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Trawl discards in the diets of tropical seabirds of the northern Great Barrier Reef, Australia

S. J. M. Blaber[1,*], D. A. Milton[1], G. C. Smith[2], M. J. Farmer[1]

[1]CSIRO Division of Fisheries, Marine Laboratories, PO Box 120, Cleveland, Queensland 4163, Australia
[2]Fauna Conservation & Ecology Section, QDPI Forest Service, 80 Meiers Road, Indooroopilly, Queensland 4068, Australia

ABSTRACT: The diets of 12 species of tropical seabirds were investigated in 2 areas of the far northern Great Barrier Reef, Australia, with particular reference to the effects of bycatch discarded from trawlers on diets and reproduction. The species whose diets included at least 20% discard taxa are *Sterna bergii, S. dougallii* and perhaps *S. anaetheta*; between 5 and 19% — *Hydroprogne caspia, Anous stolidus, Sterna bengalensis, Sula leucogaster* and *Fregata ariel*, less than 5% — *Sterna sumatrana*; and none — *Fregata minor, Sula dactylatra* and *Sula sula*. There was a marked contrast in the diet of *S. bergii* in closed and open trawling seasons: in the closed season only 5% of the prey were benthic species, whereas in the open season they made up about 70% of the diet. Differences in the diets of birds from areas open and closed to fishing were less marked, probably because birds from the closed zone can forage in adjacent areas open to trawling. About half the bycatch discarded by the trawlers is of a size suitable for one or more of the seabirds, and most of this half floats, some of it for up to 6 h. *S. bergii, S. leucogaster* and *F. ariel* are actively opportunistic, feeding around trawlers, but *S. anaetheta* and *S. dougallii* may be passive discard feeders, feeding on floating discards away from the site of dumping. The provision of discards has not changed the size ranges of prey taken by any of the species. It may, however, have increased overlap in the diets of the various seabirds and changed some feeding strategies. There is little evidence that discards have directly affected breeding cycles or nesting periodicity. Nevertheless, most species breed mainly in late summer and the largest quantities of bycatch are discarded in March, immediately post-fledging. This may lead to juvenile birds becoming conditioned to feeding on discards and may also reduce juvenile mortality rates.

KEY WORDS: Seabirds · Diets · Great Barrier Reef · Discards · Trawling · Breeding

INTRODUCTION

The interactions of seabirds and fisheries have been comprehensively investigated in northern temperate waters (e.g. Furness 1984, Furness et al. 1988, 1992, Montevecchi et al. 1988, Garthe & Huppop 1994), in the Benguela region of southern Africa (Abrams 1983, Ryan & Moloney 1988), and in the eastern Pacific and, to a lesser extent, Hawaii (MacCall 1984, Harrison & Seki 1987). These studies indicate that commercial fisheries may have a variety of direct and indirect effects on seabirds, including influencing their feeding ecology and behaviour, reproductive success and population sizes. However, despite numerous studies of the diets of most tropical seabirds (e.g. Diamond 1984, Harrison et al. 1984, Hulsman et al. 1989, Seki & Harrison 1989, Morris & Chardine 1992), relatively little is known of their relationships with fisheries.

The coupling of food availability and the timing and success of reproduction may be very tight in tropical seabirds (Harris 1977, Nelson 1984, Diamond & Prys-Jones 1986). Hence if food availability changes significantly as a result of trawlers discarding bycatch, fluctuations in population sizes and success of reproduction may relate to changes in commercial fishing effort and location. Demersal trawling for penaeid prawns is the largest and most widespread fishery in tropical Australia (Kailola et al. 1993), including large areas of the Great Barrier Reef. This fishery has a bycatch to prawn ratio of up to 14:1 (Pender et al.

*E-mail: steve.blaber@qld.ml.csiro.au

1992). The bycatch, mainly small fish, is discarded and available to scavenging birds (Blaber & Wassenberg 1989, Hill & Wassenberg 1990). Seabirds are a conspicuous component of the northern Great Barrier Reef which, as a protected area, has a global significance in terms of its large seabird populations and numerous breeding sites (Blaber et al. in press). To examine the possibility that trawling affects seabirds in the far northern Great Barrier Reef a study of its effects was initiated in 1991. It is part of a large CSIRO and Queensland Department of Primary Industries (QDPI) programme into the effects of trawling on the far northern Great Barrier Reef.

The objectives of the seabird study reported in this paper were to: (1) find out which species of seabirds feed on discards; (2) quantify and assess the importance of discards in their diets; and (3) relate discard feeding to: (i) availability of discards in terms of (a) species and sizes of discards, and (b) fishing effort, location, and closed fishing seasons; and (ii) seabird breeding seasons.

MATERIALS AND METHODS

Study areas. Islands in 2 areas of the Great Barrier Reef were sampled. The first is in the Far Northern Section between 11° S and 12° S. It encompasses the Marine National Park 'B' zone cross-shelf area, which has been closed to trawling since 1983, but which is bordered by areas open to trawling (Fig. 1). The second area is around Lizard Island between 14° 36' S and 14° 55' S (Fig. 1). It is closed to trawling between 15 December and 1 March each year. Samples were also obtained from collections made by the Australian Nature Conservation Agency on Northeast Herald Cay (16° 55' S, 149° 20' E) in the Coral Sea, more than 200 km from the nearest trawl grounds.

Species of birds. Diet samples were collected from 9 species in the Far Northern Section of the Great Barrier Reef; 7 species from the Lizard Island area; and 5 species from Northeast Herald Cay (Table 1) Altogether 12 species were investigated. Data on breeding seasons were collected as part of a longer term study of the seabird populations.

Seabird diets. ***Field sampling:*** Regurgitated pellets and regurgitated prey were collected from roosting and breeding seabirds in the far northern Great Barrier Reef in July 1992, March, April, August, October, November and December 1993 and April 1994. Similar samples were collected from the Lizard Island area in January and August 1992 and in February and June of 1993 and 1994. Northeast Herald Cay samples were collected in November/December 1992 and August 1993. Pellets and regurgitated material were either frozen or placed in 70% ethyl alcohol for transport to the laboratory.

