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Impacts of lost fishing gear on coral reef sessile invertebrates in the Florida Keys National Marine Sanctuary

Mark Chiappone [a,*], Helga Dienes [a], Dione W. Swanson [b], Steven L. Miller [a]

[a] Center for Marine Science and NOAA's National Undersea Research Center, University of North Carolina at Wilmington, 515 Caribbean Drive, Key Largo, FL 33037, USA

[b] Division of Marine Biology and Fisheries, Rosenstiel School of Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, FL 33149, USA

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Abstract

The Florida Keys coral reef ecosystem supports multimillion-dollar commercial and recreational fisheries. The ecological effects caused by fishing gear that is lost when cut or broken after snagging on the bottom is a growing concern to managers and scientists. Few data exist, however, to assess the impacts of lost fishing gear to benthic organisms and habitat structure. In this study, 63 offshore coral reef and hard-bottom sites were surveyed during 2001 to quantify the impacts of lost fishing gear to coral reef sessile invertebrates. Lost hook-and-line fishing gear accounted for 87% of all debris ($N = 298$ incidences) encountered and was responsible for 84% of the 321 documented impacts to sponges and benthic cnidarians, predominantly consisting of tissue abrasion causing partial individual or colony mortality. Branching gorgonians (Octocorallia) were the most frequently affected (56%), followed by milleporid hydrocorals (19%) and sponges (13%). Factors affecting the impacts of lost fishing gear include sessile invertebrate density, the density of lost fishing gear, and gear length. While lost hook-and-line fishing gear is ubiquitous in the Florida Keys, less than 0.2% of the available milleporid hydrocorals, stony corals, and gorgonians in the habitats studied are adversely affected in terms of colony abrasions and partial mortality.

Keywords: Fishing gear; Florida Keys; Marine pollution; Protected areas; Stratified sample design

1. Introduction

Fishing is the most widespread exploitative activity on coral reefs and poses significant threats to the biodiversity and condition of marine ecosystems (Jennings and Polunin, 1996). Marine fishery resources on a global scale are under intensive pressure from fishing (Botsford et al., 1997), and from the perspectives of fisheries managers, environmentalists and scientists, there is general agreement than habitat degradation is the most important threat to the long-term recovery of exploitable fisheries stocks (Benaka, 1999). Fishing can influence the population structure of species by affecting their abundance, size, growth and mortality, but can also modify species interactions such as competition and predation by altering structural complexity (Russ, 1991; Auster and Langton, 1999). Various ecological effects occur when traps and bottom trawls are deployed, but impacts may also occur when large numbers of anglers use hook-and-line gear to fish (Jennings and Lock, 1996; Jones and Syms, 1998). Derelict fishing gear can destroy benthic organisms and entangle both benthic and mobile fauna, including endangered species (Donohue et al., 2001). While the direct and indirect effects of fishing on marine ecosystems are a growing concern (Dayton et al., 1995; Jennings and Polunin, 1996), the extent and possible effects of lost fishing gear and other debris on organisms and ecological processes is still largely unknown in many coastal ecosystems. The exceptions to this pattern are a breadth of studies evaluating the effects of mobile fishing gear on benthic habitat structure (Auster and Langton, 1999; Benaka, 1999).

* Corresponding author. Tel.: +1-305-451-0233; fax: +1-305-453-9719.
E-mail address: chiapponem@uncwil.edu (M. Chiappone).

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Commercial and recreational fishing are economically important in the Florida Keys and target an enormous array of fish and invertebrate species using a variety of gear types (Tilmant, 1989; Bohnsack et al., 1994). For example, pink shrimp (*Farfantepenaeus duorarum*) are captured using otter trawls throughout the Florida Keys and on the Florida west coast, while roller-frame trawls are used on the entire Florida west coast for bait for recreational fisheries. Stone crabs (*Menippe mercenaria*) are fished mostly in Florida Bay and the Florida west coast. Spiny lobster (*Panulirus argus*) traps are set both in Florida Bay and in the shallow flats along the Florida Keys and the offshore reef tract to the Dry Tortugas. Currently there are over 4500 registered commercial fishing vessels that use traps or hook-and-line to fish. Of those commercial vessels using traps, they have the capacity to deploy over 540,000 lobster traps and 750,000 crab traps per season in Monroe County alone (DiDomenico, 2001).

There is mounting concern about the possible effects of fishing on the Florida Keys marine environment. Both commercial and recreational fishing have greatly expanded in south Florida in terms of effort and landings, largely reflecting an economy dependent upon tourism (Ault et al., 1998; Schittone, 2001). In 2000, for example, over 25 million recreational fishing trips were made in Florida (43% on the east coast and 57% on the west coast) and over 64 million pounds of recreationally caught fish were landed (NMFS, 2001). The number of registered recreational vessels in Monroe County (Florida Keys) increased nearly ten times between 1964 (2242 vessels) and 1998 (21,336 vessels) alone; while these data indicate large increases in the number of boats, these figures constitute boat registrations for recreational vessels which may or may not engage in fishing (Ault et al., 2001). During the same period, the number of commercial fishing vessels expanded from 2311 to 4414 vessels. Moreover, relative fishing power has increased due to better hydroacoustics, global positioning systems, and improved vessel designs (Bohnsack and Ault, 1996). Recreational fishing is a particular management challenge because of the numbers of targeted species, multiple access points for vessels, and gears used, but also because of the absence of limitations on the number of recreational fishing licenses sold (Bohnsack et al., 1994). Recreational fishing increasingly resembles commercial fishing as technological improvements are adopted (e.g. better hydroacoustics, global positioning systems) that lead to increases in effective fishing power (Bohnsack and Ault, 1996). Angling dominates recreational fishing in the Florida Keys and most of the environmental impact to benthos from lost gear is likely to result from lost monofilament line, fishing wire, leaders, lead sinkers, and hooks, although a significant percentage of impacts are also due to lost lobster traps (DiDomenico, 2001).

