THE EFFECTS OF WIND AND SEA ON THE FEEDING OF ANTARCTIC TERNS AT THE SNARES ISLANDS, NEW ZEALAND*

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ABSTRACT

The effect of wind and sea conditions on the feeding of Antarctic Terns *(Sterna vittata bethunei)* was studied during three visits to the Snares Islands. The terns preyed upon fish and swarms of crustaceans. Increasing wind speed significantly reduced the terns' capture rate and feeding success. The terns fed in similar ways with calm and moderate seas. However, rough seas significantly reduced the attempt rate, capture rate, and feeding success of terns feeding on fish and the capture rate and success of terns feeding on crustaceans. Foraging techniques varied with the type of prey sought and sea conditions. To catch fish, the terns mostly plunge dived in calm seas but contact dipped for 40-46% of attempts in moderate and rough seas. They caught crustaceans mainly by contact dipping, but used partial plunge diving more in moderate and rough seas. Wind speed and sea conditions seemed to affect terns feeding on crustaceans by making prey move away from the surface. Several other species of seabirds joined the terns to feed on crustacean swarms. Interspecific interactions were minor; however, large flocks of Sooty Shearwaters *(Puffinus griseus)* displaced terns from feeding on swarms.

INTRODUCTION

Most terns of the genus *Sterna* feed at sea by diving. Because they find their prey by sight and then do elaborate aerial manoeuvring their ability to feed is affected by such environmental factors as wind speed and sea conditions. For example, the fishing success of Arctic Terns *(Sterna paradisaea)* decreased in windy conditions (Bengtson 1966). However, although increasing wind significantly reduced the capture rates of Common Terns *(S. hirundo)* and Sandwich Terns *(S. sandvicensis)*, their capture success did not change (Taylor 1983). Dunn (1973) observed Common Terns and Sandwich Terns feeding at sea and, although he was unable to observe birds feeding in high winds, found that capture rates were greater in moderate than in calm sea conditions. Reed & Ha (1983) also found that the capture rate of aerial feeding Forster's Terns *(S. forsteri)* increased from calm to mild-wind conditions.

Wind and sea conditions, by affecting the food capture rate of adult terns, may also affect the growth rate of tern chicks. Dunn (1975) showed that greater wind speed markedly slowed the growth rate of Roseate Tern *(S. dougallii)* chicks, that even light winds may reduce the growth rate of Common Tern chicks, but that wind speed had negligible effect on the growth rate of Sandwich Tern chicks. Presumably the terns could not feed their chicks sufficiently in windy conditions (Roseate Terns) or calm conditions (Common Terns).

The Antarctic Tern *(S. vittata)* is circumpolar, breeding in coastal areas from about 47°S to 68°S (Watson 1975). In the New Zealand region it breeds

