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Population size, breeding, and annual cycle of the New Zealand Antarctic tern (*Sterna vittata bethunei*) at the Snares Islands

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Abstract The population size, breeding, and annual cycle of Antarctic terns (*Sterna vittata bethunei*) at the subantarctic Snares Islands were studied intermittently from 1976 to 2002. During the 1983/84 and 1984/85 breeding seasons the population comprised a minimum of 65 breeding pairs. Laying dates extended from mid Sep to late Mar, with peak laying in late Oct-early Nov. Clutch size averaged 1.33 (range 1-2 eggs) and did not change through the breeding season. Both parents incubated. Hatching success was 92.7% and both parents fed the young. Fledging success was 75%, and so overall breeding success was 69.6%. Chicks were fed mostly fish by both parents and 1-chick broods were fed smaller fish and less frequently than 2-chick broods. The youngest bird recorded breeding was at least 3 years old. After the breeding season (from Mar), the terns formed flocks and moulted in the vicinity of the Snares Islands. Following the completion of moult (from Apr) they tended to move offshore, only returning to the shelter of the islands during severe weather. From mid Jul, the terns tended to roost in flocks at the Snares Islands before dispersing to form pairs and defend nesting sites.

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Keywords clutch size; site retention; chick diets; provisioning rates; *Sterna vittata*

INTRODUCTION

New Zealand Antarctic terns (*Sterna vittata bethunei*) breed on southern parts of Stewart Is and outlying islands, and at the subantarctic Snares, Antipodes, Bounty, Auckland, Campbell, and Macquarie Islands (Turbott 1990). The Macquarie Is population is sometimes considered a separate subspecies *S. v. macquariensis* (e.g., del Hoyo *et al.* 1996). The total population, including that on Macquarie Is, was estimated at <1000 pairs (Robertson & Bell 1984), and so it is considered a threatened taxon (Taylor 2000).

Little information is available about Antarctic terns in the New Zealand region. Sagar (1978) studied the breeding of a few pairs at the Snares Is during 1 season and determined general breeding parameters (incubation period averaged 24 days, chicks were guarded for 2-3 days, chicks fledged after 27-32 days). Sadleir *et al.* (1986) reported the breeding timetable, nesting sites, and annual movements of birds at Campbell and Antipodes islands. The feeding ability of Antarctic terns at the Snares Is under different wind and sea conditions was reported by Sagar & Sagar (1989), who found that feeding success decreased with increasing wind speed. Information on breeding and feeding ecology at the Snares Is was summarised by Miskelly *et al.* (2001). Other information is scattered in some general papers or short notes (e.g., Stead 1948; Bailey & Sorensen 1962; Kinsky 1969) and was summarised by Higgins & Davies (1996). Here, we provide new information on the population size at the Snares Is and describe details of the breeding and annual cycle of this poorly-known tern using observations made over several years.