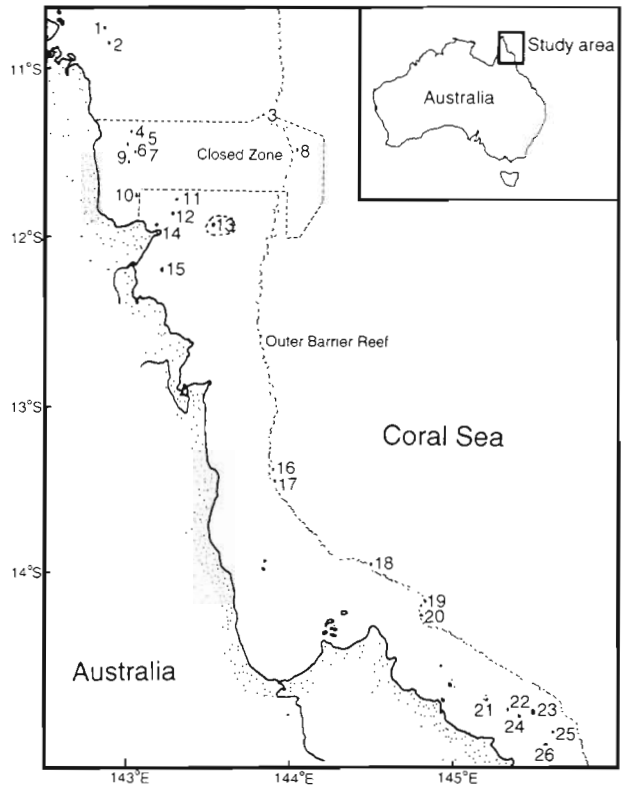

Fig. 1. Study area and list of islands where diet samples were collected from seabirds. (1) Middle Brother Is.; (2) Frigate Is.; (3) Maclennan Cay; (4) Jardine Is.; (5) Cholmondeley Is.; (6) Boydong Is.; (7) Little Boydong Is.; (8) Raine Is.; (9) Saunders Is.; (10) Bird Is.; (11) Buchan Rock; (12) Magra Is.; (13) Sir Charles Hardy Is.; (14) Sunday Is.; (15) Kay Reef; (16) Sandbank No. 8; (17) Sandbank No. 7; (18) Tydeman Reef; (19) Sandbank No. 1; (20) Stapleton Reef; (21) Turtle Is.; (22) Nymph Is.; (23) Lizard Is. group; (24) Eagle Is.; (25) North Direction Is.; (26) Rocky Is. (Note that no. 13 is in a detached portion of the closed zone)

Laboratory analyses: Fish prey items in pellets were identified from otoliths by comparing them to a reference collection. This collection was also used to construct otolith weight to fish length (standard length) regressions in order to back-calculate fish lengths. Cephalopoda were identified as far as possible from beaks or shells. Whole regurgitated prey were identified, measured and weighed. Diets were analysed in terms of the numerical frequency of each prey taxon.

Identification of benthic prey and prawn trawl discards. In the Far Northern Section the bycatch from the research trawler 'Gwendoline May' was collected as part of the overall 'Effects of Fishing' project (T J Wassenberg et al. unpubl.). This included a very large number of fishes (>50000) in samples from 69 stations in May 1992 and 79 stations in March 1993 from both

Table 1. Seabirds from which diet data were obtained from 3 areas in tropical northeast Australia. FNS: Far Northern Section of Great Barrier Reef; Liz: Lizard Island area; Her: NE Herald Cay; +: samples collected

Species	FNS	Liz	Her
Sterna bergii (crested tern)	+	+	–
Sterna bengalensis (lesser-crested tern)	–	+	–
Sterna sumatrana (black-naped tern)	+	+	–
Sterna anaetheta (bridled tern)	–	+	–
Sterna dougallii (roseate tern)	+	–	–
Anous stolidus (common noddy)	+	+	–
Hydroprogne caspia (caspian tern)	–	+	–
Sula leucogaster (brown booby)	+	–	+
Sula dactylatra (masked booby)	+	–	+
Sula sula (red-footed booby)	+	–	+
Fregata ariel (least frigatebird)	+	–	+
Fregata minor (greater frigatebird)	–	–	+

the closed area and the adjacent area open to trawling (Fig. 1). The 'Gwendoline May' used standard commercial 'Florida Flyer' prawn trawls. These trawls are demersal and the bycatch consists almost entirely of benthic species not normally available to seabirds.

In the Lizard Island area information on the composition of discards was obtained from 26 stations trawled by the 'Gwendoline May' during a research cruise in June 1993. All discard samples were frozen on board the vessel and taken to the laboratory for sorting, identifying and measuring. Discard species were classified as benthic (following Blaber et al. 1990) and as floating or sinking (following Harris & Poiner 1990). The composition of discards in trawled and untrawled areas and between seasons and sites was compared by Spearman's Rank Correlations.

Prawn trawling effort and location in the study areas. The prawn catch can be used as a guide to the amount of bycatch discarded. Prawns usually represent 10 to 20% of the catch. The remaining 80 to 90% consisting of bycatch, mainly fish, is discarded (Pender et al. 1992). Data on the number of trawlers and the number of days they spent trawling in the study areas were extracted from the 'QFISH' database which is maintained jointly by the QDPI and Queensland Fish Management Authority. It is compulsory for all trawlers to supply these authorities with logbook data.

RESULTS

Diets

The proportions of benthic and pelagic prey for each species are shown in Fig. 2.

Laridae

***Sterna bergii* (crested tern).** A total of 755 regurgitated pellets and 462 regurgitated whole fish samples were used in the analysis.

In the Lizard Island area the diet of *Sterna bergii* changed markedly between closed and open trawling seasons (Table 2). During the closed season the prey consisted mainly of pelagic species such as *Amblygaster sirm* and *Atherinomorus lacunosus*, whereas in the trawling season it consisted mainly of benthic groups such as Apogonidae and Gobiidae. The benthic prey are from taxa characteristic of prawn trawler discards that float when discarded (Table 3). They include the penaeid prawns *Metapenaeus endeavouri* and

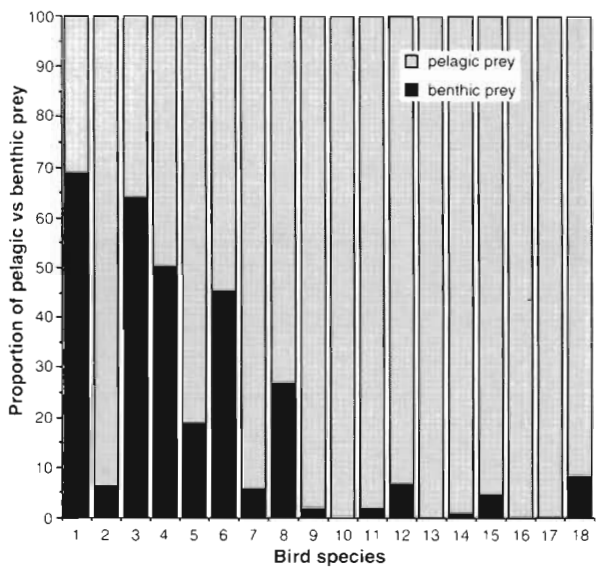

Fig. 2. Proportions of pelagic and benthic prey eaten by each seabird species. (1) *Sterna bergii* at Lizard Is. in open trawl season; (2) *S. bergii* at Lizard Is. in closed season; (3) *S. bergii* in Far Northern Section trawl grounds; (4) *S. bergii* in Far Northern Section zone closed to fishing; (5) *S. bengalensis*; (6) *S. dougallii*; (7) *Hydroprogne caspia*; (8) *S. anaetheta*; (9) *S. sumatrana* at Lizard Is.; (10) *S. sumatrana* in Far Northern Section; (11) *Anous stolidus* at Lizard Is. in closed season; (12) *A. stolidus* at Lizard Island in trawl season; (13) *A. stolidus* in the Far Northern Section; (14) *Sula leucogaster* in Far Northern Section trawl grounds; (15) *S. leucogaster* in Far Northern Section closed zone; (16 & 17) *S. sula* and *S. dactylatra* in Far Northern Section closed zone; (18) *Fregata ariel* in Far Northern Section closed zone

