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Prevalence and composition of fishing gear debris in the nests of northern gannets (*Morus bassanus*) are related to fishing effort

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ABSTRACT

Bycatch and indirect mortality associated with global fishing operations affect non-target species. Northern gannets (*Morus bassanus*) and other seabirds incorporate marine debris, much of it originating in fisheries, into their nests, at times resulting in entanglement. We compared the prevalence and composition of marine debris in nests at two gannet colonies in Newfoundland before and after a basin-wide ground fish closure in 1992, and at the species' largest colony in the Gulf of St. Lawrence, where fishing effort is low. The proportion of nests with marine debris decreased following the fishery closure, and the proportion of nests with fishing gear was related exponentially to the number of gillnets set around breeding colonies. Assessing the composition of gannet nests could provide a useful index of the prevalence of fishing debris and could be used to assess entanglement risk of other animals in the marine environment over decadal scales.

1. Introduction

Fisheries have numerous effects on non-target animals. By-catch and entanglement in active, abandoned, lost or discarded gear can result in direct mortality (Lewison et al., 2004; Good et al., 2010). Plastics and other anthropogenic marine debris, much of it originating in fisheries, are ubiquitous and increasing in the world's oceans (Colton et al., 1974; Robards et al., 1997; Thompson et al., 2004; Howell et al., 2012). This debris can have detrimental effects on wildlife, particularly through entanglement and ingestion by marine birds and mammals (Ryan, 1987; Sievert and Sileo, 1993; Laist, 1997). Despite the observed consequences of marine debris on seabirds, few studies have examined changes in seabirds' association (use, ingestion, entanglement) with debris over time (Robards et al., 1995; Provencher et al., 2009).

Seabirds are used frequently as sentinels of the health of the marine environment (Burger and Gochfeld, 2004; Durant et al., 2009). The frequency of seabird interactions with synthetic debris can provide indices of this persistent marine pollution (Robards et al., 1995; van Franeker et al., 2011) that could be useful in assessing threats at-sea.

Gannets, boobies and gulls frequently collect and incorporate plastic netting and strapping into their nests, where birds can become entangled (Schrey and Vauk, 1987; Norman et al., 1995; Votier et al., 2011). Northern gannets (*Morus bassanus*) have a well-documented practice of incorporating marine debris, and in particular derelict fishing gear, into their nests (Bourne, 1977; Nelson, 1978), and entanglement causing death has been documented (Votier et al., 2011). In the northwest Atlantic Ocean, almost all gannet nests examined at two colonies (Funk Island and Cape St. Mary's, Newfoundland) contained marine debris in the late 1980s, much of it being fishing gear debris (Montevecchi, 1991). While plastic pollution in the ocean has a relatively long half-life, large pieces are over time broken into smaller segments (Andrady, 2008), making is less likely to be collected by a gannet. The amount of exposed debris in gannet nests is dynamic and the result of several factors. Some is eroded away through storms, and snow/ice melt, and a portion is covered by new nesting material, though it may become exposed again through erosion of the nest pedestal.

A fishing moratorium on northern cod (*Gadus morhua*) in the northwest Atlantic Ocean since the early 1990s (Hutchings and Myers, 1994) has greatly reduced the amount of fishing gear in the water. Owing to this massive reduction in fishing effort over an ocean-basin scale in eastern Canada, we expected that the frequency and composition of marine debris in gannet nests changed

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since 1989. We also assessed if gannets could provide an indication of the abundance of marine debris originating in fisheries.

Our objectives in this paper are to: (1) assess changes in plastic debris in gannet nests at colonies in the fisheries closure zone before and after the moratorium; (2) examine differences in plastic debris in nests by colony location, including the species' largest colony in the Gulf of St. Lawrence; and (3) assess the extent to which gannets can provide indication of the amount and type of plastic debris in the ocean.

