THE COMPOSITION AND ORIGIN OF MARINE DEBRIS STRANDED ON THE SHORES OF SUBANTARCTIC MACQUARIE ISLAND

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ABSTRACT

The coastline of subantarctic Macquarie Island (lat. 54°35'S, long. 158°55'E) was surveyed over an 8-week period in 1988 to determine types, quantities, and possible sources of marine debris. Lost fishing gear consisted of buoys, ropes, and net fragments. Gear from both trawling and longline fishing operations were represented, with debris identified from Russian, Polish, Japanese, Taiwanese, and South American sources. Three types of litter which potentially entangle marine mammals were found: plastic packing straps, ropes, and net fragments. Plastic bottles, small plastic fragments from broken plastic bottles, and small pieces of expanded polystyrene were common. Litter accumulated in highest densities on open beaches of the west coast of the island. Overall density of marine debris was less than densities reported for islands in the South Atlantic Ocean and the Indian Ocean, or from the coast of Alaska.

INTRODUCTION

Plastic litter and other man-made debris have been recognized as major pollutants of open ocean and coastal surface waters (Shomura and Yoshida 1985; Day and Shaw 1987; Pruter 1987). The distribution of this debris is widespread. Debris has been reported from coastlines near populated, industrial regions of the world (Shiber 1979, 1982), and from open water such as the Mediterranean Sea and the North Sea, which are traversed by busy shipping lanes (Morris 1980; Dixon and Dixon 1983; McCoy 1988), as well as from remote areas such as Alaska (Merrell 1984; Merrell and Johnson 1987) and islands in the Southern Ocean (Gregory 1987; Ryan 1987b; Ryan and Watkins 1988). The slow breakdown of many artifacts allows them to disperse over long distances, often distant from their source (Carpenter and Smith 1972; Ryan 1987b).

Little is known of the impact and fate of much of this debris, although adverse effects through entanglement and ingestion have been documented in seabirds (Azzarello and van Vleet 1987) and marine mammals (Bonner and McCann 1982; Fowler 1985; Laist 1987). The long lifespan and

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widespread dispersal of such litter make it important to monitor strandings of artifacts in remote sectors of the Southern Ocean in order to identify the major sources of debris and to determine a baseline index of distribution and relative abundance. Parties to the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) have agreed to monitor and report the occurrence of artifacts in the Southern Ocean (Morris 1985). Difficulties in monitoring floating debris, particularly small plastic artifacts, highlight the importance of beach surveys in determining densities, abundance, and sources of such debris.

The present study identifies the types and origins of marine litter stranded at Macquarie Island.

STUDY AREA AND METHODS

Macquarie Island (lat. 54°35'S, long. 158°55'E) is situated in the Southern Ocean. It lies on the Macquarie Ridge approximately 1,500 km south-southeast of Tasmania and 640 km southwest of the Auckland Islands. The island is approximately 34 km long and varies in width from 250 m at the northern isthmus to a maximum of 5 km midway along the island. Commercial sealing took place on the island from 1810 until 1919 (Cumpston 1968). Since 1948, the Australian National Antarctic Research Expeditions (ANARE) have maintained a permanent station on the island. Most of the present day land-based activity on the island is centered around the isthmus and at the six field huts on the island. The nearest ship-based fishing activities occur over the Campbell Plateau, about 700 km to the northeast, and around the Kerguelen group, 5,000 km to the west.

The entire coastline of Macquarie Island (ca. 94 km) was surveyed for stranded artifacts over a 6-week period from June to August 1988. All sizable artifacts (excluding wooden objects) were identified (where possible) from manufacturers' marks in order to determine their origins. All objects were collected and removed from the beaches. Larger objects, such as fishing buoys and floats, were recorded, marked, and stockpiled above high water level at various locations around the island. The rocky nature of much of the coastline precluded sampling of items smaller than 10 mm. Artifacts were categorized according to type of material: plastic, metal, glass, and other. Objects collected from the beach below the ANARE station refuse dump were not included in the survey. Similarly, wooden objects were not included, to avoid confounding the results with wooden remains from sealing activities and old shipwrecks.