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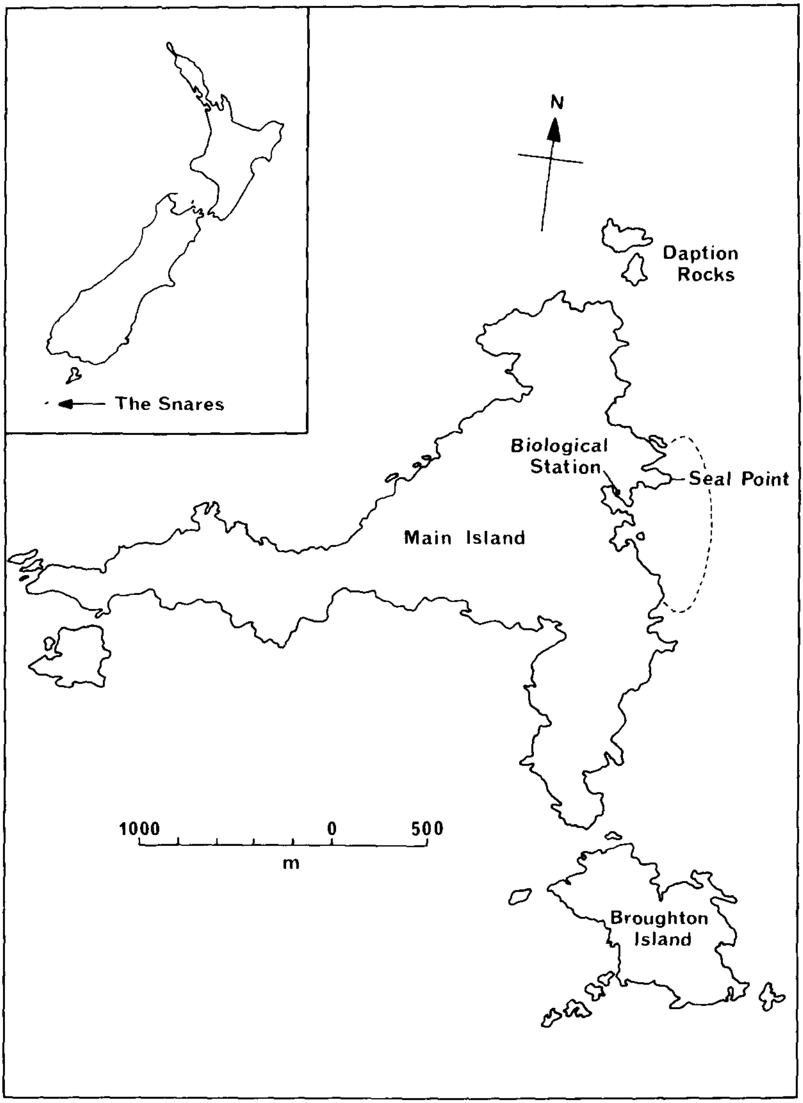

FIGURE 1 — The Snares Islands, showing the location of place names mentioned in the text (Western Chain and Vancouver Rock excluded from the map). Dotted line indicates approximate limit of observations made from Seal Point

on Campbell, Auckland, Snares, Antipodes, Bounty and South Cape Islands (Falla *et al.* 1970). The climate at these islands is very windy and the seas are rough, and so we expected them to affect the feeding ability of Antarctic Terns. Bad weather at the Snares can severely restrict the growth of Antarctic Tern chicks and be a major factor in chick mortality (Sagar 1978), and so our aim during three visits to the Snares was to study more precisely the effects of wind speed and sea conditions on the feeding of Antarctic Terns.

STUDY AREA

The coastline of all the islands of the Snares (44°02'S, 166°36'E) (Figure 1) consists of precipitous cliffs and there is no shallow water in the vicinity. Kelp *(Durvillea antarctica)* predominates in the intertidal zone of the cliff faces, and its fronds may extend several metres offshore, depending on the tidal surge.

The climate is cool temperate, moist and windy. In the daily weather records taken on Station Point at 0900 h during the three summers of this study, the main wind directions were westerly (28%), northerly (20%), and northwesterly (13%). The most recorded surface-wind strength during November to January was 3 on the Beaufort scale (12-19 km/h), with winds of 20 km/h and above occurring 38% of the time. Gales (8 and above on the Beaufort scale) were recorded on up to 8 days each month.

METHODS

The feeding of Antarctic Terns at the Snares was observed during visits from 3 to 26 January 1984, 2 to 21 November 1985, and 22 October to 16 November 1986. How many terns fed about the islands and where they fed was noted. The main study site, however, was near the tip of Seal Point (within the dotted line in Figure 1), where the terns were observed as they foraged close inshore. All observations were made by PMS using a 20-45x telescope. In estuaries the availability of food for terns can vary according to the state of the tide (Taylor 1983) and so, although this may not apply to the relatively deep water off the Snares, all observation periods were restricted to two hours about mid-tide. Sea spray prevented observations at wind speeds above 50 km/h (i.e. gale force).