Table 2. *Sterna bergii*. Diets of crested tern in the Lizard Island area of the Great Barrier Reef during closed and open trawl seasons (data combined for 3 samples in each season), and in the Far Northern Section in the zone closed to trawling (data combined from 5 samples) and in adjacent zones open to trawling (data combined from 3 samples), expressed as percentages of the number of food items eaten. *Benthic taxa

Prey taxa	Lizard Island area		Far Northern Section	
	Closed season	Open season	Closed zone	Trawl ground
Agamid lizard	–	0.6	–	–
*Alpheidae	–	–	–	0.9
Amblygaster sirm	87.5	–	0.6	–
**Anchisomus multistriatus*	<0.1	–	–	–
*Apogonidae	1.0	39.2	5.2	25.5
Atherinomorus lacunosus	3.7	4.0	20.6	0.9
Beloniformes	0.6	–	–	–
*Blenniidae	0.1	–	–	–
*Brachyura	0.4	0.6	0.6	0.9
**Callianassa* sp.	–	–	28.4	–
Caranx sp.	0.6	–	0.6	–
**Choerodon* sp.	0.2	–	1.9	7.5
Clupeidae	0.2	–	–	0.9
*Gerreidae	–	3.4	–	–
*Gobiidae	0.2	30.7	22.6	18.9
Green turtle hatchlings	–	–	2.6	–
Halichoeres sp.	<0.1	–	0.1	–
Hemiramphidae	–	–	–	1.9
Herklotsichthys quadrimaculatus	0.2	–	0.6	–
Isopoda	–	–	–	0.9
Megalaspis cordyla	0.1	–	–	–
**Metapenaeus endeavouri*	0.1	–	–	0.9
Mulloides sp.	0.1	–	–	–
**Nemipterus* sp.	0.1	1.1	–	–
Paraexocoetus sp.	0.1	–	–	–
**Penaeus latisulcatus*	–	1.1	0.6	0.9
**Penaeus plebejus*	–	–	–	1.9
*Pomacentridae	1.6	9.7	–	–
**Pristotis jerdoni*	0.8	–	–	–
**Pseudochromis* sp.	<0.1	–	–	–
Scombridae	0.1	–	–	–
Sepia sp.	0.5	–	–	–
**Sillago* sp.	–	–	–	8.5
Spratelloides sp.	0.2	1.1	0.6	–
Stethojulis strigiventer	0.2	–	–	–
Sthenoteuthis sp.	0.1	–	–	1.9
*Terapontidae	–	0.6	–	–
Teuthoidea	0.2	1.1	3.9	–
Unidentified cephalopods	0.7	–	–	–
Unidentified teleosts	0.4	6.3	9.7	26.4
Total number of prey	1037	176	155	106

Penaeus latisulcatus — the benthic target organisms of the fishery — small numbers of which are discarded if broken or damaged. The length ranges of pelagic and benthic prey were similar (Table 4) and were within the size range of fishes discarded by trawlers.

All the diet samples from the Far Northern Section were collected during the trawling season. Nevertheless, in both the zone open to fishing and the zone closed to fishing, the diet consisted predominantly of benthic species (Table 2) characteristic of trawl discards (Table 3), including several species of penaeid prawns. Only in the closed zone in November 1993 were more pelagic prey (*Atherinomorus lacunosus* — 70% of numbers) than benthic prey eaten.

***Sterna bengalensis* (lesser-crested tern).** Diet samples were only available from the Lizard Island area in the closed season. In the 39 regurgitated pellets, the prey consisted mainly of pelagic species, although some benthic trawl discard species were recorded (Table 5, Fig. 2). The maximum prey length was smaller than that of *S. bergii* (Table 4).

***Sterna dougallii* (roseate tern).** Only 16 regurgitated pellets were collected, all from the Far Northern Section from Sir Charles Hardy (13 in Fig. 1, detached portion of closed zone) and Sunday Islands (14 in Fig. 1, open zone). In the zone closed to trawling half the prey were pelagic, the remainder were Gobiidae; in the zone open to trawling it was all pelagic (Table 5). The overall proportions of benthic and pelagic prey are shown in Fig. 2. The longest prey (58 mm) was shorter than the largest prey eaten by any of the other tern species studied. The prey were within the length ranges discarded by trawlers.

***Hydroprogne caspia* (caspian tern).** A total of 98 regurgitated pellets were obtained from the Lizard Island area, all in the trawling season. Although much of the prey was unidentifiable, most of those that could be identified were pelagic (Table 5, Fig. 2). The maximum prey length recorded (250 mm) was greater than that of other terns (Table 4).

***Sterna anaetheta* (bridled tern).** Samples were collected during closed fishing seasons from the Lizard Island area. A total of 117 regurgitated pellets and 43 regurgitated whole prey samples were obtained. The diet was dominated by pelagic species (Table 5) except in February 1994 when the quantities of Apogonidae were significant.

***Sterna sumatrana* (black-naped tern).** Data from 237 regurgitated pellets collected from the Lizard Island area in both open and closed trawl seasons, and from the trawl grounds and closed zone of the Far Northern

Table 3. Trawl discards that were found in seabird diets, expressed in terms of the percentage contribution of each taxon (by numbers) to the total number of discards. Also shown for each taxon is whether the discards float or sink (F, S) and their length range (standard length in cm, SL) for each site and time. –: no data

Prey taxa	F/S	Lizard Island area		Far Northern Section							
		Jun 1993		May 1992 Trawl area		May 1992 Closed		Mar 1993 Trawl area		Mar 1993 Closed	
		%	SL	%	SL	%	SL	%	SL	%	SL
Apogonidae	F	5.4	2–11	3.4	5–7	3.1	3–15	5.7	3–10	7.0	3–11
Cephalopoda	F	2.0	–	1.0	–	0.9	–	1.1	–	1.0	–
Choerodon spp.	–	1.8	–	2.1	8–14	1.1	7–13	1.3	7–14	0.9	7–14
Decapterus spp.	F	–	9–16	0.1	10–20	<0.1	6–16	0.1	18–22	<0.1	11–20
Gerreidae	F	0.3	5–15	0.2	10–14	1.1	8–14	0.3	13	0.3	8–14
Gobiidae	F/S	0.1	6–12	0.2	9–13	0.2	8–13	0.2	11–13	0.2	10–14
Leiognathidae	F	0.1	6–11	0.4	6–12	0.4	3–12	0.6	6	1.4	8–12
Lethrinus genivittatus	F	26.0	3–16	12.9	8–17	10.9	9–17	8.1	3–17	7.6	9–17
Pentapodus spp.	F	5.3	5–20	3.2	6–22	1.2	5–23	2.8	7–20	1.8	9–21
Pomacentridae	F	1.2	3–9	0.1	5–8	0.6	6–9	1.1	5–10	2.0	5–10
Selar spp.	S	–	9–16	0.1	13–18	<0.1	6–16	<0.1	13–21	<0.1	11–20
Sillago spp.	F	0.5	12–20	0.7	13–18	1.2	11–17	0.4	13–19	0.2	15–19
Terapontidae	F	0.5	5–11	0.1	11–14	3.4	9–15	0.8	–	0.1	–
Mullidae	S	8.4	4–16	5.7	8–17	9.3	–	5.4	6–16	6.0	5–23
Monacanthidae	F	3.5	2–16	4.6	7–19	3.5	7–21	10.2	7–23	8.7	4–36
Priacanthus sp.	F	0.2	8–21	1.2	12–20	1.5	4–22	0.5	8	<0.1	8–23
Tetraodontidae	F/S	0.9	5–15	2.1	6–16	2.8	4–46	3.6	4–32	1.3	5–29
Invertebrata											
Penaeidae	S	0.2		0.07		0.2		0		0.03	
Squid	F/S	0.2		0.07		0.07		0.3		0.55	
Sepia spp.	F	1.6		0.9		0.77		0.7		0.58	
Bivalvia	S	0.1		8.6		4.9		5.4		9.8	
Alpheidae	S	0		<0.1		<0.1		0		<0.1	
Total percentages		61.8		47.8		44.3		48.7		49.9	
Number of species		155		128		145		282		184	