2. Methods

During the 2007 breeding season, we recorded the number of gannet nests with anthropogenic debris at three of the six North American gannet colonies – Cape St. Mary's (46°50′, 54°12′W), Funk Island (49°46′N, 53°11′W) and Bonaventure Island (48°30′N, 64°09′W; Fig. 1). We used the same methods and categorizations as Montevecchi (1991), whereby the type of debris in each nest was visually recorded (often using 10 × 40 mm binoculars or 15 × 60 power spotting scopes) in the following categories: strapping (thin, flat pieces of plastic used to bundle items), heavy cord, rope, twine, monofilament line, netting, tape, plastic bag/sheet, and other (including hard plastic, straws, ballpoint pens, shotgun shells, and unidentified plastic). These data were compared with data collected at Cape St. Mary's and Funk Island in 1989 (Montevecchi, 1991). We then grouped debris from all colonies and years into two broad categories: debris typically originating in fisheries operations (cord, rope, twine, monofilament line, netting) and other anthropogenic debris (strapping, tape, bags, hard plastic).

The total number of gillnets set from May to August (northern gannets' breeding season) in the immediate vicinity of Funk Island (North Atlantic Fisheries Organization (NAFO) management area 3KI) and Cape St. Mary's (NAFO areas 3LQ and 3Psc; Fig. 1) were calculated for the pre- and post-moratorium nest survey years (1989 and 2007, respectively). We used gillnet fishing effort data (number of gillnets set) as a proxy of fishing gear available to northern gannets for nest material as most of the fishery-originating debris in 1989 was from gillnet operations.

2.1. Statistical methods

We used a generalized linear model with a binary error structure in SPSS 19 to test for differences in the proportion, and the type of marine debris among colonies, and within colonies before and after the fishing moratorium. Differences were considered significant when 95% confidence intervals around parameter estimates did not overlap.

To test for relationship between the number of gillnets set and fisheries debris in northern gannet nests, we used a logarithmic regression in R 2.12.1 (R Development Core Team, 2010), as we expected the relationship to reach an asymptote where all nests contained debris regardless of the amount of debris available (number of gillnets set).

3. Results

We examined 741 gannet nests in 1989 and 1080 nests in 2007 (Table 1). There was significantly more debris at Funk and Cape St. Mary's in 1989 than 2007 (Wald $\chi^2 = 190.41$, df = 1, $p < 0.001$). In 1989, there was no significant difference in the proportion of nests with marine debris at Funk Island and Cape St. Mary's (Wald $\chi^2 = 3.42$, df = 1, $p = 0.07$), but in 2007, there was a greater proportion of nests with debris at Cape St. Mary's than at Funk Island, and

