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POPULATION SIZE AND BREEDING SUCCESS OF GOULD'S PETREL *Pterodroma leucoptera leucoptera* ON CABBAGE TREE ISLAND, NEW SOUTH WALES: 1996–97 TO 2005–06

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Gould's Petrel *Pterodroma leucoptera leucoptera* breeds only on Cabbage Tree and Boondelbah islands at the entrance to Port Stephens, New South Wales. Annual surveys to estimate population size and reproductive output of the colony on Cabbage Tree Island, where more than 96 per cent of the population nest, have been conducted since 1989–90. In the period 1989–90 to 1991–92, the number of breeding birds was small (186–252 pairs), breeding success was poor (16.5–19.8%) and few fledglings (31–48 individuals) were produced each year. Recovery actions to reduce the mortality of breeding adults and fledglings on Cabbage Tree Island began during the 1992–93 breeding season. The removal of island-borne threats resulted in an immediate two-fold increase in the number of pairs incubating eggs. Breeding success also increased, and since 1993–94 has averaged 49.4 per cent. The breeding population has steadily increased (by about 37 pairs per annum) and now numbers 800–1000 pairs. The number of fledglings has also increased (by about 18 per annum) and annual production now exceeds 400 individuals. As a result of the sustained improvement in population size and breeding success, a change in the species' conservation status from *endangered* to *vulnerable* is warranted.

INTRODUCTION

Gould's Petrel *Pterodroma leucoptera leucoptera* breeds at only two locations worldwide: Cabbage Tree Island and Boondelbah Island, both located at the entrance to Port Stephens on the east coast of Australia. The vast majority of the population (>96%) breeds on Cabbage Tree Island (Priddel and Carlile 1997b). Only about 12 pairs breed naturally on Boondelbah Island (Priddel and Carlile 1997a), although an additional expanding colony of about 20 or more pairs has recently been established through the creation of artificial habitat and the translocation of nestlings from Cabbage Tree Island (Priddel *et al.* 2006).

The first survey of Gould's Petrel on Cabbage Tree Island was undertaken by Fullagar in 1970 (Fullagar 1976). Counts of incubating birds in 37 sample plots (each 4.5 m^2) yielded a total population estimate of 375 ± 102 pairs breeding within the two gullies (Fullagar cited in Marchant and Higgins 1990). From data collected during irregular trips to the island over a six-year period Fullagar (1976) estimated breeding success (the proportion of eggs that produce fledglings) to be 38 per cent (*n* = 69 eggs).

In 1992, the total number of adult Gould's Petrels ashore on Cabbage Tree Island was estimated to be 1157 birds. Comparison with previous mark-recapture data suggested that the population had declined by 26 per cent over the previous 22 years (Priddel *et al.* 1995). A number of threatening processes were identified, including predation by Pied Currawongs *Strepera graculina* and Australian Ravens *Corvus coronoides*, entanglement in the sticky fruits of the Birdlime Tree *Pisonia umbellifera*, and habitat degradation due to grazing by the introduced European Rabbit *Oryctolagus cuniculus* (Priddel and Carlile 1995).

Recovery actions aimed at ameliorating these threats commenced in late 1992 and have continued thereafter. Control of avian predators and removal of seedlings of the Birdlime Tree are now routine practices on Cabbage Tree Island. Rabbits were eradicated from Cabbage Tree Island in 1997 (Priddel *et al.* 2000). In addition, the population of Gould's Petrel on Boondelbah Island was augmented by the translocation of near-fledged birds from Cabbage Tree Island (Priddel *et al.* 2006). These actions, together with annual surveys to estimate (i) the size of the breeding population, (ii) breeding success and (iii) the number of fledglings produced, are identified as high priorities within the Gould's Petrel Recovery Plan (NPWS 2001, DEC 2006).

In a review of Australian recovery plans Parker (1999) identified the absence of regular monitoring and poor reporting provisions as recurring weaknesses. Recovery programs often lacked measurable, realistic criteria against which the recovery of the species could be assessed. Parker (1999) recommended annual reporting of estimated numbers of individuals for threatened species, and that this information be publicly posted. Detailed systematic surveys of Gould's Petrel have been conducted annually since 1989–90. Full details of the methodology are described in Priddel *et al.* (1995). To make this information publicly available it is intended, henceforth, to publish the results of the Gould's Petrel surveys undertaken on Cabbage Tree Island annually. This, the initial paper in the proposed series, contains results of all surveys up to 2005–06.

METHOD

Study Area

Cabbage Tree Island (152°14'E, 32°41'S; 30 ha) is dominated by sub-tropical rainforest growing on volcanic-derived soils of toscanite (Werren and Clough 1991). A full description of the island, its fauna and ornithological history is contained in Priddel and Carlile (2004).

