Laboratory, 1975 *pers comm.*), this is the first time it has been recognised in New Zealand waters. *M. tuberculata* also occurs on pellets from beaches at Nambucca and Botany Bay, Australia, at Raoul (Kermadec Islands), and on the Coral Coast of Fiji (author's unpublished data). This encrustation and the anomalously high numbers of pellets found on some North Island west coast beaches leads me to conclude tentatively that there has been eastwards dispersal of pellets across the north Tasman Sea *via* the East Australian Current from Australia. Similarly, pellets may have spread eastwards from New Zealand to the Chatham Islands.

Small polystyrene spherules have been found in larval and juvenile fish (Carpenter *et al.* 1972, Kartar *et al.* 1973) and in the droppings of terns (Hays & Cormons 1974). These spherules, and irregularly shaped plastic particles having jagged edges, are also reported in the stomach contents of Leach's petrels *Oceanodroma leucorhoa* from the northwest Atlantic by Rothstein (1973) who noted that their consumption could result in internal injury. Carpenter *et al.* (1972) expressed similar concern that death could follow blockage of the intestinal tract in smaller fish after ingestion of these spherules. Polyethylene pellets have been found in the stomach contents of several species of procellariiform seabirds from around New Zealand (M. J. Imber, N.Z. Wildlife Service, 1976 *pers. comm.*); he considers that the pellets were picked up at sea, probably as an unwitting substitute for bits of pumice that the birds use as crop-stones, but not that pellets were the primary cause of any mortality.

Although plastics are generally inert (Cooney *et al.* 1973, Scott 1973, Staudinger 1970), biodegradation can help in their progressive deterioration (Mills 1974), even if it never reaches the horrifying spectre of uncontrolled plastic-consuming bacteria envisaged by Pedlar & Davis (1973). However, susceptibility to biodegradation may reflect non-polymer components (plasticizers, stabilisers, colourants, biocides, inhibitors, and fillers) of plastics (Rodriguez 1971, Rosato 1968). The evidence for microbiological deterioration of plastics and their powdered weathering products is confused and contradictory (Heap & Morrell 1968).

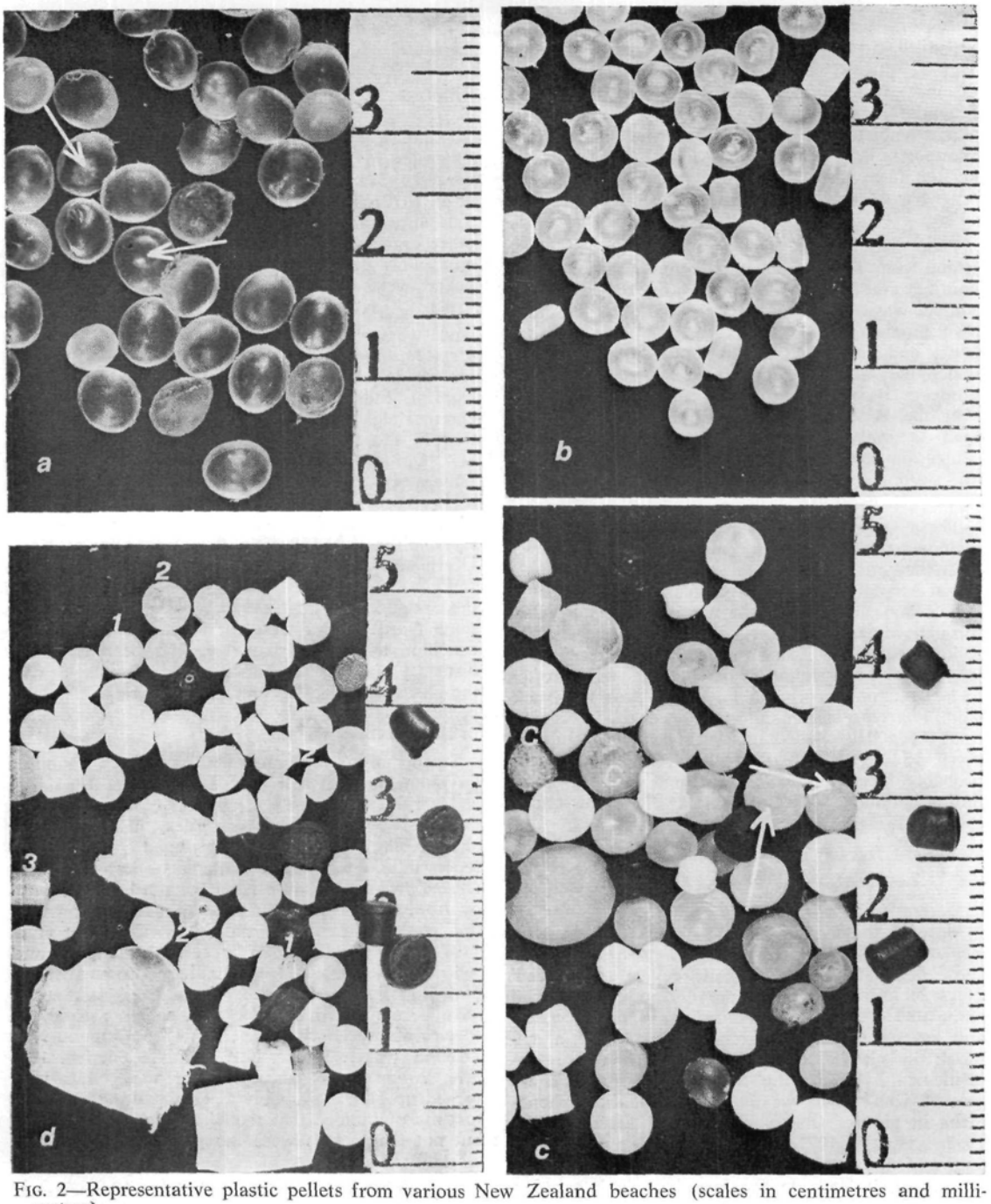


FIG. 2—Representative plastic pellets from various New Zealand beaches (scales in centimetres and millimetres).

(a) Ovoid, transparent/translucent polyethylene pellets of uniform size; note the wispy attachments, fresh non-degraded appearance and occasional shallow indentation (arrowed). Cape Kidnappers, May 1974;

(b) Colourless, cylindrical disc-shaped polyethylene pellets; note solitary white pellet, fresh appearance and shallow indentations on terminal faces. Ocean Beach, immediately south of Cape Kidnappers, January 1975;

(c) Variously shaped and sized virgin polyolefin pellets; note the large translucent disc and black cylinders. Several pellets contain gas bubbles (arrowed) and others are affected by crazing (c). Petone Beach, January 1975;

(d) Variously shaped and coloured pellets and some larger fragments from embrittlement and degradation of manufactured plastic articles; note the crazed pellets (1), gas bubbles (2), and a solitary virgin polystyrene rod (3). Takapuna Beach, December 1973 ;