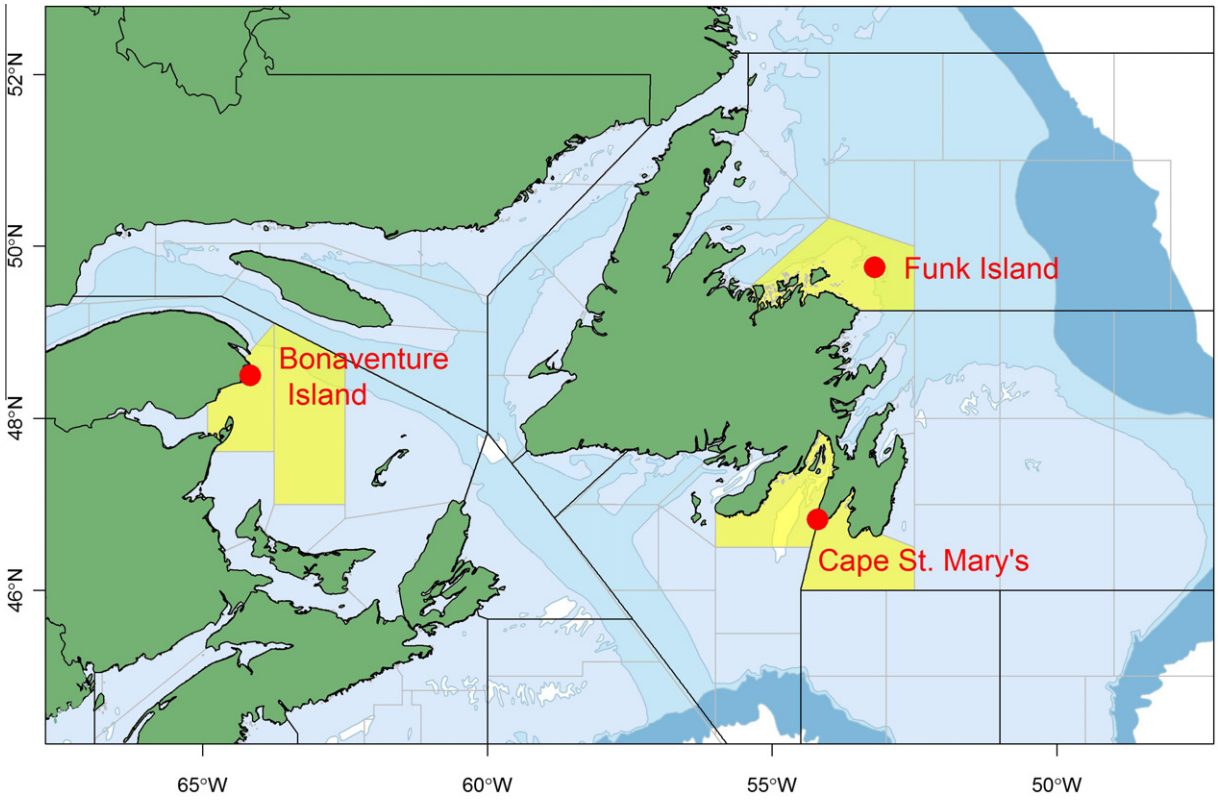

Fig. 1. Marine debris in northern gannet nests was recorded at Funk Island and Cape St. Mary's Newfoundland in 1989 and 2007, and at Bonaventure Island, Quebec in 2007. Yellow fishing zones where northern gannets foraged and for which gillnet fishing effort was documented from Fisheries and Oceans Canada. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Table 1
Numerical occurrence and frequency of different types of debris varied among northern gannet colonies and years. Percentages do not sum to 100% because some nests contained multiple types of debris. Data from 1989 are from Montevecchi (1991).

Type of debris	Funk 1989 (n = 624)	Funk 2007 (n = 230)	Cape St. Mary's 1989 (n = 117)	Cape St. Mary's 2007 (n = 300)	Bonaventure 2007 (n = 550)
No debris	13 (2%)	123 (53%)	6 (5%)	96 (32%)	539 (98%)
Fishing gear (rope, line, netting)	472 (76%)	80 (35%)	102 (87%)	201 (67%)	4 (1%)
Strapping	77 (12%)	34 (15%)	1 (<1%)	9 (3%)	4 (1%)
Bag/sheet	54 (9%)	1 (<1%)	1 (<1%)	0	1 (<1%)
Hard plastic (shotgun shell, lobster tag, misc.)	22 (4%)	0	0	0	0

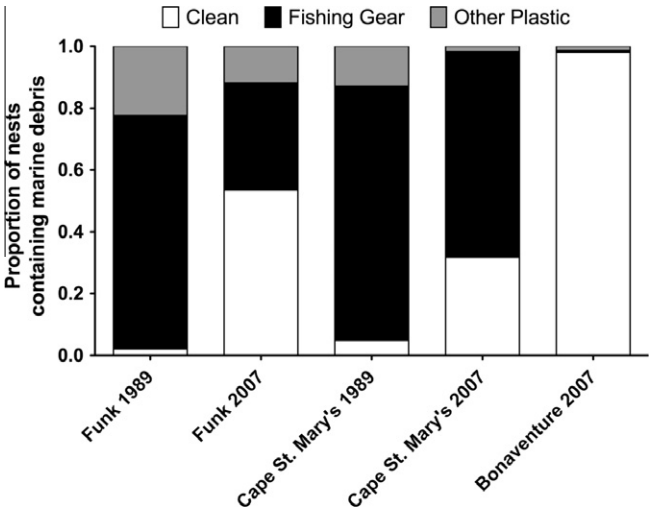

Fig. 2. The proportion of northern gannet nests with marine debris decreased between 1989 and 2007.