TABLE 1 — Summary of Antarctic Tern feeding observations recorded at the Snares

		Sea conditions								
		Calm			Moderate			Rough		
Main prey	Year	No. days	No. birds	No. feeding attempts	No. days	No. birds	No. feeding attempts	No. days	No. birds	No. feeding attempts
Fish	1984	6	45	510	9	99	874	4	32	189
	1985	1	6	14	0	0	0	2	16	103
	1986	0	0	0	0	0	0	2	20	26
Crustacea	1984	2	15	521	2	24	893	1	8	169
	1985	7	71	1718	1	11	138	4	40	717
	1986	10	101	1309	3	30	480	2	20	439

During each of 56 observation periods (Table 1) we watched adult terns in breeding plumage foraging (flying with bill pointed down) for at least 2 minutes per tern. We attempted to record the timed foraging activities of at least 10 terns during each observation period, but this was not always possible.

We recorded each tern's capture attempts, successful captures, foraging action and, when possible, the kind of prey captured.

Any distinct initiation of a dive towards the water was taken as a capture attempt. When a bird did not reach the water the attempt was recorded as aborted. The capture of fish was easy to observe because the tern emerged from the water with the fish held across its bill. The capture of a crustacean, however, could only be assumed, based on a tern swallowing shortly after emerging from the water.

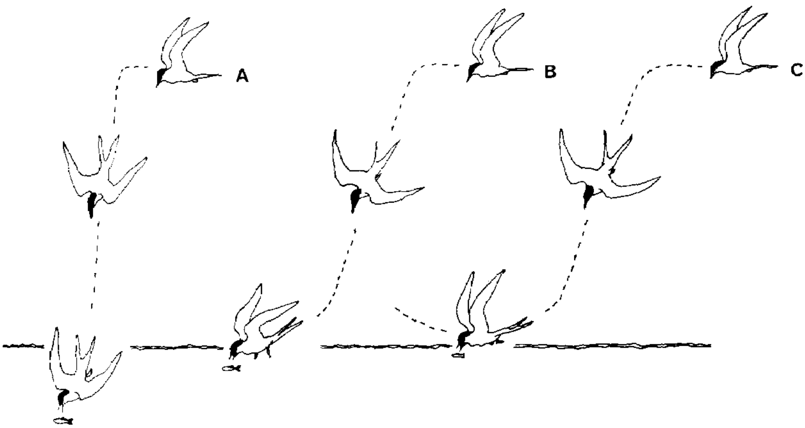

FIGURE 2 — Prey capture methods used by Antarctic Terns. A – Full plunge. B – Partial plunge. C – Contact dip.

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The terns used three capture methods (Figure 2), the same as Taylor (1983) recorded during his study of Common and Sandwich Terns:

1. *Contact dipping:* A bird descended to the water but only its bill came into contact with the water, the prey being caught from near the surface and the tern remaining in flight throughout.
2. *Full plunge:* A tern descended almost vertically and submerged completely.
3. *Partial plunge:* This was like the full plunge but the bird levelled out partly before reaching the water so that only its head and breast were submerged.

By combining observations of all birds recorded during an observation period we calculated their mean attempt rate (number of feeding actions each minute), mean capture rate (number of prey caught each minute), and mean percentage feeding success (proportion of successful feeding actions).

Terns feeding alone usually defended fishing areas and chased off other terns, but this behaviour was rare when the terns fed in a flock. Although wind and sea conditions presumably affect them in the same way, solitary and flock feeders feeding on fish on the same days might differ in their attempt and success rates. We have therefore omitted observations of terns in flocks feeding on fish. In the following analyses all terns feeding on fish were solitary and all terns feeding on crustaceans were in flocks.

For each observation period, the sea surface was classified as calm (surface smooth or slightly ruffled and a light swell), moderate (wind chop and a light swell), or rough (white water and swell greater than 1 m). Wind speeds during each observation period were taken at the Biological Station about 200 m from the study area (1984) or from a hand-held anemometer at the observation site (1985 and 1986).

RESULTS

Feeding areas

Whenever we arrived at or left the Snares (by boat) we did not see Antarctic Terns more than about 1 km offshore. From the shore, the terns were seen to favour the small bays of the east coast of Main and Broughton Islands, the channels between islands or islets, and kelp-covered submerged or partly submerged rocks.

The bays of the east coast of Main and Broughton Islands provided relatively calm water and sheltered conditions during the prevailing westerly winds. Here, single terns tended to concentrate their foraging just off the kelp. Groups of 10-20 feeding terns were usually seen in the channels between islands, where the tidal current was strong. Swarms of crustaceans off Seal Point attracted up to 55 terns, which took mainly crustaceans but also a few fish.