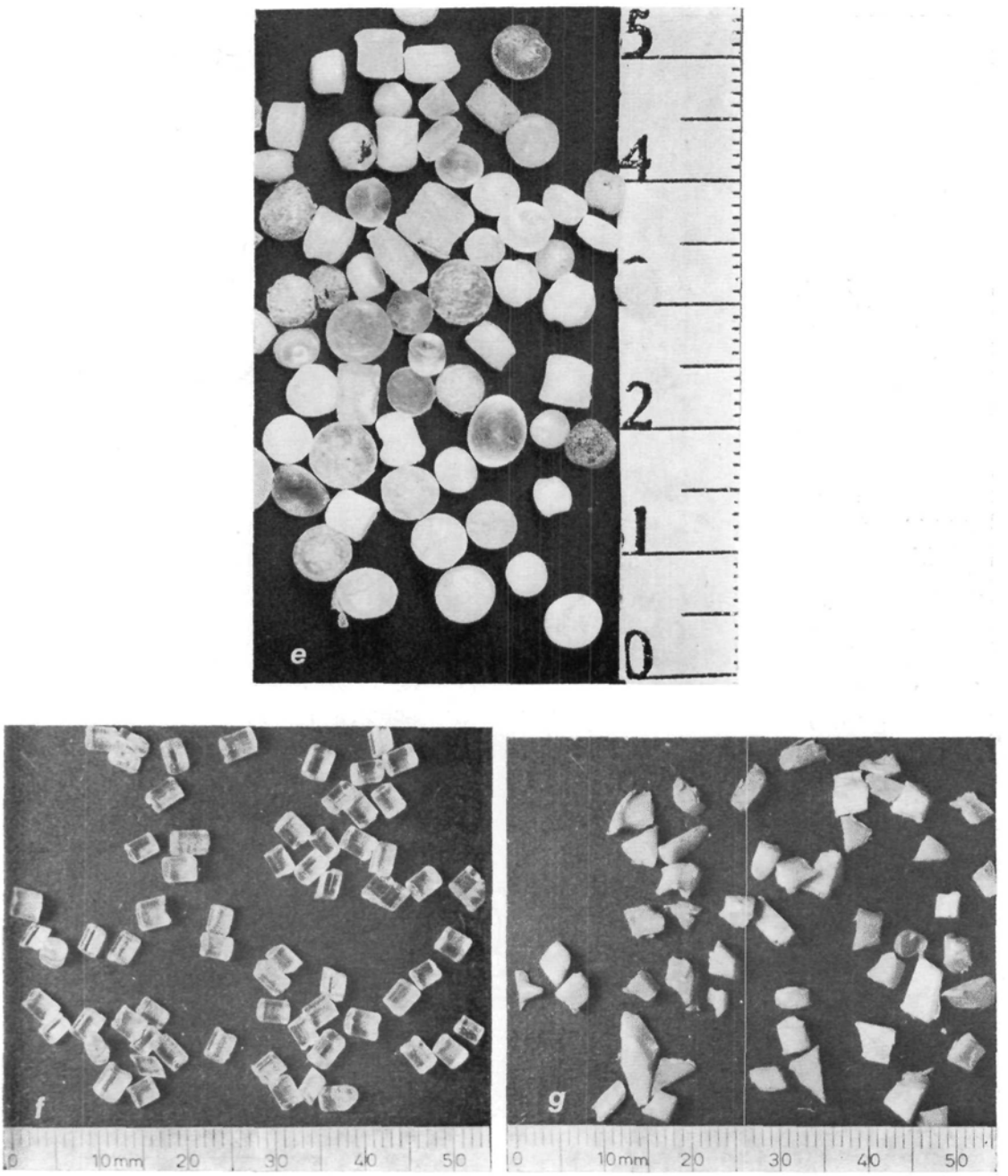


FIG. 2—(*Continued*) Representative plastic pellets from various New Zealand beaches (scales in centimetres and millimetres).

(e) Assorted plastic pellets that exhibit varying degrees of degradation (crazing and chalkiness); gas bubbles are quite common. Bethells Beach, November 1975;

(f) Fresh virgin polystyrene rods, selectively picked from several Auckland beaches, November 1975; and

(g) Jagged, coloured polyethylene fragments chipped for recycling, selectively picked from several Auckland beaches, 1973–75.

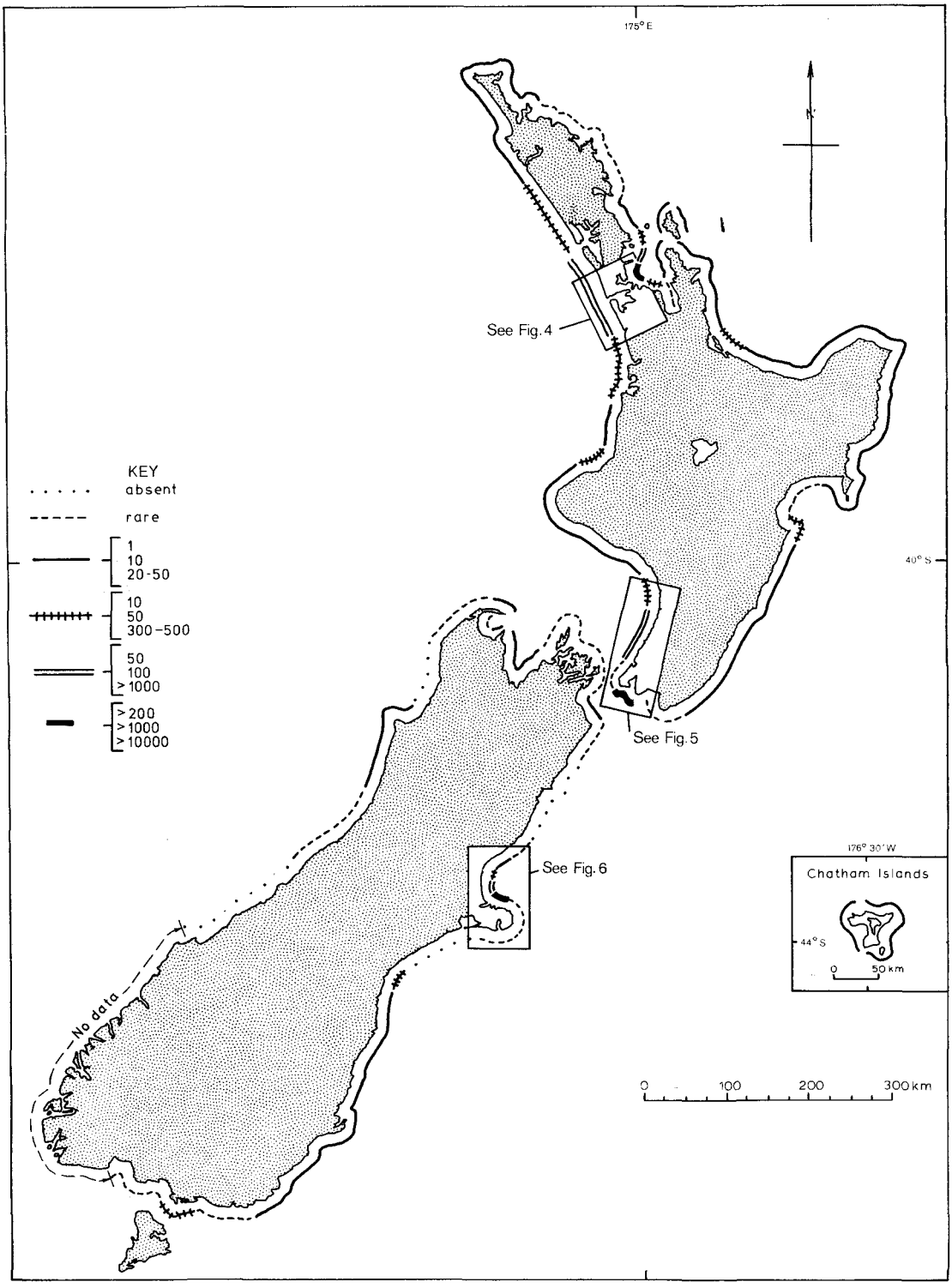


FIG. 3—Regional distribution of virgin polyolefin pellets on New Zealand beaches expressed as number per metre of shoreline, based on data collected between November 1972 and December 1976. The three values given under each line code indicate abundance levels at which the pellets are (i) reasonably consistent (lowest value, but top of list in key), (ii) commonly encountered (middle value, middle of list), and (iii) locally concentrated (greatest value, bottom of list).