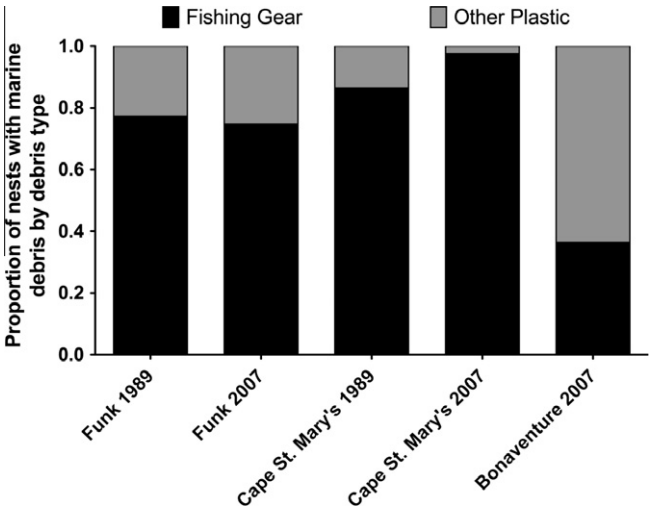

Fig. 3. Of the northern gannet nests with marine debris, the proportion of debris originating in fishing operations did not change between 1989 and 2007.

a significantly lower proportion at Bonaventure Island compared to Funk (Wald χ^2 = 201.47, df = 2, p < 0.001; Table 1, Fig. 2).

Of nests with marine debris, there was no significant difference in the proportion of nests with fishing gear debris between 1989 and 2007 (Wald χ^2 = 0.33, df = 1, p = 0.56), though there was a significant difference among colonies, with a higher proportion of nests with fishing debris at Cape St. Mary's, and a lower proportion at Bonaventure Island (Table 1, Fig. 3).

Using the numbers of gillnets set as a proxy of fishing effort (Fig. 4), we found that fishing effort was related exponentially to percentage of nests with fishing gear debris at the different colonies and during the pre- and post-moratorium periods ($F_{1,3}$ = 67.2, r^2 = 0.96, p = 0.004). With as few as 20,000 gillnets set, we predict that close to 75% of gannet nests would contain fishing debris (Table 2, Fig. 5).

4. Discussion

The extensiveness of fishing gear debris incorporated into northern gannet nests in different colonies is associated with the levels of gillnet fishing effort in adjacent waters. Northern gannet colonies on the east coast of Newfoundland, where intensive gillnet fisheries were carried out, had high proportions of nests with fishing gear. The level of fishing gear debris in nests exhibited a marked reduction following the eastern Canadian ground-fishery closure for northern cod. High percentages of nests with fishing gear debris were recorded at Funk Island and Cape St. Mary's off the northeast and southeast coasts of Newfoundland. Following the fishery closure in 1992, the proportion of nests in the colony on Funk Island with fishing gear debris fell to less than half of pre-moratorium levels. In contrast, at Cape St. Mary's the proportion of nests with fishing gear debris only dropped about 23%. Interestingly, Cape St. Mary's is situated on the border of the fishing zone closure, and northern gannets forage and collect nesting material in fishing zones that are open to fishing activity and in those that are not. The relatively low level of gillnet fisheries in the Gulf of St. Lawrence is reflected in the very low proportion of northern gannet nests with fishing gear debris at Bonaventure Island. There might also be more natural nesting material available in the vicinity of Bonaventure compared to the other colonies, as the St. Lawrence River carries large patches of drifting seaweed downstream past the colony.