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STUDY AREA & METHODS

The study was carried out at the Snares Is (48°02′S,

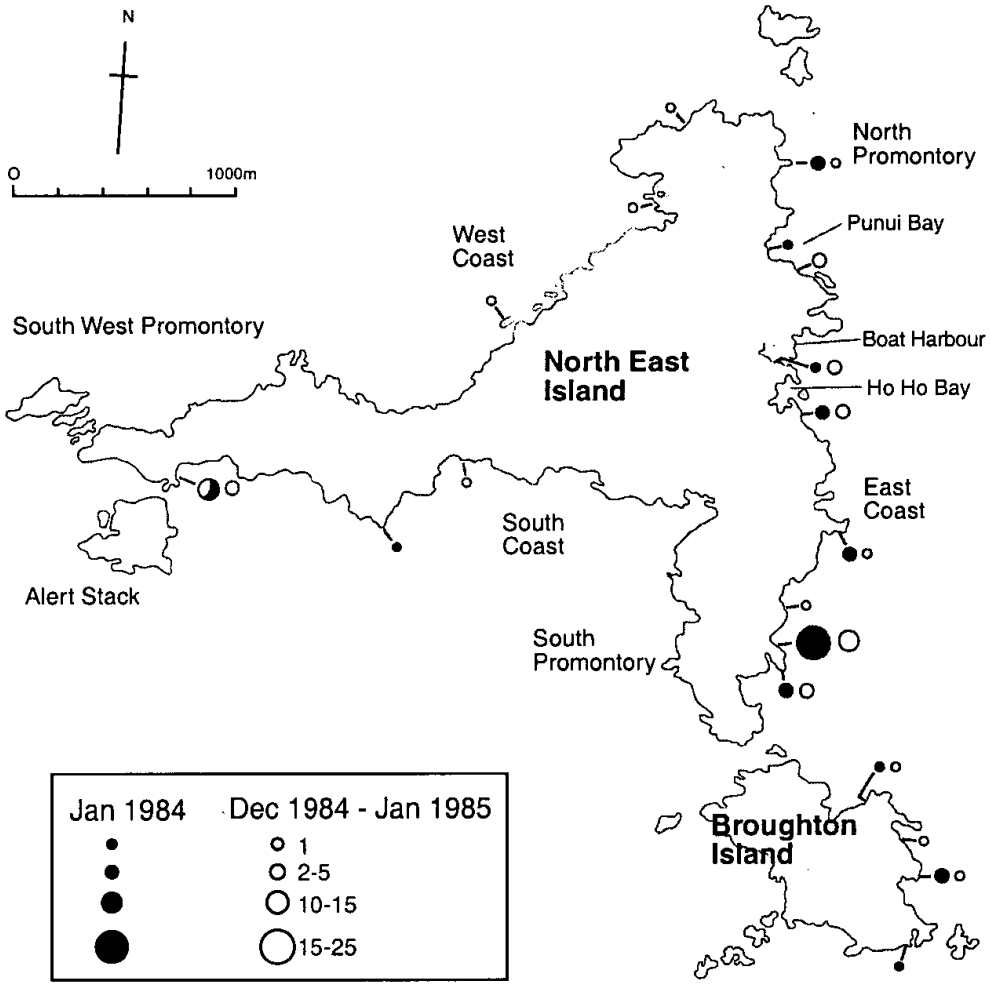

Fig. 1 The Snares Is, showing locations and numbers of Antarctic tern (*Sterna vittata bethunei*) nests or defended nesting sites, Jan 1984 and Dec 1984-Jan 1985.

166°36′E) and is based on observations made during 26 visits between Nov 1976 and Aug 2001, as follows: 9 Nov 1976 - 2 Mar 1977, 30 Nov 1983 - 26 Feb 1984, 26 Nov 1984 - 16 Feb 1985, 22 Sep - 1 Oct 1985, 2 Nov 1985 - 10 Mar 1986, 1 Dec 1985 – 10 Mar 1986, 22 Oct 1986 - 20 Feb 1987, 7 Nov - 8 Dec 1987, 3-17 Mar 1992, 1-22 Mar 1993, 22-28 Jul 1994, 23 Feb - 17 Mar 1995, 20 Jul - 2 Aug 1995, 1-19 Mar 1996, 1-20 Mar 1997, 17-27 Jul 1997, 24 Feb - 13 Mar 1998, 26 Jun 1998, 27 Jul - 5 Aug 1998, 24 Feb - 20 Mar 1999, 4-11 Jul 1999, 23 Feb – 14 Mar 2000, 15 Feb – 5 Mar 2001, 27 Jul – 6 Aug 2001, 17 Feb – 7 Mar 2002, 4 – 23 Jul 2002.