This study evaluated the spatial extent of marine debris, represented mostly by lost hook-and-line fishing gear, and the corresponding impacts to sessile invertebrates inhabiting shallow (<10 m) coral reefs and low-relief hard-bottom habitats in the Florida Keys. The study was undertaken as part of an ongoing assessment of the community structure of reefs in the Florida Keys National Marine Sanctuary (Miller et al., 2002) and was a continuation of an assessment of lost fishing gear and its impacts to sessile invertebrates in the Florida Keys (Chiappone et al., 2002). Three questions were addressed: first, what sessile reef invertebrates are adversely affected by lost fishing gear in terms of partial or complete colony or individual mortality? Second, are the impacts by lost fishing gear related to the density and length of the lost gear and/or to the densities of sessile invertebrates? Third, does lost fishing gear significantly affect coral reef habitats in the Florida Keys?

2. Methods

The region of maximum coral reef development in the continental US occurs from 25 m to 13 km offshore of the Florida Keys archipelago, a chain of more than 1700 Pleistocene islands (Key Largo Limestone and Miami Oolite) extending ~360 km from Soldier Key east of Biscayne Bay to the Dry Tortugas (Florida Department of Environmental Protection, FDEP, 1998). The reef tract is a discontinuous series of offshore reefs forming an arc paralleling the islands in a general southwesterly trend and separated from them by Hawk Channel, a V-shaped basin (5–12 m depth) dominated by seagrasses, sand, and patch reefs (FDEP, 1998). Reef development and distribution on the south Florida shelf reflect exchange processes between Florida Bay and the Atlantic Ocean, the position of the Florida Current relative to the platform margin, and underlying Pleistocene topography (Shinn et al., 1989; Ginsburg and Shinn, 1993). Offshore bank reefs with high-relief spur and groove topography, for example, are most numerous in the upper and lower Keys regions where they occur preferentially seaward of the islands, while vast areas of sand and hard-bottom characterize the middle Keys (Marszalek et al., 1977; FDEP, 1998).

Sixty-three sites were surveyed southwest of Key West to northern Key Largo during June to September 2001, spanning over 200 km of the offshore reef tract in the Florida Keys National Marine Sanctuary (FKNMS) (Fig. 1). Two habitat types, high-relief spur and groove and low-relief hard-bottom, were selected for sampling based upon their prevalence in the study area and their inclusion within the FKNMS no-fishing zones described below. Previous regional classifications of the Florida Keys marine environment (Shinn et al., 1989; Ginsburg and Shinn, 1993) were modified for the present study

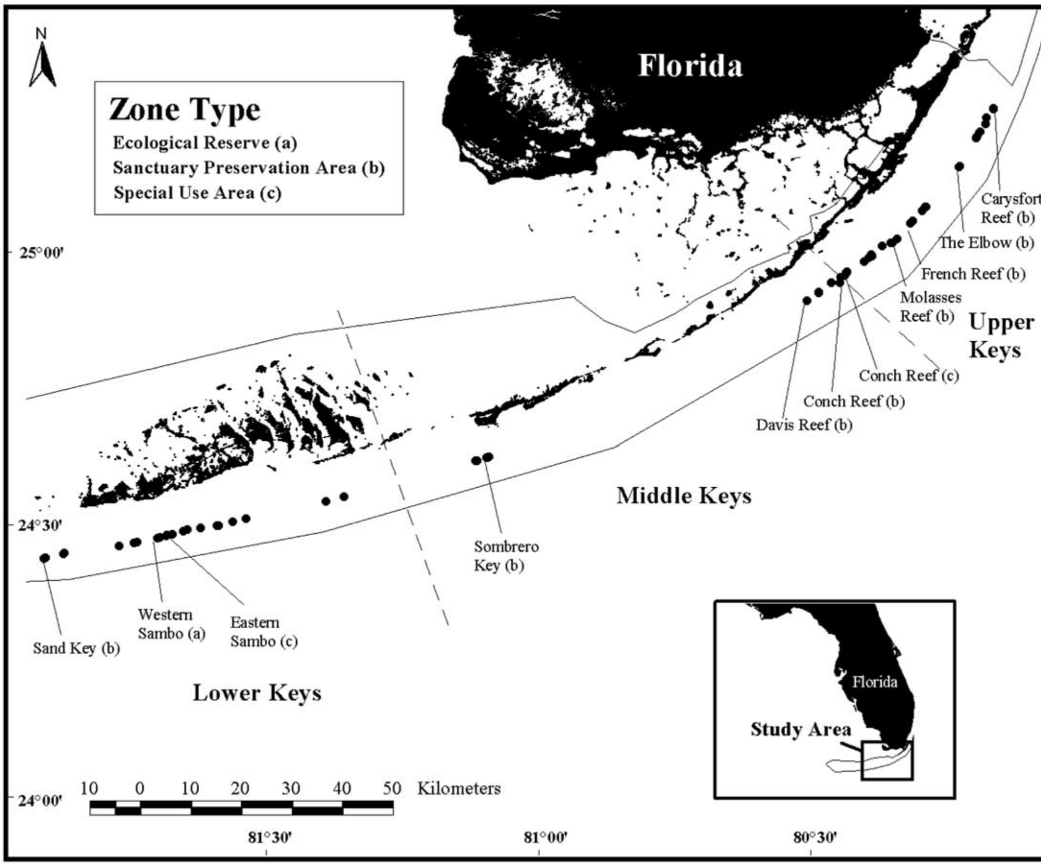

Fig. 1. Sites assessed for the effects of fishing gear to coral reef benthos in the Florida Keys National Marine Sanctuary, with approximate locations of no-fishing zones.