The coastline was surveyed in seven convenient arbitrary sectors (Fig. 1), which varied in size and topography. Some sectors were dominated by rock shelf coastline with large boulders, while others had more open beach (Table 1). This is the first survey of marine debris undertaken at Macquarie Island.

RESULTS

A total of 1,034 man-made artifacts was recorded from 94 km of shoreline at Macquarie Island. This represents a density of 11

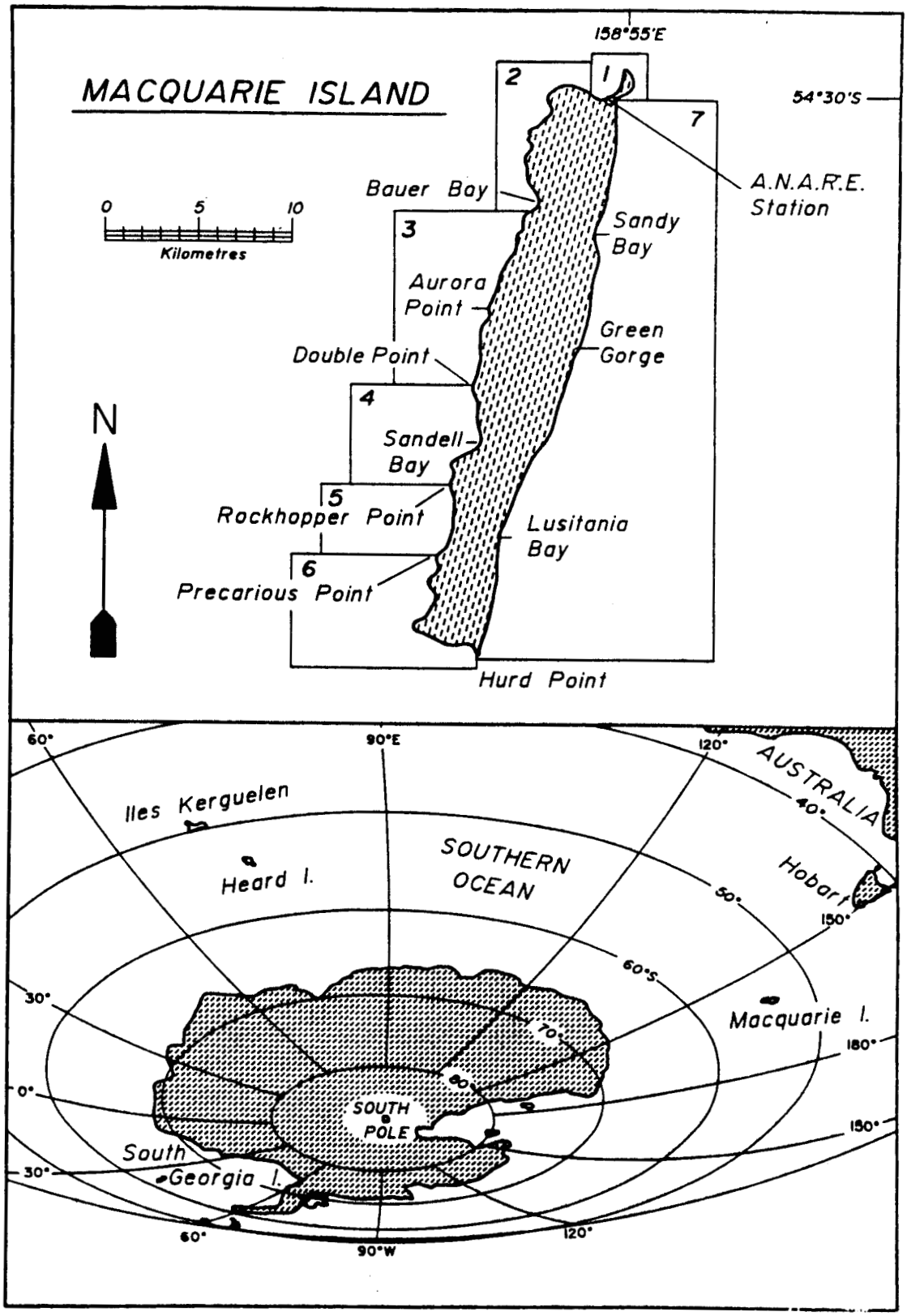

Figure 1.--Macquarie Island, showing its position in the Southern Ocean and the location of the survey areas.

Table 1.--Relative topography and density of artifacts on sectors of coastline at Macquarie Island.

Sector	Length of coastline (km)	Open beach (%)	Density of artifacts (items/km)	Density of artifacts (items/km open beach)
1	4	25	2.5	10
2	16	38	12.2	32.5
3	16	16	19.4	124
4	8	44	39.0	89.1
5	5	20	13.8	69
6	8.5	24	11.6	45.5
7	36	67	0.6	0.9

artifacts/km coastline. Densities of artifacts varied over the island, with the greatest found in sector 4 (39 items/km) and the least (0.6 item/km) on the east coast (Table 1). Plastic items were most abundant, accounting for 60% of all objects. A wide variety of plastic items was recorded. Containers and bottles of various shapes, sizes, and uses were common, while fragments from degrading bottles and polystyrene pieces of various sizes were ubiquitous. Plastic bottles and containers made up 28% of plastic artifacts, while expanded polystyrene and other foamed products contributed 13% of plastic items. Miscellaneous small plastic pieces, including fragments of a size easily ingested by birds, made up 26% of plastic objects. Metal objects contributed 34%, while glass and miscellaneous items such as cork, hemp, cloth, and wax contributed 6% (Table 2). Objects of fisheries origin (buoys, ropes, and netting) accounted for 47% of all stranded artifacts, 29% of all plastic objects, and 89% of all metal objects.

Fishery Debris