The Snares Is consist of North East Island (280 ha), Broughton Is (90 ha), and many islets and rock stacks (Fig. 1). Both main islands are cliffed along the north, south, and west coasts, but tend to slope more gently to the east. The highest point (152 m) is on the South West promontory of North East Is. The group consists of granite with a gneissic structure (Fleming 1953), overlain by peat. Most of the coastal cliffs are bare, but on ledges and more gentle slopes there is vegetation mainly composed of *Poa astonii, P. tennantiana,* and *Hebe elliptica.*

Birds and nests were counted during Jan 1984 and Dec 1984 to Jan1985. The procedure was to walk around the coastal perimeter of North East Island and Broughton Island and to record the numbers of birds ashore, active nests, and defended nesting sites. On the east coast of North East Is, all nesting sites were accessible, and so were searched on foot, but on the more precipitous western coast birds and defended nesting sites in inaccessible areas were counted from vantage points, using binoculars. Most pairs had completed breeding by the end of Jan when many abandon their breeding sites to roost in flocks nearby (Sagar 1978), and so during Jan 1984 observations concentrated on counting the numbers and determining the ages of birds present at breeding sites. In contrast, the count made Dec 1984-Jan 1985 recorded mainly the numbers of active nests and defended nesting sites.

The annual cycle and breeding biology were studied during all visits to North East Is. During the visits made from 1976 to 1987, the breeding biology was studied by visiting nests along the east coast of North East Is, from Punui Bay to South Promontory (Fig. 1) every 1-7 days. The information recorded included number and status (based on plumage) of birds, locations and contents of nests, and measurements of eggs and chicks. The frequency of feeding of chicks was determined by continuous observation periods of up to 3 h over

several days. Adult terns carry single prey items in their bills and the rate at which chicks were fed was calculated from direct observation. Prey were identified as either fish or crustaceans. Prey size of fish was assessed in relation to the length of the bill of parents, which averaged about 36 mm in live birds measured at the Snares Islands (P.M. Sagar & C.M. Miskelly, unpubl. data). The size of prey was recorded to the nearest bill length of the adult, and so fish were divided into 4 size categories: <36 mm; 37-72 mm; 73-108 mm; and >109 mm. Almost all diet and feeding observations were made by PMS. Observations of individual broods were made over several days, and so to account for changes in provisioning rates associated with the ages of the chicks the data were combined into 3 periods, for chicks aged 3-10 days, 11-20 days, and 21-32 days. For all data concerning provisioning rates, data were analysed for the number of broods observed and not the number of chicks.

Eggs were measured to the nearest 0.1 mm with vernier calipers and weighed to the nearest 0.5 g with a Pesola™ spring balance. Date of laying was the date on which the 1st egg was laid and was used only if it could be estimated to within 5 days. Laying dates were estimated where clutches were incomplete when first located or by the subtraction of the incubation period (24 days, Sagar 1978) from known hatching dates. Clutch size was recorded where there was no change in the number of eggs within three days. Clutch size was not recorded if observations began after the egg(s) had hatched. Hatching was considered successful if chicks were observed with parents or if parental behaviour indicated the presence of chicks. The latter usually involved an increase in intensity of aggression compared with that exhibited during incubation. Hatching success was calculated as the number of eggs that hatched compared to the number laid.

In addition, a hand net was used to catch breeding adults in flight, which were then fitted with unique colour band combination. In terns, males bring fish to females during courtship and incubation (Nisbet 1977), and so observation of this behaviour was used to assign gender to banded birds. Non-flying young were fitted with a numbered metal band and most also with a colour band combination to indicate year cohort.

The timing of visits from 1992 was outside the usual breeding season, and so observations then were mainly to record numbers, the presence of banded birds, and state of plumage of the birds. We compared means and standard errors using Student's *t* tests and Bartlett's tests of homogeneity of variances were used before *t* tests were applied (Zar 194). Where appropropriate, Yates' correction was applied to calculations of χ^2. Two-way analysis of variance (ANOVA) was used to estimate the effects of brood size and age of chicks on feeding frequency. Yates' correction was applied to the calculation of χ^2 testing the significance of clutch size variation between early and late in the season.