Effects of wind speed and sea conditions on feeding

The attempt and capture rates and percentage of successful attempts of terns preying on fish decreased significantly at higher wind speeds (Figure 3). Increasing wind speed had no apparent effect on attempt rate when the terns were preying on crustaceans but caused a significant decrease in the capture rate and a highly significant decrease in success (Figure 4).

TABLE 2 — Mean attempt rate, capture rate and percentage success (± 1 s.e.) of Antarctic Terns preying upon fish and crustaceans in calm, moderate and rough sea conditions

	Prey					
	Fish			Crustacea		
Sea Conditions	Attempts (min^{-1})	Prey (min^{-1})	Success (%)	Attempts (min^{-1})	Prey (min^{-1})	Success (%)
Calm	1.88 ± 0.17 (n = 51 birds)	1.00 ± 0.01	49.8 ± 3.47	6.88 ± 0.36 (n = 187 birds)	4.49 ± 0.24	66.4 ± 1.19
Moderate	1.87 ± 0.11 (n = 99 birds)	0.93 ± 0.06	49.6 ± 2.21	5.91 ± 0.36 (n = 60 birds)	3.84 ± 0.26	65.1 ± 1.46
Rough	1.19 ± 0.19 (n = 68 birds)	0.39 ± 0.05	32.0 ± 4.10	7.24 ± 0.63 (n = 68 birds)	3.51 ± 0.27	52.4 ± 2.10

For both kinds of prey, wind speed was clearly not the variable influencing the feeding ability of the terns. We therefore examined the effect of sea conditions (Table 2).

There was no significant difference ($P > 0.05$) between the attempt rate, capture rate and success of terns feeding on fish and crustaceans in calm and moderate sea conditions (Table 2.) In rough sea conditions, however, the attempt rate, capture rate and success of terns feeding on fish were significantly less than during calm and moderate seas combined ($z = -3.09$, 5.99 and -3.78 respectively, $P < 0.01$). Terns feeding on crustaceans were not significantly different ($P > 0.05$) in their attempt and capture rates in any sea conditions and in their success in calm and moderate seas. The success of terns feeding on crustaceans, however, was significantly less in rough seas than that recorded in calm and moderate seas combined ($z = -4.97$, $P < 0.01$).

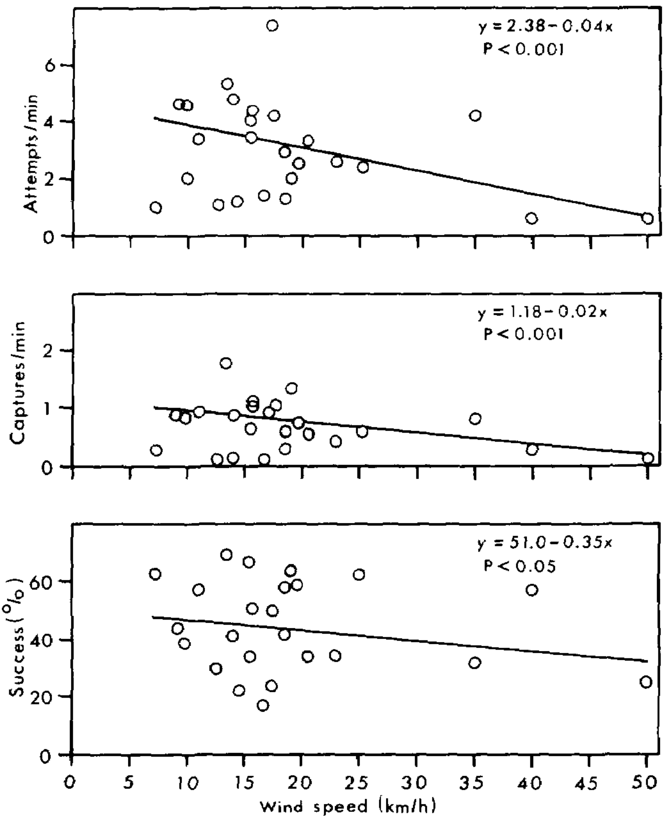

FIGURE 3 — The relationship between wind speed and attempt rate, capture rate and feeding success of Antarctic Terns preying on fish. Each point is the mean for the observation period

