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Ingestion of fishing gear and entanglements of seabirds: monitoring and implications for management

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Ingestion of fishing gear and entanglements of seabirds: Monitoring and implications for management

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ABSTRACT

Fisheries are increasingly adopting ecosystem approaches to better manage impacts on non-target species. Although deliberate dumping of plastics at sea is banned, not all fisheries legislation prohibits discarding of gear (hooks and line) in offal, and compliance is often unknown. Analysis of a 16 year dataset collected at South Georgia indicated that the amount of gear found in association with wandering albatrosses was an order of magnitude greater than in any other species, reflecting their wider foraging range and larger gape. Unlike other taxa, most gear associated with grey-headed albatrosses was from squid and not longline fisheries, and mistaken for natural prey rather than the result of direct interaction. Observed rates of foul-hooking (entanglement during line-hauling) were much higher in giant petrels and wandering albatrosses than black-browed albatrosses, and no grey-headed albatross was affected. The index of wandering albatross gear abundance showed two peaks, the most recent corresponding with a substantial increase in the number of multifilament snoods (gangions), suggesting that the widespread adoption of a new longline system (Chilean mixed) may have been responsible. Although all identified gear was demersal, given the widespread use of similar hooks, little could be assigned to a specific fishery. Stomach content analysis suggested that 1300–2048 items of gear are currently consumed per annum by the wandering albatross population. Many hooks are completely digested by chicks, long-term effects of which are entirely unknown. We suggest a number of management approaches for addressing the problem of gear discarding, and guidelines for monitoring schemes elsewhere.

1. Introduction

High levels of incidental mortality in marine fisheries have been linked in many regions to observed population declines of seabirds, marine mammals, turtles and non-target fish (Baker et al., 2002; Baum et al., 2003; Gales, 1998; Spotila et al., 2000). Human harvesting of stocks of fish, squid, decapods, etc., can also bring fisheries into direct competition with natural predators feeding on the same resources (Furness, 2002; Karpouzi et al., 2007; Thompson, 1992). However, fisheries may bring potential benefits, as scavenging seabirds exploit the large quantities of non-target catch and offal discarded by demersal (including semi-pelagic) longline, and trawl fisheries in particular (Freeman, 1998; González-Zevallos and Yorio, 2006; James and Stahl, 2000; Votier et al., 2008). This can have major implications for foraging behaviour and population dynamics, as well as indirect ecosystem-level impacts on alternative prey that may include smaller seabirds (Oro et al., 2004; Oro and Furness, 2002; Petersen et al., 2008; Rolland et al., 2008; Votier et al., 2004). Moreover, if discards are of lower nutritional quality than natural prey, there may be negative repercussions for reproductive success according to the so-called "junk-food" hypothesis (Österblom et al., 2008), and they may contain hooks and other fishing gear that seabirds with large gapes will ingest at the same time (Nel and Nel, 1999).

Given the high profile of potential stock over-exploitation, discarding and other issues, fisheries regulatory bodies have been encouraged to adopt ecosystem approaches to management: with regard to seabirds, these may include mandatory or recommended protocols that help mitigate bycatch, such as the use of streamer lines, improved line weighting regimes, trawl net binding and cleaning, night-setting, introduction of a closed season and better discard management (Brothers et al., 1999; FAO, 2003). Deliberate dumping of certain types of waste at sea is banned under the 1978 Protocol to the International Convention for the Prevention of Pollution from Ships (MARPOL), and subsequent international and national legislation (Lentz, 1987). Resolutions passed by the United Nations General Assembly in 2005 and 2008 on sustainable fisheries encourage international cooperation to address the issue of

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abandoned and lost fishing gear. In addition, the FAO International Plan of Action (IPOA) on reducing incidental catch of seabirds in longline fisheries includes the removal of hooks from offal prior to discarding as a suggested operational measure (FAO, 1999). Indeed, this is a prescribed licence condition in several longline fisheries, including in the Falkland Islands, South Africa, and those operated by the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) (Anonymous, 2008; CCAMLR, 2008; Sullivan, 2004).

Without independent scrutiny, it is often difficult or impossible to verify levels of vessel compliance with such conservation measures. Even in fisheries with observer programmes, data on seabird bycatch rates reported by individuals dedicated to that task are typically more reliable than those provided by general fisheries observers, who tend to concentrate on rules governing catch and quotas (Bugoni et al., 2008a). As few observers report levels of dumping of plastics and fishing gear (but see CCAMLR, 2008; Otley et al., 2007b), despite the risks posed to scavenging seabirds, another possibility is to use information collected from the seabirds themselves. Although seabirds are considered to be useful biomonitors of various characteristics of marine environments, including plastic pollution (Furness and Greenwood, 1993; Ryan et al., 2009), surprisingly few studies have addressed their potential for monitoring discard rates of hooks and other fishing gear (but see Huin and Croxall, 1996; Nel and Nel, 1999). Here we report on the analysis of a long-term (16 year) dataset on the quantity of fishing gear found in colonies and entangled with seabirds breeding at South Georgia. The purposes of this study were to: (i) examine inter-specific and annual variation in the amount of associated gear and entanglements; (ii) estimate the total amount of gear ingested; (iii) determine relationships with changes in fishing effort and practices in foraging areas, with associated implications for management; (iv) attempt to assign the different types of fishing gear (hooks and snoods) to particular fisheries using reference material; (v) provide advice on data collection protocols that could be used in monitoring schemes elsewhere.

2. Methods

2.1. Monitoring at bird colonies

Monitoring of marine debris and fishing gear associated with seabird nests and adults at Bird Island, South Georgia (54°00′S, 38°03′W) was initiated in austral summer 1993/1994 (Huin and Croxall, 1996), and has since been carried out annually using consistent methodology. This involves daily to weekly visits to wandering albatrosses *Diomedea exulans*, black-browed albatrosses *Thalassarche melanophris*, grey-headed albatrosses *Thalassarche chrysostoma*, northern giant petrels *Macronectes halli*, southern giant petrels *Macronectes giganteus*, gentoo penguins *Pygoscelis papua* and macaroni penguins *Eudyptes chrysolophus* in demarcated study colonies/areas to record items of gear and other man-made debris found on the ground or in nests. The majority of fishing gear is found in pellets (boluses) of undigested material regurgitated spontaneously by wandering albatross chicks shortly before fledging. These mainly consist of accumulated squid beaks and are collected as part of a long-term diet monitoring program (Xavier et al., 2003a). Timing of gear recovery depends on the species: mainly December to January for wandering albatrosses, and January to April for the other albatrosses and giant petrels. In some years, a few items of fishing gear (⩽5 wherever noted in reports) were found in spontaneous regurgitations of wandering albatross chicks during routine ringing, and some chicks (always ⩽4) were observed with line protruding from their beaks. Following standard recording practice, these were pooled with items found on the ground in the annual totals.

Albatross populations at South Georgia are decreasing (Poncet et al., 2006), such that the numbers of nest sites checked regularly (at least weekly) and less frequently (monthly or less) over the course of the study (summer 1993/1994–2008/2009) of wandering albatrosses were, respectively, 140 and 1193 (total 1333), declining to 105 and 767 (total 872), and of grey-headed albatrosses were 663 and 2734 (total 3397), declining to 551 and 2123 (total 2674). The number of nests visited regularly and less frequently of black-browed albatrosses declined from 480 and 3612 (total 4092) in 1993/1994, to 249 and 2717 (total 2966) in 2006/2007, but changed to 807 and 2409 (total 3216) in 2007/2008, and 736 and 2325 (total 3061) in 2008/2009, following the inclusion of a new colony of c. 500 breeding pairs into an expanded demographic monitoring program. As the vast majority of fishing gear was associated with wandering albatross chicks, numbers of which have declined substantially, an index of relative gear abundance was calculated for this species as the total number of items divided by the number of chicks fledged in each year (hereafter termed "WALB Gear Index"). This index excluded any items obtained from, and the number of chicks involved in, the targeted diet sampling that took place in 2007 and 2008 (see below).