RESULTS

Population size and distribution

During Jan 1984 totals of 81 adults in breeding plumage, 26 fledglings, and 5 birds in immature plumage were counted. From Dec 1984 to Jan 1985 totals of 60 active nests (containing eggs or chicks) or pairs in breeding plumage, 5 fledglings, and 3 birds in immature plumage were recorded. Of the active nests or pairs in breeding plumage, 56 were on North East Is and 4 on Broughton Is. In addition, 1 adult in breeding plumage was seen ashore on Toru Islet of the Snares Western Chain, but no nest was located.

The distributions of birds and breeding sites were similar in both seasons with most on the east coast of North East Is (Fig. 1). The largest concentrations of nests or defended nesting sites were 25 scattered across ledges of a small cove on the South Promontory and 15 on the eastern face of a rocky promontory on the south side of the South West Promontory. No more than 5 nests or pairs were recorded at any other site.

Nest sites

On the Snares Is, Antarctic terns generally bred in small (2-25 pairs) colonies, although some pairs nested solitarily. Of 14 sites where breeding was recorded during Dec 1984 – Jan 1985, 7 contained just 1 pair.

All breeding sites were on steep slopes or cliffs next to the sea and inaccessible to New Zealand fur seals (*Arctocephalus forsteri*); no birds nested inland. For 73 nests, the mean height above sea level was 10.5 m (SD = 4.46, range, 2-21 m). Most nests were on ledges or in crevices where there was short vegetation. Of 102 nests, only 8 (7.8%) were on bare rock or peat, vegetation at the other 92.2% of sites was the tussock *Poa astonii* and/or the woody shrub *Hebe elliptica*. At 13 nests, *H. elliptica* provided complete overhead cover.

Nest site retention

Seventeen colour banded birds were found breeding in successive years and the nest site changed >5 m in 5 of 38 (14.7%) bird-years. In the 5 instances where the nest site changed, 1 changed within a breeding season and 4 changed between seasons; the distances moved ranged from 20 m to 500 m. Although observations were not made every intervening year, 2 colour-banded birds, from separate pairs, were breeding at the same sites in 6 of the 11 years between 1976 and 1987.

Table 1 Clutch size of Antarctic terns (*Sterna vittata bethunei*) at the Snares Is in relation to the median laying date.

	Clutch size (%)	
Stage of breeding season	1	2
Early 21 Sep – 31 Oct	26 (58)	19 (42)
Late 1 Nov – 20 Mar	23 (59)	16 (41)
Total	49 (58)	35 (42)

Table 2 Clutch size of Antarctic terns (*Sterna vittata bethunei*), by season at the Snares Is.

Breeding season	Clutch size (%)		
	1	2	Number of nests
1976-77	6 (60)	4 (40)	10
1983-84	0 (0)	3 (100)	3
1984-55	22 (79)	6 (21)	28
1985-86	14 (50)	14 (50)	28
1986-87	19 (76)	6 (24)	25
1987-88	28 (72)	11 (28)	39
Total	89 (67)	44 (33)	133

Mate retention

Observations over successive years of pairs where both birds were colour banded were made only twice. One pair bred together for at least 4 years and the other pair for at least 2 years.

Laying and incubation

Over all years combined the estimated laying period was from 21 Sep to the end of Dec, rarely extending into Feb and Mar (Fig. 2). Peak laying was at the end of Oct until early Nov with a 2nd, smaller, peak at the end of Nov. A replacement clutch was recorded only once. In this instance, on 10 Dec 1985 an adult with a recently hatched chick and an egg that was pipped was caught and banded with a unique colour combination. On 29 Dec 1985, this adult bird was seen incubating a single egg at a nest about 500 m away.