Few gillnets were set around Funk Island in 2007, yet 35% of northern gannet nests contained fisheries debris. This implies that northern gannets collect fishing gear debris as nest material, even when relatively little is available, though as suggested this could be related to the relative abundance of natural and synthetic material on the sea surface.

Because our records are based on visual observations they are subject to a number of caveats. First, they are easily executed for comparative study and do not involve the destruction of nests. However, because nest material, synthetic and otherwise, is retained over years and possibly even from the pre-moratorium period in this study, it would be difficult to observe reductions in nest debris over the short term, (i.e., years). Over the long-term (i.e., several years to decades), heavy rains, storms, snow and ice remove nest material during the non-breeding seasons. Visual scans likely detect the most obvious and recent material, and over the two decade interval used in the present study much of that older material has been well buried in nests and is no longer visible.

In the northeast Atlantic Ocean, fisheries debris was disproportionately present in northern gannet nests relative to its proportion as beach-cast debris, and was present in nearly all nests at Grassholm, UK (Votier et al., 2011). This suggests positive selection

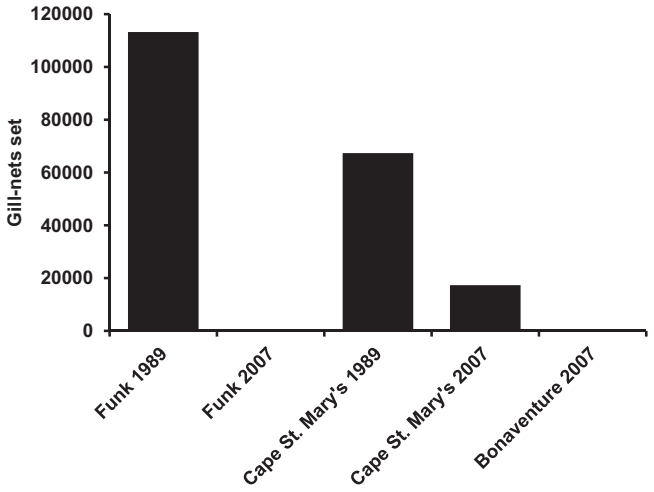

Fig. 4. Number of gillnets set in (i.e. fishing effort) in fishing zones adjacent to Funk Island and Cape St. Mary's in 1989 and 2007, and adjacent to Bonaventure Island in 2007.

Table 2
Parameter estimates of the exponential relationship between the proportion of northern gannet nests with fisheries debris, and the number of gillnets set in adjacent NAFO management areas as a proxy of fishing effort.

Parameter	Estimate	Standard error	*p*-Value
Intercept	−7.97	1.86	0.023
Proportion of nests with fisheries debris	24.68	3.01	0.004

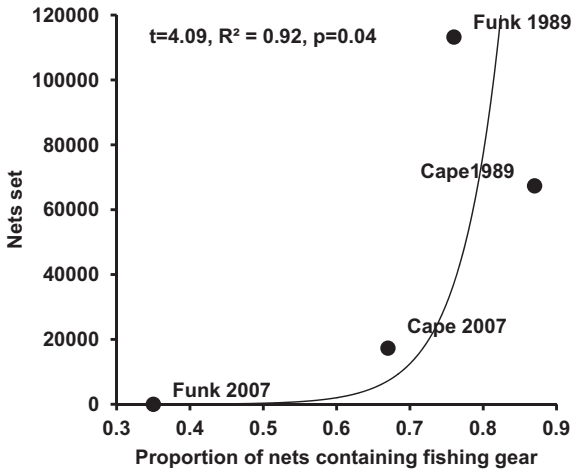

Fig. 5. The proportion of nests with fishing gear debris was related exponentially to the number of gillnets set (i.e. fishing effort) in fishing zones adjacent to Funk Island and Cape St. Mary's in 1989 and 2007, and adjacent to Bonaventure Island in 2007.

for long, filamentous nest material. At the Grassholm colony, the proportion of nests with debris increased from 49% in the 1970s to approximately 80% in recent years (Votier et al., 2011). Fisheries debris also comprised the greatest proportion of marine debris in Australasian gannet (*Morus serrator*) nests in Australia (Norman et al., 1995). Interestingly, marine debris has not been recorded in Cape Gannet (*Morus capensis*) nests (P.G. Ryan, pers. comm.).