Sampling effort for giant petrels has been more variable. Although the area checked has remained the same, research intensity has fluctuated and breeding populations have increased (González-Solís et al., 2000, BAS unpublished data). However, following the introduction of systematic demographic monitoring, the number of nests checked regularly (at least weekly) is known to have increased from 304 in 2000/2001 to 560 in 2008/2009. For penguins, although the size of the area checked has also been constant, the number of nests of gentoo penguin visited twice per season increased from 2796 to 4095, of macaroni penguin visited three times per season increased marginally from 1138 to 1148, and of macaroni penguin visited at least weekly dropped from 912 to 511, from 1993/1994 to 2008/2009.

The incidence of fishing gear was also recorded in stomach contents obtained by induced regurgitation of birds targeted for diet studies (for details and effects, see Phillips, 2006). Numbers of samples were as follows (unpublished data unless indicated otherwise): (i) 30 from black-browed albatross chicks in every year from 1996; (ii) 30 from grey-headed albatross chicks in every year from 1996; (iii) 18 and 29 from adult wandering albatrosses in 1999 and 2000, respectively (Xavier et al., 2003b, 2004); (iv) 45 and 25 from wandering albatross chicks in 2007 and 2008; (v) 37 from adult Antarctic prions *Pachyptila desolata* in 2002; (vi) 20, 10 and 21 from adult white-chinned petrels *Procellaria aequinoctialis* in 1996 and 1998 (Berrow and Croxall, 1999), and 2002, respectively; (vii) 20 and 30 from white-chinned petrel chicks in 1996 and 1998, respectively (Berrow and Croxall, 1999); (viii) 40 from adult macaroni penguins *E. chrysolophus* in every year from 1993; (ix) 40 from adult gentoo penguins *P. papua* in every year from 1993.

In addition, all observed incidences of entanglements (foul-hooking) of adult seabirds were recorded. Hooks were located in the foot, leg, wing, bill or throat, and whenever possible, individuals were captured and the gear removed. Results do not include chicks seen with line protruding from their beaks (which results from gear ingestion rather than direct interaction with a fishing vessel), nor the small number of birds with rope or twine around their tarsi, which could represent entanglement with floating debris.

2.2. Relationship with fishing effort and practices

Candidate fisheries with which birds might interact were those within the maximum extent of the foraging distribution of wandering albatrosses (the most wide-ranging species). This distribution was based on 292 trips from 197 individual birds fitted with satellite-transmitters or GPS loggers during chick-rearing in 1990–2004 (Phillips et al., 2009; Prince et al., 1998; Xavier et al., 2004). As all identified hooks were demersal (see Section 3), the fleets of interest for which data were available were those of Argentina, Chile, the Falkland Islands, and legal and Illegal, Unregulated and Unreported (IUU) vessels operating within CCAMLR waters. These mainly target toothfish or, on the South American continental shelf, hake *Merluccius* spp. or kingclip *Genypterus blacodes*. Where effort data were unrecorded, unavailable or incomplete, values were estimated using proxies from the literature, catch or catch rates from adjacent positions or time (Tuck, 2004; Tuck et al., 2003).

In addition to changes in effort, there have been a number of pertinent changes in fishing practices. The South Georgia fishery falls under the auspices of CCAMLR and is closely regulated, reflected in its accreditation as an internationally recognised sustainable fishery by the Marine Stewardship Council (MSC) in 2004 (Varty et al., 2008). In 1997, in order to reduce the high observed seabird bycatch rates, CCAMLR imposed a seasonal area closure from 1 September to 30 April inclusive, corresponding to the main breeding period of all seabirds with the exception of wandering albatrosses. Removal of hooks from offal prior to discarding was recommended by CCAMLR in the 2003 fishing season and became mandatory in 2004. A similar recommendation was made in the Falklands toothfish fishery in July 2001, was widely adhered to from 2003, and became mandatory in 2007 (Sullivan, 2004, Pompert pers. comm.).

Demersal longlining systems consist of a mainline weighted with anchors which sits on the sea-bed, or, if incorporating submerged buoys as in a semi-pelagic system, is suspended a short distance above the bottom, to which snoods (branch lines or gangions) with baited hooks are attached either directly or via a secondary line (Brothers et al., 1999; Tuck et al., 2003). The type of mainline, snood and hook vary according to the target species, fishery and fishing conditions, with a clear distinction between autoline (single line) and 'Spanish' (double line) systems. Generally, but not always, snoods attaching hooks to the single mainline are twisted multifilament/multistrand on autoliners, and monofilament nylon on vessels operating the Spanish system (FAO, 1999; Sullivan, 2004; Varty et al., 2008, Clark pers. comm.). A new gear configuration – the Chilean mixed (also called umbrella or 'cachalotera') longlining system, the last term derived from the Spanish word for sperm whale *Physeter catodon*, 'cachalote', which reduces depredation of captured toothfish by sperm and killer whales *Orcinus orca* – previously deployed in the artisanal toothfish fishery, was modified and then adopted increasingly in toothfish fisheries in the southwest Atlantic from 2006 (Moreno et al., 2008). In this system, the hooks are set in clusters, and a net sleeve drops down over the catch during hauling. Snoods can be monofilament or multifilament on Chilean industrial vessels, but are monofilament on the 1–2 vessels in the Falklands toothfish fishery that adopted this system in mid 2007 (Pompert, Yates and Robertson pers. comm.).

Analyses of relationships between gear found at colonies and changes in fishing effort and practises included the following parameters: (i) annual changes in effort (total hooks) in different fisheries (available up to 2006); (ii) a dummy binary variable reflecting the year of introduction of the closed season in the South Georgia fishery (1997); (iii) a dummy ternary variable with values of 0, 0.5 and 1.0 representing, respectively, years with no limitations on hook discard, recommended hook removal and mandatory/effective hook removal in the South Georgia fishery (1993–2002, 2003 and 2004 onwards), and the Falklands fishery (1993–2000, 2001–2002 and 2003 onwards); (iv) a dummy binary variable reflecting the introduction of the Chilean mixed longline system (2006). Note that because wandering albatross chicks are reared over the austral winter, gear reported in association with this species in December and January reflects fisheries interactions, and potentially changes in effort and practices, during the preceding 9–10 months. Given the small sample sizes, non-parametric tests were used in analyses of data collected for other species.

2.3. Origin of fishing gear

Fishing gear collected at the study site in 2000/2001–2005/2006 was compared with a reference collection assembled from material of known origin provided by co-ordinators of fisheries observer programmes. A total of 44 reference hooks (23 actual hooks and 21 photographs), and 25 reference snoods were provided. As a first step in the process of assigning potential origin, 251 items of fishing gear collected at colonies (comprising hooks with snoods, hooks without snoods, snoods without hooks and incomplete/damaged hooks), and reference material were categorised according to 21 different hook characters relating to the eye, point, overall shape and dimensions, and eight different snood characters relating to filament type, design and direction of twist (Fig. 1). Characters were scored as present or absent, and hook measurements recorded to ±0.1 mm using digital callipers, and categorised as medium (±1 SD of the mean), short (>1 SD below the mean) or long (>1 SD above the mean). In order to test the utility of photographs, two randomly-selected hooks were photographed against a scale, and scored as above. Identical scores from hooks and photographs indicated that data from the latter were reliable.

