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Benthic Marine Debris, with an Emphasis on Fishery-Related Items, Surrounding Kodiak Island, Alaska, 1994–1996

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Composition and abundance of benthic marine debris were investigated during three bottom trawl surveys in inlet and offshore locations surrounding Kodiak Island, Alaska, 1994–1996. Debris items were primarily plastic and metal regardless of trawl location. Plastic bait jars, fishing line, and crab pots were the most common fishery-related debris items and were encountered in large amounts in inlets (20–25 items km^{-2}), but were less abundant outside of inlets (4.5–11 items km^{-2}). Overall density of debris was also significantly greater in inlets than outside of inlets. Plastic debris densities in inlets ranged 22–31.5 items km^{-2}, 7.8–18.8 items km^{-2} outside of inlets. Trawls in inlets contained almost as much metal debris as plastic debris. Density of metal debris ranged from 21.2 to 23.7 items km^{-2} in inlets, a maximum of 2.7 items km^{-2} outside of inlets. Inlets around the town of Kodiak had the highest densities of fishery-related and total benthic debris. Differences in benthic debris density between inlets and outside of inlets and differences by area may be due to differences in fishing activity and water circulation patterns. At the current reduced levels of fishing activity, however, yearly monitoring of benthic debris appears unnecessary. Published by Elsevier Science Ltd.

Introduction

Attention has been given to surface marine debris in oceanic waters and on beaches (Coe and Rogers, 1997) but the status of marine debris on the seafloor has been largely neglected. Previous benthic marine debris surveys which have investigated the amount and composition of debris caught in benthic trawls are limited to the Mediterranean Sea (Galil *et al.*, 1995; Galgani *et al.*, 1995b), Bering Sea (Feder *et al.*, 1978; June, 1990), Gulf of Alaska (Jewett, 1976), Oregon coast (June, 1990), and in the Bay of Biscay and Seine Bay (Galgani *et al.*, 1995a).

Potential impacts of benthic debris to marine biota are high; entanglement and ingestion hazards have been documented for many marine animals (Laist, 1997). Areas with concentrated fishing activity may contain increased amounts of marine debris (Pruter, 1987). Lost fishing gear is a concern due to the persistence of discarded or broken gear which may continue to catch fish and shellfish; this is called "ghost-fishing" (Smolowitz, 1978; Breen, 1990; Guillory, 1993; Carr and Harris, 1997). Benthic marine debris may also have detrimental effects on fishing by increasing the risk of damage to operational equipment (Nash, 1992).

Commercial fishing is an important industry in southcentral Alaska, with the Gulf of Alaska having large catches of groundfish and salmon (e.g., 230,488 mt of groundfish in 1997 and 115,135 mt of salmon in 1997 (National Marine Fisheries Service, 1998; Alaska Department of Fish and Game, 1998a)). Detrimental effects of marine debris in this area are a concern, particularly ghost-fishing by lost crab pots. We investigated benthic marine debris surrounding Kodiak Island, an area with important commercial and subsistence fisheries but where only limited research on ghost-fishing has been conducted (Vining *et al.*, 1997; Stevens *et al.*, in press). Our objectives were to determine (1) overall distribution, density, and composition of marine debris, with a focus on fishery-related items, and (2) whether debris was more abundant in the inlets or outside of the inlets around Kodiak Island or in different regions around Kodiak Island.

Materials and Methods

We asked the Alaska Department of Fish and Game to collect information on benthic debris caught in