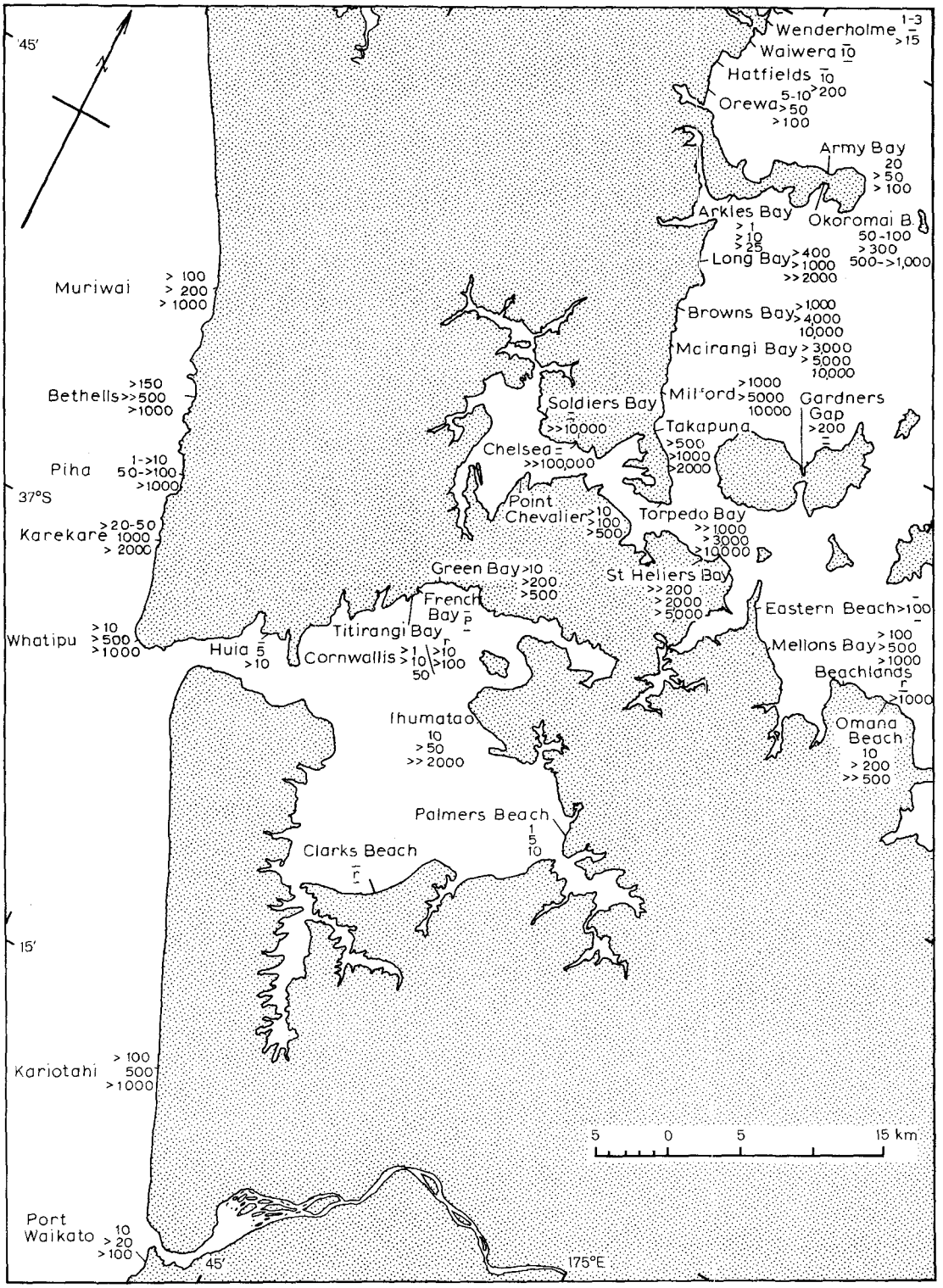


FIG. 4—Numbers of virgin polyolefin pellets on beaches of the Auckland region, 1972–76. The three values given indicate levels of abundance at which pellet numbers are reasonably consistent (lowest value, but top of list), commonly encountered (middle value, middle of list) and locally concentrated (greatest value, bottom of list); r = <1 per metre, vr = <<1 per metre, and p = present in quantities not determined but generally rather low.

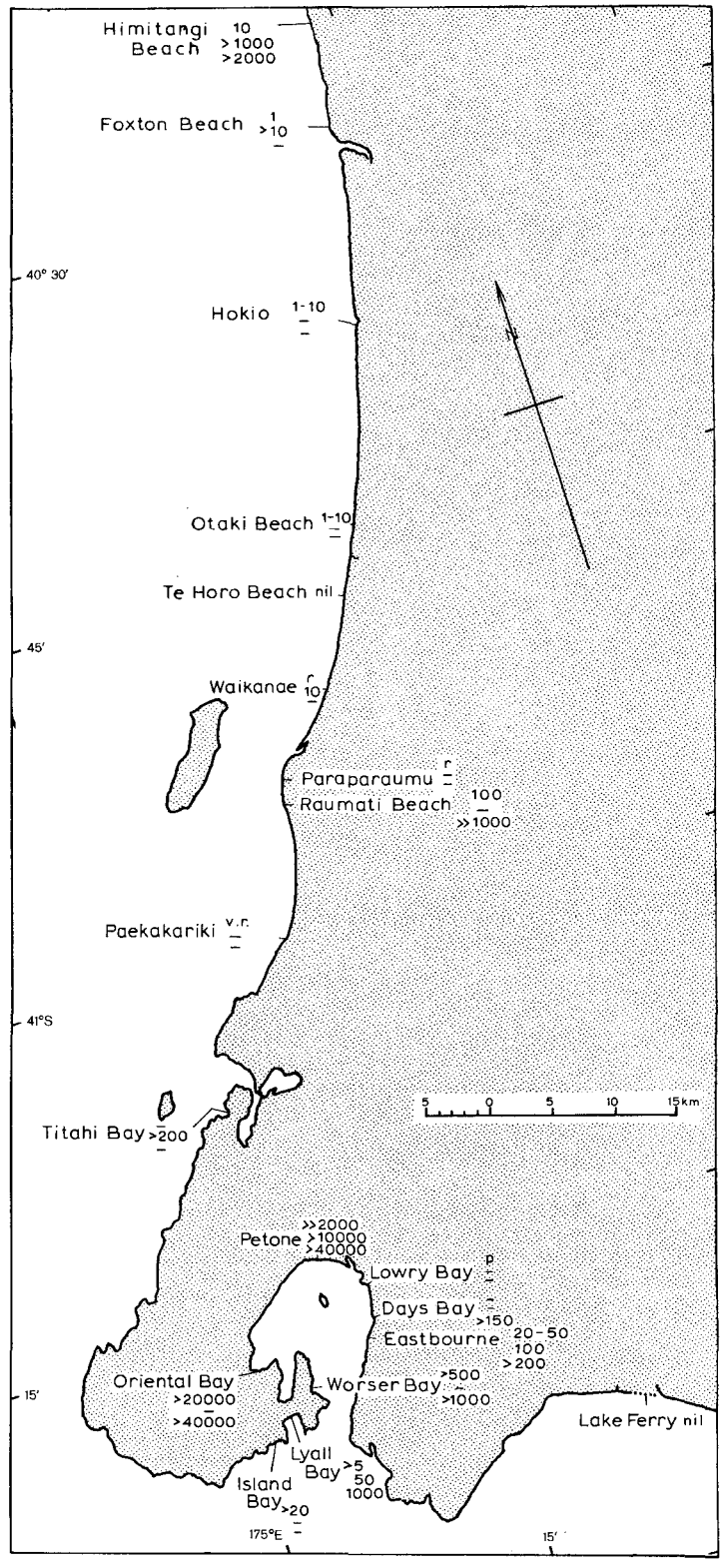


FIG. 5—Numbers of virgin polyolefin pellets on beaches of the Wellington region, 1975-76. The three values given indicate levels of abundance at which pellet number are reasonably consistent (lowest value, but top of list), commonly encountered (middle value, middle of list) and locally concentrated (greatest value, bottom of list); r = <1 per metre, vr = <<1 per metre, and p = present in quantities not determined but generally rather low.

