

Rockhopper penguin (*Eudyptes chrysocome filholi*) foraging at Antipodes Islands

P.M. SAGAR

National Institute of Water and Atmospheric Research, P.O. Box 8602, Christchurch, New Zealand.
p.sagar@niwa.co.nz

R. MURDOCH

National Institute of Water and Atmospheric Research, P.O. Box 14-901, Kilbirnie,
Wellington, New Zealand

M.W. SAGAR

38A Yardley Street, Christchurch 8004, New Zealand

D.R. THOMPSON

National Institute of Water and Atmospheric Research, P.O. Box 14-901, Kilbirnie,
Wellington, New Zealand

Abstract Foraging of female rockhopper penguins (*Eudyptes chrysocome filholi*) during the chick stage was investigated at Antipodes Islands during December 2002 – January 2003. During the guard stage eight birds were tracked to foraging areas 22 – 54 km NNE or E from their nests. Birds foraging NNE did so over waters 500-1500 m deep, while those that travelled E foraged in water > 1500 m deep. The mean duration of these foraging trips was 1.37 days, significantly ($p < 0.05$) longer than trips undertaken by control birds. During the post-guard stage two birds were tracked during trips of 5 – 7 days, up to 119 km from the nest and in water > 1500 m deep. Male parents guarded the chicks more or less continuously, with most females returning to feed the chicks from mid afternoon. In the post-guard stage, most male parents returned to the nest each evening, but fewer females attended the nest at this time. Weight increases indicated that chicks were fed, on average, about once per day during both the guard and early post-guard stages. The foraging trips of female rockhopper penguins at Antipodes Islands were usually of longer duration and extended farther from the nest than birds breeding at Amsterdam, Kerguelen and Crozet Islands, but occupied a similar time and covered a greater distance than birds breeding at Staten Island. However, they were of considerably shorter duration and distance than birds breeding at Macquarie Island. This may be related to the differing marine environments around each of these breeding locations.

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INTRODUCTION

The rockhopper penguin (*Eudyptes chrysocome*) is the most widespread of the crested penguins (*Eudyptes* spp), breeding on islands in the southern Atlantic, Indian and Pacific Oceans (Marchant & Higgins 1990). The distribution of the penguins also encompasses oceanic conditions ranging from south of the Antarctic Polar Front (e.g., Heard Island) to north of the Subtropical Front (e.g., Tristan da Cunha, Amsterdam and St Paul Islands; Marchant & Higgins 1990). Three subspecies are recognised, based mainly on differences in the size of the crest and the extent and colour of bare skin about the base of the bill (Marchant & Higgins 1990). In the New Zealand region, the Eastern rockhopper penguin

(*E.c. filholi*) breeds at the Antipodes, Auckland, Campbell and Macquarie Islands, whereas the Western rockhopper penguin (*E.c. chrysocome*) and Moseley's rockhopper penguin (*E.c. moseleyi*) occur as vagrants (Heather & Robertson 1996).

Recently, most breeding populations throughout its range have declined substantially. For example, in the South Atlantic Ocean, the population of Western rockhopper penguins at the Falkland Islands was estimated at ≈ 3 million breeding pairs in the early 1930s, but has declined to $\approx 275,000$ pairs by the 2000-01 breeding season (Pütz *et al.* 2002). Likewise, in the Indian Ocean, the population of Moseley's rockhopper penguins breeding on Amsterdam Island declined at a rate of 2.7% per year between 1971 and 1993, with the population decreasing from 58,000 pairs to 24,890 pairs (Guinard *et al.* 1998). A similar trend has been observed in the New Zealand

region, where numbers of Eastern rockhopper penguins breeding at Campbell Island declined from an estimated 1.6 million pairs in the early 1940s to 103,100 pairs in 1984-87 (Cunningham & Moors 1994). Also, at Antipodes Islands a decline in numbers of breeding pairs is indicated by a decrease in the number of colonies from 86 in 1972/73 to about 76 in 1989/90 (Ellis *et al.* 1998).

The reasons for these substantial declines remain unclear. A decrease in sea surface temperature was suggested as the cause of decline at Amsterdam Island (Guinard *et al.* 1998). In contrast, Cunningham & Moors (1994) noted that the decline coincided with sea surface temperature increases recorded in Pervance Harbour, Campbell Island, and suggested that warmer seas resulted in fewer euphausiids, the preferred prey of the penguins. Consequently, Cunningham & Moors (1994) argued that rockhopper penguins had been forced to switch to prey of lower quality, primarily small fish, with subsequent detrimental consequences to their population size.

