

Productivity of kakapo (*Strigops habroptilus*) on offshore island refuges

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Abstract The reproduction of kakapo (*Strigops habroptilus*) on offshore island refuges was monitored between 1990 and 2002. Productivity was primarily determined by the proportion of females that nested each breeding year. Within the same island, the proportion of females nesting each breeding year ranged between 33 - 95% but, as a proportion of the total female population, was just 5 - 42% between 1990 and 1999. The deliberate placement of the entire adult female population on Codfish Island (Whenua Hou) in anticipation of an exceptional fruit crop resulted in 95% of them nesting in 2002, raising 24 fledglings and increasing the total population by 39%. Although efforts to increase the frequency of kakapo breeding by providing supplementary food have been unsuccessful, nesting and fledging success increased significantly following the introduction of new, more intensive, management methods in 1995. Hatching success has, however, remained poor, with just 42% of eggs hatching. Comparison with related parrot species suggests that the kakapo's hatching success is unusually low, perhaps because of inbreeding. Despite infrequent breeding and poor hatching success, the kakapo population has increased by 69% from 51 birds in 1995 to 86 in 2002. The female population has increased from 21 birds in 1995 to 41 in 2002, 20 of which are presently less than 10 years old.

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INTRODUCTION

The kakapo (*Strigops habroptilus*) is a critically endangered, endemic New Zealand parrot. Widespread and abundant on the three main islands of New Zealand before the arrival of humans c.1000 years ago, the kakapo had already disappeared from much of its former range by the late 1800s, in part because of forest clearance, but primarily because of predation by humans and introduced mammals (Butler 1989). By 1976 the kakapo was thought to be functionally extinct, since fewer than 15 male birds were known to exist (Powlesland *et al.* 1995). Fortunately, in 1977, a population of 70 - 200 birds, including the first females seen in a hundred years, was found in southern Stewart Island (Butler 1989; Powlesland *et al.* 1995). Severe predation on this population by feral cats (*Felis catus*) necessitated the removal of all known birds to cat and mustelid-free offshore islands between 1980 and 1997 (Lloyd & Powlesland 1994; Powlesland *et al.* 1995). By the end of 2002 kakapo had lived on four different islands; Little Barrier, Maud, Codfish (Whenua Hou) and Pearl (Powlesland *et al.* 2006). Currently (2005), the total kakapo population is 86 birds, and located on Codfish Island and two other offshore islands from which mammalian predators have now been eradicated (Elliott *et al.* 2001).

The transfer of kakapo to offshore islands stopped the high adult mortality that was rapidly driving the species to extinction (Clout & Merton 1998). Although annual adult survival on offshore islands has been as high as 99% (Elliott 2006), low productivity caused the population to decline to a nadir of 51 birds in 1995 (Clout & Merton 1998). Since then, a variety of management methods have been employed to improve productivity, including supplementary feeding, protection of nests from rats, modification of nests to eliminate potential hazards to eggs or young, manipulation of clutch and brood sizes to balance maternal work-loads and encourage females to re-nest, placing a heat-pad on eggs or nestlings to prevent them chilling when females are away from the nest, artificial incubation of eggs, and hand-raising of nestlings that fail to thrive (Elliott *et al.* 2001).

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Table 1 Nesting and productivity of kakapo on different islands, 1981 – 2002. Islands: STI = Stewart Island, LBI = Little Barrier Island, CI = Codfish Island, P = Pearl Island, Maud = Maud Island. Parameters: Nesting success = % of total nests (*n*) raising fledglings; Hatching success = % of eggs laid (*n*) that hatched; Fledging success = % of chicks hatched (*n*) that fledged; Fledglings per female = number of fledglings relative to the total number of females. “Fledging success” and “Fledglings per female” include hand-reared chicks. * $P \geq 0.05$; ** $P \geq 0.01$.