(*Note*: for Himitangi read Himatangi.)

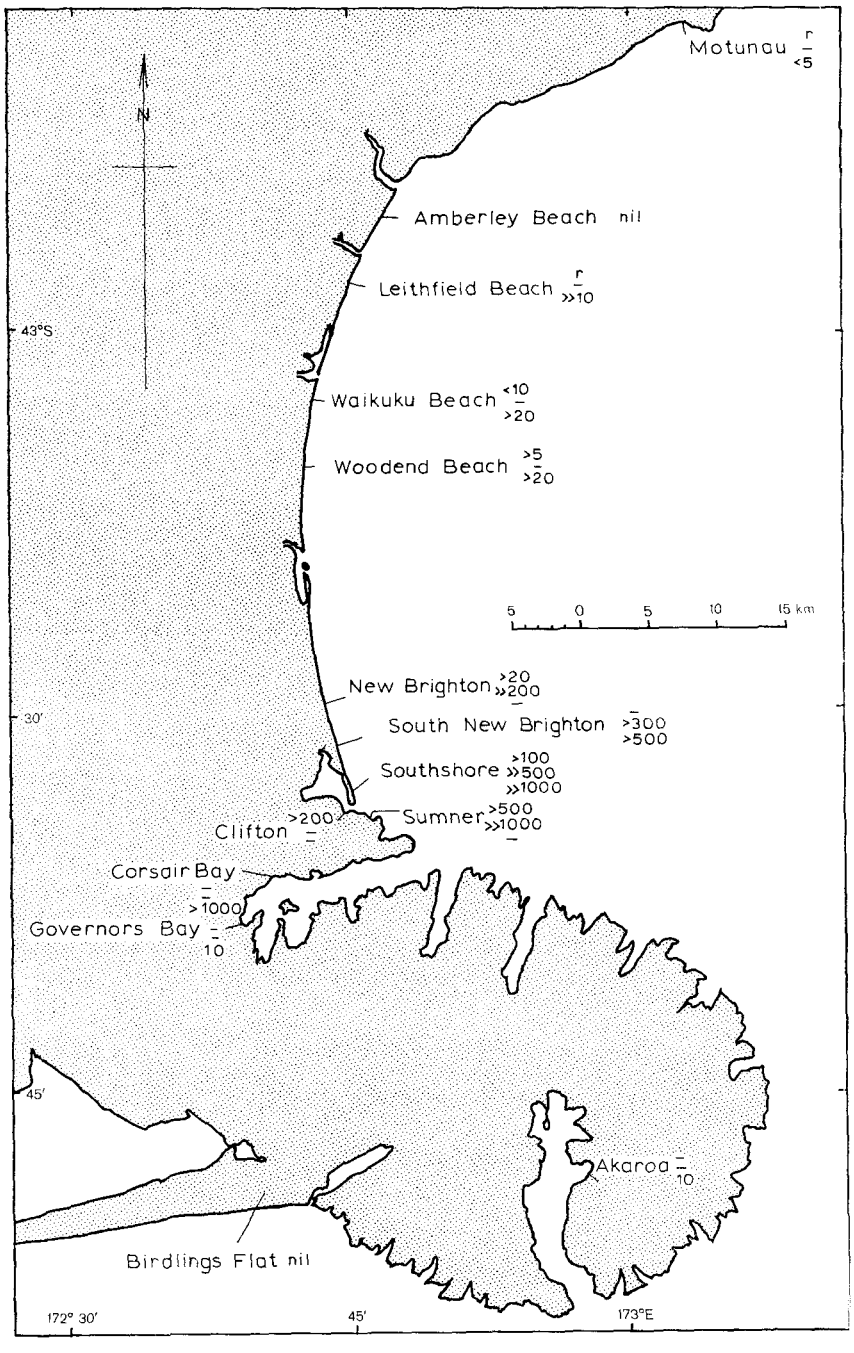
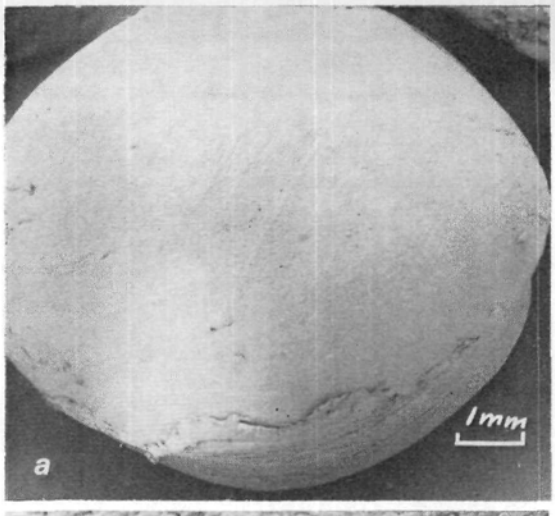
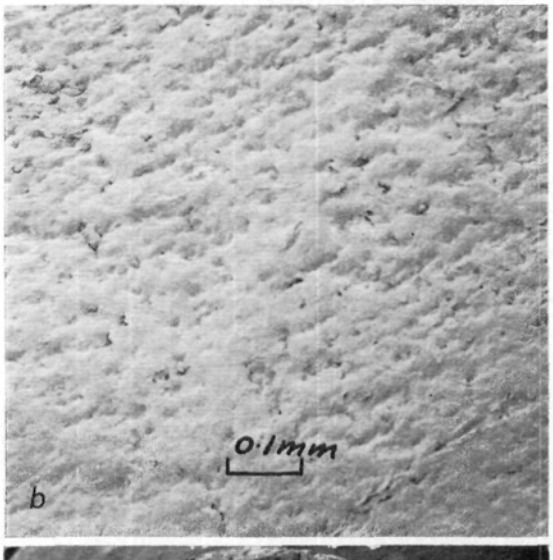
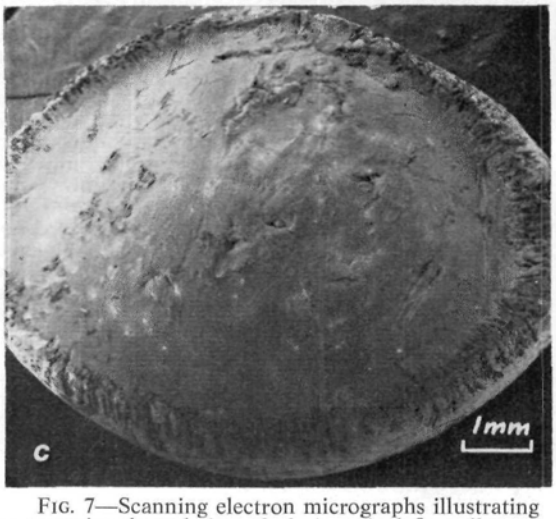
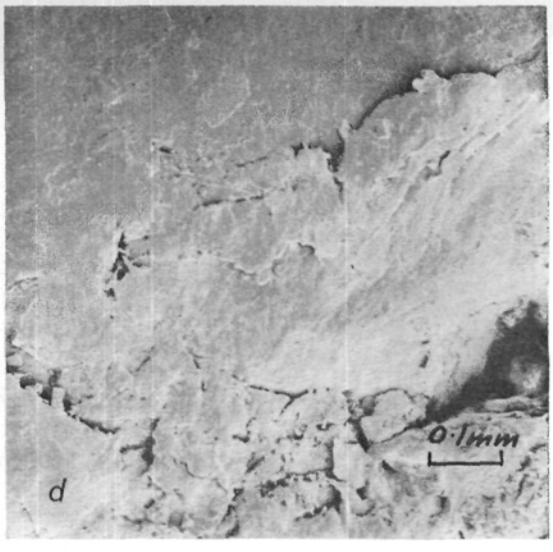