Section, show that this species feeds almost exclusively on small pelagic clupeids, engraulids and atherinids (Table 6, Fig. 2).

***Anous stolidus* (common noddy).** A total of 412 regurgitated pellets and 155 regurgitated whole fish samples were collected. In the Lizard Island area in both open and closed seasons the birds were eating mainly small pelagic species, and small quantities of species from the benthic trawl bycatch. No benthic prey were recorded from the Far Northern Section (Table 6, Fig. 2).

Sulidae

Data on the boobies were collected only from the Far Northern Section.

***Sula leucogaster* (brown booby).** In the closed zone, 11 regurgitated pellets and 79 regurgitated prey samples were collected from Raine Island; in the trawl grounds, 18 regurgitated prey samples were collected from Sandbanks numbers 7 and 8. The diet was very diverse but consisted mainly of pelagic prey (Table 7, Fig. 2). Small quantities of benthic trawl bycatch taxa were recorded from both the open and closed zones. They included Apogonidae, *Kyphosus* sp., *Lethrinus* sp. and Terapontidae, as well as bivalves.

***Sula dactylatra* (masked booby) and *Sula sula* (red-footed booby).** Regurgitated prey samples were collected from Raine Island in the closed zone: 81 from *Sula dactylatra* and 36 from *S. sula*. The diets of both species consisted entirely of pelagic prey, but whereas *S. dactylatra* had eaten mainly flying fishes and a few squid, *S. sula* had eaten mainly squid with only a few flying fishes (Table 8, Fig. 2).

Fregatidae

***Fregata ariel* (least frigatebird).** The data from 88 regurgitated prey samples from Raine Island suggest this species feeds on a wide variety of pelagic prey in the closed zone of the Far Northern Section. Small numbers of benthic trawl bycatch taxa such as lethrinids and leiognathids were, however, recorded in both March and December 1993 (Table 9, Fig. 2).

Table 4. Length ranges (SL in mm) of prey of terns in the Lizard Island area and Far Northern Section

Prey	*Sterna bergii*	*Sterna bengalensis*	*Sterna sumatrana*	*Sterna anaetheta*	*Sterna dougalli*	*Anous stolidus*	*Hydroprogne caspia*
Amblygaster sirm	32–121	–	61–81	24–110	–	–	–
Apogonidae	33–108	74	33–41	30–49	–	33–42	60
Atherinomorus lacunosus	23–102	43–74	19–66	22–82	25–58	23–71	61–87
Blenniidae	–	–	–	12	–	–	–
Caranx sp.	52–98	–	–	–	–	–	–
Encrasicholina spp.	–	–	20–34	25–35	35–46	–	–
Gerreidae	64–75	–	–	–	–	–	–
Gnathanodon speciosus	–	–	–	13	–	–	–
Halichoeres sp.	103	–	–	–	–	–	–
Herklotsichthys quadrimaculatus	41–85	–	12–30	24	18–22	11–33	–
Lagocephalus lunaris	–	–	–	18–19	–	–	–
Lutjanus spp.	–	–	–	–	–	–	250
Megalaspis cordyla	110	–	–	–	–	–	–
Monacanthidae	–	–	–	17–19	–	–	–
Mulloides sp.	–	–	–	32–48	–	55–58	–
Myripristis sp.	–	–	–	49	–	–	–
Paraexocoetus sp.	84	–	–	–	–	–	–
Pomacentridae	20–64	–	10–58	6–89	–	13–43	39
Priacanthus sp.	–	–	–	11–13	–	–	–
Pristotis jerdoni	43–55	–	–	39–41	–	–	–
Pseudochromis sp.	65	–	–	–	–	–	–
Sepia sp.	34–90	–	–	31	–	–	–
Sillago sp.	78–138	–	–	–	–	–	–
Spratelloides sp.	9–24	18	–	10–55	8–13	8–31	–
Stethojulis strigiventer	48–66	–	–	44	–	–	–
Sthenoteuthis sp.	–	–	–	–	–	–	–
Teuthoidea	91	–	–	–	–	–	–
Upeneus tragula	–	–	–	23–35	–	53–58	–
Xiphasia spp.	–	–	–	48	–	–	–
Overall length range	9–138	18–74	8–81	6–110	8–58	11–71	39–250

Diets from the Coral Sea

The food of 3 Sulidae and 2 Fregatidae identified from samples collected on Northeast Herald Cay consisted predominantly of at least 4 species of flying fishes (Exocoetidae) and the pelagic squid *Sthenoteuthis* sp. There were also smaller numbers of other pelagic fishes such as *Auxis* (tuna), *Coryphaena* (dolphin fish) and *Encrasicholina* (anchovy) (Table 10). No benthic prey were recorded. Although the 5 bird species ate much the same species, they ate them in different proportions (Fig. 3). *Sula dactylatra* and *Fregata minor* ate >50% flying fish whereas the other species took <20% *S. sula*, *F ariel* and *F. minor* ate >30% squid while *S. leucogaster* and *S. sula* were the only species to eat engraulids.

Prawn trawl discards

The taxonomic composition of the bycatch discarded by prawn trawlers in each study area is listed in Table 3. Only taxa found in seabird diets are shown.