(Fig. 1) to evaluate potential regional differences in sessile coral reef invertebrates impacted by lost fishing gear and other marine debris. Ginsburg and Shinn (1993) defined three regions in the Keys as follows: upper Keys (Hen and Chickens or Plantation Key north), Middle Keys from Upper Matecumbe (including Alligator) to Big Pine Key, and lower Keys (west of Big Pine Key). Shinn et al. (1989) defined the regions as upper (Miami to Molasses Reef), middle (Molasses to Marker G), and lower Keys (west of Marker G), while FDEP (1998) divided the Keys into upper (Northern Key Largo to Upper Matecumbe), middle Keys from Upper Matecumbe to Pigeon Key, and Lower Keys from Little Duck Key to the Dry Tortugas. Our regional classification differs only in the division between upper and middle regions, in which our division between the upper and middle Keys occurs southwest of Molasses Reef (between Pickles and Conch Reef), reflecting the absence of shallow spur and groove development further southwest (except for Sombrero Key) until the lower Keys region.

Ten of the 23 no-fishing zones established in the FKNMS in 1997 (NOAA, 1996) were sampled during this study, including one ecological reserve (Western Sambo, 31 km^2) encompassing representative benthic habitats across the continental shelf in the lower Keys, eight Sanctuary Preservation Areas (SPAs, average of 0.82 km^2 in area, range of 0.16–3.27 km^2), and one special-use zone (Research Only Area) (Fig. 1). SPAs are designed to protect the most sensitive and intensively used, high-relief coral reef habitat from extractive human activities. They include many popular diving reefs and were additionally intended to reduce conflicts between divers and fishers. Access to special-use areas is limited, as they are intended for research and to assess the effects of diving activities. The no-fishing zones are an essential component of the management plan for the FKNMS, and provide a unique opportunity to evaluate the direct and indirect effects of fishing and other activities (Bohnsack and Ault, 1996). Most of the offshore zones extend seaward to only 13–15 m depth, with the fore reef environment usually consisting of high-relief spur and groove (ridge and trough zone) topography or low-relief hard-bottom from 2 to 8 m depth (Chiappone and Sullivan, 1997) and low-relief spur and groove or low-relief hard-bottom at >8 m depth (FDEP, 1998). The shallowest portions of many fore reef areas were historically dominated by elkhorn coral (*Acropora palmata*), with staghorn coral (*A. cervicornis*) locally abundant in some back reef and deeper fore reef areas (Dustan and Halas, 1987; Porter and Meier, 1992).

This spatially intensive study employed a two-stage stratified random survey design (Cochran, 1977; Ault et al., 1999) to optimize sampling effort and to choose sampling locations for determining the density of lost fishing gear and the impacts to coral reef sessile invertebrates. The Florida Keys sampling domain, limited for our study from northern Key Largo to southwest of Key West (Fig. 1), was partitioned into unique habitat strata based on geographic location and benthic habitat characteristics, using information provided by Florida Department of Environmental Protection (FDEP) habitat maps for the Sanctuary (FDEP, 1998). Surveys for debris density and impacts to sessile invertebrates focused on the shallow platform margin from 1 to 7 m depth and included two habitat types (high-relief spur and groove and low-relief hard-bottom), three geographic regions (upper, middle and lower Keys), and ten of the Sanctuary's 23 no-fishing zones (Table 1). The sampling domain was overlain in a Geographic Information System (GIS) with a grid of 200 m × 200 m sites that were the primary sample units, of which 63 were surveyed. Each site that contained high-relief spur and groove or low-relief hard-bottom habitat was assigned a unique number and randomly selected for sampling from a discrete uniform probability distribution to ensure that each site had equal selection probability. The sampling effort was determined by the availability of the two habitat types selected for study and the distribution of the Sanctuary no-fishing zones (Miller et al., 2002). No-fishing zones are concentrated in particular habitat types and thus the sampling was largely concentrated in high-relief spur and groove topography in the upper and lower Keys (Table 1). Logistics and funding allowed us to sample 10 of the Sanctuary's 23 no-fishing zones. Despite the relatively small sizes of most of the zones, the random allocation of two replicate sites within each zone for a particular habitat type was possible. Second-stage sample units (transect stations) were then randomly positioned in each primary unit (site) as described below. To estimate the densities of lost fishing gear and other marine debris and the impacts to sessile invertebrates, four stations of two 25-m × 2 m transects (400 m^2) were sampled in each site, while two 25-m × 4 m transects (20 m^2) were used to inventory the total densities of milleporid hydrocorals (Milleporina), stony corals (Scleractinia), and gorgonians (Octocorallia) to estimate the proportional impacts of lost fishing gear and other marine debris to sessile invertebrates.