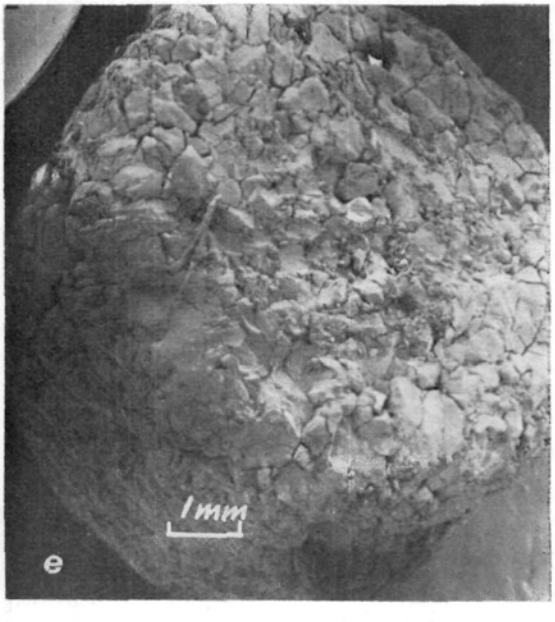
FIG. 6—Numbers of virgin polyolefin pellets on beaches of the Christchurch region, May 1976. The three values given indicate levels of abundance at which pellet numbers are reasonably consistent (lowest value, but top of list), commonly encountered (middle value, middle of list) and locally concentrated (greatest value, bottom of list); r = <1 per metre, vr = <<1 per metre, and p = present in quantities not detetrmined but generally rather low.











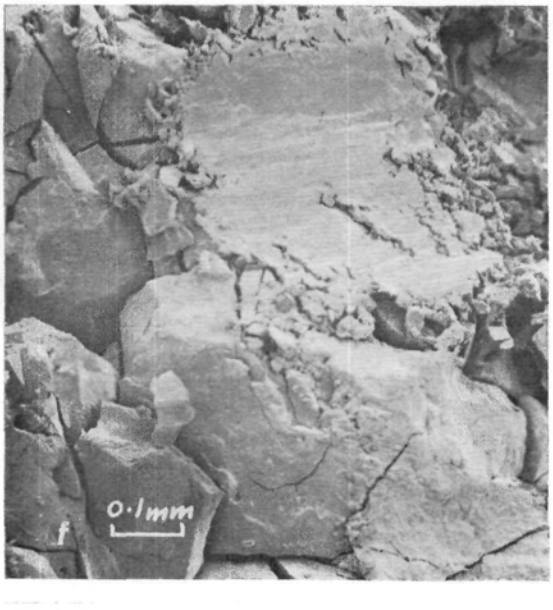


FIG. 7—Scanning electron micrographs illustrating progressive degradation of virgin polyolefin pellets.

(a) Fresh ovoidal pellet with little evidence of surficial degradation;
(b) Surface of fresh pellet (enlargement of a);
(c) Disc-shaped pellet with evidence of some minor abrasion and incipient degradation;
(d) Surficial flaking in a coloured pellet (early evidence of degradation);
(e) Intense crazing in a pellet of chalky appearance.
(f) Enlargement of (e).

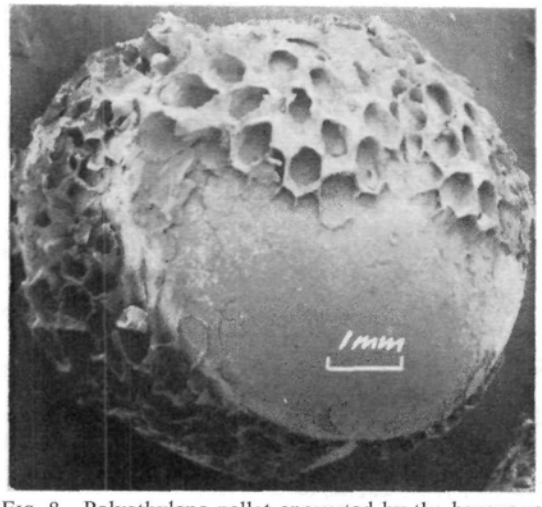


FIG. 8—Polyethylene pellet encrusted by the bryozoan *Membranipora tuberculata* (Bosc).

Polychlorinated biphenyls (PCBs) are widely dispersed in oceanic waters and contaminate much marine life (Goldberg 1975, Risebrough 1971). These compounds are present in some New Zealand sea birds (Solly & Shanks 1976). Polystyrene spherules and polyethylene cylinders in surface waters of the Northwestern Atlantic ocean commonly contain PCBs (to 5 ppm), apparently absorbed from ambient sea water (Carpenter & Smith, 1972; Carpenter *et al.* 1972). However, where PCBs have been used as a plasticizing additive during manufacture or where they have been an accidental contaminant, it is quite conceivable that they are lost to seawater during weathering and embrittlement. Even at very low levels, PCBs have a detrimental impact on marine organisms (Goldberg 1975, and these pellets could be a minor route through which they enter marine food-chains (Carpenter & Smith 1972, Cundell 1974, Rothstein 1973).

Four samples of plastic pellets from New Zealand were analysed for PCBs by S. R. B. Solly (Wallaceville Animal Research Centre, Lower Hutt, 1977, pers. comm.). He reports that PCBs were not detected (i.e., <0.1 ppm) in fresh polystyrene and polyethylene pellets. PCBs whose peaks on gas chromatograms coincide with the standard Aroclors© 1221, 1232, 1242, and 1248 were found in coloured polyethylene chipped for recycling (4 ppm) and in a sample of somewhat degraded mixed polyethylene pellets from the Auckland foreshore (1 ppm). PCBs were not considered to be present in sufficient amounts to constitute a biological problem and furthermore they were kinds low in chlorine, most of which are more readily metabolised than the highly chlorinated biphenyls (Solly, pers. comm.).

DISCUSSION

New Zealand purchases virgin plastics from many suppliers (Bullen unpublished 1968) and these pellets have been imported for the past 20 y or so. Thus, the specific sources remain unidentified. At present roughly equivalent quantities ($\approx$15 000 t.y^{-1}) of polystyrene, polyvinyl chloride, and polyolefin granules are imported annually. And yet, only polyolefin granules are found in any number on the New Zealand foreshore – the other kinds are rare ($<1\%$) or absent. There is no adequate explanation for this: packaging, handling, and shipping procedures are the same. There are no apparent significant differences in resistence to degradation processes. Virgin polystyrene and polyvinyl chloride granules often have densities >1.00 g.cm^{-3} and hence could sink and be less likely to concentrate on beaches, but in coastal waters and on shorelines about the North Atlantic, polystyrene and polyethylene granules are more or less equally abundant (Carpenter 1976, Colton *et al.* 1974). These granules are unlikely to have been missed during the survey.

It is difficult to make direct comparisons between the numbers of pellets on New Zealand beaches and those found on beaches around the North Atlantic. However, extrapolation from data presented by Carpenter & Smith (1972), Carpenter *et al.* (1972), Colton *et al.* (1974), Morris & Hamilton (1974) suggest that they are much less numerous on New Zealand beaches, perhaps by several orders of magnitude. From data given in the appendix, the regional distribution illustrated in Fig. 3, and using an average pellet weight of 0.026 g it is estimated that over 1000 t of these pellets are today stranded on New Zealand's coast. This estimate may be low, for in the survey little account was taken of pellets covered by drifting sand, and a careful search on most beaches shows that abundance is invariably much greater than any initial appraisal suggests, perhaps by a factor of 2–5 or even by an order of magnitude.

Today's value of virgin plastic granules is approximately NZ$1.00 per kilogram. Thus the replacement value of this material lying along New Zealand's coast could exceed NZ$1 000 000.