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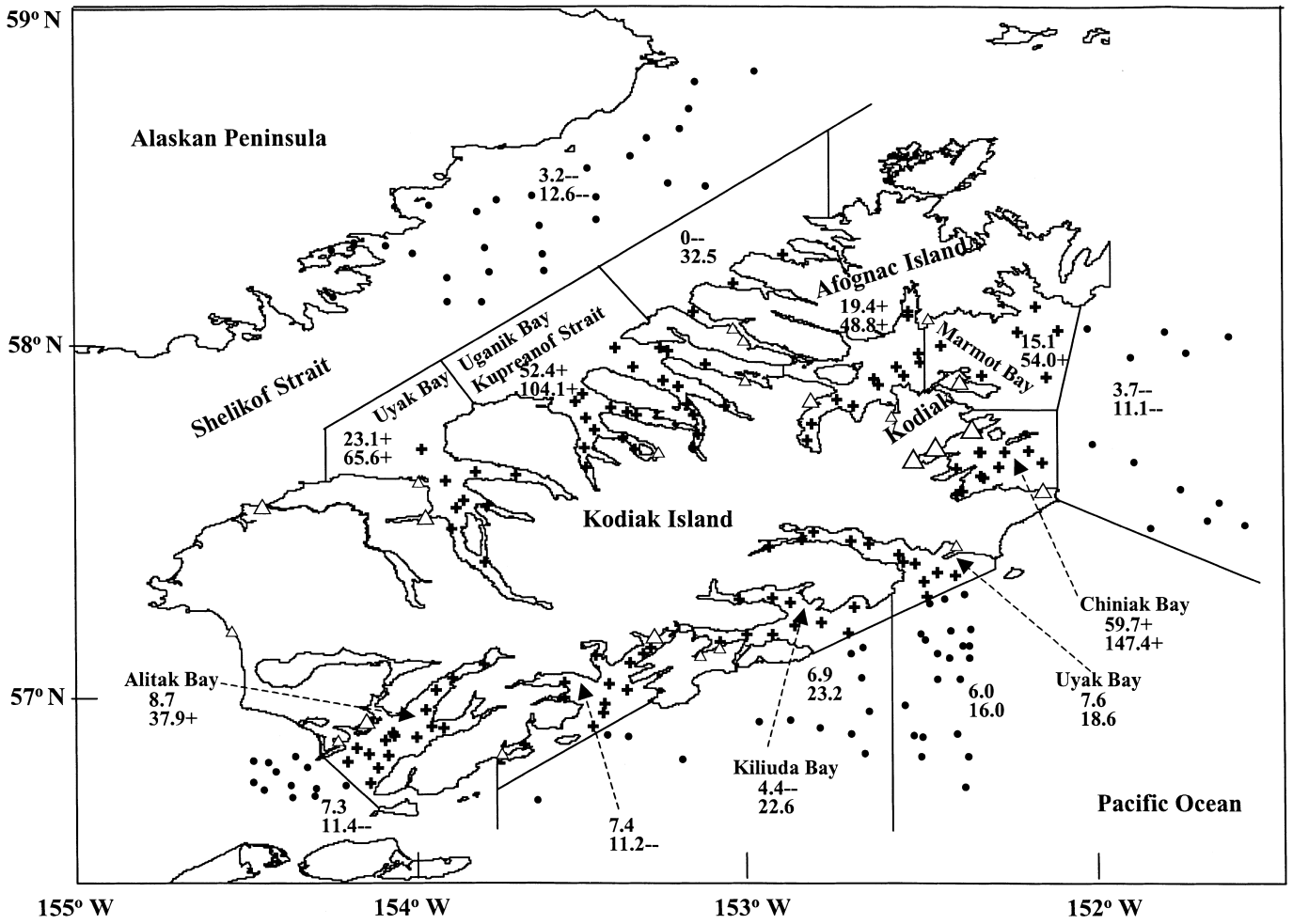

Fig. 1 Location of 1994 benthic marine debris surveys around Kodiak Island, Alaska; sites are also representative of trawl locations in 1995 and 1996. Trawls made in inlets are indicated by plus signs. Trawls made outside of inlets are indicated by dots. The study area was divided into 15 regions, indicated by the solid lines. Average fishery-related debris density (number km^{-2}) (top) and average total benthic debris (number km^{-2}) (bottom) are presented by region. Significantly low densities are indicated with a – and significantly high densities are indicated with a +.

bottom trawl surveys of crab and groundfish resources near Kodiak Island during summers of 1994, 1995, and 1996 (Fig. 1). Trawls were inside inlets or bays of Kodiak Island, or outside of inlets (outside of inlets or bays but within 100 km of Kodiak Island). Surveys consisted of benthic tows approximately 1.85 km long. Length and location of tows were determined with a Global Positioning System (GPS) and recorded on a "Haul Form". A 400-mesh trawl net with a 12.2 m opening was used. All marine debris items caught in a tow were categorized, counted, and recorded and, except for crab and cod pots, placed in trash bags, and disposed of at port. The webbing was cut from each derelict pot and the pots dumped at a pre-approved location.