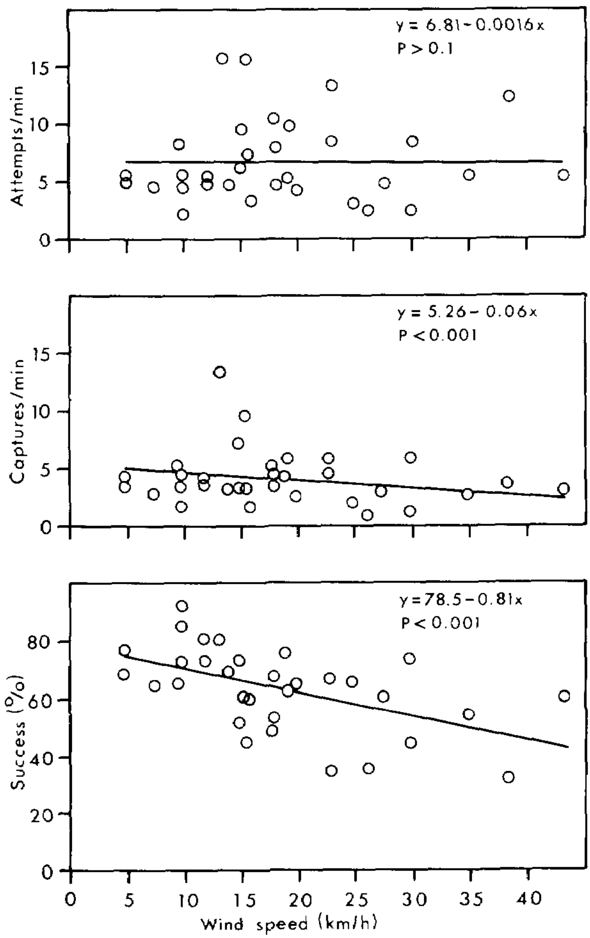

FIGURE 4 — The relationships between wind speed and attempt rate, capture rate and feeding success of Antarctic Terns preying on crustacea

Wind speed and sea conditions were highly correlated for terns feeding on fish, and their individual effects could not be statistically separated. However, for terns feeding on crustacean prey we could compare capture rates in different wind speeds with capture rates in different sea surface conditions. The range of wind speeds recorded during moderate sea conditions (5.0-25.0 km/h) overlapped completely wind speeds recorded during calm seas (5.0-27.7 km/h). For any particular wind speed within the range 5.0-25.0 km/h, the capture rate of crustaceans was higher in calm than moderate seas (Figure 5).

Neither the calm nor the moderate regression was significant, however, and there was no significant difference between the mean capture rates (calm $\bar{x}$ 4.70 s.d. 3.33, moderate $\bar{x}$ 3.84 s.d. 2.03, t = 2.32 P > 0.05). The overlap in wind speeds between calm and rough seas was in the range 14.4 to 27.7 km/h. Neither regression was significant (P > 0.05), and there was no significant difference between the mean capture rates (calm $\bar{x}$ 3.65 s.d. 2.75, rough $\bar{x}$ 4.10 s.d. 2.37, t = 0.87 P > 0.05). In addition, the elevation of all three regressions in Figure 5 suggest that sea conditions do not significantly affect capture rates independently of wind speed when Antarctic Terns prey on crustaceans.