Principal Components Analysis (PCA) was used to reduce the numerous characters related to hook/snood size and shape to fewer variables that retained the main features of the dataset and corresponded to different generic gear categories. Analysis was performed using MVSP 3.1 (Kovach, 2008), initially on reference hooks, and subsequently on the hooks of unknown origin. Kaiser's rule (Kaiser, 1960) was applied to PCA in order to identify the most important axes (those with a value $\geqslant 1$). The first three axes accounted for >50% of the total variance. Euclidean biplots, mapping variables as vectors against case scores (Kovach, 2008), were employed to investigate the influence of the characters on the groups, with longer vectors indicating higher loadings. Initially, analysis was completed on the overall data set, but once hook types were established, replicates were removed and the analysis repeated using one representative per hook type, and outliers. This was to identify and eradicate any sampling variance that may have been present as a direct result of multiple coincident points.

Based on the analysis of reference hooks, it was possible to make inferences about characters absent from corroded/damaged hooks of unknown origin. This was achieved by locating the identifiable characters of incomplete hooks within the Euclidean biplots. Ten hooks were 'completed' in this way, and a further 48, lacking sufficient identifiable characters, excluded from further analysis. Cluster analysis was then carried out in conjunction with PCA to validate the assignment of unknown hooks to specific groups. As a common character absence could not indicate affinity with a particular fishery, Sorensen's similarity coefficient (S_s) was used to examine the ratio of matching binary scores indicating presence to the total number of scores, whilst ignoring absent characters (Everitt, 1993). A high S_s value ($\geqslant 0.95$) was used to ensure that hooks were grouped into identical and not just similar clusters for the purposes of assignment.

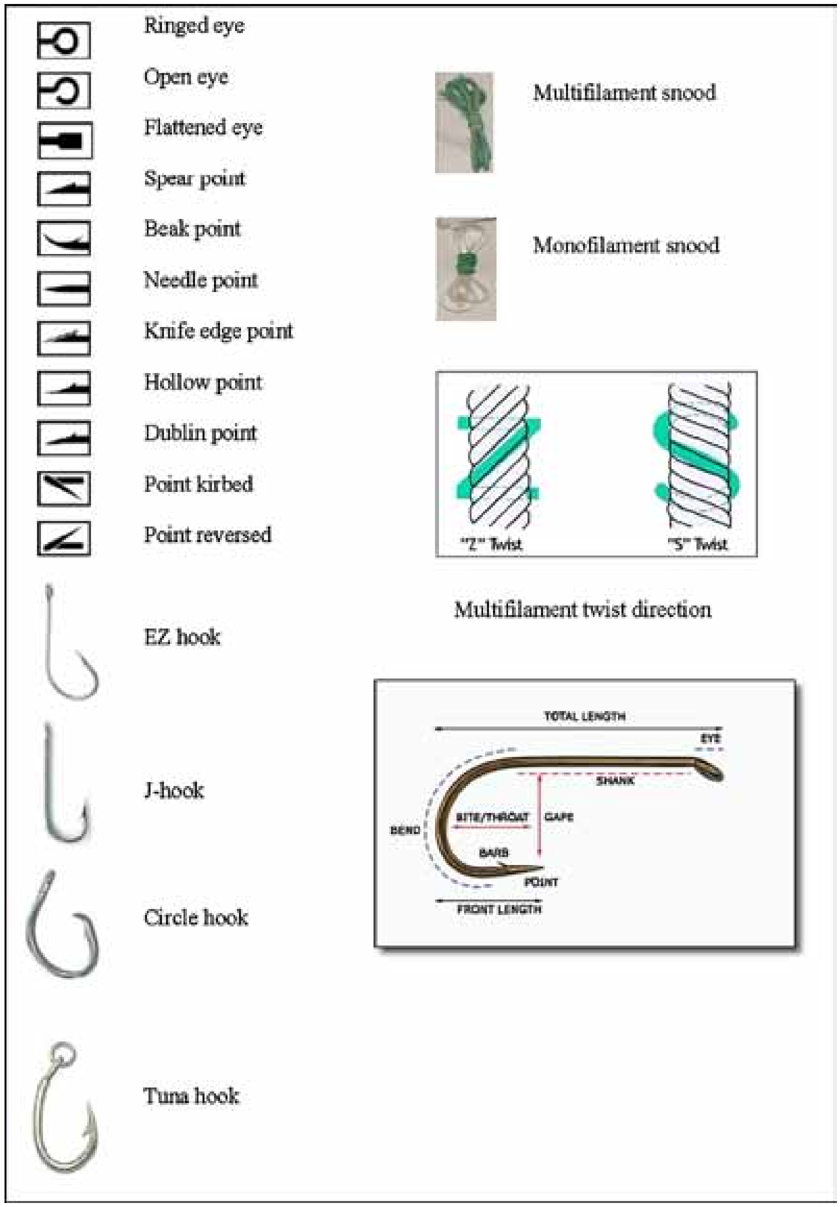

Fig. 1. Hook and snood characters scored as present/absent, and measurements (based on information from Mustad and Son www.mustad.no; images reproduced with permission).

3. Results

3.1. Fishing gear in colonies

The total number of items of fishing gear found associated with wandering albatrosses, black-browed albatrosses, grey-headed albatrosses and giant petrels during routine monitoring each year ranged, respectively, from 5 to 105 (mean of 48.0), 0 to 7 (mean of 2.7), 0 to 12 (mean of 3.9) and 0 to 6 (mean of 1.8), during the 16-year study (Fig. 2). On average the amount of gear associated with wandering albatrosses was therefore an order of magnitude greater than in any other species, despite sample sizes (in terms of the number of nests visited) that were 60–80% lower. Excluding the last two seasons of data for black-browed albatrosses when monitoring intensity increased, for none of the four taxa did the amount of gear show a significant linear trend over time (Spearman rank correlations $r_s = -0.36$ to 0.42, $n = 15$–16, $P = 0.10$–0.28). Nor were there significant correlations between any of the four taxa in the amount recorded in each year ($r_s = -0.43$ to 0.20, $n = 15$–16, $P = 0.12$–0.89). The WALB Gear Index, which corrected for annual variation in number of chicks fledged, showed an overall positive increase over time ($r_{14} = 0.56$, $P = 0.02$). However, examination of the trend suggests four phases: comparatively few items in 1993/1994–1997/1998 and 2003/2004–2005/2006, compared with 1998/1999–2002/2003 and 2006/2007–2008/2009 (Fig. 3). No item of fishing gear was found on the ground in gentoo or macaroni penguin colonies during the 16 years of study.