Previously I have stressed the virtual indestructibility of these pellets and the prospect of their continued accumulation on beaches (Gregory 1977). However, the evidence for some degradation is unquestionable, and accumulation rates will not be as rapid as I initially envisaged. Even so, the number of pellets to be found on our beaches is likely to increase during the foreseeable future.

Is it wise to regard the powdered products of plastics degradation solely from an aesthetic aspect, accepting as desirable that these become invisible in the environment as is sometimes implied (see Sheldrick & Vogl 1976)? Out of sight, out of mind – although never stated quite so explicitly. Whilst the products may well be rapidly absorbed by the environment (Scott 1972), because of evidence for their possible incorporation into food chains, detrimental effects to the biota could occur. Clearly, because plastics pose possible biological hazards in the marine environment, there is need for further investigations (Goldberg 1975, Hood & Kelley 1972).

CONCLUSION

Virgin polyolefin pellets are a significant contaminant on beaches around New Zealand. Whilst they are not yet aesthetically offensive they could well become so in the future. This material is not casual litter or waste; the pellets have been lost through accidental spillages from ships and during handling and transport. They make their way into coastal waters through streams, storm water drainage, and perhaps sewerage systems. They float and are dispersed by waves and currents which tend to drive them up on to beaches where they accumulate.

Auckland, Wellington and Lower Hutt, and Christchurch are the important source areas. There is some evidence that pellets spread from Australia across the Tasman Sea to northern New Zealand waters. They have also spread to the Chatham Islands.

The value of material lost annually in this way is great and demonstrates a need for some improvement in handling procedures. Furthermore, the biological effects are uncertain.

It is proposed to repeat the survey in 5 y or 10 y, so that rates of accumulation and degradation may be determined with some accuracy.

ACKNOWLEDGMENTS

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LITERATURE CITED

ANON. 1973: NMFS find tons of plastic debris on Alaskan Island. *NOAA Week 4*: 1.

AUSTIN, H. M. & STOOPS-GLAS, P. M. 1977: The distribution of polystyrene spheres and nibs in Block Island Sound during 1972–1973. *Chesapeake Science 18*: 89–92.

BAUM, B. 1974: The weathering degradation of polyolefins. *Polymer Engineering and Science 14*: 206–11.

BRODIE, J. W. 1960: Coastal surface currents around New Zealand. *N.Z. Journal of Geology and Geophysics 3*: 235-52.

BULLEN, W. J. unpublished 1968: The location of plastics industry in New Zealand. MA thesis, lodged in University of Canterbury Library, N.Z. 149 pp.

CARPENTER, E. J. 1976: Plastics, pelagic tar and other litter. Pp. 77–89 (Chapter 5) *in* Goldberg, E. D. (ed.) "Strategies for Marine Pollution Monitoring". Wiley-Interscience, New York. 310 pp.

CARPENTER, E. J., ANDERSON, S. J., HARVEY, G. R., MIKLAS, H. P. & PECK, B. B. 1972: Polystyrene spherules in coastal waters. *Science 178*: 749–50.

CARPENTER, E. J. & SMITH, K. L. 1972: Plastics on the Sargasso Sea surface. *Science 175*: 1240–1.

CHOTTINER, J. & BOWDEN, E. B. 1965: How plastics resist weathering. *Materials Engineering 62*: 97–9.

COLTON, J. B., KNAPP, F. D. & BURNS, B. R. 1974: Plastic particles in surface waters of the northwest Atlantic. *Science 185*: 491–7.

COONEY, J. P., COLIN, G. & WILES, D. M. 1973: Sunlight and the microbial susceptibility of thermoplastics. Pp. 17-27 *in* "Disposal of Plastics with Minimum Environmental Impact". *ASTM Special Technical Publication 533*. 62 pp.

CUNDELL, A. M. 1973: Plastics materials accumulating in Narragansett Bay. *Marine Pollution Bulletin 4*: 187–8.

——— 1974: Plastics in the marine environment. *Environmental Conservation 1*: 63-8.

ESTEVEZ, J. M. J. 1965: Some thoughts on the weathering of plastics. *Transactions and Journal of the Plastics Institute, London 33*: 89-94.

EVANS, E. M. 1974: Degradability of plastics. Pp. 157–82 (Part V) *in* Staudinger, J. J. P. (ed.) "Plastics and the Environment". Hutchinson, New York. 190 pp.

FERGUSSON, W. C. 1974: Plastics, their contribution to society and considerations of their disposal. Pp. 1–52 (Part I) *in* Staudinger, J. J. P. (ed.) "Plastics and the Environment". Hutchinson, New York. 190 pp.

GOLDBERG, E. D. 1975: Marine pollution. Pp. 39–89 (Chapter 17) *in* Riley, J. P. & SKIRROW, G. "Chemical Oceanography". Volume 3 (2nd ed.). Academic, London. 564 pp.

GREGORY, M. R. 1977: Plastic pellets on New Zealand beaches. *Marine Pollution Bulletin 8*: 82–4.

HASLAM, J., WILLIS, H. A. & SQUIRREL, D. C. M. 1972: "Identification and Analysis of Plastics". (2nd ed.). Iliffe Books, London. 748 pp.

HAYS, H. & CORMONS, G. 1974: Plastic particles found in tern pellets, on coastal beaches and at factory sites. *Marine Pollution Bulletin 5*: 44–6.

HEAP, W. M. & MORRELL, S. H. 1968: Microbiological deterioration of rubbers and plastics. *Journal of Applied Chemistry 18*: 189-94.

HOOD, D. W. & KELLEY, E. 1972: Contamination and coastal pollution through waste disposal practices. Pp. 146–86 (Chapter 7) *in* Ketchum B. H. (ed.) "The Water's Edge: Critical Problems of the Coastal Zone." MIT Press, Cambridge, Massachusetts. 393 pp.

ILGENFRITZ, E. M. 1975: Plastics waste handling practices in solid waste management. *Water, Air and Soil Pollution 4*: 191–9.

IVES, G. C., MEAD, J. A. & RILEY, M. M. 1971: "Handbook of Plastics Test Methods". Iliffe Books, London. 476 pp.

KAMAL, M. R. & SAXON, R. 1967: Recent developments in the analysis and prediction of the weatherability of plastics. Pp. 1–28 *in* Kamal, M. R. (ed.) "Weatherability of Plastic Material" *Applied Polymer Symposia 4*. Interscience, New York. 306 pp.

KARTAR, S., ABOU-SEEDO, F. & SAINSBURY, M. 1976: Polystyrene spherules in the Severn estuary – a progress report. *Marine Pollution Bulletin 7*: 52.

KARTAR, S., MILNE, R. A. & SAINSBURY, M. 1973: Polystyrene waste in the Severn Estuary. *Marine Pollution Bulletin 4*: 144.

MILLS, J. 1974: The bioterioration of synthetic polymers and plasticizers. *CRC Critical Reviews in Environmental Control 4*: 341-51.

MORRIS, A. W. & HAMILTON, E. I. 1974: Polystyrene spherules in the Bristol Channel. *Marine Pollution Bulletin 5*: 26–7.

PEDLAR, K. & DAVIS, G. 1973: "Mutant 59 the Plastic Eater". Pan, London. 252 pp.

RISEBROUGH, R. W. 1971: Chlorinated hydrocarbons. Pp. 259-86 (Chapter 10) *in* Hood, D. W. (ed.) "Impingement of Man on the Oceans". Wiley-Interscience, New York. 738 pp.

RODRIGUEZ, F. 1971: The prospects for biodegradable plastics. *Chemical Technology (July 1971)*: 409–15.

ROSATO, D. V. 1968: Other properties and characteristics. Pp. 733–1102 (Chapter 8) *in* Rosato, D. V. & Schwartz, R. T. (eds) "Environmental Effects on Polymeric Materials. Vol. I: Environments". Interscience, New York. 1228 pp.

ROTHSTEIN, S. I. 1973: Plastic particle pollution of the surface of the Atlantic Ocean: evidence from a seabird. *Condor 75*: 344–5.