Within each site, four randomly positioned transect stations were located using differential GPS. At each of the four stations per site, two 25 m transects were deployed from inshore to offshore. At sites with spur and groove topography, transects were oriented along the

Table 1
Sampling effort for marine debris and impacts to coral reef sessile invertebrates in the Florida Keys

Sampling strata[a]	Available sites	Sampling domain (%)	No. sites surveyed	Sampling effort (%)	Sampling area (m^2)
High-relief spur and groove	148	15.42	34	53.97	13,600
Lower Keys Sector	88	9.17	17	26.98	6,800
No-fishing zones	48	5.00	8	12.70	3,200
Fished areas	40	4.17	9	14.29	3,600
Middle Keys Sector	11	1.15	3	4.76	1,200
No-fishing zones	7	0.73	2	3.17	800
Fished areas	4	0.42	1	1.59	400
Upper Keys Sector	49	5.10	14	22.22	5,600
No-fishing zones	34	3.54	8	12.70	3,200
Fished areas	15	1.56	6	9.52	2,400
Low-relief hard-bottom	812	84.58	29	46.03	11,600
Lower Keys Sector	53	5.52	7	11.11	2,800
Fished areas	48	5.00	7	11.11	2,800
Middle Keys Sector	244	25.42	13	20.63	5,200
No-fishing zones	27	2.81	4	6.35	1,600
Fished areas	217	22.60	9	14.29	3,600
Upper Keys Sector	515	53.65	9	14.29	3,600
Fished areas	487	50.73	9	14.29	3,600
Total	960	100.00	63	100.00	25,200

Eight 25 m × 2 m transects (100 m^2 per station and 400 m^2 per site) were sampled for marine debris at each site, with sites defined as 200 m × 200 m cells or blocks on the existing habitat map of the sampling domain. Sampling domain refers to the proportion of habitat area available and effort refers to the proportion of each stratum sampled relative to the total sites available.

[a] No-fishing zones sampled in high-relief spur and groove were Carys fort/S. Carysfort SPA, Elbow Reef SPA, Molasses Reef SPA, Sombrero Key SPA, Eastern Sambo RO, Western Sambo ER, Eastern Dry Rocks SPA and Sand Key SPA. No-fishing zones sampled in low-relief hard-bottom were Conch Reef SPA and Davis Reef SPA.

Table 2
Frequency of fishing gear and other marine debris sampled in the Florida Keys National Marine Sanctuary during June-September 2001

Debris type	Spur and groove (34 sites)		Hard-bottom (29 sites)		Total
	Protected areas (18 sites)	Fished areas (16 sites)	Protected areas (4 sites)	Fished areas (25 sites)	(63 sites)
Hook-and-line gear					
Fishing rod				1 (1)	1 (1)
Fishing weight	1 (1)			1 (1)	2 (2)
Fishing wire	29 (14)	16 (10)	10 (3)	29 (11)	84 (38)
Fishing wire w/hook	3 (1)				3 (1)
Fishing wire w/leader		2 (2)			2 (2)
Fishing wire w/weight	2 (1)		1 (1)	1 (1)	4 (3)
Monofilament line	31 (14)	31 (10)	14 (4)	46 (10)	122 (38)
Monofilament w/hook	5 (3)	4 (3)	1 (1)	8 (7)	18 (14)
Monofilament w/leader	1 (1)			5 (4)	6 (5)
Monofilament w/weight	3 (2)		1 (1)	5 (4)	9 (7)
Wire leader	6 (4)	3 (2)			9 (6)
Subtotal	81 (18)	56 (13)	27 (4)	96 (17)	260 (52)
Lobster trap gear					
Rope w or w/o buoy	5 (3)	6 (5)		6 (5)	17 (13)
Wire grating			1 (1)		1 (1)
Wooden slats	3 (2)	2 (1)		7 (6)	12 (9)
Subtotal	8 (5)	8 (6)	1 (1)	13 (10)	30 (22)
Other debris types					
Anchor				1 (1)	1 (1)
Beer bottle			1 (1)		1 (1)
Bottle cap	1 (1)				1 (1)
Diving knife				1 (1)	1 (1)
Diving weight		1 (1)			1 (1)
Metal pipe	1 (1)				1 (1)
Nylon bag				1 (1)	1 (1)
Plastic mesh bag	1 (1)				1 (1)
Subtotal	3 (3)	1 (1)	1 (1)	3 (3)	8 (8)
All debris categories	92 (18)	65 (14)	29 (4)	112 (22)	298 (58)

Values in parentheses are the number of sites where particular debris types were recorded.

tops of the spurs and not in sand grooves. Lost fishing gear and other marine debris (Table 2) were surveyed by searching an area 1 m out from each transect side, yielding a sample area of 100 m^2 per station and 400 m^2 per site. The transect dimensions were selected to maximize the area sampled, given the number of personnel available and other variables monitored in the assessment program (Miller et al., 2002). The type of marine debris, dimensions (length, width, height), numbers of sessile invertebrates impacted, and whether or not the marine debris was possibly recently lost (as determined by biological fouling) were noted. Impacts from marine debris ranged from partial mortality from tissue abrasions to complete tissue loss and mortality of sponge individuals or cnidarian colonies. Organisms were considered impacted by marine debris if tissue damage was obvious and thus did not include organisms that were simply entangled. Coral reef sessile invertebrates affected by marine debris were categorized into five groups comprising the majority of sessile invertebrate cover on Florida Keys reefs: milleporid hydrocorals (*Millepora alcicornis* and *Millepora complanata*), scleractinian corals (Scleractinia), gorgonians (Octocorallia), sponges (Demospongeae), and the colonial zoanthid *Palythoa mammillosa* (Zoanthidea). To compare densities of stony corals and gorgonians impacted by marine debris relative to total invertebrate densities, two of the 25 m transects deployed per site were surveyed for the total numbers of milleporid hydrocoral, scleractinian coral, and gorgonian colonies by searching a 0.4 m swath on one side of each of the transects, yielding a total sample area per site of 20 m^2.