The principal nesting habitat of the Gould's Petrel on Cabbage Tree Island is located within two steep gullies on the western side of the island (Fullagar 1976; Priddel and Carlile 2004). These gullies are characterised by steeply sloping rock scree with a canopy of Cabbage Tree Palms *Livistona australis*, Deciduous Fig *Ficus superba*, Sandpaper Fig *F. fraseri* and Native Plum *Planchonella australis*. Gould's Petrels nest predominantly in natural rock crevices among rock scree, but also in hollow fallen palm trunks, under mats of fallen palm fronds, and in cavities among the buttresses of fig trees. A few records, dating back to 1967, also report nesting in open areas among tussocks of Spiny-headed Mat-rush *Lomandra longifolia* bordering the South Gully (D'Ombrain 1970).

Estimates of breeding pairs

Surveys to estimate the numbers of breeding pairs were conducted in December (in the 50th calendar week) and timed to follow the peak period of the birds' moderately synchronous egg laying. A series of parallel and uniformly spaced, four-metre-wide transects of unequal length sampled the full expanse of nesting habitat within each of the two gullies. Sampling intensity (the proportion of habitat surveyed within each gully) was approximately 40 per cent. Nests, birds and eggs were counted along each transect. Each nest site was marked with a numbered plastic tag attached to a 1-metre length of 6-millimetre diameter aluminium rod. All petrels were examined for leg bands, and all unbanded birds were banded with individually numbered metal bands provided by the Australian Bird and Bat Banding Scheme (ABBBS).

The number of pairs breeding in each gully was based on the number of eggs found, and was calculated using the analysis described by Jolly (1969), but for unequal-sized transects sampled without replacement (Krebs 1989). These estimates were corrected (by a factor of 1.14) to adjust for eggs lost prior to the survey and eggs laid after the survey (for details see Priddel *et al.* 1995).

Previously, Gould's Petrels were thought to nest only in the two large gullies on the western side of the Island (Hindwood and Serventy 1943; Fullagar 1976). However, we now know that a significant number of Gould's Petrel breed in sites scattered across the island. The exact number of pairs that nest outside the gullies is not known, but from observations we reason this to be about 20 per cent of the total population (Priddel and Carlile 1997b). Thus, the size of the total Gould's Petrel population breeding on Cabbage Tree Island was calculated by multiplying the estimated number in the gullies by a factor of 1.25. This correction has been applied to all population estimates presented in this paper. However, due to a previous lack of knowledge regarding the extent of breeding occurring outside the gullies this correction was not included in earlier published estimates of total population size (e.g. Priddel *et al.* 1995; Priddel and Carlile 1997b).

Estimates of breeding success and reproductive output

All nest sites found in December were checked in the following March (during the 10th calendar week) for the presence of a young petrel. Breeding success was calculated as the proportion of eggs present in December that produced young in the following March. This estimate of breeding success was adjusted (by a factor of 0.863) to compensate for eggs lost before the survey in December and mortalities of fledglings after the March survey (for details see Priddel *et al.* 1995).

Reproductive output (the total number of fledglings produced) was estimated as the product of the number of breeding pairs and breeding success. All fledglings were banded with ABBBS bands.

RESULTS

Estimates of breeding pairs

Annual estimates of the breeding population of Gould's Petrel on Cabbage Tree Island between 1989–90 and 2005–06 are shown in Table 1. From 1989–90 to 1992–93 the population numbered between 186 and 252 breeding pairs. Recovery actions were initiated midway through the 1992–93 breeding season. The following season (1993–94) the number of breeding pairs increased two-fold to 515 pairs. Thereafter, the population has increased steadily (linear regression analysis, $F_{1, 11} = 27.414$, $P < 0.001$, $r^2 = 0.71$), on average increasing by about 37 pairs annually.

Table 1

Annual estimates (1989–90 to 2005–06) of the size of the breeding population of Gould's Petrel on Cabbage Tree Island (pairs ± SE), breeding success and fledgling production. Figures are corrected for egg losses before and after the December survey and chick losses after the March survey. See Priddel *et al.* (1995) for a detailed explanation of methods.

Year	Breeding pairs	Breeding success (%)	Fledglings
1989–90	252 ± 46	19.8	48
1990–91	186 ± 33	18.1	31
1991–92	198 ± 46	16.5	38
1992–93	229 ± 48	24.7	55
1993–94	515 ± 66	44.6	224
1994–95	578 ± 59	58.6	331
1995–96	599 ± 61	25.5	150
1996–97	582 ± 54	56.3	321
1997–98	818 ± 71	53.8	431
1998–99	759 ± 70	50.3	374
1999–00	856 ± 68	57.0	477
2000–01	911 ± 78	53.6	474
2001–02	1025 ± 75	48.7	488
2002–03	882 ± 75	47.3	374
2003–04	932 ± 72	46.1	420
2004–05	991 ± 51	48.5	470
2005–06	823 ± 51	52.0	417

Breeding success

Annual breeding success between 1989–90 and 2005–06 is shown in Table 1. Between 1989–90 and 1991–92 breeding success was less than 20 per cent (range 16.5–19.8%). Recovery actions initiated during the 1992–93 breeding season resulted in a minor increase in breeding success in that year (24.7%). Thereafter, breeding success has averaged 49.4 per cent (range 25.5–58.6%). Breeding success was particularly poor in 1995–96 (Table 1). Aside from this anomaly, breeding success has fluctuated little (46.1–58.6%) since recovery actions began.