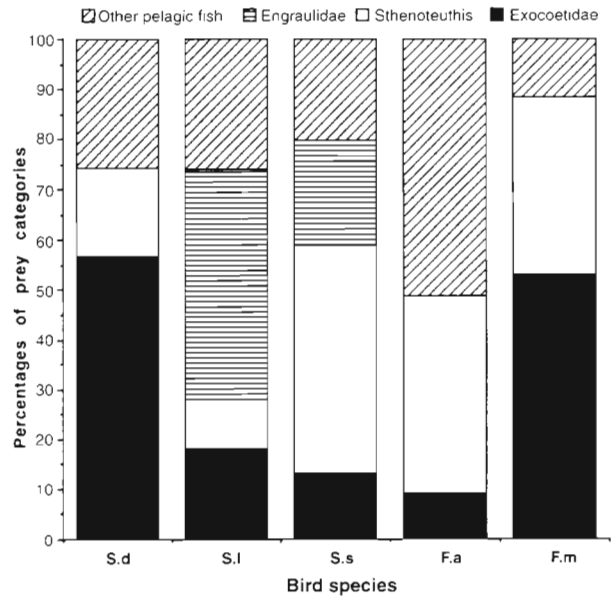

Fig. 3. Proportions of 4 prey categories in the diets of seabirds from Northeast Herald Cay. S.d: *Sula dactylatra*; S.l: *S. leucogaster*; S.s: *S. sula*; F.a: *Fregata ariel*; F.m: *F. minor*

Table 5. Diets of *Sterna bengalensis* (lesser-crested tern), *S. dougallii* (roseate tern), *Hydroprogne caspia* (caspian tern) (combined Aug 1992, Jun 1993, Jun 1994) and *S. anaetheta* (bridled tern) (combined Jan 1992, Feb 1993, Feb 1994) in the Lizard Island and Far Northern Section (FNS) of the Great Barrier Reef, expressed as percentages of the number of food items eaten. *Benthic taxa

Prey taxa	*S. bengalensis* Lizard Island Closed season Feb 1994	*S. dougalli* FNS Closed zone Jul 1992	*S. dougalli* FNS Trawl ground Jul 1992	*H. caspia* Lizard Island Open season Combined	*S. anaetheta* Lizard Island Closed season Combined
*Alpheidae	–	–	–	2.9	–
Amblygaster sirm					24.4
*Apogonidae	6.2	–	–	2.9	19.9
Arramphus sp.	–	–	10.0	–	–
Atherinomorus lacunosus	43.9	37.5	–	11.8	8.6
Blenniidae	–	–	–	–	0.4
**Choerodon* sp.	12.5	–	–	–	–
Clupeidae	–	–	–	–	1.5
Encrasicholina sp.	–	–	90.0	–	6.4
Exocoetidae	–	–	–	17.6	0.4
Gnathanodon speciosus	–	–	–	–	0.4
*Gobiidae	–	53.6	–	–	1.1
Herklotsichthys quadrimaculatus	–	5.3	–	–	0.4
Lagocephalus lunaris	–	–	–	–	0.8
*Lutjanidae	–	–	–	2.9	–
Monacanthidae	–	–	–	–	0.8
Mulloides sp.	–	–	–	–	1.5
**Myripristis* sp.	–	–	–	–	0.4
*Penaeidae	–	–	–	2.9	–
*Pomacentridae	–	–	–	2.9	8.6
**Priacanthus* sp	–	–	–	–	1.5
**Pristotis jerdoni*	–	–	–	–	0.8
Spratelloides sp.	12.5	3.6	–	–	2.7
Stethojulis strigiventer	–	–	–	–	0.4
**Upeneus tragula*	–	–	–	–	4.1
Xiphasia matsubaria	–	–	–	–	0.4
Cephalopoda (unidentified)	18.7	–	–	–	1.2
Teleostei (unidentified)	6.2	–	–	55.9	10.2
Total prey (n)	16	56	10	34	266

They make up approximately half the total numbers of organisms discarded, and most float after being discarded (Harris & Poiner 1990). The composition of discards was similar at both study sites, with significant rank order correlations regardless of time of year (Spearman's ρ 0.7, $p < 0.01$). The composition of discards in the Far Northern Section was similar in trawled areas and the closed area (Spearman's ρ 0.86, $p < 0.001$ for March, 0.81, $p < 0.001$ for May).

The length ranges of the species that form the bycatch are listed in Table 3. The Sulidae and Fregatidae ate even the longest specimens of these species, but none of the terns, except *Hydroprogne caspia*, could apparently do so (Table 4).

The overall proportions of benthic trawl bycatch prey and pelagic prey are shown for each species in Fig. 2. The species whose diets consist of at least 20% discard taxa are *Sterna bergii, S. dougallii* and perhaps *S. anaetheta*; those with between 5 and 19% are *Hydroprogne caspia, Anous stolidus, Sula bengalensis, S. leucogaster* and *F. ariel*; those with <5% are *Sterna sumatrana*; and those with none, *Sula dactylatra* and *S. sula*. This categorisation is not rigid, however, as considerable variations within species were recorded, both in relation to open and closed fishing seasons and open and closed zones.

Prawn trawling effort and seabird breeding in the study areas

March of each year, which is immediately after the opening of the trawling season, had the greatest number of trawling days per month (Fig. 4). The bycatch would also have been at its greatest. Around Lizard Island catches became smaller as the year progressed, but discards would have been available throughout the season, until it ended in mid-December (Fig. 4b). In the southern part of the Far Northern Section the pattern was similar, but north of the

Table 6. *Anous stolidus* and *Sterna sumatrana*. Diets of common noddy and black-naped tern in the Lizard Island area during closed and open seasons and in the Far Northern Section (FNS) closed zone and trawl grounds expressed as percentages of the number of food items eaten. *Benthic taxa

Prey taxa	*Anous stolidus*			*Sterna sumatrana*			
	Lizard Island		FNS	Lizard Island		NFS	
	Closed season	Open season	Trawl ground	Closed season	Open season	Closed zone	Trawl ground
Amblygaster sirm	–	–	–	0.5	–	–	–
*Apogonidae	0.6	6.8	–	1.6	0.6	–	–
Atherinomorus lacunosus	54.4	14.1	11.4	59.5	77.0	80.0	36.9
**Choerodon* spp	–	<0.1	–	–	–	–	–
Clupeidae	–	1.3	–	2.4	–	–	–
Encrasicholina sp.	–	0.6	–	7.9	–	–	–
*Gobiidae	–	0.3	–	–	–	–	–
Herklotsichthys quadrimaculatus	33.7	39.3	82.9	17.9	18.2	16.9	59.5
*Pomacentridae	1.0	0.1	–	5.0	–	–	–
Spratelloides gracilis	–	0.1	–	–	–	–	–
Spratelloides sp.	2.8	21.9	5.7	–	3.7	4.1	2.4
Teuthoidea	0.2	–	–	–	–	–	–
**Upeneus tragula*	1.2	–	–	–	–	–	–
Mullidae	–	0.1	–	–	–	–	–
Unidentified teleosts	6.1	1.3	–	1.1	0.4	–	1.2
Total number of prey	507	1569	35	380	488	59	84

Table 7. *Sula leucogaster*. Diets of brown booby from the closed zone (Jul 1992, Mar 1993, Dec 1993 combined) and adjacent trawl grounds (Apr 1992) of the Far Northern Section of the Great Barrier Reef expressed as percentages of the number of food items eaten (*benthic taxa; ml: mantle length). The length ranges (SL in mm) of prey are also shown