Mean densities of sessile invertebrates impacted by lost fishing gear or other marine debris (= no. of injured organisms per 100 m^2), were compared between habitat types, among geographic regions, and between protected and fished areas. Statistical comparisons of mean densities were made by calculating confidence intervals (CI) based on the equation $CI = mean \pm t_{[\alpha,df]} \times SE$, with SEs estimated by the two-stage, stratified sampling design (Cochran, 1977). Confidence intervals were adjusted for multiple comparisons using the Bonferroni procedure (Miller, 1981). The experiment-wise error rate was held at $\alpha = 0.05$ and the comparison-wise error rate was adjusted based on the number of multiple comparisons using the equation: comparison-wise error rate $= \alpha/c$, where $c = k(k-1)/2$ and k = number of comparisons. Spearman rank correlation analysis was used to explore statistically significant relationships among the density of impacted sessile invertebrates, total invertebrate densities, lost fishing gear or other marine debris, and fishing gear length (Zar, 1996).

3. Results

3.1. Marine debris types and distributions

Sixty-three sites encompassing 25,200 m^2 of shallow spur and groove and hard-bottom habitat were surveyed for lost fishing gear and other marine debris on the Florida Keys reef tract. Transect surveys yielded 298 pieces of marine debris, representing three major debris categories allocated and 22 individual debris types or combinations (Table 2). A more detailed account of the debris encountered is available in a companion paper (Chiappone et al., in press). Marine debris was recorded from 92% of the sites, including all no-fishing zones surveyed in both habitat types. Lost hook-and-line fishing gear was the predominant debris type ($N = 260$), representing 87% of all marine debris items recorded, followed by lobster trap gear (10%). The hook-and-line gear was mostly monofilament line (47%) and fishing wire (32%), or combinations of these items with leaders, hooks, and lead sinkers.

3.2. Coral reef sessile invertebrates impacted by marine debris

A total of 321 sessile invertebrates were in contact with marine debris from the 63 sites (25,200 m^2). Gorgonians were the most commonly affected ($N = 178$, 55%), followed by milleporid hydrocorals ($N = 54$, 17%), sponges ($N = 40$, 13%), scleractinian corals ($N = 30$, 9%), and the colonial zoanthid *P. mammillosa* ($N = 19$, 6%) (Fig. 2, top). Hook-and-line gear caused the majority of impacts for all five benthic invertebrate groups assessed for injuries or mortality, damaging 272

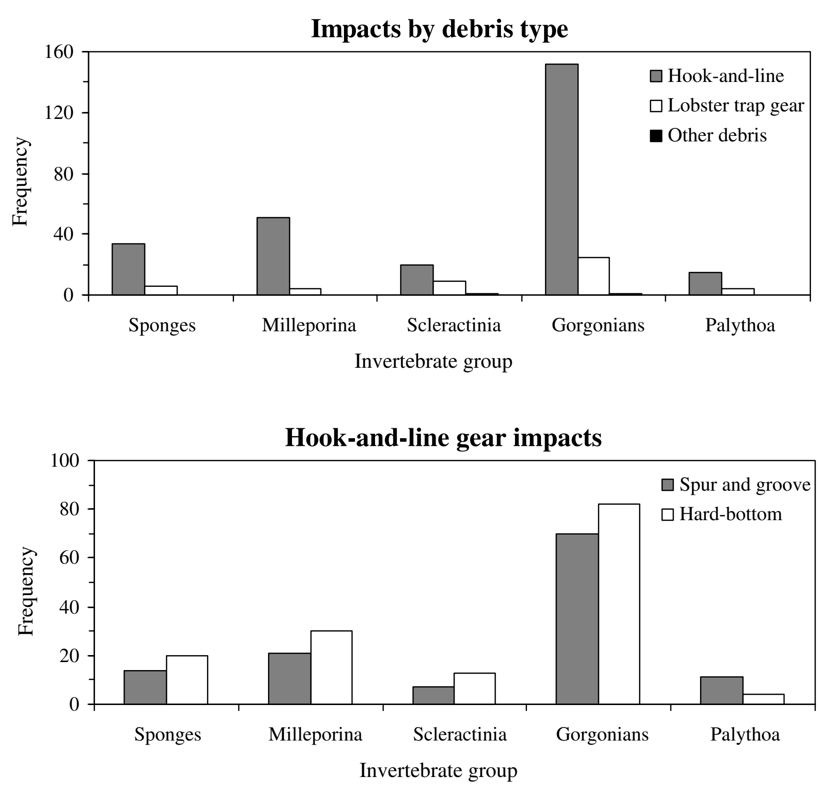

Fig. 2. Frequency of impacts caused by debris types (top) and frequency of benthic taxa impacted by hook-and-line gear by habitat type (bottom) in the Florida Keys National Marine Sanctuary.

organisms (Fig. 2, bottom), mostly gorgonians ($N = 152$, 55.9% of the total), milleporid hydrocorals ($N = 51$, 18.9%), and sponges ($N = 34$, 12.6%).