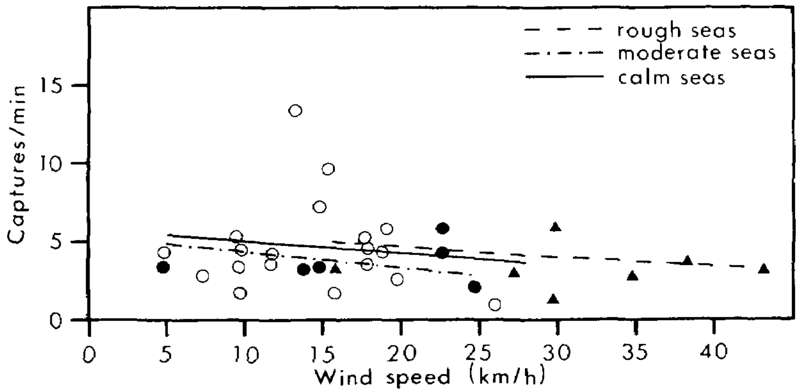

FIGURE 5 — Capture rates of crustacea by Antarctic Terns in calm (o) (y = 5.85 - 0.08x), moderate (●) (y = 5.31 - 0.10x) and rough (▲) (y = 4.90 - 0.04x) sea conditions

Changes in capture behaviour

The terns used different capture methods for fish and crustaceans and sea conditions (Table 3). They contact dipped much more when catching crustaceans than when catching fish, presumably because the crustaceans were closer to the surface than the fish. By contact dipping, the terns could feed faster than by plunge or partial plunge diving. When contact dipping, the terns usually descended from a height of only 1-3 m above the sea and, because only their bill touched the water, could regain height rapidly, ready for the next dip. The crustaceans were usually in dense swarms, as we could see from the shore, and so the terns did not have to search for each crustacean. With fish, however, they usually had to plunge dive or partial plunge dive from 3-10 m high and enter the water, which took longer than dipping. The fish were less clumped than the crustaceans, and so the terns took longer to find them – hence the greater feeding rate of terns preying on crustaceans than on fish (Table 2).

Sea conditions also affected the terns' feeding methods (Table 3). When preying on fish in calm seas, they plunge dived or partial plunge dived. With rising seas, however, they did more contact dipping, about 33% more in moderate seas, and even more in rough seas, when almost half the feeding actions were contact dips. When contact dipping in rough seas the terns usually picked the fish off the top of waves.

TABLE 3 — The relative use (%) of capture methods by Antarctic Terns when catching crustaceans and fish under different sea conditions. Sample size in brackets. Percentages calculated for each prey type and sea condition. X^2 fish = 149.4, d.f. = 4, P<0.001; X^2 crustacea = 43.2, d.f. = 4, P <0.001

	Percentage of Total Attempts					
	Fish			Crustacea		
Sea conditions	Full plunge	Partial plunge	Contact dipping	Full plunge	Partial plunge	Contact dipping
Calm	50.1 (207)	42.6 (176)	7.3 (30)	2.8 (43)	29.5 (449)	67.7 (1,029)
Moderate	42.1 (109)	17.4 (45)	40.5 (105)	2.5 (11)	40.4 (180)	57.2 (225)
Rough	32.9 (51)	21.3 (33)	45.8 (71)	2.4 (10)	44.7 (190)	52.9 (225)

Crustacea were rarely taken by full plunge diving, whatever the sea conditions. The large number of observations involved in calculating the X^2 value results in a bias towards showing a significant change in feeding techniques. As the sea rose, however, the terns increased their use of partial plunge diving to catch crustaceans (Table 3).

Interspecific interactions

The terns feeding on fish usually fed alone and covered a relatively large area in their search. Dense swarms of crustaceans, however, attracted not only more terns (maximum count 55) but also large numbers of other species.

Terns were recorded feeding on crustaceans during 32 observation periods. Other birds feeding in the same area were Cape Pigeons *(Daption capense australe)* 30 times; Red-billed Gulls *(Larus novaehollandiae)* 27; Sooty Shearwaters *(Puffinus griseus)* 16; Snares Crested Penguins *(Eudyptes robustus)* 9; Diving Petrels *(Pelecanoides urinatrix)* 7; Fairy Prions *(Pachyptila turtur)* 5; Buller's Mollymawk *(Diomedea bulleri)* 4; Salvin's Mollymawk *(Diomedea cauta salvini)* 3.

Sooty Shearwaters disrupted the terns the most. Flocks of several thousand shearwaters would arrive, diving into the water over the swarm of crustaceans, forcing the terns to go elsewhere. Usually, as soon as the terns found another swarm of crustaceans nearby and began contact dipping, the shearwaters would move and disrupt the terns again.