A variety of objects originating from fisheries was recorded, including artifacts from both trawl fisheries (eastern European), and longline fisheries (predominantly Japanese). Common items included plastic and metal head line floats from trawl nets, and longline tellings (marker buoys) or surface floats (Table 3). Head line floats were often found attached to fragments of trawl net, and were occasionally found strung together with polypropylene rope in groups of up to six. Three varieties of metal head line floats were recorded: an aluminium alloy float with two separate attachment lugs bearing a Polish manufacturer's mark (55% of all metal buoys), an aluminium alloy float with a single attachment lug containing two holes (26%), and a steel float (17%). Longline tellings were usually covered in rope mesh, often with fragments of rope or mesh trailing from the floats. Ten inflatable plastic floats possibly used as longline pickup buoys or fenders were recovered. Two Japanese glass longline fishery floats, both covered in mesh, were found. Eleven

Table 2.--Numbers of artifacts found on beaches along different sectors of coastline at Macquarie Island.

Artifacts	Sector 1	2	3	4	5	6	7	Total
Plastic objects (total)	6	141	198	175	34	52	15	621
Fisheries floats	3	33	53	46	18	18	6	162
Polypropylene ropes	--	2	3	2	--	1	--	8
Netting	--	4	--	--	--	1	--	5
Expanded polystyrene	--	20	26	7	4	11	5	73
Other foamed plastics	--	--	2	1	--	1	--	4
Bags	--	3	--	--	--	--	--	3
Packing straps	--	5	4	1	--	1	--	11
Bottles and containers	--	39	54	61	6	5	3	168
Drift cards	3	3	1	6	2	--	--	15
Miscellaneous	--	32	55	51	4	14	1	157
Metal objects (total)	6	48	79	131	30	43	5	342
Fishery floats	5	40	72	117	28	39	4	305
Containers	--	4	2	6	2	1	--	15
Aerosol cans	--	3	3	8	--	1	--	15
Satellite buoys	--	--	1	--	--	2	1	4
Miscellaneous	1	1	1	--	--	--	--	3
Other objects (total)	1	9	34	12	8	5	2	71
Glass floats	--	--	--	--	1	1	--	2
Bottles and globes	1	7	25	6	3	2	1	45
Cork objects	--	--	1	--	--	2	--	3
Hemp rope	--	--	--	4	2	--	--	6
Bamboo	--	1	1	--	--	--	--	2
Miscellaneous	--	1	7	2	2	--	1	13
Grand total	13	198	311	318	72	100	22	1,034