As part of a larger project to test the hypothesis that changes in diet quality have contributed to the decline of rockhopper penguin populations in the New Zealand region, the main aim of this study was to monitor the foraging trips of female rockhopper penguins during the brooding stage using satellite telemetry, and so to identify areas of the sea important during this stage of the breeding cycle. We chose female rockhopper penguins for this study for the practical reason that during the brooding period females make daily foraging trips and this behaviour permits foraging areas to be determined by fitting different females with satellite transmitters at a high turnover rate. Information was also obtained on the frequency and timing at which adults fed their chicks.

METHODS

Field-work was completed between 18 December 2002 and 3 January 2003 at Anchorage Bay, Antipodes Islands (49° 41'S, 178° 48'E, Fig. 1A). Here there were mixed breeding colonies of rockhopper penguins and erect-crested penguins (*E. sclateri*). On 18 December 2002, 30 rockhopper penguin nests containing single chicks and one nest containing two chicks were located and numbered for monitoring; an adult was guarding or brooding the chick(s) at each of these nests. Eighteen of these nests were at the periphery of erect-crested penguin colonies and 13 nests were in caves occupied solely by rockhopper penguins. Adult rockhopper penguins associated with all of the nests were captured and bill dimensions were measured to 0.1 mm using vernier calipers to determine their gender (Warham 1972; Hull 1996). These birds were then marked with stock marker so that they could be recognised without further handling.

Satellite tracking

Females associated with eight nests were captured opportunistically in mid-afternoon or early evening, after chick feeding. A platform transmitter terminal (PTT), was attached directly to the back feathers using TesaTM tape, care being taken to ensure that the preen gland was not covered. The PTTs were packaged in black epoxy resin and were streamlined at the front to reduce hydrodynamic drag (Culik *et al.* 1994). The attachment procedure took <5 mins. After deployment the PTTs ran continuously with a transmission interval of 90 secs. Six of these birds were tracked for one foraging trip and then the birds were recaptured and the PTT removed. The remaining two birds were tracked for two consecutive foraging trips before the PTTs were removed.

Locations were received through the Argos system (Argos CSL, Toulouse, France). They were assigned by Argos into one of six classes (3,2,1,0,A,B) depending on their accuracy. Classes 1-3 gave positions accurate to within a kilometre, and the accuracy of classes 0, A and B was to be determined by the user. To avoid arbitrarily discarding reliable locations, all location classes were used for the reconstruction of the foraging tracks. Improbable locations were limited by first setting the maximum speed at 10 km/h (estimated swimming speed for rockhopper penguins at Marion Island averaged 7.4 km/h, range 7.0 - 8.2 km/h: Brown 1987). We then plotted a provisional foraging track and locations of unknown accuracy (0, A, B) were deleted when isolated, but regarded as reliable when aligned. The time spent travelling to/from the full extent of the foraging areas was estimated from the estimated maximum range (km) of each bird from the nest and divided by 7.4, the average travelling speed of a commuting rockhopper penguin (Brown 1987). This assumes that the penguins travelled continuously at a constant speed and in a straight line within their foraging areas.

Parental attendance and feeding frequency of chicks

Chicks at each of the 31 nests were weighed to the nearest 25 g within an hour of dawn and shortly before dark each day from 18 December 2002 to 3 January 2003. However, sea conditions prevented access to some nests on occasions. Increases of > 50 g between consecutive visits were assumed to indicate that the chick had been fed during the intervening period. No account was taken of weight loss due to digestion and excretion. Chicks at each nest were fitted temporarily with tape around one flipper; a unique number was written on the tape so that each chick was identifiable.

The number and gender of adults attending each of 20 of the nests was recorded hourly from 07.00h