Cape Pigeons and Red-billed Gulls caused 10 and 7 aborted feeding attempts respectively to single terns by flying underneath as the tern was diving.

DISCUSSION

Effects of wind speed and sea conditions on feeding

The results show that high winds and rough seas reduce the feeding ability of Antarctic Terns. Rough seas significantly reduced the capture rates and plunge diving of terns feeding on fish. Taylor (1983), who had similar results with Common Terns and Sandwich Terns, suggested that changes in wave amplitude were probably more important than wind speed. This was based on the assumption that, as wave action increased, fish became harder or impossible to see. Other suggestions are that terns cannot dive well in high winds and that the fish stay deeper in rough seas (Dunn 1973).

We could not distinguish between the effects of wind speed and sea conditions for terns feeding on fish. However, Dunn (1973) reported that, for any particular wind speed, moderate sea conditions were generally associated with higher capture rate for Sandwich Terns than were calm conditions. He proposed two explanations:

1. With a light wind, terns flap less than in calm conditions while hovering before plunge diving, making them less noticeable to fish; and
2. With a slight disturbance of the sea surface, the terns may be less visible to fish.

The study of the foraging efficiency of Forster's Tern by Reed & Ha (1983) supported the second explanation. Diamond (1973), commenting on Dunn's results, suggested that, in calm conditions, the fish easily sense the tern's entry into the water and so escape (the "Mauthner Reflex" or startle-response of teleost fish). A choppy sea, however, creates enough background noise to mask the tern's splash. By this attractive explanation, prey that can be taken by contact dipping should be more vulnerable to predation than those which lie deeper in the water.

Antarctic Terns feeding on crustaceans seemed less affected by stronger winds and rough seas than terns feeding on fish. As wind speed increased, terns feeding on crustaceans increased their diving rate and so, despite a significant decrease in feeding success, their overall capture rate remained much the same. In moderate and rough seas they used partial plunge diving more and contact dipping less. One conclusion is that changes in wind and sea do not change the flying ability of the terns, possibly because the wave troughs give enough shelter from the wind for the terns to dive well. The change from contact dipping to partial plunge diving in stronger winds and rougher seas may indicate that the crustaceans had moved deeper from the rough surface waters. To catch crustaceans, the terns may need to see them well because the terns rarely plunge dived for crustaceans in any sea conditions and had less success when using partial plunge diving in rough seas.

Importance of crustaceans

Swarms of crustaceans are important for Antarctic Terns at the Snares. During this study they were the major prey of the terns during 32 of the 56 observation periods. Fenwick (1978) reported two species of euphausiids and three species of hyperiid amphiods in swarms close to the Snares. He recorded that, on two occasions, several swarms were present and that each swarm was very dense, measured about 1 m x 2 m x 2 m and moved at

2-4 m/min at 0.5-4.0 m depth. Loose swarms were at the surface, between the dense swarms. Schools of fish fed on these swarms. Presumably the swarms of crustaceans we saw were similar to those described by Fenwick (1978). Certainly fish were with the swarms because terns caught fish occasionally while feeding mainly on the crustaceans.

Most of the feeding areas favoured by Antarctic Terns at the Snares have sharply defined topographical features (e.g. narrow straits between islands and around submerged rocks) that are affected by strong tidal flow. Fenwick (1978) also noted that the sea around the Daption Rocks is often very turbulent because of strong tidal currents flowing over the irregular bottom. The resulting patches of upwelling concentrate some kinds of prey, making tern feeding very localised (Brown *et al.* 1979). Thus Braune & Gaskin (1982) were able to study large numbers of migrating gulls and terns feeding on surface concentrations of euphausiids and small fish off New Brunswick, Canada.