Trawl sets spanned from 154° 49′ W to 151° 37′ W, 56° 08′ N to 58° 49′ N. Two hundred trawls were made in 1994, 208 in 1995, and 217 in 1996; areas surveyed were 4.28, 4.49, and 4.72 km^2, respectively. Area was width of net opening multiplied by length of the trawl. In 1994, 114 trawls were made in inlets and comprised 57% of the total area surveyed (2.36 km^2), 115 trawls in inlets in 1995 comprised 54% (2.42 km^2) of the total area surveyed. In 1996, 117 trawls (54%) occurred in inlets covering 2.49 km^2 of the total area surveyed.

All debris was assigned to one of six categories based on materials making up the debris: plastic, metal, clothing, glass, styrofoam, and other (Ribic *et al.*, 1992). Since fishery-related items were of particular interest, a separate category of fishing-related items, regardless of composition, was made.

To understand the spatial distribution of benthic debris, we divided the survey area into 15 regions, based on geographic position (N/S/E/W), and whether trawls were in an inlet or outside of an inlet around Kodiak Island (Fig. 1). Differences between densities in the two groups were tested for each category of debris using a Mann–Whitney test (Conover, 1980) for each year. For each region and year, fishery-related debris density and overall debris densities were calculated. Regional differences in fishing-related debris and overall debris densities were tested with Friedman's test with posterior comparisons (Conover, 1980). The total human population for each region was calculated using the Alaska Community Database (Alaska Department of Community and Regional Affairs, 1998). We correlated regional average fishing-related debris and overall debris densities with regional human population using Spearman's ρ (Conover, 1980). Significance of all tests were assessed at $\alpha = 0.05$. Analyses were done using S+, version 3.4 (Statistical Sciences, 1995).

Results

Global patterns

Fishery-related debris made up 46%, 42%, and 38% of the total benthic debris items in the three years. The most common items in the fishing gear category were plastic fishing line, bait jars, and crab pots (Table 1). Debris which has been identified as potentially harmful to marine life (i.e., pots, line, and netting) amounted to 64%, 52%, and 42% of the total fishery-related debris in the three years and 29%, 22% and 16% of the total benthic debris. Fishery-related debris was found on 19% of all the trawls in 1994, 21% in 1995, and 16% in 1996.

The majority of benthic debris was plastic (1994: 49%; 1995: 59%; 1996: 47%) and metal (1994: 38%; 1995: 28%; 1996: 38%). Fishing line, bait jars, and garbage bags combined were the most abundant plastic items (Table 1), accounting for at least 60% of the plastic waste in all three years. The majority of metal items were cans (1994: 68%, 1995: 78%, 1996: 60%); cans were the single most abundant debris item regardless of category in every year (Table 1), making up

TABLE 1

Counts of benthic debris found near Kodiak Island Alaska, from 1994 to 1996 by item and category.

Category	Year		
	1994	1995	1996
Plastic			
Bottles	7	2	2
Garbage bags	5	16	21
Netting[a,b]	0	5	1
Fishing line[a,b]	30	32	15
Plastic buoys[b]	2	9	5
Bait jars (plastic)[b]	16	22	8
Other plastic[b]	2	3	4
Other plastic[c]	15	26	18
Total plastic	77	115	74
Metal			
Cans (< 1 gallon)	41	42	28
Crab pots[a,b]	16	6	9
Fish pots[a,b]	1	1	1
Other metal[b]	0	2	16
Other metal[d]	2	3	7
Total metal	60	54	61
Clothing			
Rain gear	1	0	0
Gloves	3	6	5
Other	4	9	7
Total clothing	8	15	12
Glass			
Jars and bottles	6	7	8
Total glass	6	7	8
Styrofoam			
Styrofoam buoys[b]	5	2	1
Total styrofoam	5	2	1
Other	2	2	2
Total other	2	2	2
Total pieces counted	158	195	159