RUGGER, G. R. 1968: Weathering. Pp. 339-411 (Chapter 4) *in* Rosato, D. V. & Schwartz, R. T. (eds) "Environmental Effects on Polymeric Materials. Vol. I: Environments". Interscience, New York. 1228 pp.

SCOTT, G. 1972: Plastics packaging and coastal pollution. *International Journal of Environmental Studies 3*: 35–6.

SCOTT, G. 1973: Improving the environment: chemistry and plastic waste. *Chemistry in Britain 9*: 267–72.

SHELDRICK, G. E. & VOGL, O. 1976: Induced photodegradation of styrene polymers: a survey. *Polymer Engineering and Science 16*: 65–73.

SOLLY, S. R. B. & SHANKS, V. 1976: Organochlorine residues in New Zealand birds and mammals. 2. Polychlorinated biphenyls. *N.Z. Journal of Science 19*: 53–5.

STAUDINGER, J. J. P. 1970: "Disposal of Plastics Waste and Litter". *Society of Chemical Industry Monograph 35*. 100 pp.

——— 1972: Plastics waste and the environment. *International Journal of Environmental Studies 3*: 65–7.

WONG, C. S.; GREEN, D. R. & CRETNEY, W. J. 1974: Quantitative tar and plastic waste distribution in the Pacific Ocean. *Nature 247*: 30–2.

APPENDIX 1—Numbers of plastic pellets found per linear metre of New Zealand beaches, 1972–76. Localities are from sheets of the N.Z. Geological Map 1:250 000 or of the NZMS 1 series; they are grouped by Geological Map sheet name and number, and generally run from north to south or west to east. Numbers and extent of traverses varied greatly, hence no grid references are given. Levels of abundance: A = normal concentrations, found reasonably consistently; B = higher concentrations, found quite commonly; C = abnormally high local concentrations; – = not recorded or negligible; r = rare (< 1 per metre); vr = very rare (<< 1 per metre); p = present, quantities not determined but generally low; * = some pellets encrusted with bryozoan *Membranipora tuberculata*.

Location	Level of Abundance A	B	C
NORTH CAPE (1)			
Sandy Bay	1–5	–	20
Twilight Beach*	⩾10	–	–
Ninety Mile Beach			
The Bluff	10–25	–	>50
Hukatere*	2–5	>20	–
Waipapakauri*	>5	>20	50
Ahipara*	>5	>20	–
Tapotupotu*	–	⩾100	–
Spirits Bay*	r	<10	50
Kurahaupo Rocks*	–	50–100	>100
Waikuku Beach	r	1–2	5
Whareana Bay	r–5	–	>150
Rarawa Beach*	2–10	–	–
Henderson Bay*	<5–>10	50	>100
Puheke Beach*	–	1–5	–
Karikari Beach	r	–	–
Matai Bay	r	–	>5
Tokerau Beach*	r	>15	200
Taipa Beach	–	r	–
Cable Bay	–	r	–
Coopers Beach	–	r	–
Taupo Bay	–	>20	50
Tauranga Bay	–	r	–
Mahinepua Bay	–	r	–
Wainui Bay	1	–	–
Taiaue Bay	> 1	–	–
Matauri Bay	–	>5	–
Paihia	Nil	–	–
Oneroa Bay (Long Beach)	r	>1	–
Pahi Beach	r	–	>2
Helena Bay	Nil	–	–
Whananaki (north)	r	1–2	5
WHANGAREI (2A)			
Omapere	–	–	>50
Waimamaku River mouth	1	5	>20
Kawarua	5	20	–
Maunganui Bluff	Nil	–	–
Baylys Beach	20	>100	>1000

Location	Level of Abundance A	B	C
Mahuta Gap	>20	>100	>>1000
Glinks Gully	10	>100	–
Sandy Bay	1–2	–	>5
Matapouri Bay	r	–	5
Ocean Beach (Whangarei Heads)	1–2	>20	–
Urquharts Bay	r	–	–
McLeods Bay	r	1	–
Parua Bay	–	–	r
Marsden Bay	–	>10	–
Waipu Cove	–	vr	50
Langs Beach	–	–	vr
McKenzie Cove	–	>20	>50
Mangawhai Heads	r	–	5
Pakiri	>2	10	20–50
Te Rere Bay	r	–	>5
Mathesons Bay	–	2	>5
Omaha Beach	–	100	⩾400
Christian Bay	–	–	5
Mellins Bay	r	–	–
Sandspit	r		10
Snells Beach	r	–	–
Martins Bay*	>10–100	200	>300
BARRIER (2B)			
Okiwi	–	–	p
Kaitoke Beach	–	p	–
Medlands Beach	–	20	–
AUCKLAND (3)			
Muriwai Beach	>100	>200	>1000
Bethels Beach	>150	>>500	>1000
Piha	1–>10	50–>100	>1000
Karekare	>20–50	1000	>2000
Whatipu	>10	>500	>1000
Huia	–	5	>10
Cornwallis	>1	>10	50
Mill Bay	–	–	>>20
Laingholm	r	–	–
Titirangi	r	>10	>100
French Bay	–	p	–
Green Bay	<10	>200	>500
Hillsborough/ Onehunga	50–100	>500	>>2000
Ihuhatao/ Mangere	10	>50	>>2000
Palmers Beach	1	5	10
Clarks Beach	–	r	–
Kariotahi	>100	500	>1000
Port Waikato	10	>20	>100
Wenderholme	1–3	–	>15
Waiwera	–	10	–
Hatfields Bay	–	10	>200
Orewa	5–10	>50	>100
Red Beach	10	–	>150
Stanmore Bay (east)	–	r	–
(west)	>20	>100	250
Manly (east)	–	r	–
(west)	⩾10	20	>150
Tindalls Beach	r	5	–
Army Bay	20	>50	>100
Arkles Bay	>1	>10	>25
Little Manly	p	>50	–
Matakatia	>50	>100	>200

Location	Level of Abundance A	B	C
Okoromai Bay	50–>100	>300	>1000
Te Haruhi Bay	50	500	>1000
Whangaparaoa Head	–	p	–
Long Bay	>400	>1000	>>2000
Torbay	500	–	>1000
Browns Bay	>1000	>4000	10000
Murrays Bay	500–1000	>2000	>6000
Mairangi Bay	>3000	>5000	10000
Campbells Bay	>200	1000	>2000
Castor Bay	>500	>2000	>>20000
Milford Beach	>1000	>5000	>10000
Gardners Gap (Rangitoto)	>200	–	–
Takapuna	>500	>1000	>2000
Narrow Neck	>>200	>1000	>>2000
Cheltenham Beach	>500	>>1000	>2000
Beachhaven	–	–	<100
Island Bay	<100	–	>1000
Soldiers Bay	–	–	>>10000
Chelsea	–	–	>>100000
Little Shoal Bay	–	–	>>10000
Stanley Bay	–	–	>2000
Torpedo Bay	>>1000	>3000	>10000
Point Chevalier/ Westmere/ Herne Bay	>10	>100	>500
Okahu Bay	>200	>1000	>>2000
Mission Bay	–	>200	>1000
Kohimaramara	>>200	–	>1000
St Heliers Bay	>>200	>2000	>5000
Buckland Beach	>10	>100	>200
Eastern Beach	–	>100	–
Mellons Bay	>100	>500	>1000
Howick	100	>200	1000
Beachlands	r	–	>1000
Omana Beach	10	200	>>500
Maraetai	10	>250	–
Duders Beach	10	250	>400
Kawakawa Bay	r	–	10
Orere Point	–	–	r
Matingarahi Bay	Nil	–	–
Port Charles	>20	>100	>500
Goat Bay	vr	–	5
Big Bay (Colville)	>>20	150	>200
Waitete Bay	>150	300	–
Oamaru Bay	50	–	–
Long Bay (Coromandel)	10	50	–
Coromandel Harbour	–	p	–
Te Mata	Nil	–	–
Tapu	Nil	–	–
Te Puru	vr	–	–
Thortons Bay	Nil	–	–
Thames	r	1–5	–
Fletchers Bay	r	10	>20
Waikawau	Nil	–	–
Whangapoua	vr	–	2
Kuaotunu	r	5	20
Wharekaho Beach	5	10	>20
Buffalo Beach (Whitianga)	2	5	–
Hahei	r	–	5
Hot Water Beach	1	–	5
Tairua	–	–	p
Pauanui	1–10	>100	>200
Whangamata	1	5	10
Whiritoa	Nil	–	–
Waihi Beach	10	50	>>200