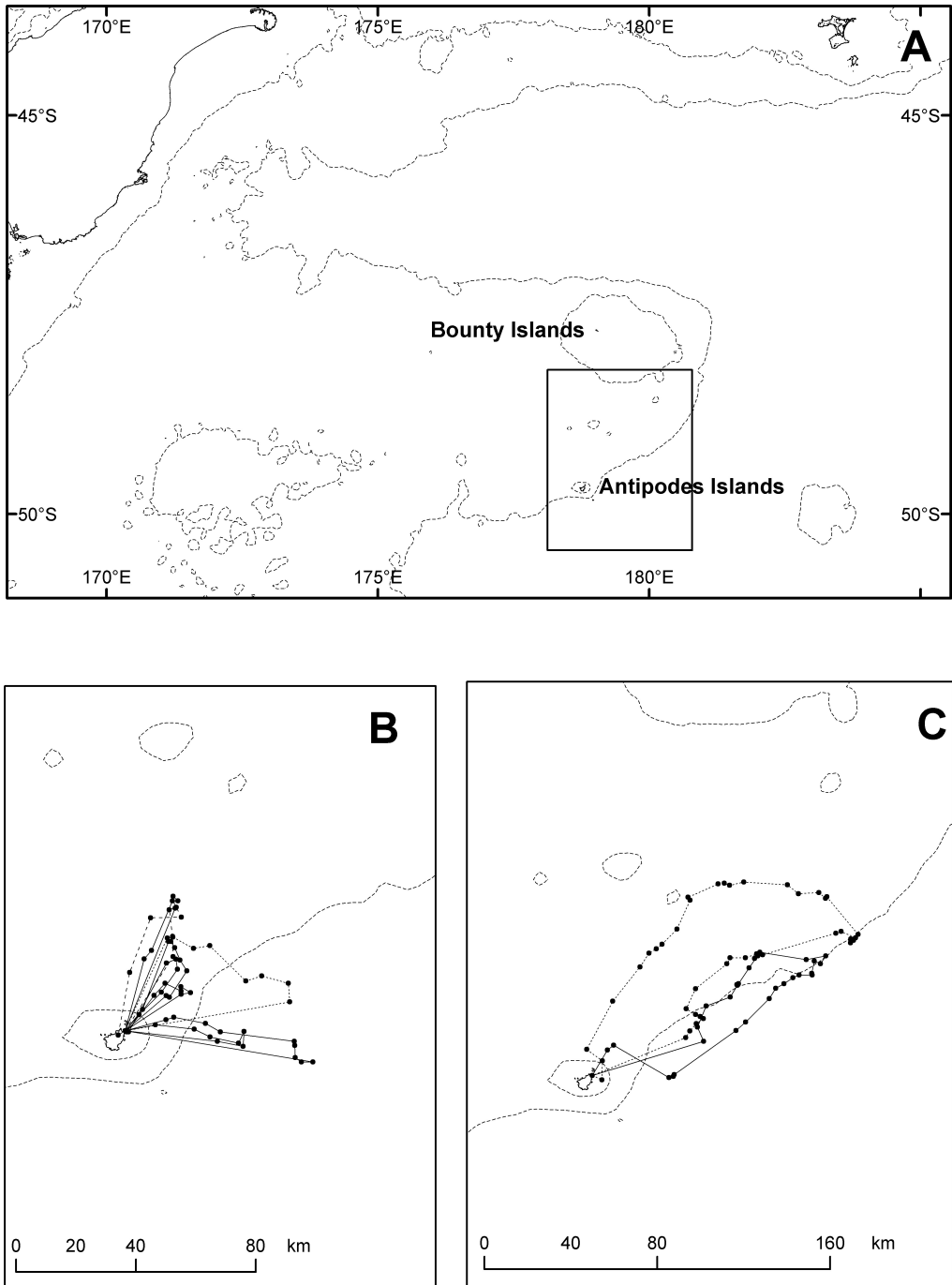


Figure 1 Maps of the Pacific Ocean south-east of New Zealand: A - location of Antipodes Islands. The inset indicates the area detailed in B and C; B - tracks of foraging trips from Antipodes Islands taken by eight female rockhopper penguins during the guard stage; C - tracks of foraging trips of two female rockhopper penguins from Antipodes Islands taken during the post-guard stage. In both B and C the dots on the plotted tracks indicate reliable locations obtained from satellite telemetry. In all maps the bathymetry at 500 m and 1500 m is indicated by the dotted lines.

to 22.00 h New Zealand Standard Time (NZST) during two 5-day periods, 20–24 December 2002 and 29 December 2002–2 January 2003.

RESULTS

Foraging pattern during the guard stage

Single foraging trips by eight different females were tracked during the guard stage (Table 1). During these trips the birds swam to the north or east of Antipodes Islands over water depths > 500 m (Fig. 1B). The three birds that travelled east of the islands generally also spent time over water depths > 1500 m. The mean duration of foraging trips of eight birds fitted with satellite transmitters, 1.37 d (range 0.82–1.74 d, $sd = 0.40$ d; Table 1), was significantly ($t = 2.205$, $P < 0.05$, $df = 30$) longer than the estimated mean duration of 24 control birds not fitted with satellite transmitters (1.00 d, range 0.54–2.33 d, $sd = 0.40$ d).

The maximum range from the nest during these trips averaged 36.4 km (range 22–54 km, $sd = 10.4$ km) and the average distance covered during a trip was 81.6 km (range 50–114 km, $sd = 24.9$ km). These figures and plots of the tracks (Fig. 1B) indicate that most birds travelled the shortest distance to and from the farthestmost point of their foraging area.