3.2. Fishing gear in stomach samples

The incidence of fishing gear was far higher in the stomach contents of wandering albatross chicks than in adult wandering albatrosses or in chicks or adults of any other species: 30 items were found in 45 samples, and 15 items were found in 25 samples from wandering albatross chicks in 2007 and 2008, respectively (gear:sample ratios of 0.67 and 0.60); one item in 47 samples from

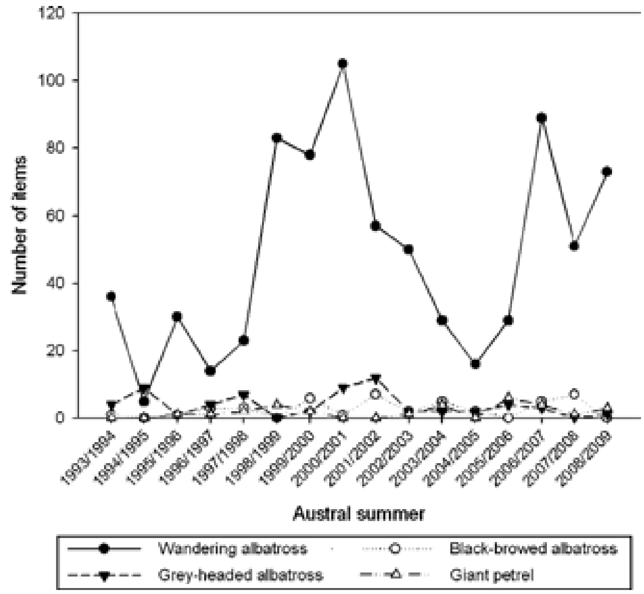

Fig. 2. Annual changes in the amount of fishing gear recorded in seabird colonies at Bird Island, South Georgia in austral summers 1993/1994–2008/2009.

adult wandering albatrosses in 1999 and 2000 (gear:sample ratio of 0.02), three items (one in 2000 and two in 2001) in the 420 samples collected over 14 years from black-browed albatross chicks (gear:sample ratio of 0.007); three items (one in 1999 and two in 2000) in the 420 samples collected over 14 years from grey-headed albatrosses (gear:sample ratio of 0.007), and; no items in the 680 samples collected over 17 years from adult macaroni penguins or gentoo penguins, 37 samples from adult Antarctic prions in 2002, or 101 samples from adult/chick white-chinned petrels in 1996, 1998 and 2002 (all gear:sample ratios of 0).

Based on the gear:sample ratios in wandering albatross chicks of 0.67 in 2007 and 0.60 in 2008, a total of 584 and 665 chicks fledged from the island (BAS unpublished data), that these represent 61% of the overall South Georgia population (Poncet et al., 2006), and that the median date of diet sample collection was mid July which is half-way through chick-rearing, an estimated mean of $(0.67 + 0.60)/2 \times (584 + 665)/2 \times 1/0.61 \times 2 = 1300$ items of fishing gear would have been fed to chicks per annum. Alternatively, given the gear:sample ratio of 0.02 in stomach contents of wandering albatross adults, and that chicks receive a meal every c. 2.5 days (Berrow et al., 2000) for the first 250 days of the 278 days from hatching to fledging (i.e. allowing for reduced provisioning rates in the last month), an estimated $(250/2.5) \times 0.02 \times (665 + 584)/2 \times 1/0.61 = 2048$ items of fishing gear would have been fed to chicks. These results are compatible, as a proportion of hooks are completely digested and so remain unrecorded (see below).

3.3. Type of gear recovered

The fishing gear found around nests was assigned to five categories: longline snood, longline hook, longline hook with attached snood, net/string/rope, and squid jigs (usually just the plastic portion) (Table 1). There was a highly significant difference between the four taxa in the frequencies of these five gear types ($\chi^2_{12} = 455.7$, $P < 0.001$), and if the three longline gear types were pooled into a single category ($\chi^2_6 = 443.8$, $P < 0.001$). The majority of fishing gear associated with wandering albatrosses, black-browed albatrosses and giant petrels was longline (84.8%, 70.5% and 66.7% of all items, respectively), whereas most (69.8%) associated with grey-headed albatrosses was incomplete squid jigs. Longline hooks were often partially corroded, and a high proportion of snoods without attached hooks were still knotted, indicating that many hooks are partly or completely digested after ingestion. Snoods were of variable lengths, and most appeared to have been cut rather than stretched and snapped. Of the 63 squid jigs recovered during the study, 44 (69.8%) were associated with grey-headed albatrosses, and 11 (17.5%), 5 (7.9%) and 3 (4.8%) with wandering albatrosses, black-browed albatrosses and giant petrels, respectively. The vast majority (84.6–100%) of line found in association with wandering albatrosses was monofilament until 2004/2005, and subsequently has mainly (56.7–86.1%) been multifilament (Table 2).

3.4. Correspondence with fishing effort and changes in fisheries practices

There were no significant changes in the amount of gear found each year in black-browed albatross, grey-headed albatross or

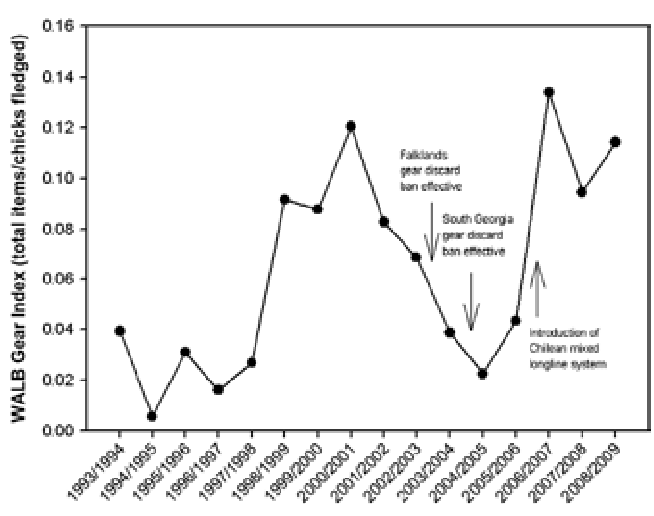

Fig. 3. Annual changes in the Wandering albatross Fishing Gear Index at Bird Island, South Georgia in austral summers 1993/1994–2008/2009 in relation to changes in fisheries practices.

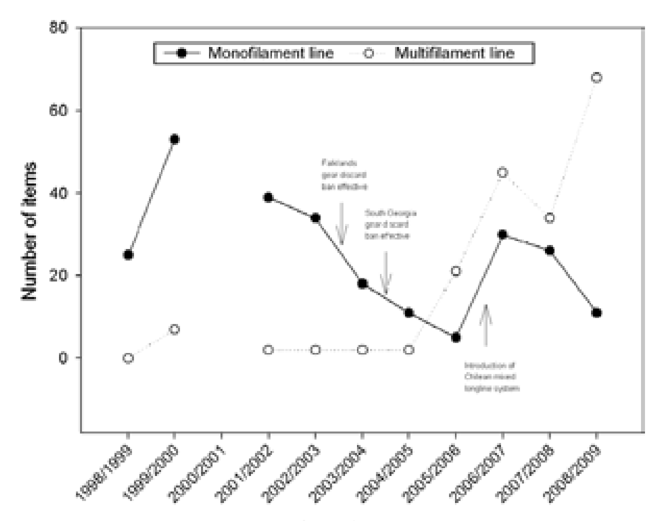

Fig. 4. Changes in the amount of monofilament and multifilament line found in association with wandering albatrosses at Bird Island, South Georgia in austral summers 1996/1997–2008/2009 in relation to changes in fisheries practices.

Table 1
Types of fishing gear associated with seabirds at Bird Island, South Georgia in 1993/1994–2008/2009.

Species	Number (percentage) of each gear type						Total
	Longline snood	Longline hook	Longline hook and snood	Total longline gear	Net/string/rope	Squid jig[b]	
Wandering albatross[a]	266 (33.2%)	100 (12.5%)	314 (39.2%)	680 (84.8%)	111 (13.8%)	11 (1.4%)	802
Black-browed albatross	8 (18.2%)	0 (0%)	23 (52.3%)	31 (70.5%)	8 (18.2%)	5 (11.4%)	44
Grey-headed albatross	8 (12.7%)	1 (1.6%)	6 (9.5%)	15 (23.8%)	4 (6.3%)	44 (69.8%)	63
Giant Petrel	10 (33.3%)	1 (3.3%)	9 (30.0%)	20 (66.7%)	7 (23.3%)	3 (10.0%)	30

[a] Includes items recovered in stomach samples in the last two seasons.
[b] Usually incomplete.