3.3. Lost hook-and-line gear impacts to coral reef sessile invertebrates

Of the 260 occurrences of pieces of lost hook-and-line debris, 49% caused no apparent injury to any of the sessile invertebrate groups assessed. Other pieces of gear ($N = 133$, 51%) injured 272 organisms, ranging from 1 to 11 injured organisms per piece of gear. More than 75% of the pieces of lost hook-and-line gear damaged one ($N = 70$, 53%) or two organisms (25%). For all 63 sites, mean $\pm$ 1 SE densities (no. per 100 m^2) of sessile invertebrates impacted by lost hook-and-line gear were as follows: 0.13 ± 0.04 sponges, 0.20 ± 0.04 milleporid hydrocorals, 0.08 ± 0.03 scleractinian corals, 0.60 ± 0.10 gorgonians, 0.06 ± 0.02 *P. mammillosa*, and 1.07 ± 0.19 for all groups combined (Table 3). Thus, about one sessile invertebrate per 100 m^2 was impacted by lost hook-and-line gear on the Florida Keys shallow fore reef during the study.

We found no significant differences ($P > 0.05$) in the spatial variations in mean densities of damaged sessile invertebrates between habitat types for the five invertebrate groups considered (Table 3). Relative to the estimates of total densities of milleporid hydrocorals, scleractinian corals, and gorgonians, the relative impacts of hook-and-line gear were <0.2% of the total densities of these sessile invertebrate groups (Fig. 3).

3.4. Factors affecting lost hook-and-line gear impacts

Several factors affect the damage of lost hook-and-line gear to sessile invertebrates, including the density of lost fishing gear, the size of lost fishing gear, and invertebrate density. We found significant relationships between the density of lost hook-and-line gear with the densities of impacted sponges (Spearman correlation

Table 3
Mean ($\pm$1 SE) densities (no. organisms/100 m^2) of coral reef sessile invertebrates impacted by hook-and-line fishing gear in the Florida Keys National Marine Sanctuary

Strata/site location (no. sites)	Sponges	Milleporina	Scleractinia	Gorgonians	Palythoa
High-relief spur and groove (34)	0.10 ± 0.03	0.15 ± 0.05	0.05 ± 0.02	0.51 ± 0.12	0.08 ± 0.03
Lower Keys Sector (17)	0.13 ± 0.05	0 ± 0	0.09 ± 0.04	0.29 ± 0.12	0.07 ± 0.03
No-fishing zones (8)	0.13 ± 0.07	0 ± 0	0.06 ± 0.04	0.19 ± 0.16	0.06 ± 0.04
Sand Key SPA (2)	0.25 ± 0.25	0 ± 0	0 ± 0	0.63 ± 0.63	0.25 ± 0.25
E. Dry Rocks SPA (2)	0.25 ± 0.25	0 ± 0	0.25 ± 0.25	0.25 ± 0.25	0.25 ± 0.25
Western Sambo ER (2)	0.00 ± 0.00	0 ± 0	0 ± 0	0 ± 0	0 ± 0
Eastern Sambo RO (2)	0.25 ± 0.25	0 ± 0	0.25 ± 0.25	0 ± 0	0 ± 0
Fished areas (9)	0.14 ± 0.07	0 ± 0	0.11 ± 0.07	0.39 ± 0.18	0.08 ± 0.05
Middle Keys Sector (3)	0.17 ± 0.11	0.75 ± 0.41	0.08 ± 0.08	1.58 ± 1.01	0.42 ± 0.26
No-fishing zones (2)	0.13 ± 0.13	0.63 ± 0.42	0 ± 0	1.00 ± 1.00	0.50 ± 0.38
Sombrero Key SPA (2)	0.13 ± 0.13	0.63 ± 0.42	0 ± 0	1.00 ± 1.00	0.50 ± 0.38
Fished areas (1)	0.25 ± 0.25	1.00 ± 1.00	0.25 ± 0.25	2.75 ± 2.43	0.25 ± 0.25
East Delta Shoal (1)	0.25 ± 0.25	1.00 ± 1.00	0.25 ± 0.25	2.75 ± 2.43	0.25 ± 0.25
Upper Keys Sector (14)	0.05 ± 0.04	0.21 ± 0.06	0 ± 0	0.55 ± 0.12	0.02 ± 0.02
No-fishing zones (8)	0 ± 0	0.31 ± 0.09	0 ± 0	0.59 ± 0.15	0.03 ± 0.03
Molasses Reef SPA (2)	0 ± 0	0.63 ± 0.26	0 ± 0	0.75 ± 0.31	0.25 ± 0.25
Elbow Reef SPA (2)	0 ± 0	0.25 ± 0.25	0 ± 0	0.25 ± 0.16	0 ± 0
Carysfort Reef SPA (4)	0 ± 0	0.19 ± 0.10	0 ± 0	0.69 ± 0.24	0 ± 0
Fished areas (6)	0.13 ± 0.09	0.08 ± 0.06	0 ± 0	0.50 ± 0.22	0 ± 0
Low-relief hard-bottom (29)	0.17 ± 0.07	0.26 ± 0.06	0.11 ± 0.06	0.71 ± 0.17	0.03 ± 0.02
Lower Keys Sector (7)	0.36 ± 0.26	0.18 ± 0.09	0.39 ± 0.26	0.71 ± 0.54	0.04 ± 0.04
Fished areas (7)	0.36 ± 0.26	0.18 ± 0.09	0.39 ± 0.26	0.71 ± 0.54	0.04 ± 0.04
Middle Keys Sector (13)	0.08 ± 0.01	0.27 ± 0.04	0.04 (0.03)	0.54 ± 0.16	0
No-fishing zones (4)	0.06 ± 0.02	0.06 ± 0.02	0.06 (0.06)	0.50 ± 0.22	0
Davis Reef SPA (2)	0	0.13 ± 0.13	0.13 (0.13)	0.88 ± 0.40	0
Conch Reef SPA (2)	0.13 ± 0.13	0	0	0.13 ± 0.13	0
Fished areas (9)	0.08 ± 0.06	0.36 ± 0.14	0.03 (0.03)	0.56 ± 0.21	0
Upper Keys Sector (9)	0.17 ± 0.07	0.31 ± 0.10	0	0.94 ± 0.30	0.08 ± 0.05
Fished areas (9)	0.17 ± 0.07	0.31 ± 0.10	0	0.94 ± 0.30	0.08 ± 0.05