fragments of rope were recorded. These were of varied length up to about 30 m. Two fragments of teased nylon antichafing blankets were collected, as well as a 2-m fragment of 120-mm stretched mesh codend.

Origin of Artifacts

The country of origin of some of the artifacts could be identified. Most objects were of South American, eastern European (mainly Polish or Russian), or oriental origin (Table 4). The items of fishing debris were identified from writing on floats. Country of origin of fishing floats does not necessarily imply use by that country's fishing fleet, as several nationalities are known to use Japanese floats, although Japanese floats produced for the export market are imprinted in English (R. Burbury pers. commun.). The metal head line floats (Table 3) were of the variety used by

Table 3.--Artifacts which originated from fishing activity washed ashore at Macquarie Island.

Fishing activity debris	Number
Longline fishery debris	
Longline tellings (plastic)	72
Dahn-pole floats	1
Polystyrene surface floats	4
Inflatable pickup floats	10
Trawl fishery debris	
Plastic head line floats	79
Metal head line floats	297
Steel bobbins	8
Trawl-web netting fragments	4
Ropes	11
Antichafing blanket	2
Codend net fragment	1
Miscellaneous fishery debris	
Fender or marker buoy	5
Plastic top buoys (use unknown)	6

the Russian and Polish trawl fisheries, although 55% of these bore a Polish manufacturer's mark. Plastic head line floats included 52 of Russian origin and 2 varieties of Argentinian float (brand names Moscuzza and Arex, Table 4). Plastic containers and other litter were identified to country of origin where brand names or manufacturers' names could be read. Most of these artifacts were discarded containers of household consumables such as detergents, shampoos, drinks, aerosol cans, and general food items.

Fifteen plastic drift cards were collected from the coast of Macquarie Island. Of these 13 were of South African origin (Shannon et al. 1973; Lutjeharms et al. 1988), and 2 were Australian.

State of Decay

Plastic objects were found in various stages of decay, ranging from almost pristine with easily discernible printing and little or no sign of ultraviolet degradation to brittle and disintegrating. Most plastic fishing floats had broken lugs, and 32% were in fragments. Generally, fishing floats made of aluminium alloy showed little sign of degradation, although some had broken lugs while others showed signs of pitting. All steel objects were corroded. Many plastic bottles were disintegrating into small fragments, and this type of fragment contributed 46% of miscellaneous plastic objects (Table 2). Most glass bottles were whole.

Table 4.--Countries or regions of origin of artifacts found on Macquarie Island. Where regions only are used, sources of the objects could not be identified more specifically.

Country or region	Fisheries gear	Plastics	Other litter
South America	1	3	4
Argentina	17	4	1
Orient	23	--	--
Japan	37	10	4
China	3	1	--
Scandinavia	1	4	1
Germany	--	1	4
Switzerland	--	--	1
Britain	--	2	2
France	2	--	3
Eastern European	168	--	--
U.S.S.R.	51	3	12
United States	--	2	--
Australasia	--	2	9
South Africa	--	--	13

DISCUSSION

The artifacts stranded at Macquarie Island can have either local or oceanic sources. Some objects may have resulted from the activities of the ANARE station, as rubbish has been dumped in the isthmus area in the past. However, in recent years all plastic, metal, and glass refuse generated by the station has been removed from the island. Thus, in the essential absence of a local source, the stranded artifacts were all derived from oceanic sources, that is, they drifted to the island from distant source-regions.