Table 2
Type of longline found in association with wandering albatrosses at Bird Island, South Georgia in 1998/1999 and 2001/2002–2008/2009.

Austral summer	Relevant fishing year	Monofilament	Multifilament
1998/1999	1998	25 (100%)	0 (0%)
2001/2002	2001	39 (95.1%)	2 (4.9%)
2002/2003	2002	34 (94.4%)	2 (5.6%)
2003/2004	2003	18 (90%)	2 (10%)
2004/2005	2004	11 (84.6%)	2 (15.4%)
2005/2006	2005	5 (19.2%)	21 (81.8%)
2006/2007	2006	30 (40%)	45 (60%)
2007/2008	2007	26 (43.3%)	34 (56.7%)
2008/2009	2008	11 (15.9%)	68 (86.1%)

giant petrel colonies after the introduction in the South Georgia fishery of the closed season in 1997, the mandatory ban on hook discarding there in 2004, or its effective elimination in the Falklands in 2003 (Mann Whitney U tests, $U = 11–18$, $P = 0.11–0.46$, $U = 14–25$, $P = 0.17–1.00$ and $U = 12.5–19$, $P = 0.13–0.51$, respectively), or with the introduction of the Chilean mixed longline system (Mann Whitney U test, $U = 8–14.5$, $P = 0.12–0.50$). In contrast, on average, the WALB Gear Index was greater after the introduction of the South Georgia closed season (T-test, $t_{14} = -2.8$, $P = 0.015$), and of the Chilean mixed longline system (T-test, $t_{14} = -2.9$, $P = 0.011$), but did not change after hook removal became mandatory/effective either in the Falklands or South Georgia (T-tests, $t_{12} = -0.95$, $P = 0.363$ and $t_{13} = -1.1$, $P = 0.295$, excluding years when procedures were partially effective). There were no correlations between the WALB Gear Index and annual effort (hooks deployed) within the region of overlap with the hake and kingclip fisheries of Argentina or Chile, the toothfish fisheries of Argentina, CCAMLR (legal or IUU), Chile, or the Falkland Islands (Pearson correlations $r_{12} = -0.42$ to 0.49, $P = 0.077–0.766$). In stepwise multiple regression analysis, with fishing effort of these fleets and dummy variables reflecting the changes in operational procedures (see Section 2) available for entry, the WALB Gear Index (to 2006) was significantly related positively to the use of the Chilean mixed longline system and Falklands toothfish effort, and, having accounted for this variation, negatively with hook removal practises in the South Georgia fishery (overall $F_{3,13} = 19.8$, $P < 0.001$, $r^2 = 0.81$), i.e. contrary to the univariate analysis, the local ban on hook discarding was reflected in a reduction in gear found in wandering albatross colonies.

Table 3
Number of adults recorded foul-hooked (entangled by fishing gear) at Bird island, South Georgia in 1993/1994–2008/2009.

Austral summer	Wandering albatross	Black-browed albatross	Giant petrels
1993/1994	1	1	1
1994/1995	1	0	0
1995/1996	4	1	0
1996/1997	1	0	3
1997/1998	0	0	0
1998/1999	2	1	3
1999/2000	2	0	2
2000/2001	2	0	4
2001/2002	5	2	2
2002/2003	1	0	5
2003/2004	1	1	2
2004/2005	3	0	1
2005/2006	4	0	1
2006/2007	2	0	0
2007/2008	1	0	1
2008/2009	1	0	2
Total	31	6	27

Table 4
Reference ('R') hook types and their defining characters.

Character	'R' hook types								
	1	2	3	4	5	6	7	8	9
EZ hook					√			√	
J hook			√	√		√	√		√
Circle hook		√							
Tuna hook	√								
Ringed eye		√		√	√	√	√	√	√
Flattened Eye			√						
Eye with ring	√								
Spear point	√								
Knife edge point							√		
Beak point								√	√
Needle point					√	√			
Curved in point		√							
Dublin point			√	√					

The effects of changes in fisheries practices were evident in the relative proportions of snood types: a decline in the number of monofilament snoods following both the effective removal of hooks from offal in the Falklands fishery in 2003, and the mandatory ban on hook discarding in the South Georgia fishery in 2004, and a subsequent increase of multifilament, and to a lesser extent monofilament snoods after the adoption of the Chilean mixed system by industrial vessels in 2006 (Fig. 4).

3.5. Foul-hooking (fishing gear entanglements)

Over the course of the 16-year study, 31 wandering albatrosses, six black-browed albatrosses and 27 giant petrel adults, but no grey-headed albatrosses, were seen foul-hooked at Bird Island (Table 3). In only one year was no foul-hooked wandering albatross recorded. In none of the three taxa did the number of adults foul-hooked show a significant linear trend over time (Spearman rank correlations $r_s = -0.33$ to 0.15, $n = 16$, $P = 0.21–0.68$), correlate with the amount of gear recorded on the ground each year (Spearman rank correlations $r_s = -0.02$ to 0.28, $n = 16$, $P = 0.29–0.94$), or show any correlations between taxa (Spearman rank correlations $r_s = -0.02$ to 0.31, $n = 16$, $P = 0.24–0.96$), There were also no significant changes in the numbers of birds foul-hooked per year after the introduction of the closed season at South Georgia (Mann Whitney *U* tests for each taxon, $U = 15.0–19.5$, $P = 0.26–0.57$).

3.6. Provenance of fishing gear: hooks

All hooks appeared to be from demersal longlines, i.e. none were the wider-diameter, heavy-duty hooks typical of pelagic tuna or swordfish fisheries. Following rigorous hook character validity testing, nine distinct longline reference hook types ('R' hooks) were identified (Table 4, Fig. 5). Hook types R1, R3, R4, R5, R6 and R7 each contained hooks from one fishery only, and hook types R2 and R8 included hooks from two fisheries. Type R9 accounted for 34% of the 'R' hooks and was comprised of hooks from three of the four fisheries in the analysis. The only reference hook types unique to a single fishery were from Brazil (four hook types) and Argentina (two hook types).

Seventeen distinct types within 89 hooks of unknown origin ('U' hooks) were identified using PCA, where 69% of the total variance was spread over three axes. Once replicates were removed and the PCA repeated using just one representative per hook type and outliers, this was reduced to 56% of the total variance. When analysed without replicates, 72% of the 'U' hooks formed joint clusters with the established 'R' hooks. Of the 'U' hooks, 72% could be placed geographically in accordance with the origin(s) of the corresponding 'R' hook types (Table 5). The most common 'U' hook found at the colony (type UI, 44 replicates), was typical of those used by demersal long-line vessels operating in Argentina, the Falkland Islands and South Georgia. Although the second most common (type UII, 12 replicates) did not correspond to any of the reference hook types, the next most common (type UIII, nine replicates) was used by vessels in Brazil and South Georgia. There were no clear trends in the relative frequencies of different hook types across years (Table 5).

3.7. Provenance of fishing gear: snoods

Following rigorous character validity testing, snoods attached to hooks ($n = 97$) were analysed with the aim of determining relationships with hook types and fisheries. Nine distinct snood types emerged. Replicates were removed and the analysis repeated using just one hook type/fishery per snood type. Three snood types were represented exclusively by Argentinean 'R' hook type 5. The origin of snood type 1 was determined as South Georgia, although this group encompassed two types of 'R' hook. None of the remaining snood types could be assigned to particular hook types or fisheries either because they were typical of several reference types, or were associated with hooks of unknown origin. Unattached snoods ($n = 103$) were also analysed, with the aim of determining origin by the association with a particular reference (attached) snoods, but only 4.8% of these could be allocated via this approach.