Overall, the clutch size was 1-2 (mean = 1.33, SD = 0.47, n = 133) and there was no change in clutch size through the season (Table 1; $\chi^2_1 = 0.373$, $P>0.05$). Clutch size varied little between years, except during 1985/86 when the proportion of 2-egg clutches was greater than all other years except 1983/84 (Table 2).

Average egg size varied little with year (Table 3: length: $F_{5,153} = 0.858$, $P > 0.05$; width: $F_{5,153} = 0.095$, $P > 0.05$) or clutch size (length: $t = 0.0026$, $df = 151$, $P > 0.1$; width: $t = 0.042$, $df = 151$, $P > 0.1$).

Incubation was completed by both parents, with assumed males undertaking significantly longer shifts than assumed females, although the sample sizes were small (males: mean = 65.8 minutes, SD = 22.9 minutes, n = 8 incubation shifts, 5 birds; females: mean = 41.3 minutes, SD = 7.3 minutes, n = 6 incubation shifts, 3 birds; $t = 3.14$, $df = 6$, $P < 0.05$). The assumed males fed a fish to the incubating females on 6 of the 8 occasions immediately before incubation changeover at the nest; assumed females did not reciprocate before they resumed incubation shifts.

Chick diets and provisioning rates

Diet and provisioning data were collected from 6 broods of 1 chick and 4 of 2 chicks. Of 332 prey items fed to the chicks, over 94% comprised fish, the remainder were crustaceans. The sizes of fish fed to 1-chick broods were significantly smaller than those fed to 2-chick broods ($\chi^2_3 = 38.5$, $P < 0.01$), with fish of <36.0 mm comprising about 61% (114/186) of the diet of 1-chick broods compared to about 30% (38/127) of the diet of 2-chick broods. Over 90% of fish delivered to chicks were up to 108 mm long.

Feeding frequency brood^{-1} increased with brood size (2-way ANOVA: $F_{1,8} = 12.89$, $P < 0.01$), and was similar irrespective of the age of the chicks (2-way ANOVA: $F_{2,8} = 1.21$, $P > 0.05$) (Fig. 3).

Although only fish and crustaceans were recorded during observations of chick diet and provisioning rates, a small, fresh seahorse was found beside a nest in Jan 1986, while in Jan 1985 a small chick regurgitated a bolus of food comprised of euphausiids.

Breeding success

For all seasons combined, hatching success was 92.7% (64/69 eggs, n = 48 clutches) and fledging success was 75.0% (48/64), and so overall breeding success was 69.6%.

Age of first breeding

One bird, banded as a near fully-feathered chick on 14 Jan 1984, was observed incubating a single egg at its natal colony on 17 Dec 1986; when aged at least 3 years. Another bird, banded as a well-feathered chick on 2 Dec 1984, was observed at its natal colony on 15 Feb 1987. This 3-year-old was in full adult breeding plumage, except that it had a dark bill tip.

Non-breeding season

The end of breeding and onset of moult out of breeding plumage was indicated by increasing numbers of the terns roosting together daily on the south side of Ho Ho Bay and Boat Harbour. Counts of terns of all ages at these roosts ranged from 4 to 10 during Jan, 10 to 74 (x = 31, SD = 20, n = 10 counts) during Feb and 13 to 101 during Mar (x = 39, SD = 23.8, n = 35 counts). During Jul-Aug, terns were seen on 31 out of 82 days, with the frequency