Prey taxa	Closed zone	Trawl grounds	SL
Amblygaster sirm	2.0	–	115–195
*Apogonidae	9.3	–	26–98
*Bivalvia	–	0.4	–
Caesio caerulaurea	–	1.6	92–149
Coryphaena hypura	–	0.8	94–101
Decapterus russelli	0.3	4.8	40–110
Euleptorhamphus viridis	0.3	–	203
Exocoetidae (7 taxa)	8.0	8.0	49–256
Green turtle hatchlings	3.9	–	38–54
Halichoeres sp.	0.3	–	79
Hyporhamphus affinis	–	5.2	87–250
**Kyphosus* sp.	0.3	–	78
**Lethrinus* sp.	0.3	–	140
Megalaspis cordyla	0.3	–	115
Mulloides sp.	26.2	28.7	38–59
*Pomacentridae	–	0.8	26–52
Psenes sp.	–	1.2	92–105
Scomberoides sp.	0.6	–	80
Scomberomorous sp.	0.3	–	79
Scombridae	0.3	–	170
Selar sp.	0.3	–	100
Sepia sp.	0.3	–	95 (ml)
Seriola sp.	–	1.2	38–64
Spratelloides delicatulus	25.1	–	25–55
Sthenoteuthis sp.	14.1	38.2	26–185 (ml)
**Terapon jarbua*	–	2.8	48–90
Teuthoidea	7.3	–	28–212 (ml)
Unidentified teleosts	0.6	6.1	29–200
Total number of prey	355	251	

closed zone (Fig. 1), catches were more evenly spread through the fishing season (Fig. 4a).

The breeding times for each bird species in the 2 areas are also shown in Fig. 4. Around Lizard Island *Sterna bergii*, *S. bengalensis*, *S. anaetheta* and *S. sumatrana* all nested and raised young in the closed fishing season (CSIRO unpubl. records), whereas *Hydroprogne caspia* nested in June and July (Fig. 4b). In the Far Northern Section most species likewise showed peak breeding activity from November to February, but some *S. bergii*, *S. anaetheta* and *Anous stolidus* also nested in June and July (CSIRO and Queensland Department of Environment and Heritage unpubl. records) (Fig. 4a).

DISCUSSION

Diets

In both study areas the diet of *Sterna bergii* (crested tern) contained trawl bycatch species except in the closed season (Table 2, Fig. 2). This tern took larger prey than any of the other tern species except *Hydro-*

progne caspia (Table 4). Its ability to eat the longer fish, which has been recorded in other areas (Blaber & Wassenberg 1989, Hulsman et al. 1989, Smith 1993), increases the range of discard taxa it can eat. *S. bergii* actively follows trawlers and feeds on bycatch as it is being discarded (Blaber & Wassenberg 1989, Hill & Wassenberg 1990, Blaber & Milton 1994). Outside the trawling season, *S. bergii* eats almost solely pelagic species, as reported elsewhere (Hulsman et al. 1989, Smith 1993). The other 2 tern species that ate considerable quantities of benthic species (*S. anaetheta* and *S. dougallii*) have not been recorded following trawlers (Blaber & Milton 1994). However, many of the discard species, particularly apogonids, float for up to 6 h and are thus available to birds foraging down wind or down current from trawling (Harris & Poiner 1990). The high incidence of benthic gobiids in *S. dougallii* is harder to explain as gobies sink when discarded (Harris & Poiner 1990). Some might have been taken from reef crests during natural foraging (Hulsman 1987), but it is likely that most were bycatch of trawlers. The high incidence of trawl discards in *S. anaetheta* diets in February 1994 and not in previous years may be attributable to trawlers 'dipping their nets' while travelling north for the opening of the season at the beginning of March (Gribble pers. comm., QDPI unpubl. records).

Data on *Sterna bengalensis* were only available from the Lizard Island area at the end of the closed season in February 1994. They indicate there was some discard feeding — possibly also from 'net dipping'. *S. bengalensis* seldom forages far from land (Harrison 1983).

The smaller terns (*Anous stolidus* and *Sterna sumatrana*) feed on smaller prey (Table 5; Hulsman 1988) and trawl discard

Table 8. *Sula sula* and *S. dactylatra*. Diets of red-footed booby and masked booby in the closed zone of the Far Northern Section of the Great Barrier Reef in December 1993, expressed as percentages of the number of food items eaten. The length ranges (SL in mm) of prey are given

Prey taxa	*S. dactylatra* %	*S. dactylatra* SL	*S. sula* %	*S. sula* SL
Beloniformes	1.3	200	–	–
Caesio caerulaurea	1.3	200	–	–
Cheilopogon sp.	2.6	199–205	2.3	153
Cypselurus sp.	15.8	162–260	11.4	127–190
Decapterus russelli	–	–	6.8	50–59
Exocoetidae	40.8	100–240	13.6	35–170
Exocoetus volitans	2.6	176–180	–	–
Fodiator sp.	1.3	147	–	–
Hirundichthys sp.	23.7	145–225	–	–
Paraexocoetus sp.	1.3	135	–	–
Prognichthys sp.	1.3	166	–	–
Scombridae	1.3	200	–	–
Sthenoteuthis sp.	6.7	57–80	54.6	30–85
Teuthoidea	–	–	4.5	50–55
Unidentified teleost	–	–	6.8	50–60
Total number of prey	76		44	
Overall length ranges		57–260		30–190