4. Discussion

4.1. Inter-specific variation

Although seabirds have been advocated as biomonitors of a diverse range of anthropogenic processes (Furness and Greenwood, 1993), this is to our knowledge the first attempt to test their efficacy for monitoring long-term changes in the discarding rates of hooks and other fishing gear into the marine environment, or of the level of foul-hooking. One of our most compelling results was the variation in the amount and type of fishing gear associated with each study species. Considering gear either found on the ground or in stomach contents, the incidence was highest (by an

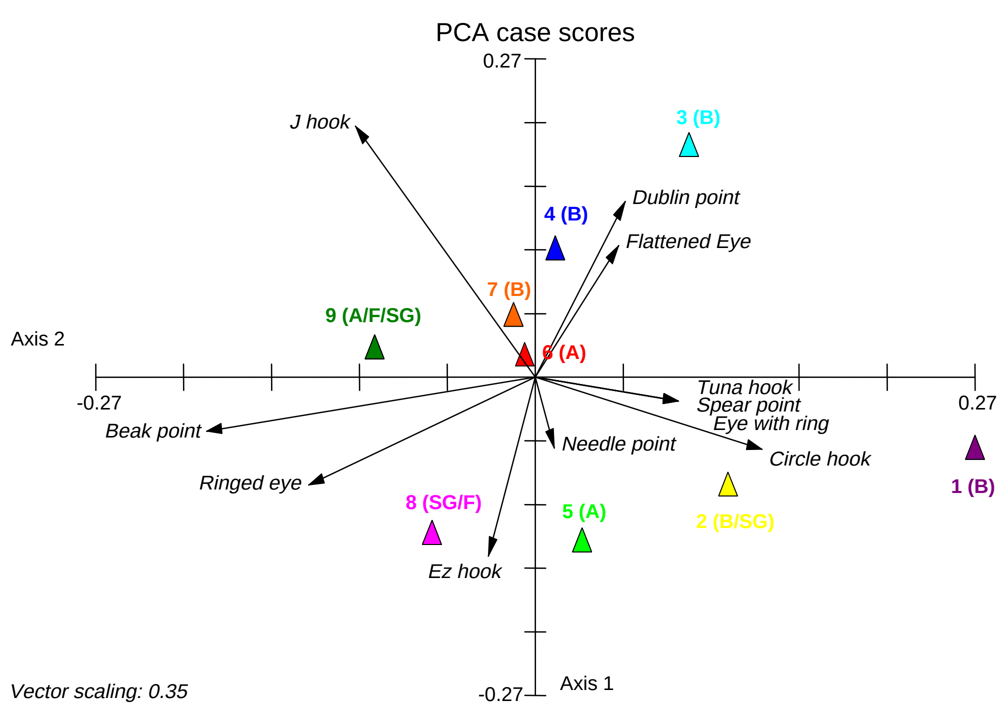

Fig. 5. Euclidean biplot of reference hook data investigating the influence of characters on hook types from different fisheries (B = Brazil, A = Argentina, F = Falklands, SG = South Georgia).

Table 5
Occurrence of unknown ('U') hooks of different types associated with seabirds at Bird Island, South Georgia in 2000/2001–2005/2006 (ranked by abundance). Fisheries as follows: B = Brazil, A = Argentina, SG = South Georgia, F = Falklands, Un = unknown.

Year	'U' hook type and fishery							
	I (A/F/SG)	II (Un)	III (B/SG)	IV (A)	V (A)	VI (SG/F)	VII (B)	All remaining U hook types (unknown)
2000/2001	13	4	2	1	1			5
2001/2002	1	3	4					4
2002/2003	10	1	2	2		2		2
2003/2004	9	3	1		2		1	1
2004/2005	4				3	1		4
2005/2006	11	1		1	1			1
Total	48	12	9	4	7	3	1	17

order of magnitude) in wandering albatrosses, low in black-browed and grey-headed albatrosses and the giant petrels, and zero in white-chinned petrel, Antarctic prion, macaroni and gentoo penguins. These differences were robust to variation in the number of birds monitored, and were highly consistent across years: with the exception of Antarctic prion, data were available in at least three, and in some cases up to 16 seasons, and in every year except one (1994/1995), conclusions would have been the same. In addition, they correspond with the few published data from other sites: in 2 years of monitoring at Marion Island, a much greater proportion of fishing gear was recorded in association with wandering albatrosses than grey-headed albatrosses or southern giant petrel (Nel and Nel, 1999); in 3 years of sampling at the Diego Ramirez islands (Chile), hooks (three in total) were recorded in regurgitates of black-browed, but not of grey-headed albatrosses (Arata et al., 2004; Arata and Xavier, 2003).

Given that the South Georgia toothfish fishery has been restricted to winter months only since 1997 (Varty et al., 2008), and previously vessels would have been operating well within their foraging range, the complete absence of fishing gear from colonies and stomach samples of the two penguin species presumably means they have little, if any, reliance on discards. In contrast, all the other species are wide-ranging procellariids known to feed at least to some extent on demersal discards (Cherel et al., 1996; Favero et al., 2003; Otley et al., 2007b), and therefore the observed differences in the incidence and type of fishing gear must relate to the relative overlap or level of interaction with particular fleets or vessels, or to differences in behaviour. The wider gape of wandering albatrosses means they are better equipped to ingest toothfish heads or sizeable discarded non-target fish such as *Antimora rostrata* and grenadiers (Macrouridae), which also have large heads and are the main bycatch in toothfish fisheries (Laptikhovsky and Brickle, 2005; Nel et al., 2002). However, black-browed and grey-headed albatrosses can also readily ingest prey that weigh in excess of 500 g (Xavier and Croxall, 2007), and giant petrels, which are considerably larger and have more robust beaks, can presumably do the same. Hence, gape *per se* is not the sole factor, and the physical and behavioural dominance of wandering albatrosses is also important.

On the assumption that most although not necessarily all gear found around nests has been regurgitated by chicks, it is more pertinent that the wandering albatross, with which by far the most gear was associated, is the only species in which a high proportion of birds travel routinely to the Patagonian Shelf and shelf-slope to feed during chick-rearing (Phillips et al., 2009; Xavier et al., 2004). In addition, although much of their prey is caught naturally, tracking and re-sighting data indicate persistent associations of individual birds with fishing vessels (Otley et al., 2007a; Xavier et al., 2004). In contrast, adult grey-headed and black-browed albatrosses spend the great majority of their time at or south of the Antarctic Polar Frontal Zone (APFZ) during chick-rearing (Phillips et al., 2004, 2009), where no licensed long-line vessels would have operated in summer since the introduction of the South Georgia closed season in 1997. Similarly, although both giant petrels spend more time than the small albatrosses on the Patagonian Shelf, the bulk of their distribution, particularly in chick-rearing, is also south of the APFZ (González-Solís et al., 2008). Finally, white-chinned petrels use the Patagonian Shelf extensively during pre-laying and incubation, but the great majority (89%) of trips during chick-rearing are to the local shelf and shelf-slope, and south to the South Orkney Islands (Phillips et al., 2006). With a mass of c. 1300 g, white-chinned petrels are considerably smaller than albatrosses or giant petrels, but are caught in high numbers in many longline fisheries (Phillips et al., 2006), and so are clearly capable of ingesting baited hooks during setting. Hence, the absence of gear from stomach samples collected from this species in 1998 and 2002 could reflect the introduction of the closed season in the local fishery in 1997. The absence of gear recorded in 1996 may result from the small number of samples, or, as suggested above, because hooks tend to be discarded in large fish or fish heads which are monopolised by the larger scavengers.