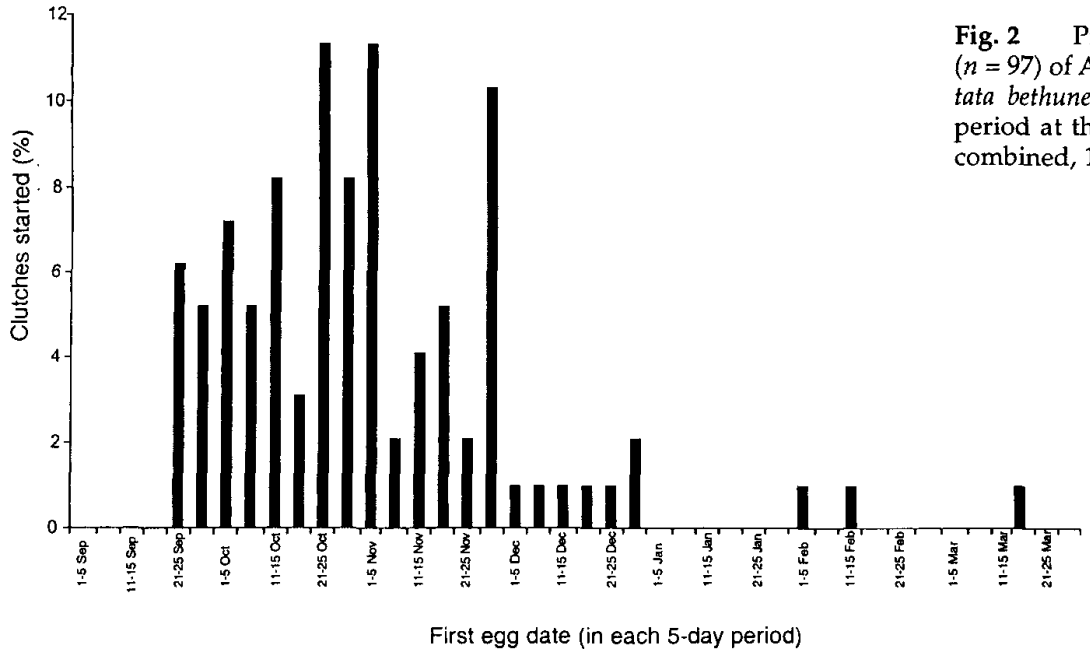

Fig. 2 Proportion (%) of clutches (n = 97) of Antarctic terns (*Sterna vittata bethunei*) started in each 5-day period at the Snares Is, for all years combined, 1976 – 1987.

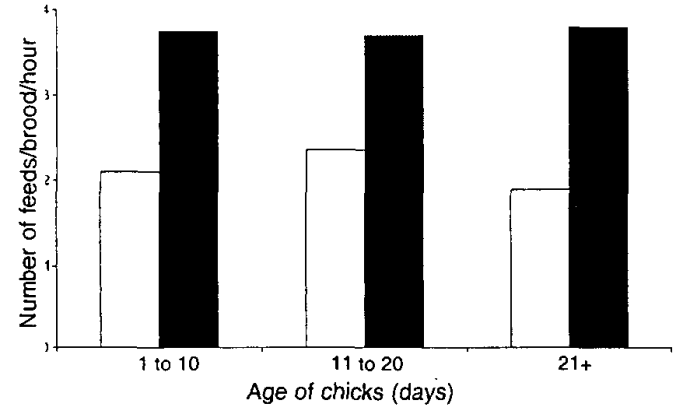

Fig. 3 Feeding rate of Antarctic tern (*Sterna vittata bethunei*) chicks in each of 3 age categories: open, 1-chick broods; filled, 2-chick broods.

of sightings and abundance of birds both increasing from mid Jul. For example, during a severe storm 30 July- 2 Aug 1998 up to 51 fed off Boat Harbour, and on 28 Jul 2001, at least 58 roosted at the south side of Ho Ho Bay.

DISCUSSION

This study provides the 1st complete count of Antarctic terns from any archipelago in the New Zealand subantarctic. With an estimated minimum population of 65 breeding pairs, the Snares Is supports an important proportion of the total population of this subspecies.