The only exception was a bird that initially foraged north of the island before swimming east over water > 1500 m deep before returning to the colony.

The estimated times spent travelling between the nest and the farthestmost point of their foraging areas averaged 0.41 d (range 0.25–0.61 d, $sd = 0.12$ d; Table 1), which represented about 30% (range 24–39%) of the time each bird was away from the nest.

Foraging pattern during the post-guard stage

Two females tracked during the guard stage were also tracked during their first foraging trip of the post-guard stage (Table 1). Both birds travelled north-east from Antipodes Islands and appeared to forage along the subantarctic slope over water depths > 1500 m (Fig. 1C). One bird undertook a trip of 5.67 d, reached a maximum of 104 km from the nest and travelled an estimated total distance of 243 km. The other bird undertook a trip of 6.92 d, during which it reached a maximum of 119 km from the nest and travelled a total distance of 325 km. The track of the latter bird tended to be more elliptical than the shorter trips undertaken during the guard stage (Fig. 1B, 1C), indicating that the birds did not travel directly to a foraging area, and so an estimation of commuting time (Table 1) is not reliable.

Table 1 Parameters of foraging trips for eight female rockhopper penguins breeding at Antipodes Islands, December 2002–January 2003. Estimated commuting time calculated assuming a constant travelling speed of 7.4 km/h (Brown 1987).

Bird no.	Trip no.	Stage	Duration (days)	Range (km)	Distance travelled (km)	Estimated travelling time (days)
1	1	Guard	2.01	54	114	0.61
2	1	Guard	0.97	34	75	0.38
3	1	Guard	0.94	22	50	0.25
4	1	Guard	1.38	29	65	0.33
5	1	Guard	1.38	41	85	0.46
6	1	Guard	0.82	25	52	0.28
7	1	Guard	1.74	48	122	0.54
7	2	Post-guard	5.67	104	243	1.17
8	1	Guard	1.70	38	90	0.43
8	2	Post-guard	6.92	119	325	1.34

Parental attendance

The guard stage for each chick continued until at least 27 December. Subsequently an increasing number was left alone at the nest or in a crèche, and by 3 January only two chicks were still at the guard stage (median end of guard stage 30 December, $n = 30$). The mean weight of chicks on the day that their guard stage ended was 1153 g (range 975–1375 g, $sd = 132$ g, $n = 28$).

During the guard stage males were at the nest continuously throughout daylight (Fig. 2), except

for brief periods when they were seen bathing or drinking at the shoreline (Fig. 2). The numbers of females attending nests varied with time of day. Average numbers increased slowly but steadily from 07.00 h to 12.00 h, then declined until 15.00 h before increasing again until they peaked at 21.00 h when about 37% of nests had a female in attendance (Fig. 2). Females were usually recorded at the nest over several consecutive observation periods and were often still present at dusk, though they had departed by dawn.

Males were also more often at the nest during the immediate post-guard stage, when about 40% (8/20) of nests were attended from 07.00 to 12.00 h (Fig. 2). From 12.00 h numbers increased until peaking at 20.00 when about 75% (15/20) of nests were attended. During this period fewer females were observed at nests than during the guard stage, usually averaging < 1 bird until 10.00 h, after which numbers increased to about 3 birds by 16.00 h and 4 birds by 19.00 h. Numbers then declined until observations ended at 22.00 h.

Feeding frequency of chicks

During the guard stage, weight increases of > 50 g indicating that the chick had been fed, averaged 0.892/24 hrs (range 0.556 – 1.375, *sd* = 0.162, *n* = 22). Similarly, the number of occasions that a chick was fed during the post-guard stage averaged 0.896/24 hrs (range 0.6 – 1.167, *sd* = 0.435, *n* = 25). The occurrence of these weight increases indicated that in both the guard and post-guard stages, each chick usually received one meal each day. Sometimes chicks were either not fed or received two feeds during a 24 hr period.

DISCUSSION

This is the first study to report foraging tracks of rockhopper penguins in the New Zealand region. Elsewhere, foraging studies of rockhopper penguins during the guard stage mostly indicate daily trips, which is typical of crested penguins (Warham 1975). A study of the foraging behaviour of rockhopper penguins at Amsterdam Island, the Kerguelen Archipelago and the Crozet Archipelago showed that during the guard stage females mainly made foraging trips of 11–12 hours, mostly within 10 km of the islands (Tremblay & Cherel 2003). Similarly, female rockhopper penguins breeding at Staten Island, Tierra del Fuego, undertook foraging trips of 15.7–34.8 hours within 20 km of their nests

(Schiavini & Raya Rey 2004). At Marion Island, female rockhopper penguins spent 15–148 hours at sea at distances ranging from 4 to 157 km from the nest (Brown 1987).