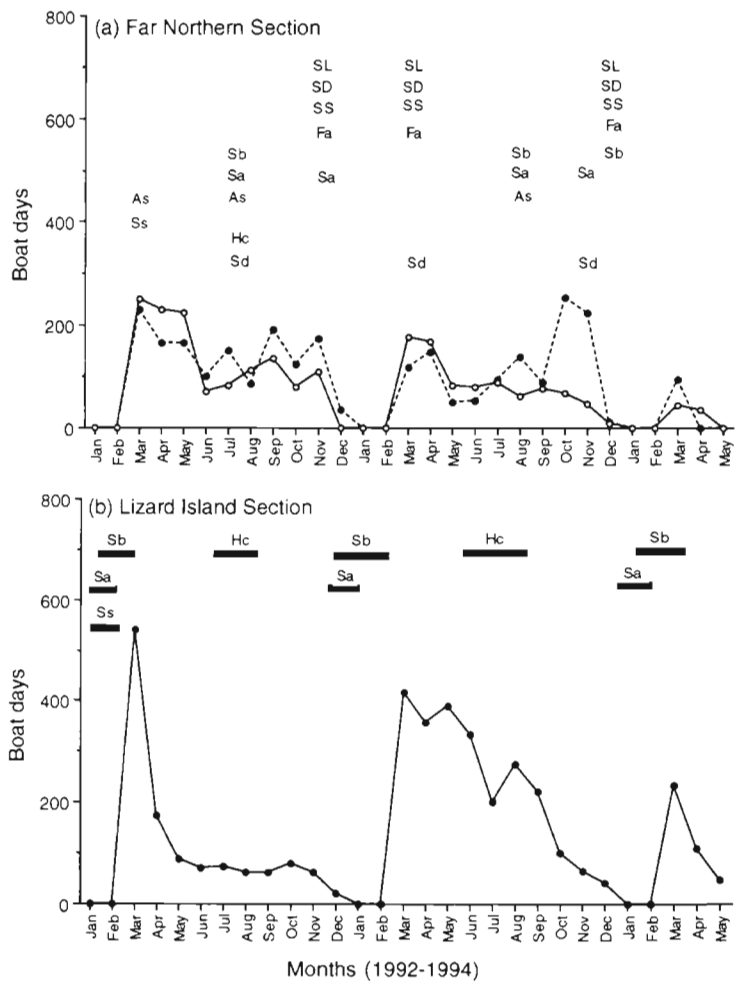

Fig. 4. Prawn trawling effort (a) in the Far Northern Section, north (●) and south (○) of the closed zone, and (b) around Lizard Island during the study period. Breeding records are shown for the Far Northern Section and full nesting periods (solid bars) for the Lizard Island area. As: *Anous stolidus*; Hc: *Hydroprogne caspia*; Sa: *Sterna anaetheta*; Sb: *S. bergii*; Sd: *S. dougallii*; Ss: *S. sumatrana*; Fa: *Fregata ariel*; SD: *Sula dactylatra*; SL: *S. leucogaster*; SS: *S. sula*

taxa are probably only incidental in their diets, either being taken in natural foraging or from floating material.

Hydroprogne caspia took a large size range of prey (Table 5) as has been previously recorded (Whitfield & Blaber 1978), but few were discard species. It has not been recorded following ships and the incidence of benthic prey must either be natural or from floating bycatch.

On Northeast Herald Cay, far from any trawling, the diets of the 3 boobies consisted of similar pelagic taxa but in different proportions (Table 10, Fig. 3). Of the boobies in the closed zone of the Far Northern Section, only *Sula leucogaster* was recorded feeding on discard taxa, presumably coming from adjacent areas open to trawling. However, discards were only a small portion of its diet. In northern Australian waters *S. leucogaster* actively follows trawlers and takes discards as they are jettisoned (Blaber & Milton 1994). It is noteworthy that *S. leucogaster* eats a wider variety of prey than the other boobies. These results support Harrison et al. (1984), who suggested that *S. leucogaster* is highly opportunistic and able to exploit almost any available prey, whereas throughout its range, *S. dactylatra* has a remarkably stable diet of flying fishes and squid. In our study, *S. dactylatra* and *S. sula* took no discard species.

The diet of *Fregata ariel* in the closed zone of the Far Northern Section included a relatively small proportion of discard taxa, probably scavenged from trawlers working to the north or south of the closed area. In areas far from trawling both *F. ariel* and *F. minor* eat only pelagic species (Table 10). As our data were obtained from breeding colonies in the closed zone, they may underrepresent the importance of discards to nonbreeding birds, which are very active around trawlers in northern Australia, both scavenging from the surface and pirating from other species (Blaber & Milton 1994).

Table 9. *Fregata ariel*. Diets of least frigatebird in the Far Northern Section closed zone in March and December 1993 expressed as percentages of the number of food items eaten. The prey length ranges (SL in mm) are given. *Benthic taxa

Prey taxa	March 1993		December 1993	
	%	SL	%	SL
Alepes sp.	1.3	100	–	–
Amblygaster sirm	–	–	1.0	170–184
Argyropelecus sp.	10.5	50–90	5.0	45–80
Beloniformes	–	–	0.4	160
Carangidae	6.6	85–115	–	–
Cheilopogon sp.	6.6	60–101	–	–
Clupeidae	1.3	95	–	–
Cypselurus sp.	–	–	0.4	190
Decapterus russelli	–	–	0.4	65
Encrasicholina sp.	18.4	28–36	–	–
Exocoetidae	9.2	100–150	6.5	114–220
Gerres oyena	2.6	112–120	–	–
Gymnocaesio gymnoptera	2.6	113–130	–	–
Hirundichthys sp.	2.6	155–180	2.5	170–196
*Labridae	–	–	0.4	115
*Leiognathidae	1.3	90	0.4	90
Lethrinus sp.	1.3	90	–	–
*Lethrinus nematacanthus	4.0	83–115	–	–
Nemipterus sp.	–	–	1.0	120–160
Paramonacanthus sp.	–	–	2.2	24–33
Pentapodus paradiseus	1.3	125	1.5	130–160
Rhabdamia sp.	–	–	0.4	20
Scombridae	5.3	100–140	0.7	54–121
Selar sp.	2.6	80–135	0.4	164
Selaroides leptolepis	–	–	7.3	95–142
Sepia sp.	–	–	0.4	100
*Sillaginidae	4.0	100–120	–	–
Sthenoteuthis sp.	2.6	37–42	41.1	22–102
Teuthoidea	15.8	40–105	21.5	30–90
*Upeneus luzonius	1.3	95	–	–
Unidentified teleosts	–	–	6.5	50–170
Total number of prey	76	28–180	275	20–220

Availability

Although considerable quantities of discards were available in the study areas, their impact on the diets and feeding ecology of the various seabirds was not uniform. Some species — notably *Sterna bergii* — fed predominantly on discards in the trawling season, but others — such as *Anous stolidus* and *Hydroprogne caspia* — changed their diets little. About half the bycatch that is discarded is of a size suitable for one or more of the seabirds, and as most of this half floats, it may be available for up to 6 h after discarding (Harris & Poiner 1990). Species such as *S. bergii*, *Sula leucogaster* and *Fregata ariel* are actively opportunistic, feeding around trawlers during discarding, but *Sterna anaetheta* and *S. dougallii* may be passive discard feeders, taking floating discards some distance away from the site of dumping.

There is no evidence that the availability of discards has resulted in the birds taking larger specimens of their normal prey (Diamond 1978, Hulsman 1988, Blaber & Wassenberg 1989, Smith 1993). However, it may have affected feeding strategies. The greater availability of discards of similar taxa may have led to greater over-

lap in the diets of the seabird species. For example, the diets of *Sterna bergii*, *S. anaetheta*, *Sula leucogaster* and *Fregata ariel* overlap, whereas previously this might have been minimised by behavioural or morphological characteristics. Ashmole & Ashmole (1967) stated that 'competition is reduced mainly by differences in feeding methods'; this important paradigm may be less significant where a superabundance of food of a limited range of taxa is provided artificially, as with trawl discard. Also, although discarding may not have greatly affected the sizes of prey taken (for there are still weight and size limitations, as well as differences in bill morphology; Hulsman 1988), it may have changed the mix of prey species and could have affected feeding behaviour. For example, *S. bergii* now feed behind trawlers at night (Blaber & Wassenberg 1989) and *F. ariel*, instead of pirating from other species, pick up prey directly from the surface. Hence, as in the northern hemisphere (Furness et al. 1988), the availability and quantity of discards in tropical waters may cause major changes in the feeding ecology of some seabird species, changes that may be facilitated by the essential 'dynamism of their niches' (Hulsman 1987).

Effects of fishing on reproduction

Fluctuations in the availability of prey are thought to have a marked impact on the timing of breeding in tropical seabirds (e.g. Seki & Harrison 1989, Morris & Chardine 1992, Smith 1993). As the quantities of bycatch on the northern Great Barrier Reef are large, it is important to find out whether the seabirds on the reef are affected.