[a] Types of fishing debris associated with risk to fish and crabs (Laist, 1997; Carr and Harris, 1997).
[b] Debris items considered as fishing gear. Other plastic fishing gear consisted of bait sacks, tanner board, and a line spool end. Other metal fishing gear included hooks, gangions, a leader, and a grappling hook.
[c] Other plastic consisted of other plastic items not including fishing gear, such as food bags, sheeting, strapping, weather balloon, toys, and hard-hat liner.
[d] Other metal consisted of other metal items not including fishing gear, such as radio antennae, and paper towel dispenser.

26%, 22%, and 18% of the total debris in the three years. Clothing was primarily comprised of gloves and 'other' (Table 1). The only glass items counted were jars and bottles while styrofoam was almost exclusively from buoys or floats (Table 1). Benthic debris was found in 34% of the trawls in 1994, 38% in 1995, and 32% in 1996.

Inlet/outside inlet comparisons

Composition of debris by category varied between inlet and outside-of-inlet trawls (Table 2). Fishing-related items comprised 38–43% of the debris in inlets and 34–65% of the debris outside of inlets. Plastic debris composed half or just under half of the items found in inlets, whereas, outside of inlets, 66–89% of the offshore debris was plastic. Metal was the second most abundant category of debris found in inlets. Trawls conducted outside of inlets, however, recovered much less metal (Table 2). Clothing made up a small percentage ($\leqslant 10\%$) of the debris, within or outside of inlets, while glass and styrofoam were found exclusively in inlets (Table 2).

Fishing-related debris densities ranged from 20.1 to 25.0 items km^{-2} in inlets; this was significantly higher than densities found outside of inlets (range: 4.5–11.1 items km^{-2}) ($U = 6$, $df = 2$, $p < 0.05$) (Table 2). Densities of plastic were significantly higher inside inlets (range: 22.1–31.5 items km^{-2}) than outside (range: 7.8–18.8 items km^{-2}) (Table 2) ($U = 6$, $df = 2$, $p < 0.05$). Metal densities were also significantly higher within inlets (range: 21.1–23.7 items km^{-2}) than outside (range: 1.4–2.7 items km^{-2}) ($U = 6$, $df = 2$, $p < 0.05$) (Table 2). Clothing, glass, and styrofoam densities varied between inlet and outside-of-inlet trawls, with inlet trawls having significantly higher densities (all $p < 0.05$) (Table 2).

Regional patterns

Densities of fishing-related debris varied by region ($T = 3.45$, $df_1 = 14$, $df_2 = 28$, $p < 0.01$). Specifically, significantly greater densities of fishery-related items were found in inlets around the town of Kodiak (Chiniak Bay and Afognac Island) and in inlets on the west side of the island (Uyak and Uganik Bays) (Fig. 1). The lowest densities of fishery-related items were found outside of inlets on the north and east side of the island as well as in inlets north and southeast (Kiliuda Bay) around Kodiak Island (Fig. 1). Higher fishing-related debris densities were correlated with regions with higher human population totals ($\rho = 0.65$, $p < 0.005$, $n = 15$).

Total benthic debris densities also varied by region ($T = 4.98$, $df_1 = 14$, $df_2 = 28$, $p < 0.01$). Significantly greater densities of benthic debris were found in inlets around the town of Kodiak (Chiniak Bay, Marmot Bay, Afognac Island) and in inlets on the south (Alitak Bay) and west sides of the island (Uyak and Uganik Bays) (Fig. 1). Lowest densities of benthic debris were found outside of inlets as well as in an inlet around the southern part of Kodiak Island (Fig. 1). Larger total debris densities were correlated with regions with higher human population totals ($\rho = 0.60$, $p = 0.01$, $n = 15$).

Discussion

Jewett (1976) early noted the frequent occurrence of marine debris in benthic trawls on the Northeast Gulf of Alaska continental shelf. Feder *et al.* (1978) said Bering Sea fishing areas had higher amounts of benthic debris than areas not fished. Our results indicate that marine debris, particularly fishery-related debris, is commonly found in benthic trawls in the Kodiak Island region. Furthermore, we found higher densities of fishery-related debris and overall debris inside inlets.