Disruption by shearwaters

Large numbers of petrels breed at the Snares. For example, Warham & Wilson (1982) estimated that 2.75 million pairs of Sooty Shearwaters were breeding on the islands. Sooty Shearwaters, like the terns, feed largely on such planktonic crustaceans as euphausiids and hyperiid amphipods (Fenwick 1978). Sooty Shearwaters seemed to disrupt the Antarctic Terns most, their sheer numbers driving them away from the swarms of crustaceans. In these circumstances the terns left the area, initially to avoid being hit by flying shearwaters and then because the resulting dense raft of shearwaters covered the seas where the swarm occurred. The terns then looked for other swarms nearby, and so did not seem to lack food. Shearwaters, being mainly offshore feeders, displaced terns feeding on swarms during only 50% of the observation periods. Other species seen with the terns seldom disrupted their feeding.

Although this study shows that high winds and rough seas hinder the feeding of Antarctic Terns, whether their breeding is affected is still not known. The mortality of Antarctic Tern chicks was high during a prolonged period of wet and windy weather at the Snares in 1976-77 (Sagar 1978), but the food supplied to chicks was not estimated. Ideally, food abundance and chick growth should be measured at the same time.

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LITERATURE CITED

BENGTSON, S-A. 1966. Några iakttagelser rörande pirattendenser hos tärnor och trutar. Fauna Flora: 24-30.

BRAUNE, B. M.; GASKIN, D. E. 1982. Feeding ecology of nonbreeding populations of larids off Deer Island, New Brunswick. Auk 99: 67-76.

BROWN, R. G. B.; BARKER, S. P.; GASKIN, D. E. 1979. Daytime surface swarming by *Meganyctiphanes norvegica* (M. Sars) (Crustacea, Euphausiacea) off Brier Island, Bay of Fundy. Can. J. Zool. 57: 2285-2291.

DIAMOND, J. 1973. Diving success of terns. Nature 245: 397-398.
DUNN, E. K. 1973. Changes in the fishing ability of terns associated with windspeed and sea surface conditions. Nature 244: 520-521.
DUNN, E. K. 1975. The role of environmental factors in the growth of tern chicks, J. Anim. Ecol. 44: 743-755.
FALLA, R. A.; SIBSON, R. B.; TURBOTT, E. G. 1970. A Field Guide to the Birds of New Zealand. 2nd ed. Auckland: Collins.
FENWICK, G. D. 1978. Plankton swarms and their predators at the Snares Islands. NZ J. Mar. Freshw. Res. 12: 223-224.
REED, J. M.; HA, S. J. 1983. Enhanced foraging efficiency in Forster's Terns. Wilson Bull. 95: 479-481.
SAGAR, P. M. 1978. Breeding of Antarctic Terns at the Snares Islands, New Zealand. Notornis 25: 59-70.
TAYLOR, I. R. 1983. Effect of wind on the foraging behaviour of Common and Sandwich Terns. Ornis Scand. 14: 90-96.
WARHAM, J.; WILSON, G. J. 1982. The size of the Sooty Shearwater population at the Snares Islands, New Zealand. Notornis 29: 23-30.
WATSON, G. E. 1975. Birds of the Antarctic and Subantarctic. Washington, D. C.: American Geophysical Union.

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SHORT NOTE

Starlings quick to find a new source of food

Naturalists in northern New Zealand are well aware that, when the pohutukawa (*Metrosideros excelsa*) and the flax (*Phormium tenax*) are flowering in early summer, many Starlings (*Sturnus vulgaris*) become such avid nectar-feeders that often their pates and faces are stained red with pollen.

In my garden a shrubby feijoa, somewhat less than 2 metres high, began to flower about mid-October. There seems to be no limit to the enterprise of Starlings. They are always ready to extend their empire. On 14 October 1988, when the first dark-red feijoa flowers were rather inconspicuous, I noticed a pair of local Starlings darting in and out of the heart of the feijoa where nearly all the early flowers were. The birds were very active; and it appeared to me that the activity was sparked by their excitement at finding nectar-producing flowers so early in the season, a month or more before the full flush of the pohutukawa flowering.

Pohutukawa and feijoa belong to the same family, Myrtaceae, and their flowers are superficially alike, both in size and in colour.

Nearly four weeks later, on 9 November when importunate fledgling Starlings were noisy both at the nest and in the nearby trees, I again watched a pair of yellow-billed adults busily visiting new flowers on the feijoa.

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