Breeding Year	Island	% (n) monitored females nesting on each island	% (n) of total monitored female population nesting	% hatching success	% nesting success	% fledging success	Fledglings per female
1981	STI	?	?	100 (4)	?	75 (4)	?
1985	STI	?	?	36 (11)	?	25 (4)	?
1990	LBI	?	?	50 (2)	?	0 (1)	?
1991	LBI	80 (5)	29 (14)	50 (8)	50 (4)	50 (4)	0.14
1992	CI	83 (6)	42 (12)	58 (12)	20 (5)	14 (7)	0.08
1993	LBI	40 (5)	11 (18)	20 (5)	0 (2)	0 (1)	0
1995	LBI	50 (6)	16 (19)	0 (5)	0 (3)	-	0
1997	CI	60 (10)	32 (19)	42 (12)	33 (6)	60 (5)	0.16
1998	Maud	33 (3)	5 (20)	100 (3)	100 (1)	100 (3)	0.15
1999	P/LBI	46 (13)	30 (20)	47 (17)	38 (8)	75 (8)	0.30
2002	CI	95 (21)	95 (21)**	39 (67)	54 (24)	92 (26)	1.14
Average 1981 - 1993		63	27	52	23	27	0.07
Average 1995 - 2002		57	36	46	45*	82*	0.35*

Kakapo are unique among parrots in being lek breeders (Merton *et al.* 1984); females preferentially mate with just a small sub-set of the male population and subsequently raise their young without male assistance (Powlesland *et al.* 1992, 2006). Because of this, the population's capacity for growth is primarily determined by the number of females it contains, and its actual productivity by the number of females that nest each breeding season. The discovery that the proportion of female young hatched can be increased by limiting the quantity of supplementary food provided to females (Clout *et al.* 2002) has, therefore, been an important breakthrough in kakapo management.

Female kakapo nest only in years in which certain fruit crops are sufficiently abundant, a condition that, on Stewart Island, occurred every three to four years (Powlesland *et al.* 1992; Harper *et al.* 2006). Such years will subsequently be referred to as “breeding years”. In southern New Zealand, the only plants that produce fruit crops that are known to induce nesting are podocarp trees, specifically rimu (*Dacrydium cupressinum*) and pink pine (*Halocarpus biformis*) (Powlesland *et al.* 1992; Harper *et al.* 2006).

The productivity of the last natural kakapo population (on southern Stewart Island) was described by Powlesland *et al.* (1992). This was the only description of kakapo productivity since the 19th Century. This paper describes the productivity of kakapo on offshore island refuges from 1990 to 2002.

METHODS

The methods used in this study were those reported by Eason *et al.* (2006). Prior to 1995 not all females were

radio-tagged so some nests could only be found using trained dogs. Since then all females have been radio-tagged and all nests located by radio-telemetry. When a female's day-time location remained unchanged for seven days a visual inspection was made to see if she was nesting. If a nest was found, its location was marked to facilitate subsequent management and monitoring. A battery-powered infrared camera was installed while the female was away from the nest to allow remote viewing of the nest contents. The camera was connected by a cable to a television monitor inside a tent 20 to 60 m from the nest. An infrared beam was set up across the nest entrance that triggered an alarm at the tent site whenever the female left or returned to the nest. The sound of the alarm alerted nest minders to the departure of the female so that they could visually inspect eggs or chicks in her absence. Prior to the eradication of Pacific rats (kiore; *Rattus exulans*) from Codfish Island, the alarm also alerted nest minders to rats entering the nest chamber. Nest minders placed a battery powered heat pad over the eggs and chicks to prevent chilling while the female was away. Nest minders used radio-telemetry to monitor the female's whereabouts and left the nest site as soon as they detected her returning. Nest sites were modified to allow ready access to eggs and chicks when required for health checks and weighing.

Chicks were radio-tagged before they left the nest so that their movements and fate could be monitored. Details of all management techniques introduced in 1995 were described by Elliott *et al.* (2001).