Macquarie Island lies just to the north of the Antarctic Polar Front (Tchernia 1980). The main oceanic drift pattern which influences Macquarie Island is the West Wind Drift, which has a slight northerly component (Shannon et al. 1973; Lutjeharms et al. 1988). Within that westerly drift, mean surface drift speeds in the Southern Ocean at the latitude of Macquarie Island have been determined at between 14.6 and 19.0 cm/sec (Shannon et al. 1973; Bye 1988; Lutjeharms et al. 1988). Drifting buoys show a tendency to accumulate in areas corresponding to the historic locations of the various frontal systems of the Southern Ocean (Lutjeharms et al. 1988), and the pattern of drift towards these fronts is also demonstrated by the amount of plastic litter which tends to accumulate there (Gregory et al. 1984; Galt 1985; Day and Shaw 1987). Most litter stranded on Macquarie Island would have come from the west (e.g., South American debris), and the influence of the West Wind Drift together with

the prevailing westerly winds would explain the high incidence of strandings on the west coast of the island and the low incidence on the east coast. The northerly component of the West Wind Drift, the tendency of floating material to accumulate at oceanic fronts, and the movement of Antarctic Water toward Macquarie Island in winter, suggest debris stranding at Macquarie Island may originate with ships operating both to the north and to the south of the Antarctic Polar Front.

The debris stranded at Macquarie Island originated in several countries. However, the country of origin of artifacts does not necessarily represent the drift tracks, as much of this debris is probably derived from the fishing fleets and other vessels operating in the Southern Ocean. It is possible that some articles with Spanish writing originated on the coast of South America or from vessels operating in that region. Driftwood originating in South America (predominantly *Nothofagus* spp.) has been reported from South Georgia (Lewis Smith 1985), and from Macquarie Island (Barber et al. 1959).

The significant contribution of fisheries-related objects to the debris on Macquarie Island is similar to that found on other islands in the Southern Ocean (Burton and Williams 1985; Ryan 1987b; Ryan and Watkins 1988), and to the situation on remote beaches in the Northern Hemisphere (Merrell 1984). Fishing gear can become a marine pollutant as a result of accidental loss or deliberate dumping. Fragments of net, line, and associated gear can be lost through snagging, but fishing gear which is worn or damaged beyond further use is often discarded at sea (Pruter 1987). Although vessels have little control over damage to fishing gear, it is possible to control the amount of gear which is actively discarded.

There are two major types of fisheries which operate in the Southern Ocean: bottom and midwater trawling and ocean longlining. The fisheries-related debris which washed ashore on Macquarie Island originated in both these fisheries. Trawl fishing operations for fish and krill in the Southern Ocean are dominated by the U.S.S.R. and Japan, with lesser amounts taken by Poland and the German Democratic Republic. For fish and krill, significant fisheries occur in the Atlantic Ocean sector around South Georgia and the Scotia Arc, and for fish only, around Iles Kerguelen in the Indian Ocean sector (Northridge 1984; Williams 1988). The high number of metal head line floats, Russian plastic head line floats, and other trawl gear (Table 3) were probably lost from the eastern European trawlers operating in these areas, with the majority of fishing gear coming from Iles Kerguelen as they are not only closer to Macquarie Island than is South Georgia, but also closer to the Antarctic Polar Front. Some of the plastic head line floats were of Argentinian origin, and probably came from offshore trawling near the coast of South America. These, along with other South American artifacts, were probably carried to Macquarie Island by the West Wind Drift. Fishing gear from longline fisheries was probably lost from Japanese, Taiwanese, or Korean vessels operating to the north of the Antarctic Polar Front, and possibly quite close to Macquarie Island at times (Robins 1985).