Fledgling productivity

Annual fledgling productivity between 1989–90 and 2005–06 is shown in Table 1. Between 1989–90 and 1991–92 the number of fledglings produced in any one year did not exceed 48 individuals (range 31–48). Recovery actions initiated during the 1992–93 breeding season resulted in a slight increase in the number of fledglings produced in that year (55). The next year, fledgling productivity increased substantially to 224 individuals. With one exception (1995–96) annual productivity thereafter has exceeded 320 fledglings. Between 1993–94 and 2005–06 fledgling production has increased steadily (linear regression analysis, $F_{1, 11} = 9.878$, $P < 0.009$, $r^2 = 0.47$), on average increasing by about 18 fledglings annually.

DISCUSSION

In the period 1989–90 to 1991–92, prior to any recovery action, the number of Gould's Petrel breeding on Cabbage Tree Island was small (fewer than 260 pairs), breeding success was poor (less than 20%) and fewer than 50 fledglings were produced per annum. Each year more than 50 adults died while ashore (Priddel and Carlile 1997b). Clearly, this situation was unsustainable.

The two major causes of petrel mortality were entanglement in the sticky fruits of the Birdlime Tree and predation by Pied Currawongs and Australian Ravens (Priddel and Carlile 1997b). These threats affected both adults and chicks. Actions taken to remove the offending plants and to reduce the number of avian predators began during the 1992–93 breeding season. The effect was immediate and dramatic—a two-fold increase in the breeding population between 1992–93 and 1993–94. This increase (in the number of birds sitting on eggs) did not reflect a sudden increase in the total number of birds present on the island. Rather, it was the result of a marked reduction in the loss of nests, previously due to mortality and predator disturbance, between the onset of nesting (October) and the date of the survey (mid-December).

Recovery actions also produced an immediate increase in breeding success, rising from less than 20 per cent to an average of around 50 per cent. Breeding success for other small petrels (Procellariiformes) is variable, but typically is about 40–50 per cent (Warham 1990). For example, breeding success for the Snow Petrel *Pagodroma nivea* averaged 51.3 ± 16.3 per cent over a period of 27 years (Chastel *et al.* 1993). Intensive management of a petrel colony can enhance breeding success. The critically endangered Bermuda Petrel *Pterodroma cahow*, for example, has been protected from competition and predation, and provided with artificial nest sites for more than four decades. Breeding success for this species between 2000–01 and 2003–04 averaged 67 per cent (J. Madeiros, pers. comm.), up from a low of 29 per cent in 1961 (Wurster and Wingate 1968), prior to the implementation of recovery actions.

Annual productivity of fledglings has increased in line with increases in both the number of breeding pairs and breeding success. The only poor year was 1995–96, when egg production was unaffected, but breeding success was unusually low. Nothing occurred on land to account for the breeding failure, the most likely explanation being that it was due to unusually poor availability of prey to feed the chicks. The poor breeding success of Gould's Petrel on Cabbage Tree Island was coincident with the widespread mortality of Pilchards *Sardinops sagax* within southern Australian and New Zealand waters, probably caused by the introduction of a herpes virus in fish imported as feed for fish farms (Anonymous 1996). Little Penguins *Eudyptula minor* in Port Phillip Bay, Victoria, also experienced a high incidence of egg abandonment and unusually poor breeding success during the 1995–96 season (Dann *et al.* 2000).

Another possibility examined, but dismissed, was that changes in prey availability, and therefore breeding success, were linked to the El Nino Southern Oscillation (ENSO). The 1995–96 breeding failure was coincident with a strong ENSO event, a condition that has been found to affect the breeding productivity of other small petrels. For example, declines in the number of Wedge-tailed Shearwaters *Puffinus pacificus* breeding on islands in northwestern Western Australia have been attributed to ENSO events (Dunlop *et al.* 2002). Similarly, Chastel *et al.* (1993) found a lower proportion of Snow Petrels attempted to breed one year after large-scale ENSO events. However, strong fluctuations in the ENSO index since 1996 appear not to have affected the breeding success of Gould's Petrel to any noticeable extent.

Currently, the Gould's Petrel is listed as *Endangered* under both the national *Environment Protection and Biodiversity Conservation Act 1999* and the New South Wales *Threatened Species Conservation Act 1995*. As a result of the sustained improvement in population size and breeding success Garnett and Crowley (2000) recommended a change in its national status from *Endangered* to *Vulnerable*. Data presented here support that recommendation.

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