RESULTS

Because of the close proximity and similarity of the vegetation and climate of Codfish and Pearl Islands they will be collectively referred to as the “Southern Islands”.

Proportion of females nesting

The proportion of the female population nesting on individual islands varied between 33 - 95% each breeding year (Table 1). However, in terms of the total female population, the proportion of females nesting ranged between 5% - 95%, and averaged 36% from 1995 to 2002. The highest female participation in nesting (95%) occurred in 2002, when, for the first time, all adult females were concentrated on a single island and responded to an exceptionally abundant rimu fruit crop. A significantly greater proportion of females nested in 2002 than in all other years (Analysis of deviance; $P = 0.002$).

Hatching success

Only 63 of 146 eggs (42%) laid between 1981 and 2002 hatched. There was no significant difference in hatching success between Little Barrier Island (1990-1999) ($\bar{x} = 43.0\%$; 95% C.L. = 23 - 68%) and the Southern Islands (1992-1999) ($\bar{x} = 40.0\%$, 95% C.L. = 31 - 51%; Chi-squared test; $P = 0.82$). There has been no change in hatching success following the introduction of new management methods in 1995 (Table 1). Of 131 eggs laid between 1990 and 2002, 38.9% were infertile and another 18.4% died in development.

Nesting success

All nests which fledged at least one chick have been considered successful. There has been a significant (Analysis of deviance; $P = 0.05$) increase in the proportion of successful nests, from 23% to 45%, since the introduction of new management methods in 1995 (Table 1).

Fledging success

Fledging success increased significantly (Analysis of deviance; $P = 0.04$), from 27% to 82% (Table 1), following the introduction of new management methods in 1995. The highest fledging success (92%) was recorded in 2002 when 24 chicks fledged from 26 hatched (Table 1). No instance of rat predation on nestlings occurred since the implementation of new rat control methods in 1995. A rat was successfully scared away from a nest chamber on Codfish Island in 1997 by firing the detonators that had been installed for this purpose (Elliott *et al.* 2001). No instance of nestling starvation has occurred since 1997; the mother of the only chicks that starved in that year was the only nesting female that had not learned to eat supplementary food (Elliott *et al.* 2001). Before 1995 only one of four hand-reared chicks survived compared to 12 of 16 (75%) after 1995. Successfully hand-raised chicks comprise 29% ($n = 42$) of all chicks fledged since 1995.

Overall productivity

Overall productivity (the number of fledged young per female per breeding year) increased significantly after 1995 (Mann-Whitney U-test, $P = 0.029$) (Table 1); from 0.1 fledglings per female on Stewart Island 1981 - 1985 (Powlesland *et al.* 1992) and 0.07 fledglings per female during 1981 - 1993, to 0.35 fledglings per female during 1995 - 2002 (Table 1).

Nesting rate and productivity on different islands

We compared the nesting rate of kakapo on different islands by determining the number of nests per “female-year”, the total number of years individual females were present and monitored on each island. Kakapo nesting rate was highest on the Southern Islands (42 nests from 121 female-years, 0.35 nests/female-year) followed by Little Barrier Island (12/43, 0.28 n/fy), and Maud Island (1/30, 0.03 n/fy). There was no significant difference in nesting rate on Little Barrier and Codfish-Pearl Islands (Chi-squared test; $P = 0.41$).

Productivity differed considerably, however (Table 1). Southern Island nests produced 31 fledglings, including three removed from Pearl Island in 1999 and hand-raised, a mean productivity of 0.26 fledglings/ female-year. On Little Barrier Island only five fledglings were produced, including three removed in 1999 and hand-raised, a mean productivity of 0.12 fledglings/female-year. There were three fledglings from the single nest on Maud Island (0.10 fledglings/ female-year).