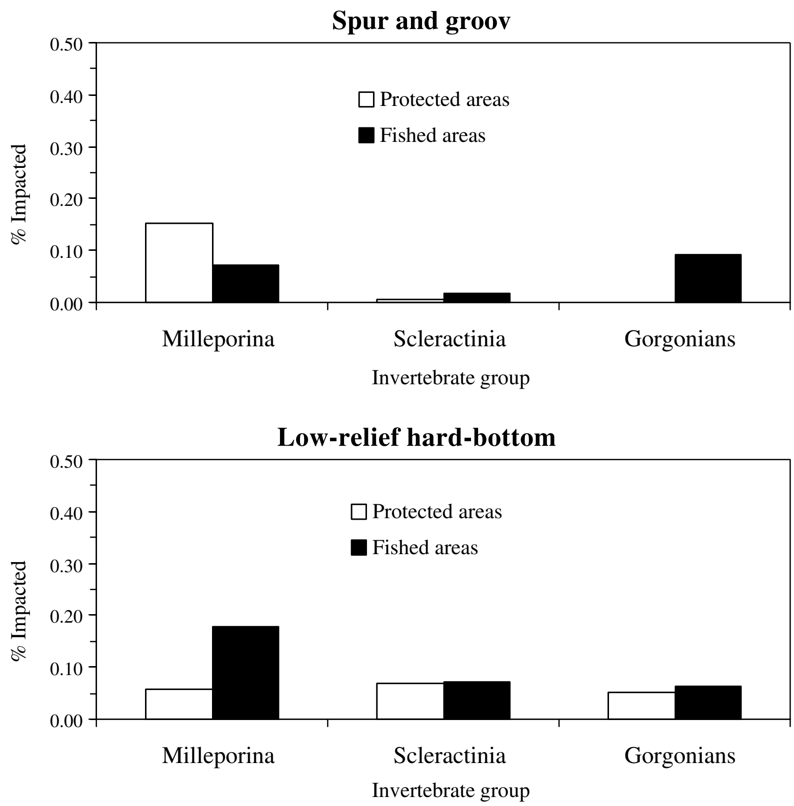

Fig. 3. Proportion of coral reef benthos impacted by hook-and-line gear by habitat type and between protected and fished areas in the Florida Keys National Marine Sanctuary.

$r = 0.469$, df = 51, $P < 0.05$), milleporid hydrocorals ($r = 0.565$, df = 51, $P < 0.05$), gorgonians ($r = 0.751$, df = 51, $P < 0.05$), and *P. mammillosa* ($r = 0.564$, df = 51, $P < 0.05$), but not scleractinian corals ($r = 0.270$, df = 51, $P > 0.05$). The length of lost hook-and-line gear was significantly correlated with the densities of damaged gorgonians ($r = 0.511$, df = 260, $P < 0.05$), but not for the other invertebrate groups. This pattern is probably due to either the relatively high densities of gorgonians in most sites (>5 colonies/m^2), regardless of habitat type, and/or to their upright and branching morphology that can more easily snag derelict fishing gear. Most sponges, scleractinian corals, and colonial zoanthids (*P. mammillosa*) exhibit a flattened or encrusting morphology in the habitat types sampled, and are thus less likely to become entangled in fishing wire or monofilament line. While the densities of sessile invertebrates is a third factor potentially affecting the relative impacts of lost hook-and-line gear (Table 4), no significant correlations ($P > 0.05$) were detected between damaged and total densities of milleporid hydrocorals, scleractinian corals, and gorgonians. This pattern indi-

Table 4
Mean (1 SE) densities (no. colonies/100 m^2) of fire coral (*Millepora* spp.), scleractinian corals, and gorgonians impacted by hook-and-line gear relative to total colony densities by habitat and geographic region in the Florida Keys National Marine Sanctuary