4.2. Interaction with squid fisheries

Further indication of variable levels of fisheries interaction is the preponderance of incomplete squid jigs recorded in association with grey-headed albatrosses. Jigging is considered to be a selective fishing method and the lack of discards means that few birds are attracted to vessels. However, large quantities of jigs must be discarded accidentally or deliberately, as they are recovered in nets of finfish trawlers to the north of the Falkland Islands (Yates pers. comm.). The nearest large jigging fleets operate on the Patagonian Shelf, which is used to some extent by grey-headed albatrosses during the non-breeding, but not the breeding period (Croxall et al., 2005; Phillips et al., 2004; Xavier et al., 2003b). Therefore either jigs are ingested in Patagonian Shelf waters during the winter by grey-headed albatrosses and eventually regurgitated after return to colonies (which would suggest a long stomach residency time), or, much more likely, given that the plastic portion is buoyant (cf. complete jigs), these are transported east in the Sub-antarctic Current and eventually mistaken for natural prey by adults foraging in the APFZ and Argentine Basin. The latter ties in with their low incidence in wandering albatrosses, which frequently forage on the Patagonian shelf and slope, and very rarely in the APFZ. Note that unlike interactions with longliners the association between birds and the squid fishery is indirect.

4.3. Provenance of longline gear

All hooks collected at South Georgia were considered to be from demersal and not pelagic longline fisheries. This is corroborated by the dominance of multifilament snoods in recent years, which are rarely if ever used in pelagic fisheries (Brothers et al., 1999). Similarly, all hooks ($n = 18$) found around nests on Marion Island in

1996/1997 and 1997/1998 originated from toothfish fisheries, and the single tuna hook was lodged in the neck of an incubating female wandering albatross (Nel and Nel, 1999). Indeed, hook discarding in pelagic fisheries is considered to be rare: fish bycatch levels are low, usually only the tail is removed from tuna and the remainder frozen whole, many fewer hooks are deployed, and hooks are relatively expensive, hence a financial incentive to avoid loss (Brothers et al., 1999; Nel and Nel, 1999; Tuck et al., 2003). This is implicit in the South African National Plan of Action on seabirds (Anonymous, 2008), in which there are stated prohibitions on gear discarding in the toothfish and hake, but not the pelagic longline fishery, presumably because it would be superfluous.

The gear collected in bird colonies consisted of a wide variety of hooks and snoods. Despite rigorous analysis, only 7% could be assigned to a single fishery, and a further 29% to one of two or three possible fisheries. The remainder (64%) could not be assigned. The lack of success reflects the widespread use of certain types of gear, particularly the J hook, which can be regarded as the industry standard (Brothers et al., 1999). In addition, given that the vessels responsible may move between fisheries (particularly as there is a closed season at South Georgia), use the same ports, and be owned by the same companies, a high proportion of the gear could have been purchased from the same manufacturer, and may also be in use in fisheries in Chile, Argentina and Brazil from which we were unable to obtain reference material. Indeed, hooks produced by the leading manufacturer, Mustad®, are documented in demersal fisheries in Argentina, Brazil and Chile (Bugoni et al., 2008b; Moreno et al., 1996; Seco Pon et al., 2007), and are almost certainly deployed elsewhere.

4.4. Variation in recorded gear, fishing effort and practices

There was no evidence of long-term trends in the amount of gear associated with black-browed or grey-headed albatrosses, or giant petrels, nor any correlation between these species or with wandering albatrosses in the number recorded each year, further suggesting variable levels of interaction with different fisheries. For the three least-affected taxa, few further insights are possible given the lack of correspondence between gear incidence and any change in fisheries practices, including the introduction of the closed season.

In comparison, the pattern for the WALB Gear Index suggests that gear discarding was at relatively low levels in fishing seasons 1993–1997, rose to a peak in 2000, showed a gradual decline until 2004, but subsequently returned to a high level that is still apparent. The first peak was despite the introduction of the closed season, probably because effort was similar even if the fishing season was shorter, and also because adults obtain hooks elsewhere in their feeding range. This second peak is the more surprising because it is despite the implementation of measures in both the Falklands and South Georgia toothfish fisheries to reduce gear discarding, with which observers indicate there are high levels of compliance (CCAMLR, 2007, 2008, Pompert pers. comm.).

The answer appears to lie in the adoption of the Chilean mixed longline system in industrial longline fisheries, because from 2006 there was a significant increase in the amount of gear associated with wandering albatrosses, and a diagnostic change in the relative numbers of monofilament *vs*. multifilament snoods (Figs. 3 and 4). Although the Chilean artisanal fleet has used a similar, mixed longline system since the mid 1990s, their snoods are monofilament and the prescribed area of operation is the Chilean west coast north of 47°S (Moreno et al., 2006), which is rarely visited by wandering albatrosses during chick-rearing. Observations on a Chilean industrial vessel in 2007 (in the early stages of adoption of the new system) revealed that snoods were routinely cut from landed fish, including bycatch such as grenadiers, in order to disentangle them from the net sleeve. Grenadiers were discarded with embedded hooks and available for seabirds to ingest, especially the larger species such as wandering and royal albatrosses *Diomedea sanfordi* and *D epomophora* (Robertson pers. comm.). The other possibility is that Argentinian autoliners targeting kingclip and toothfish on the central Patagonian shelf, which also use multifilament snoods (Seco Pon et al., 2007, Favero pers. comm.), or other vessels that do so, began in 2006 to discard gear in greater numbers. However, given the low effort in those Argentinian fisheries and no evidence for a change in practices on autoliners there or elsewhere, this explanation seems unlikely.

Although rapidly adopted by several South American fisheries, the Chilean mixed system is rarely used at South Georgia because of the rocky substrate and fewer problems with whale depredation of the catch (Belchier pers. comm.). Hence the majority of the longline gear found in more recent years at Bird Island must have been obtained elsewhere, particularly as the vessels operating in the Falklands toothfish fishery since 2004 using the Spanish, and more recently the Chilean mixed system, use monofilament snoods, as do the two vessels with the poorest recent records on hook discarding in the South Georgia fishery (Clark pers. comm.).

4.5. Foul-hooking

Birds that swallow hooks during line setting cannot break the line, so are dragged under and drowned (Brothers et al., 1999). Therefore birds seen with embedded hooks at Bird Island would almost all have fed on used bait, been captured during line-hauling, and cut free and released either at the hauling door or on board the vessel. The number of birds checked at Bird Island each year is unknown, as gear would have been noted on both breeders and non-breeders during routine fieldwork, and others would have been inspected opportunistically, including giant petrels feeding on carrion near the research station. Nevertheless, sample sizes were probably in the order of 1500–2500 of each species of albatross, and c. 1000 for giant petrels each year. Despite this uncertainty, we can conclude that the observed incidence of foul-hooking in giant petrels and wandering albatrosses at Bird Island each year is broadly similar (c. 0.1–0.2% of birds), it is much less frequent in black-browed albatrosses (c. 0.03% of birds), and no grey-headed albatross seemed to be affected.