DISCUSSION

The significant increase in the proportion of the female population that nested in 2002 reflects both the exceptional rimu fruit crop that occurred on Codfish Island that year and the deliberate concentration of adult females on this island in anticipation of this event (Table 1). In other words, 2002 was the first year all adult females were on the right island at the right time. Although placing all adult females on one island increases the potential impact of a localized catastrophe, this strategy has been the most successful management intervention employed so far, resulting in a record 39% increase in the population in a single year. As a consequence, there are now 41 female kakapo, an increase of nearly 100% from just 21 in 1995, and 20 of these are now (2005) less than 10 years old. Females become sexually mature between 9 and 11 years of age (Eason *et al.* 2006), and although the average lifespan of kakapo is unknown, these slow-breeding birds can be expected to persist for over half a century in the absence of mammalian predators (Butler 1989). The increase in productivity achieved by this strategic movement of females therefore justified the risk (Jansen 2006).

Nesting success incorporates both hatching and fledging success. The significant improvement in nesting success after 1995 (Table 1) can be attributed to improved rat control at nests, the subsequent eradication of kiore from Codfish Island, the elimination of the starvation of nestlings in poor fruiting years through the provision of supplementary food to

Table 2 Comparison of kakapo productivity parameters following the introduction of new management methods (1995-2002) with those of related parrot species (de Kloet & de Kloet 2005) for which the relevant data were available. HF = hatching failure, P = predation, CS = chick starvation, CD = chick death (unknown causes), O = other causes. Sources of data: ¹Moorhouse (1991); ²Murphy *et al.* (2002); ³Smith & Saunders (1986); ⁴Garnett *et al.* (1999); ⁵Jackson (1963), Kemp (1999).

Species	Nesting success (%)	Hatching success (%)	Fledging success (%)	Causes of low productivity
Kakapo	45	46	82	HF
Kaka ¹	40	56	46	HF, P, CS
Palm cockatoo (<i>Probosciger atterimus</i>) ²	22	63	22	P, HF
Red-tailed cockatoo (<i>Calyptorhynchus banksii</i>) ³	29	64	45	HF, CD
Glossy cockatoo (<i>C. lathamii</i>) ⁴	23	53	75	HF, P
Kea ⁵	52	76	64	P, O
Short-billed cockatoo (<i>C. funereus latirostris</i>) ²	—	76	35	—
Sulphur-crested cockatoo (<i>Cacatua galerita</i>) ²	—	60	35	—
Major Mitchell's cockatoo (<i>C. leadbeateri</i>) ²	—	75	47	—
Western corella (<i>C. pastinator</i>) ²	—	67	76	—
Little corella (<i>C. tenuirostris</i>) ²	—	83	65	—
Galah (<i>Eolophus roseicapillus</i>) ²	—	62	48	—

nesting females and the early detection and elimination of potential hazards to eggs or nestlings.

Although both nesting and fledging success improved significantly after 1995, hatching success was unaffected by the new management techniques introduced that year (Table 1). Poor hatching success has two components; infertility and embryo death. The high incidence of infertile eggs may reflect poor sperm quality. Male kakapo have a high incidence of abnormal sperm (C. McInnes unpubl. data) and male fertility may also have been reduced by dietary exposure to aflatoxins in supplementary food pellets and walnuts provided to kakapo (B. Gartrell pers. comm.). Embryo death could be the result of either nutrient deficiencies or inbreeding. Since female kakapo on offshore islands have had access to relatively nutrient-rich supplementary food since 1989, inbreeding seems the more likely explanation.

Poor hatching success is characteristic of bird populations with low genetic diversity (Briskie & Mackintosh 2004) and the surviving kakapo have lower genetic variation than any other New Zealand bird except black robin (*Petroica traversi*), in which all surviving individuals are descended from a single female (Miller *et al.* 2003; Robertson 2006). The kakapo has lower hatching success than nine of its closest relatives for which the relevant data were available. For example kaka (*Nestor meridionalis*) and kea (*N. notabilis*) have hatching rates of 56% (Moorhouse 1991) and 76% (Jackson 1963; Kemp 1999) respectively, and that of seven Australian relatives range between 63 - 83% (Murphy *et al.* 2002) (Table 2). Although dietary exposure to aflatoxins or certain fatty acid ratios through supplementary food could cause poor hatching success, the fact that hatching success was also low before the advent of supplementary feeding (Powlesland *et al.* 1992) suggests that inbreeding is the most likely cause. If so, improving hatching success will be a long-term process requiring the management of mating to maximize remaining