In contrast, at Macquarie Island female rockhopper penguins undertook foraging trips of 6.4–7.0 days and travelled up to 104 km from the nests during the guard stage (Hull 1999, 2000). However, the devices deployed on the penguins in that study may have had a deleterious effect on the foraging trip duration as an earlier study of rockhopper penguins at Macquarie Island (Warham 1963) recorded daily foraging trips during the guard stage.

The devices that we attached to the penguins also extended the average length of their foraging trips significantly, but by a matter of hours rather than days. However, the fact that in our study all birds tracked, irrespective of whether their trip duration was similar or longer than the average for control birds, foraged in similar areas gives us confidence that the devices delayed their travelling rather than changed their destination. Consequently, although the duration of foraging trips of birds breeding at Antipodes and Staten Islands were similar, the birds from Antipodes Islands travelled farther (36 km *cf* < 20 km).

The oceanic environment over which the penguins fed may explain the variations in trip duration and foraging range shown by the different populations (Schiavini & Raya Rey 2004). In a comparison of foraging trip characteristics of rockhopper penguins from Amsterdam, Kerguelen and Crozet Islands, Tremblay & Cherel (2003) proposed that penguins foraged longer in the more open waters off Amsterdam Island and Crozet Islands than they did in the shallow, sheltered waters of Kerguelen. Penguins from Staten Island foraged in shelf waters 100–200 m deep and in pelagic waters of the shelf-break and slope 12 km south of Staten

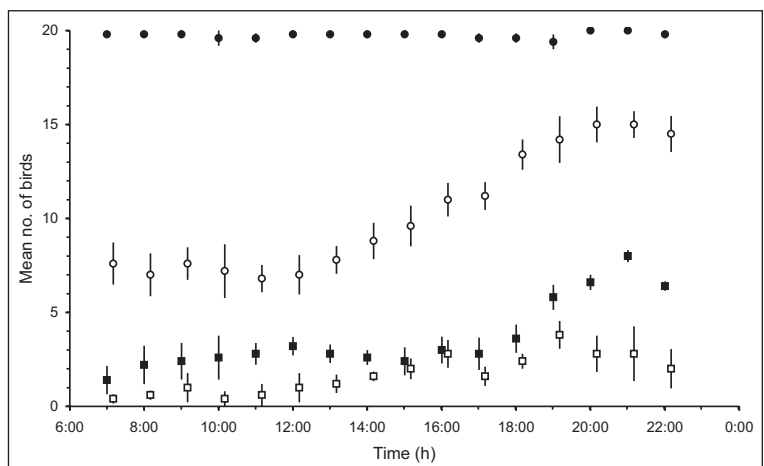


Figure 2 Hourly plots of the mean numbers of adult rockhopper penguin attending 20 nests during daylight at the Antipodes Islands. ● - males during guard stage; ○ - males during post-guard stage; ■ - females during guard stage; □ - females during post-guard stage.

Island (Schiavini & Raya Rey 2004). In contrast, penguins from Macquarie Island foraged for up to seven days in oceanic waters of the Polar Frontal Zone (Hull 1999). At Antipodes Islands, the penguins foraged in pelagic waters > 500 m deep north-north-east of the islands or east in waters > 1500 m deep along the Subantarctic Slope during the guard and the post-guard stages. Such variations in the characteristics of the foraging areas of rockhopper penguins may indicate ability of the species to vary its behaviours according to different marine environments (Tremblay & Cherel 2003; Schiavini & Raya Rey 2004).

Antipodes Islands lie along the edge of the Southern Plateau subantarctic region, an area noted for its relatively low levels of phytoplankton biomass (Murphy *et al.* 2001) and primary productivity, leading to a long food web and supporting high-level predators such as seabirds (Bradford-Grieve *et al.* 2003). At Campbell Island, the diet of rockhopper penguin chicks comprised mainly dwarf cod (*Austrophycis marginata*), and juveniles of southern blue whiting (*Micromesistius australis*) and hake (*Merluccius australis*) (Marchant & Higgins 1990). Hake has not been reported from the area of Antipodes and Bounty Islands (Anderson *et al.* 1998), and so is unlikely to feature in the diet of rockhopper penguins nesting there. However, both dwarf cod and southern blue whiting are distributed widely in the area between Antipodes and Bounty Islands, and so may comprise important proportions of the diet of rockhopper penguin chicks reared on Antipodes Islands.

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