Breeding season

The breeding season of Antarctic terns extends over several months at all subantarctic islands in the New Zealand region. Following the study of Antarctic tern breeding during a single season, Sagar (1978) reported that laying occurred from late Oct through Nov at the Snares Is. However, our study over several years shows that, in fact, laying extends from mid-Sep to the end of Dec, rarely extending into Mar. Similarly, laying at the Antipodes Is extends from Dec to Mar (Warham & Bell 1979; Sadleir *et al.* 1986; Tennyson *et al.* 2002). At the Bounty Is, 2 nests with single eggs were recorded on 18 Nov 1978 (Robertson & van Tets 1982), and in April 1927 adults were seen carrying small fish to ledges, where they were apparently feeding young (Oliver 1955). Farther south, at Campbell Is, eggs were found in Antarctic tern nests from mid-Oct to late Feb (Sadleir *et al.* 1986). These more recent reports confirm the extended breeding season (Oliver 1955) and the marked differences in the breeding timetable of Antarctic terns between localities in the New Zealand subantarctic (Sagar 1978).

Stead (1948) and Oliver (1955) suggested that the prolonged breeding season could be explained by Antarctic terns raising 2 broods a year. However, there is no evidence that this occurs on the Snares Is. Sagar (1978) reported the laying of a single egg clutch in a nest where an egg had disappeared about 10 days previously, which strongly suggests that re-laying occurred, but as neither adult attending the nest was banded, re-laying was not proven. Consequently, the only confirmed case of re-laying is the one reported here, and so the prolonged breeding season may result from other factors, such as, differences in the timing of birds coming into breeding condition.

In other parts of its range, the laying period of Antarctic terns also varies with location. In a review of the breeding season, Jablonski (1995) noted that in the Indian Ocean breeding begins latest at higher latitudes, but on the Antarctic Peninsula and South Georgia the timing and duration are similar to those occurring at the Snares Is.

Table 3 Measurements (mm) and fresh weights (g) of Antarctic tern (*Sterna vittata bethunei*) eggs at the Snares Is. -, no data.

Season	Clutch size	Length		Breadth		Weight	
		Mean±SD	Range (*n*)	Mean±SD	Range (*n*)	Mean±SD	Range (*n*)
1976-77	1	45.5±2.5	41.2-48.9 (5)	31.7±0.7	30.5-32.5 (5)	23.8±0.7	23.-25 (5)
	2	46.6±1.1	45.5-49.2 (8)	32.3±0.5	31.6-33.2 (8)	24.4±1.1	23-25 (8)
1983-84	1	-	-	-	-	-	-
	2	44.9±0.9	43.6-46.3 (6)	32.3±0.1	32.1-32.5 (6)	-	-
1984-85	1	45.9±2.4	41.2-50.6 (22)	31.8±0.7	30.7-34.0 (22)	-	-
	2	44.4±1.6	40.9-40.4 (12)	32.2±0.5	31.6-33.1 (12)	-	-
1985-86	1	47.7±1.8	41.9-48.2 (14)	32.9±1.1	31.7-36.2 (14)	24.5±1.1	23-26 (4)
	2	45.5±1.6	42.4-49.2 (28)	32.4±0.7	30.6-33.7 (28)	25.0±0.7	24-26 (4)
1986-87	1	47.7±2.1	43.0-50.5 (15)	32.1±0.7	30.9-33.8 (15)	24.6±1.8	22-27 (4)
	2	46.5±1.0	45.5-48.5 (8)	32.4±0.4	31.7-33.0 (8)	-	-
1987-88	1	46.0±1.7	43.4-48.7 (21)	32.1±0.7	30.0-33.3 (21)	26.5±0	26.5 (2)
	2	45.5±1.4	42.6-47.8 (14)	32.2±0.6	31.2-33.5 (14)	-	-
All	1	45.8±2.0	41.2-50.6 (77)	32.1±0.9	30.0-36.2 (77)	24.6±1.4	22-27 (15)
seasons	2	45.5±1.6	40.9-49.2 (76)	32.3±0.6	30.0-36.2 (77)	24.6±1.0	23-26 (12)