genetic diversity. A high priority in this regard is to increase the number of progeny of the last Fiordland kakapo, Richard Henry, a bird that is known to be genetically distinct from the rest of the population (Miller *et al.* 2003). The similar introduction of genes from new males to an inbred population of greater prairie chickens (*Tympanuchus cupido pinnatus*) resulted in a significant improvement in hatching success (Westemeier *et al.* 1998).

Comparison of nesting rate (and hence potential productivity) of kakapo on various islands indicated Maud Island in the Marlborough Sounds to be markedly inferior to the other islands and it is no longer used as a breeding location. Pearl Island has also been declared unsuitable for a breeding population because, in addition to 3 species of rats (*Rattus* spp.), it has weka (*Gallirallus australis*) which probably preyed on kakapo eggs there in 1999 (Elliott *et al.* 2002). Although potential productivity on Little Barrier was no different to that on Codfish and Pearl Islands, the island's size and steep terrain made management of kakapo there considerably more difficult than on smaller, less rugged islands. Furthermore, although nesting rate on Little Barrier was similar to that on Codfish and Pearl Island, only two chicks fledged unaided there compared to 23 on Codfish Island. It has yet to be determined whether female kakapo can raise chicks on Little Barrier without supplementary food, as occurred on Codfish Island in 2002. Thus, of the four original islands, Codfish is the only one that still has a breeding population of kakapo. Kakapo have since been transferred to two new predator-free islands in Fiordland, the suitability of which for breeding is currently being evaluated.

CONCLUSIONS

New management methods introduced in 1995 were followed by significant improvements in nesting and fledging

success. As a result the kakapo population has grown by 69% in 10 years. Juveniles now comprise 36% of the total population and nearly 50% of the female population. Low breeding frequency and poor hatching success are now the main obstacles to further increasing productivity. The single most effective management intervention was the

strategic concentration of the entire female population on Codfish Island in anticipation of an exceptional rimu fruit crop in 2002. Genetic management of the population to reduce inbreeding and maximize genetic variation is probably where the greatest gains in kakapo productivity are to be achieved.