The lower incidence in black-browed albatrosses than wandering albatrosses and giant petrels was unexpected, as all these taxa are known to routinely follow vessels. The variation must therefore reflect one or more of the propensity and willingness to approach close to vessels in order to steal bait during line-hauling, susceptibility to swallowing hooks, and the degree of spatial–temporal overlap with particular fisheries (some fishermen might be more inclined to release captured birds). The lack of foul-hooked grey-headed albatrosses suggests that they do not interact with longline fisheries in the same way. There was no clear trend in foul-hooking over time, correlations between taxa across years, or within species with the amount of gear found near nests, and so little can be said about annual variation or changes in fisheries practices, particularly as foul-hooking could have occurred during the breeding or non-breeding period months or years previously.

4.6. Management implications

Given the relative rarity of foul-hooking, little can be concluded from land-based monitoring other than that birds are affected somewhere in the year-round foraging range, and susceptibility varies with species. Therefore, the only viable approach for assessing the full severity of the problem is to encourage much greater emphasis on onboard observation (potentially video recording). Such data exist, mainly from well-regulated fisheries (CCAMLR, 2008; Otley et al., 2007b). However, these are probably unrepresentative of other fisheries, particularly those where no measures are in place to discourage birds from accessing used baits during hauling, despite this being relatively straightforward to achieve, by the use of a scaring device such as the Brickle curtain, streamer line or water cannon (CCAMLR, 2008; Otley et al., 2007b). In certain respects, observations of foul-hooked birds at colonies could be considered encouraging, as elsewhere fishermen kill birds that attempt to remove baits (Bugoni et al., 2008b).

In contrast, analysis of gear recovered on the ground clearly highlighted variation among years as well as species in levels of interaction with different fisheries, provided some useful guidance on the influence of existing fishing practices, and emphasised the need for much improved management in some areas. Wandering albatrosses in particular continue to ingest very large quantities of gear, much of which appears to originate from vessels operating the new Chilean mixed system. It is encouraging that after accounting for this change and for a positive correlation with Falklands toothfish effort, the ban on hook discarding at South Georgia can be seen to have had a positive effect (Fig. 3). Although our results indicate that the Chilean system may be the root cause of the recent increase, the solution is not to revert to previous practises as seabird bycatch rates during line setting are much lower using the new system (Moreno et al., 2008). Instead, it would be advisable to ban the discarding of hooks altogether. This is already a licence condition in toothfish fisheries in the Falkland Islands and South Georgia (see Section 1), but not, for example in demersal fisheries in Brazil, Chile or Argentina, despite recent efforts to highlight the issue (Anonymous, 2009, Neves, Favero and Moreno pers. comm.).

If levels of compliance are poor, there are operational methods for reducing the likelihood of hook discarding. During hauling in vessels configured to use the Spanish system, a roller mechanism strips used baits and non-target fish off the line. If this is jammed by a large fish, the monofilament snaps (or the line is cut) and the fish and hook may then be discarded, particularly as this occurs before the catch is passed to the processing hopper. Hence, one possibility would be to use snoods with a greater breaking strain, such that hooks are more likely to be pulled free by the de-baiter. However, this is considered to have potentially negative repercussions for operator safety in some fisheries (Pompert pers. comm.) An alternative would be to ban the dumping of offal and discards (and therefore hooks) at sea altogether, and insist on freezing and disposal in port, or processing into fishmeal; this has, however, considerable cost implications. Nevertheless, it is a CCAMLR requirement for toothfish longliners in the Ross Sea region (CCAMLR, 2008).

As with any other conservation message, increasing awareness amongst observers, operators and fishermen is a fundamental first step. Vessels in the Falklands and South Georgia toothfish fisheries, for example, are provided with an educational poster that clearly states the risks to birds and that removal of hooks is a licensing condition (CCAMLR, 2008, Pompert pers. comm.). It is also imperative to monitor compliance: even in well-regulated fisheries where discard of hooks is prohibited and observer coverage is high, practises may be negligent on particular fishing trips or be a chronic problem on particular vessels (CCAMLR, 2008; Otley et al., 2007b). One of the conclusions of this study is that very few items can unambiguously be assigned to a particular fishery, let alone vessel. If other mechanisms fail to improve the situation, fishing companies or individual vessels could be forced to use unique gear, such as a particular snood colour and type, or hooks that are colour anodised or stamped with a particular symbol. This would reveal responsibility for non-compliance at some level, and would have the added benefit that the presence of IUU vessels (assuming they used unmarked gear) could be determined. The latter would have obvious economic, as well as conservation benefit; IUU vessels are unlikely to avoid discarding hooks for animal welfare reasons, or be implementing bycatch mitigation methods to the same extent as licensed vessels carrying observers.

4.7. Recommendations for monitoring

The long-term study provided a number of useful insights for monitoring programmes which may be established elsewhere. (1) Choice of study species is clearly critical given the limited statistical power if sample sizes are small. As so little gear was associated with black-browed albatrosses and giant petrels (despite their known association with fisheries), and given that the incomplete squid jigs associated with grey-headed albatrosses were probably not the result of direct interaction with vessels, much more was learned about annual changes in fishing practices from wandering albatrosses. This was not just a consequence of reduced temporal overlap of the other species with the local fishery after the imposition of the closed season, as the amount of gear recorded was no higher in preceding years. (2) As chicks accumulate hooks during the long rearing period, they tend to yield more useful data than adults. (3) Clear conclusions can be drawn from the non-invasive technique of collecting material on the ground, requiring much less disturbance than stomach sampling. (4) As with any study, it is important to record monitoring effort, particularly if trying to draw inferences about variation across species and years. (5) All gear found at colonies should be fully described and, ideally, archived or photographed to ensure long-term consistency in categorisations and the potential to later assign provenance. (6) As much reference material as possible should be obtained to avoid inappropriately allocating responsibility where none might exist if several vessels or fisheries use similar gear. (7) Close engagement with fishery observers and operators provides practical information with which to evaluate the results of colony-based monitoring. While it may not be straightforward to trace the provenance of hooks and snoods, it may be possible to identify when changes in their frequency of occurrence suggest a change in practices has occurred. Dialogue with fisheries experts can confirm if this has an operational basis (e.g. change in fishing location, timing or gear configuration). Furthermore, as the results from this type of monitoring may be used to assess the efficacy of management decisions, such as the banning of hook discharge in offal, better engagement not only provides credibility to the process but improves opportunities for translating results into improved management.

4.8. Future research

The simple extrapolations from incidence of gear in adult and chick stomach samples suggest that currently an estimated 1300–2048 hooks and snoods are ingested by wandering albatross chicks at South Georgia each year. This is equivalent to 2–4 per chick, but some will potential ingest many more than others if they have a parent with a greater propensity to follow fishing vessels. In 1998, the stomach of a recently-dead 8-month old wandering albatross was found to contain 12 pieces of line totalling 9.3 m, but whether this was the primary cause of mortality was unknown. Although acknowledging potential problems associated with reduced capacity of the digestive system, suppression of appetite, intestinal obstruction and increased contaminant load, studies elsewhere of the impact of ingestion of plastic and other debris have failed to detect a definitive effect on chick survival (Auman et al., 1998; Azzarello and van Vleet, 1987). Furthermore, breeding success has been routinely high (65–78%) at Bird Island since the study began (BAS unpublished data). Nevertheless, wandering albatross chicks definitely digest hooks, which could lead to toxicity that is only manifested after fledging. Many heavy metals are regulated in animal tissues, and large albatrosses in particular have evolved to cope with natural levels that would kill terrestrial birds (Stewart et al., 1999). However, analysis indicates that survival from fledging to recruitment is now far lower in wandering albatrosses than it was in the 1960s–1980s (Croxall et al., 1998, BAS unpublished data). Although no concrete evidence links this decline to hook ingestion and a relationship seems unlikely, further toxicological study is warranted.

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