Strata (no. sites)	*Millepora* spp.		Scleractinian corals		Gorgonians	
	Impacted	Total	Impacted	Total	Impacted	Total
Spur and groove (34)	0.15(0.05)	134.0(14.7)	0.05(0.02)	513.8 (50.9)	0.51(0.12)	552.9(63.1)
Lower Keys (17)	0(0)	86.6(15.4)	0.09(0.04)	740.9 (80.4)	0.29(0.12)	243.5(61.9)
Middle Keys (3)	0.75(0.41)	44.0(12.8)	0.08(0.08)	351.0(72.7)	1.58(1.01)	460.0(129.1)
Upper Keys (14)	0.21(0.06)	211.0(23.3)	0(0)	272.9(33.8)	0.55(0.12)	948.6(86.4)
Hard-bottom (29)	0.26(0.06)	155.7(14.2)	0.11(0.06)	155.8(14.0)	0.70(0.17)	1121.7(84.7)
Lower Keys (7)	0.18(0.09)	146.7(31.2)	0.39(0.26)	171.2(27.8)	0.71(0.54)	915.7(82.5)
Middle Keys (13)	0.27(0.04)	166.2(19.0)	0.04(0.03)	143.7(21.6)	0.52(0.07)	1131.5(87.4)
Upper Keys (9)	0.31(0.10)	147.5(20.1)	0(0)	161.5(25.1)	0.94(0.30)	1267.8(232.5)

Values in parentheses represent 1 SE.

cates that greater densities of sessile invertebrates do not necessarily yield greater densities of damaged sessile invertebrates when lost hook-and-line gear is present.

4. Discussion

A number of studies designed assessed the impacts of commercial fishing gear, especially mobile gear such as trawls and dredges on habitat structure (reviewed in Watling and Norse, 1998). In contrast, the impacts of lost fishing gear, especially from hook-and-line fishing, to sessile organisms are poorly documented. This study indicates that hook-and-line gear is ubiquitous on the Florida Keys shallow platform margin, even within no-fishing zones protected from fishing since 1997. The results from 2001 are consistent with an earlier (2000), pilot study (Chiappone et al., 2002) illustrating widespread distribution of lost fishing gear, even within Sanctuary no-fishing zones, and are not surprising considering the large number of fishers in the Florida Keys, the cumulative properties of lost gear, and the limited number of personnel available to patrol a large marine protected area (Causey, 1995). In an earlier study of marine debris in the lower Keys, we found lost hook-and-line gear to be the most prevalent debris type encountered, with gorgonians, sponges, and milleporid hydrocorals the most commonly damaged sessile invertebrates (Chiappone et al., 2002). An important result from the present study is that while lost hook-and-line gear is widespread, the damage to sessile invertebrates caused by this lost gear appears to be minor (<0.5% of total estimated densities). It is important to note, however, that we measured prevalence (the percentage of individuals affected) and not incidence and that we have only considered sessile invertebrates and not other marine fauna (e.g. avifauna and turtles) that may be adversely affected by derelict gear. Moreover, we do not have measures of the rate at which new gear appears at sites (e.g. after reef clean-up efforts), nor do we know how quickly derelict fishing gear disappears from sites (e.g. disintegration rates assumed to be slow for stainless steel and synthetic materials). Estimates of the proportion of hook-and-line gear attributable to commercial versus recreational fishing are also unknown.

Several factors can affect the relative impacts of lost fishing gear. Not surprisingly, both the density and length of lost hook-and-line gear were significantly correlated with sessile invertebrate density, since fishermen tend to fish in habitats with greater benthic complexity. In contrast, invertebrate densities were not significantly correlated with the densities of impacted organisms. The latter result most probably reflects the low densities of hook-and-line gear compared to the relatively high densities of invertebrates. The effects of disturbances on benthic ecosystems are also partly determined by species life histories. Many marine organisms are slow growing and long lived, therefore the frequency of disturbance relative to recruitment and growth affects the severity of the impact (Watling and Norse, 1998). Other factors that can influence the amount of impact caused by fishing gear include oceanographic conditions. Rates of debris accumulation vary and can be influenced by circulation patterns as well as wind patterns (Hess et al., 1999). However, these conditions mostly affect gear that drifts before it sinks and gets entangled. We assume that most of lost fishing gear documented was lost at the same site were it was found due to hooks, weights, and entanglements that were possibly responsible for the gear snagging and being lost in the first place.

Results from this assessment have several implications for fisheries management and research in the Florida Keys. Continued monitoring of lost fishing gear and other marine debris within the Sanctuary no-fishing zones provides one measure of compliance with no-fishing regulations (Chiappone et al., 2002). The stratified design that we employed provides baseline data from which future assessments can be made between fished areas and protected zones to evaluate potential damage that may result from lost fishing gear. Although the impacts of lost hook-and-line gear on coral reef sessile invertebrates appear to be minor relative to total densities, such effects are likely to increase concomitant with expected increases in fishing effort in the Florida Keys. Moreover, there are no data that we are aware of that consider the effects of lost fishing gear and other debris on other organisms, notably marine turtles and birds. The long-term impacts to biota and the degree of recovery from lost fishing gear effects are not adequately studied. We observed several instances where hook-and-line gear, especially monofilament line, was overgrown by sponges, and it seems plausible that some marine debris will be incorporated into the habitat matrix. Future studies should consider the magnitude of lost fishing gear impacts relative to the sizes of organisms affected. Most of the damage we observed from lost hook-and-line gear generally affected <10 cm^2 of live tissue. While the magnitude of tissue loss may not be large per occurrence, it is possible that such impacts may render organisms more susceptible to predation, competitive overgrowth, and disease.

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