Clutch size

On the Snares Is we found that clutch size was 1-2, with about 33% of clutches containing 2 eggs. The proportion of 2-egg clutches varies between other islands in the New Zealand region. All 18 clutches reported by Warham & Bell (1979) and Sadleir *et al.* (1986) from the Antipodes Is were of single eggs, as were 2 clutches from the Bounty Is (Robertson & van Tets 1982). However, at Campbell Is 9 of 34 nests (26.5%) contained 2-egg clutches (Bailey & Sorensen 1962; Kinsky 1969; Sadleir *et al.* 1986; E.K. Dunn unpubl. data for Jan 1978). Both 1- and 2-egg clutches have been reported from the Auckland Islands (Sadleir *et al.* 1986), but the number of nests observed was not given.

In the Antarctic region, the clutch size was usually 1-2 (rarely 3) and averaged 1.35-1.73 eggs nest^{-1}, indicating larger clutches than reported from subantarctic regions (Jablonski 1995).

Breeding success

The main factors affecting breeding success were weather conditions and predation. At the Snares Is, there are no terrestrial predators, but predation by brown skuas (*Catharacta skua*) has been recorded on 3 occasions (Miskelly *et al.* 2001). Adverse weather was a major factor in chick mortality during 1 season (Sagar 1978). Likewise, at Campbell Is in Jan 1978 E.K. Dunn (pers. comm.) found an entire colony of 15 clutches containing well-grown embryos that had been deserted, apparently as a result of a severe storm. On Campbell Is, Norway rats (*Rattus norveigicus*) and brown skuas may also cause nest failure (Sadleir *et al.* 1986). Elsewhere, abiotic factors such as weather conditions and avalanches of rocks and snow appear to be the main causes of Antarctic tern breeding failure. For example, during 3 seasons at the South Shetland Is, 305 of 495 eggs (61.6%) were lost and 68 of 158 chicks (43%) died as a result of washouts and avalanches (Jablonski 1995). By comparison, predation by skuas and gulls accounted for 1.2% of egg and 7.1% of chick losses.

Chick diet and provisioning

There were differences in the composition of the diet of Antarctic terns observed feeding close to the breeding colonies (Sagar & Sagar 1989) and that fed to the chicks (this study). At sea, the prey captured comprised 16.5% fish and 83.5% crustaceans (calculated from tables 1 & 2, Sagar & Sagar 1989). However, the food fed to chicks comprised 94% fish and 6% crustaceans. Both studies were completed during the same visits to the Snares Is, and so temporal variations in the availability of prey do not explain the differences. The fish fed to chicks were substantially larger than the crustaceans. Consequently, the advantages of feeding chicks with larger prey items are that a greater proportion of the chick's energy and nutritional requirements can be met with 1 prey item, and that the parents can make fewer feeding trips, and so reduce their own energy expenditure (Hulsman *et al.* 1989). Small prey were not favoured, perhaps because the parents would have had to make more feeding trips to meet their chick's demands (Ricklefs 1983).

Antarctic terns take a wide variety of prey and the relative proportions of prey taxa taken varies with location (Jablonski 1995). At the South Shetland Is, Jablonski (1995) found that the prey fed to Antarctic tern chicks varied with the age of

the chick. For example, the diet of chicks 1-5 days old comprised, by weight, about 78% krill *Euphausia* spp., 3% amphipods, 15% indeterminate amphipod or krill, and 11% fish. This compares to the diet of chicks 15-20 days old that comprised, by weight, about 31% krill, 3% amphipods, 9% indeterminate amphipod or krill, and 58% fish. Here, the diet of adult terns comprised, by weight, about 50% krill, 30% amphipods, and 19% fish (Jablonski 1995). Consequently, it appears that at both the Snares and South Shetland Is, adult Antarctic terns optimise their feeding trips by feeding chicks more larger prey items than they consume themselves.

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