Location	Level of Abundance A	B	C
Athenree	–	1–5	–
Bowentown	r	1–2	5
HAMILTON (4)			
Huriwai	5	>10	>20
Taharoa	50	>100	>500
Marakopa	p	>20	>50
Kiritehere	>10	>50	>100
Waikawau	p	–	–
ROTORUA (5)			
Mount Maunganui			
Harbour Beach	10	>50	–
Ocean Beach	5–50	100	>150
Papamoa Beach	1	–	5
Maketu	1	–	>5
Pukehina	1	5	>50
Pikowai	–	–	p
Matata	Nil	–	–
Whakatane	–	p	–
West End	r	2–5	–
Ohope Beach	r	>2	–
Ohiwa	>1	5	–
Hukuwai Beach	2	5	–
EAST CAPE (6)			
Hariki Beach	1	>5	>10
Whanarua Beach	–	–	p
Oruaiti Beach	p	>5	>10
Hicks Bay	1	2–5	10
Kawakawa Bay	1	2–5	10
Hautai Beach	5	>10	>20
Waipiro Bay	5	>10	50
Tokomaru Bay	1	<5	–
Tolaga Bay	1	–	–
TARANAKI (7)			
Awakino	>5	>20	50
Mokau	1–5	–	–
Tongaporutu	>5	>10	>20
Pariokariwa Point	p	–	>100
Waiiti Beach	>10	>50	>100
Onaero			
Domain	>10	>20	>100
Beach	vr	–	<5
Urenui	vr	–	–
Waitara	1–2	5	–
Fitzroy	–	p	–
Port Taranaki	10	>20	–
Ngamotu	10	>100	–
Oakura	1–2	⩾5	⩾10
Pitone	10	>50	>100
Manganui	> 5	>20	>50
Oaonui	2	5	15
Okaweu	1–2	5	–
Opunake	>10	>20	⩾50
TAUPO (8)			
Bayview	p	–	–
Westshore	p	–	–
GISBORNE (9)			
Turihaua	–	5	–
Makorori	r	>10	>50
Wainui Beach	>1	10	30

Location	Level of Abundance A	B	C
Kaiti Beach	r	–	>5
Waikanae	–	p	–
Oraka Beach	p	–	>5
Wainuiorangi Stream (north of)	>10	>100	>500
Mahia Beach	>10	>20	>50
WANGANUI (10)			
Waihi Beach	–	–	–
Ohawe Beach	Nil	–	–
Patea	r	>5	>10
Wainui Beach	Nil	–	–
Castlecliffe	>10	>100	>200
Turikina	r	–	<5
Himatangi Beach	10	>1000	>2000
Foxton Beach	1	>10	–
DANNEVIRKE (11)			
Clifton (to east of)	–	–	100
Ocean Beach	1–5	>100	>200
Waimarama	1–5	>50	–
Red Island	–	>50	–
Kairakau Beach	r	–	–
Pourere	10–15	–	>200
Aramoana	–	1–10	10
Blackhead	–	1–10	10
Porangahau Beach	1–5	–	–
WELLINGTON (12)			
Hokio	1–10	–	–
Otaki Beach	1–10	–	–
Te Horo Beach	Nil	–	–
Waikanae	r	10	>20
Paraparaumu Beach	r	–	>10
Raumati Beach	100	–	>>1000
Paekakariki	vr	–	–
Titahi Bay	–	>200	–
Petone	>>2000	>10000	>40000
Oriental Bay	>20000	–	>40000
Scorching Bay	p	–	–
Worser Bay	>500	–	>1000
Lyall Bay	>5	50	1000
Island Bay	>20	–	–
Lowry Bay	p	–	–
Days Bay	–	–	>150
Eastbourne	20–50	100	>200
Herbertsville	⩽20	–	>>50
Akitio	⩽5	–	>20
Castlepoint	–	>10	–
Riversdale Beach	r	–	–
Flat Point	r	1	–
Lake Ferry	Nil	–	–
GOLDEN BAY (13)			
Farewell Spit (northern side)	r	5	–
Whararíki	r	>2	–
Karamea	Nil	–	–
Little Wanganui	Nil	–	–
Golden Bay (various localities)	–	–	vr
MARLBOROUGH SOUNDS (14)			
Rabbit Island	–	p	–

Location	Level of Abundance A	B	C
Nelson (Tahunanui Beach)	>1	>10	<50
Picton	–	p	–
Hakahaka Bay	–	r	–
Rarangi	–	≤10	–
Marfell Beach	r	5	>10
BULLER (15)			
Deadmans Creek	Nil	–	–
Westport	5	10	>20
Carters Beach	1–2	–	–
Tauranga Bay	–	p	–
Nine Mile Beach	r–1	<5	–
Constant Bay	>5	–	>10
Nine Mile Bluff	1	5	–
Rapahoe	r	–	–
Greymouth	–	–	>5
Blaketown Beach	r	–	–
South Beach	r	–	–
Paroa	r	–	–
KAIKOURA (16)			
Kaikoura coast (many pebble beaches)	Nil	–	–
HOKITIKA (17)			
Kumara Beach	r	–	≤5
Seaview	r	–	2
Hokitika	>1	5	–
Mananui	Nil	–	–
Ross	Nil	–	–
Okarito	Nil	–	–
Hunts Beach	Nil	–	–
HURUNUI (18)			
Motunau Beach	r	–	>5
Amberly Beach	Nil	–	–
Leithfield Beach	r	–	>>10
Waikuku Beach	<10	–	>20
Woodend Beach	>5	–	>20
MT COOK (20)			
Bruce Bay	Nil	–	–
Caroline Bay (Timaru)	>50	>100	>400
CHRISTCHURCH (21)			
New Brighton	>20	>>200	–
South New Brighton	–	>300	>500
Southshore	>100	>>500	>>1000
Clifton	>200	–	–
Sumner	>500	>>1000	–
Corsair Bay	–	–	>>1000
Charteris Bay	–	10	–
Governors Bay	–	–	10
Akaroa	p	–	≤10
Birdlings Flat	Nil	–	–
Ashburton River mouth	Nil	–	–
OAMARU (23)			
Kakanui	–	p	–
Hampden	5	10	>50
Katiki	r	–	–
INVERCARGILL (24)			
Te Waewae Bay	r	1	–
Pahia Beach	r	–	–
Riverton	Nil	–	–
DUNEDIN (25)			
Warrington	Nil	–	–
Spit Beach	–	p	–
Waipuna Bay	–	>20	–
Otekiho Beach	–	–	p
Otakou	vr	–	–
St Clair Beach	Nil	–	–
Tomahawk Beach	–	r	–
Brighton	r	>5	–
Chrystalls Beach	r	–	–
Smiths Beach (Wangaloa)	r	–	–
Kaka Point	vr	–	–
STEWART ISLAND (26)			
Oreti Beach	>50	–	>200
Omaui Beach	–	p	–
Fortrose	–	–	p
Porpoise Bay	1	5–10	>20
Tautuku Bay	1	>5	>10
Catlins	–	p	–
PITT ISLAND (CHATHAMS)			
Waihere Bay	20	50	>100
Tupuangi Beach	–	p	–