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LITERATURE CITED

- Briskie, J.; Mackintosh, M. 2004. Hatching failure increases with severity of population bottlenecks in birds. *PNAS* 101: 558-561.
- Butler, D. 1989. *Quest for the kakapo*. Auckland, Heinemann Reed.
- Clout, M.N.; Merton, D.V. 1998. Saving the kakapo: the conservation of the world's most peculiar parrot. *Bird Conservation International* 8: 281-296.
- Clout, M.N.; Elliott, G.P.; Robertson, B.C. 2002. Effects of supplementary feeding on the offspring sex ratio of kakapo: a dilemma for the conservation of a polygynous parrot. *Biological Conservation* 107: 13-18.
- de Kloet, R.; de Kloet, S. 2005. The evolution of the spindlin gene in birds: Sequence analysis of an intron of the spindlin W and Z gene reveals four major divisions of the Psittaciformes. *Molecular Phylogenetics and Evolution* 36: 706-721.
- Eason, D.K.; Elliott, G.P.; Merton, D.V.; Jansen, P.W.; Harper, G.A.; Moorhouse, R.J. 2006. Breeding biology of kakapo (*Strigops habroptilus*) on offshore island sanctuaries, 1990-2002. *Notornis* 53: 27-36.
- Elliott, G.P. 2006. A simulation of the future of kakapo. *Notornis* 53(1): 164-172.
- Elliott, G.P.; Merton, D.V.; Jansen, P.W. 2001. Intensive management of a critically endangered species: the kakapo. *Biological Conservation* 99: 121-133.
- Elliott, G.P.; Eason, D.; Climo, G. 2002. Possible weka (*Gallirallus australis*) predation of kakapo (*Strigops habroptilus*) eggs. *Notornis* 49: 177-179.
- Garnett, S.; Pedler, L.; Crowley, G. 1999. The breeding biology of the glossy black cockatoo *Calyptorhynchus lathami* on Kangaroo Island, South Australia. *Emu* 99: 262-279.
- Harper, G.; Elliott, G.; Eason, D.; Moorhouse, R.J. 2006. What triggers nesting of kakapo (*Strigops habroptilus*)? *Notornis* 53 (1): 160-163.
- Jackson, J. 1963. The nesting of keas. *Notornis* 10: 319-326.
- Jansen, P.W. 2006. Kakapo recovery: the basis of decision-making. *Notornis* 53(1): 184-190.
- Kemp, J. 1999. Nesting success and survivorship in kea (*Nestor notabilis*): implications for their conservation. Unpubl. M.Sc thesis, University of Otago, Dunedin, N.Z.
- Lloyd, B.D.; Powlesland, R.G. 1994. The decline of kakapo *Strigops habroptilus* and attempts at conservation by translocation. *Biological Conservation* 69: 75-85.
- Merton, D.V.; Morris, R.B.; Atkinson, I.A.E. 1984. Lek behaviour in a parrot: the kakapo *Strigops habroptilus* of New Zealand. *Ibis* 126: 277-283.
- Miller, H.C.; Lambert, D.M.; Millar, C.D.; Robertson, B.C.; Minot, E.O. 2003. Minisatellite DNA profiling detects lineages and parentage in the endangered kakapo (*Strigops habroptilus*) despite low microsatellite DNA variation. *Conservation Genetics* 4: 265-274.
- Moorhouse, R. 1991. Annual variation in productivity of North Island kaka on Kapiti Island, New Zealand. *Acta XX Congressus Internationalis Ornithologici*: 690-696.
- Murphy, S.; Legge, S.; Heinsohn, R. 2003. The breeding biology of palm cockatoos (*Probosciger aterrimus*): A case of a slow life history. *Journal of Zoology (London)* 261: 327-339.
- Powlesland, R.G.; Lloyd, B.D.; Best, H.A.; Merton, D.V. 1992. Breeding biology of the kakapo *Strigops habroptilus* on Stewart Island, New Zealand. *Ibis* 134: 361-373.
- Powlesland, R.G.; Roberts, A.; Lloyd, B.D.; Merton, D.V. 1995. Number, fate, and distribution of kakapo (*Strigops habroptilus*) found on Stewart Island, New Zealand. *New Zealand Journal of Zoology* 22: 239-248.
- Powlesland, R.G.; Merton, D.V.; Cockrem, J.F. 2006. A parrot apart: the natural history of the kakapo (*Strigops habroptilus*), and the context of its conservation management. *Notornis* 53(1): 3-26.
- Robertson, B.C. 2006. The role of genetics in kakapo recovery. *Notornis* 53(1): 173-183.
- Sainsbury, J. 2004. Population structure, conservation genetics and evolution of the kaka (*Nestor meridionalis*): a microsatellite study. Unpubl. PhD thesis, Victoria University, Wellington.
- Smith, G.; Saunders, D. 1986. Clutch size and productivity in three sympatric species of cockatoo (Psittaciformes) in the south-west of Australia. *Australian Wildlife Research* 13: 275-285.
- Westemeier, R.L.; Brawn, J.D.; Simpson, S.A.; Esker, T.L.; Jansen, R.W.; Walk, J.W.; Kershner, E.L.; Bouzat, J.L.; Paige, K.N. 1998. Tracking the long-term decline and recovery of an isolated population. *Science (Washington D C)* 282: 1695-1698.