A wide variety of human activity could contribute to the pattern of debris in the inlets and outside of the inlets found in our benthic trawls. The Alaska Department of Fish and Game conducts its crab and groundfish surveys during the summer months which coincides

TABLE 2

Counts of benthic debris from trawls made in inlets and outside of inlets off Kodiak Island, Alaska, 1994–1996.[a]

Category	1994				1995				1996			
	Inlets		Outside		Inlets		Outside		Inlets		Outside	
	Count	Density	Count	Density	Count	Density	Count	Density	Count	Density	Count	Density
Fishing gear[b]	59	25	13	6.8	59	24.4	23	11.1	50	20.1	10	4.5
Plastic	62	26.3	15	7.8	76	31.5	39	18.8	55	22.1	19	8.5
Metal	56	23.7	4	2.1	51	21.1	3	1.4	55	22.1	6	2.7
Clothing	8	3.4	0	0	13	5.4	2	1	9	3.6	3	1.3
Glass	6	2.5	0	0	7	2.9	0	0	8	3.2	0	0
Styrofoam	5	2.1	0	0	2	0.8	0	0	1	0.4	0	0
Other	1	0.4	1	0.5	2	0.8	0	0	2	0.8	1	0.4
Total debris	138		20		151		44		130		29	
No. trawls	114		86		115		93		117		100	

[a] Densities are averaged for all trawls (items km^{-2}) for inlet and outside of inlet trawls. Inlets = trawls done inside inlets or bays. Outside = trawls done outside of inlets or bays.

[b] Fishing gear items were counted twice, in the fishing gear category and in the compositional category.

with the Kodiak salmon season. The salmon fishery typically occurs inshore around Kodiak Island. The groundfishery around Kodiak Island, though conducted year round, typically occurs offshore of the Island and covers a much larger area. In both fisheries, the number of participants in recent years has been about the same (approximately 385 groundfishers and 439 salmon fishers) (Alaska Department of Fish and Game, 1998a; Brennan, 1998). The single most abundant item counted in our surveys, metal beverage cans, could be from a variety of sources such as beach goers, waste disposal sites, cruise ships, wildlife viewing charter boats, and fishing vessels.

In addition, benthic debris distribution is likely affected by 'hydrodynamic circulation' (Galgani *et al.*, 1995a). There are weaker currents in the inlets of Kodiak Island than offshore (Lagerloef and Cannon, 1984); debris, then, may not move far from its point of origin and accumulate on the bottom. For example, several ports, including Kodiak town, were developed in areas where the currents were relatively weak, thus fostering accumulation of debris near those areas (National Oceanic and Atmospheric Administration, 1995).

Other studies have found benthic marine debris densities of 1935 items km^{-2} and 203 items km^{-2} for the continental shelf of the Western Mediterranean Sea (Galgani *et al.*, 1995b) and the Bay of Biscay (Galgani *et al.*, 1995a). Our estimates of benthic debris densities in the Kodiak region are lower than these studies. There is a relatively small human population on Kodiak Island, however, compared to the region where the European surveys were conducted. Our results fell between the low densities found in the Eastern Bering Sea and Norton Sound (2–7.5 items km^{-2}) and off the Oregon Coast (150 items km^{-2}) (June, 1990). Densities of fishery-related debris around Kodiak Island were 10–15 times higher than those found by June (1990).

Current salmon (Brennan, 1998) and groundfish stocks (North Pacific Fishery Management Council, 1997) have been relatively stable or decreasing in both amount and effort around Kodiak Island. In addition, there is no significant crab fishery at this time (Alaska Department of Fish and Game, 1998b). An increase in benthic debris around Kodiak Island, then, is unlikely. If there were a major increase in the salmon, groundfish, or crab stocks around Kodiak leading to an increase in any of the fisheries, then further debris surveys might be appropriate. However, at the current levels of fishing activity, yearly monitoring of benthic debris around Kodiak Island appears unnecessary.

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