The density of stranded artifacts along a shoreline is determined by a number of geographical factors including beach orientation relative to

prevailing currents and winds, offshore reef structure, beach gradient and texture, and local tide and storm effects (Ryan 1987b). The overall density of artifacts on Macquarie Island (11/km) was less than the densities reported for Prince Edward Island off Africa (32/km), Gough Island (14/km), Tristan da Cunha and Inaccessible Island (from 292 to 807/km; all Ryan 1987b), or Amchitka Island in Alaska (193 to 499/km; Merrell 1980). These differences may be due, in part, to sampling methods, as the surveys above concentrated on particular beaches whereas this survey took into account the entire coastline of Macquarie Island. Surveys of stranded artifacts are often concentrated in areas of noticeably high density with the aim of determining (through repeated surveys) the accumulation rate of debris at one site over time. This may result in inflated estimates of density and make intersite comparisons of density difficult or even invalid. The almost north-south orientation of Macquarie Island results in one coast being exposed to prevailing westerly winds and currents, while the other coast is relatively sheltered. Thus, densities of artifacts in different parts of the island vary widely (Table 1). The low density of artifacts on the east coast (0.6/km) is probably due to the prevailing westerly winds, and surveys from other subantarctic islands have shown that quantities of stranded litter are greatest on the windward (westward) shores (e.g., Gregory 1987; Ryan 1987b). Despite the difficulties of interisland comparisons, the density of stranded litter on Macquarie Island appears to be less than on islands in the Atlantic and Indian sectors of the Southern Ocean (Ryan 1987b), and much less than for remote areas of Alaska (Merrell 1980). This is probably related to the proximity of fishery operations, with most fishing occurring far to the west of Macquarie Island.

The high proportion of plastics among stranded artifacts at Macquarie Island is similar to that reported on other islands of the Southern Ocean (Ryan 1987b) and elsewhere (e.g., Merrell 1980, 1984; Pruter 1987; Shiber 1987). The high incidence of plastics in stranded litter is probably due to the increased use of plastics over the last few decades, particularly for packaging, and the slow rate at which plastics degrade. Surveys in the North Sea and off the coasts of northwest Europe have shown that most marine litter is primary or secondary packaging, particularly plastic bottles, the majority of which originate with the disposal of garbage by ships at sea (Dixon and Dixon 1981, 1983). Plastics decay slowly, with little ultraviolet degradation occurring at sea (Shannon et al. 1973).

The impact of stranded artifacts on local fauna and flora is difficult to assess. Plastic particles are commonly ingested by seabirds but most ingestion probably occurs at sea (Ryan 1987a). Some seabirds at Macquarie Island ingest small fragments of plastic, some of which may have been ingested on shore (Slip pers. observ.).

The density of entanglement-type litter stranded at Macquarie Island is less than densities reported for the Northern Hemisphere (Merrell 1980, 1984). Although the southern elephant seal, *Mirounga leonina*, and fur seal, *Arctocephalus* spp., populations have been closely monitored over the last 5 years, to our knowledge there have been no recent reports of entanglements in these species at Macquarie Island, although one fur seal

was sighted with a plastic packing strap collar in 1975 (G. Copson pers. commun.). Greater concentrations of trawl debris occur in areas of concentrated fishing effort (e.g., Fowler 1987), and as the major fishing effort in the Southern Ocean is far to the west of Macquarie Island, the densities of entanglement debris may be low enough to cause little impact on the marine mammals. However, these species are wide ranging, and fatal entanglements of marine mammals at sea are believed to far outnumber those where the animal reaches shore (Fowler 1987). Thus, once debris is stranded it apparently has little impact on the marine mammals, and ingestion of small plastic fragments by some bird species is likely to be the major impact on local wildlife. The impact of these artifacts is therefore likely to be much greater prior to their stranding.

The amount and variety of stranded artifacts at Macquarie Island demonstrate the preponderance and ubiquity of plastics. The hazards posed to wildlife and shipping by marine litter demonstrate the need for active programs to prevent littering at sea and on land.

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