Filamentous debris in gannet nests can result in entanglement, usually chicks' legs or wings, often leading to death (Votier et al., 2011). Other sulids are known to become entangled in marine debris at nest sites (Conant, 1984; Norman et al., 1995). Over the years, we have observed northern gannet chicks and adults entangled at

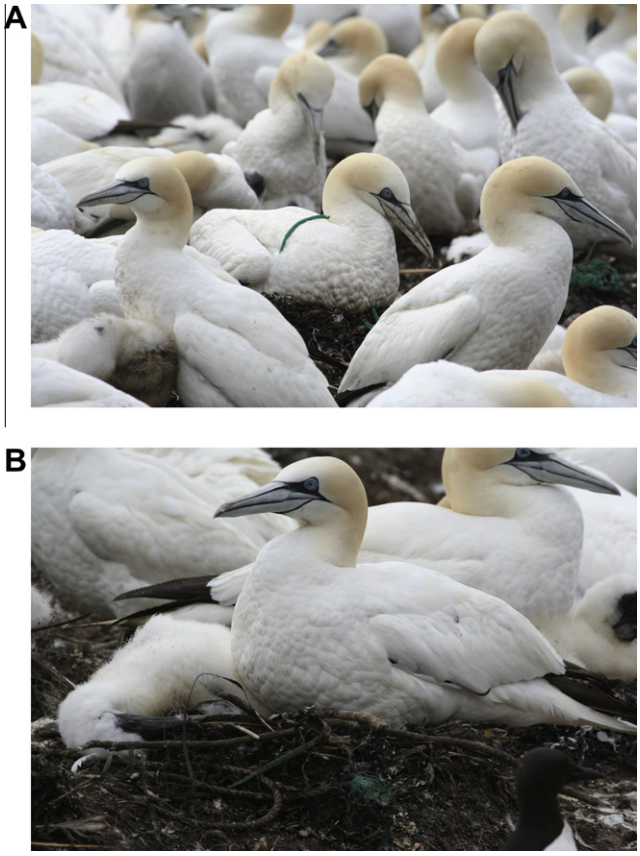

Fig. 6. (A) Nesting gannet entangled with fishing twine. (B) Gannet nest with rope, twine, netting and strapping (photos: W.A. Montevecchi).

both Funk Island and Cape St. Mary's (Fig. 6), though we did not record these systematically. There are therefore demographic implications for gannet populations directly related to the presence of fisheries debris at nest sites. Northern gannet populations in Canada are generally increasing (J.-F. Rail unpubl. data), and a small part of this increase could be attributed to the decrease in plastic pollution and likely entanglement.

Useful ecological indicators exhibit robust, predictable relationships with the phenomena they index. So, owing to the limited biodegradation and persistence of synthetic debris and because visible debris in nests might have been incorporated in nests years before being observed, annual comparisons are likely ineffective indices. Yet, on decadal scales, the proportion of fishing debris in northern gannet nests appears reflect its availability in local marine environments around colonies.

As synthetic marine debris continues to increase in the oceans (Provencher et al., 2009), the decrease in debris in northern gannet nests in eastern Canada is a positive sign, as it likely resulted in a decrease in entanglements, and fewer deaths of both adults and chicks (Votier et al., 2011). Synthetic debris in the ocean degrades slowly over time, resulting in more smaller pieces (Andrady, 2008), so while the absolute amount of debris may be increasing, the amount available to northern gannets seems to have decreased during past two decades. Yet the risks of entanglement and other negative effects of plastic and fisheries debris remain (e.g., ingestion, contamination McElwee et al., 2012).

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