In the Lizard Island area, the terns (except for *Hydroprogne caspia*) breed in the summer when there is little or no trawling activity (Fig. 4; Smith 1993). The young are usually fully fledged before the trawling season opens (Smith 1993, CSIRO unpubl.

Table 10. Diets of seabirds from Northeast Herald Cay analysed from material collected in November 1992 and August 1993. Diet values are percentage of the number of food items eaten. Length ranges (SL in mm) of prey are also given

Prey taxa	*Sula leucogaster*			*Sula dactylatra*			*Sula sula*			*Fregata minor*			*Fregata ariel*		
	Nov 92	Aug 93	SL	Nov 92	Aug 93	SL	Nov 92	Aug 93	SL	Nov 92	Aug 93	SL	Nov 92	Nov 93	SL
Auxis sp.	3.4	–	150–195	–	12.0	200–290	–	–	–	–	–		–	–	–
Beloniformes	–	–	–	–	4.0	200	–	0.9	96	–	–	–	–	50.0	51
Cheilopogon spp.	–	–	–	16.2	20.0	194–315	–	–	–	–	–	–	–	–	–
Clupeidae (unidentifiable)	1.7	–	73	–	–	–	–	–	–	–	–	–	–	–	–
Carangidae (unidentifiable)	6.8	–	80–195	–	–	–	–	–	–	–	–	–	–	50.0	43
Coryphaena sp.	–	–	–	2.3	–	133	–	–	–	–	–	–	–	–	–
Cypselurus spp.	–	–	–	–	12.0	108–149	–	–	–	–	–	–	–	–	–
Decapterus sp.	5.1	–	85–134	2.3	–	123	3.3	–	110–180	–	–	–	–	–	–
Encrasicholina heteroloba	–	92.5	20–37	–	–	–	34.4	6.9	18–69	–	–	–	–	–	–
Exocoetidae (unidentifiable)	35.6	–	50–240	37.2	8.0	80–261	24.4	0.9	66–190	5.9	100	120–170	18.2	–	–
Hemiramphidae (unidentifiable)	1.7	1.9	75–260	–	–	–	–	–	–	–	–	–	–	–	–
Hirundichthys spp.	–	–	–	16.2	4.0	85–214	–	0.9	130	–	–	–	–	–	–
Hyporhamphus quoyi	–	–	–	–	–	–	6.7	–	60–120	–	–	–	–	–	–
Katsuwonus pelamis	11.9	–	70–185	18.6	–	140–225	8.9	–	84–165	17.6	–	130–146	–	–	–
Pampus spp.	–	–	–	–	–	–	–	1.7	25–30	–	–	–	–	–	–
Paraexocoetus spp.	–	0.6	137	–	–	–	–	–	–	–	–	–	–	–	–
Seriolina sp.	–	–	–	–	–	–	–	–	–	–	–	–	2.3	–	150
Sthenoteuthis spp.	15.2	4.4	23–101	7.0	28.0	51–100	22.2	69.8	20–100	70.6	–	59–100	79.5	–	40–104
Teleostei (unidentifiable)	5.1	0.6	29–224	–	12.0	60–100	–	0.9	–	5.9	–	170	–	–	–
Xiphasia matsubarai	3.4	–	300–370	–	–	–	–	–	–	–	–	–	–	–	–
Xiphasia setifer	10.2	–	120–270	–	–	–	–	18.0	50–150	–	–	–	–	–	–
Total number of prey	59	160	20–370	36	25	51–315	90	116	18–190	17	4	59–170	44	2	40–150

data). However, *Sterna bergii*, the species that takes most discards, breeds later than the other species, and it may be significant that the largest bycatch is in March, when the juveniles are learning to forage. This could have 2 important consequences: firstly, the juvenile birds become conditioned to feeding on discards, and secondly, all the 'extra' food may reduce juvenile mortality rates. The huge increases in populations of *S. bergii* in the southeast Gulf of Carpentaria, Australia, are thought to have been due to the development of the large prawn trawl fishery, which discards large quantities of bycatch (Walker 1992, Blaber & Milton 1994).

Sterna anaetheta and *S. sumatrana* breed earlier and eat fewer bycatch species; hence discards have probably had little impact on their breeding. Likewise, the breeding pattern of *Hydroprogne caspia* is probably not affected by discards (Fig. 2); it is a winter breeder in the Lizard Island area and Far Northern Section, as it is elsewhere in the world (Whitfield & Blaber 1978, Harrison 1983).

As Smith (1993) stated, the breeding of *Sterna bergii* in the Lizard Island area is considerably more synchronous than at other sites on the Great Barrier Reef. This is thought to be due to the brevity of natural food pulses sufficient to permit breeding. During the study period *S. bergii* in the Far Northern Section also bred in summer (when there were few discards), and at mid-year (Fig. 5) (when there were many). More than half the food at this time consisted of trawl taxa, even within the closed zone (Fig. 2). These data suggest that food supply may not influence breeding times.

The other tern species in the Far Northern Section that bred in winter as well as summer were *Anous stolidus*, *Sterna anaetheta*, *S. sumatrana* and *S. dougallii*. The first 3 of these took few or no discards, but — although our sample sizes were relatively small — about half of the diet of *S. dougallii* consisted of benthic gobies. However, *S. dougallii*, which bred during the fishing season, is an unpredictable species throughout the world, particularly on the Great Barrier Reef (Smith 1991). In the northern hemisphere its breeding may be controlled by prey availability (Safina et al. 1988). There was high mortality of juvenile *S. dougallii* at breeding colonies in the Far Northern Section during the study period (Milton et al. 1996). This may have been caused by fluctuations in food supply, possibly influenced by changing availability of discards, but other factors such as weather conditions, particularly wind-speed and sea-surface conditions, can affect the fishing ability of terns (Dunn 1973).

Breeding records (1979–1987) for the 3 *Sula* species and *Fregata ariel* show that they breed for most months of the year in the closed zone of the Far Northern Section (Taplin & Blaber 1993). During our study they nested during times of declining as well as increasing abundance of bycatch. Although *S. leucogaster* and *F. ariel* from colonies in the closed zone forage discards from the trawling grounds, the quantities are small and there seems little evidence that discarding influences their times of breeding.

While it is apparent that discards have changed the diets of some seabird species in the northern Great Barrier Reef, there is little evidence that they have directly affected timing of breeding, despite the seasonal nature of bycatch availability. Breeding cycles are probably still determined mainly by the sharp peaks in abundance of pelagic prey (Smith 1993). Nevertheless, the provision of discards may have increased the overlap in the diets of most species and influenced the feeding strategies of at least *Sterna bergii, Sula leucogaster* and *Fregata ariel*. Any effects on population sizes, such as have been reported in the southeast Gulf of Carpentaria (Walker 1992), are harder to define (Ryan & Molony 1988). They will be studied over a longer term; but it is noteworthy that the effects on population sizes of changes in, or cessation of, trawling activity may be more drastic than the initial provision of discards (Furness & Monaghan 1987).

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