

Hand-rearing kakapo (*Strigops habroptilus*), 1997-2005

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Abstract Sixteen of 26 hand-reared kakapo chicks (62%) have been successfully returned to the wild. These chicks were initially kept in thermostatically-controlled brooders, then in plastic tubs in an air-conditioned room, and finally a pen in an unheated room prior to transfer to an outdoor pen and release in the wild. Brooding temperature was progressively reduced to simulate the progressively longer period kakapo chicks spend in the nest without brooding. Humidity was maintained at 80% to simulate that measured in kakapo nests. Some chicks fed a relatively high fat diet within their first 20 days after hatching developed fatty liver disease; subsequently, chicks less than 45 days of age were fed a lower fat diet and older chicks gradually converted to a higher fat diet. Normal gut flora was successfully established in chicks by adding small quantities of adult kakapo faeces that had been screened for diseases and parasites. The growth rate of hand-reared chicks was significantly slower than that of parent-reared chicks during the first 40 days after hatching but there was no significant difference in growth rate in older chicks. Half the disparity in the growth rates of hand-reared and parent-reared chicks was due to the fact that most hand-reared chicks were suffering from ill health or injury before being taken into captivity. Two male chicks reared in isolation from other kakapo display varying degrees of sexual attraction to humans. The only sexually mature hand-reared female chick has mated and hatched a chick in the wild. Hand-reared kakapo comprised 40% of all chicks fledged since 1990 and presently comprise 20% of the total population of 86 birds.

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INTRODUCTION

The kakapo (*Strigops habroptilus*) is a critically endangered, flightless parrot endemic to New Zealand. The total population (in 2005) is just 86 birds, all of which now live on predator-free, offshore island refuges. Because females rear their young entirely without male assistance, the altricial nestlings are left unattended for several hours each night while females forage for food (Powlesland *et al.* 1992; Elliott *et al.* 2001). Nestlings are, therefore, vulnerable to hypothermia and interference, including attempted forced copulation by male kakapo. The podocarp fruit that female kakapo rely on to rear their young (Cottam *et al.* 2006; Harper *et al.* 2006) not infrequently abort, or fail to ripen, causing females to spend relatively long periods foraging away from the nest. In such years the development of embryos may be retarded because of chilling, resulting in death or congenital defects at hatching, and nestlings frequently display stunted growth or die of starvation (Elliott *et al.* 2001). Even when nesting females have been provided with supplementary food some nestlings fail to thrive because of illness or injury. The ability to hand-rear such nestlings and return them to wild is, therefore, an important aspect of the conservation of this critically endangered species.

Hand-rearing was first attempted in 1991 when four eggs were collected on Little Barrier Island for artificial incubation. Only one egg was viable but the chick died three days after hatching (Elliott *et al.* 2001). The next attempt was in 1992 when three starving chicks were rescued from Codfish Island and hand-reared at Auckland Zoo. One (Hoki) survived to independence (Sibley 1994) and subsequently lived in captivity on Maud Island for five years. This bird has since been successfully returned to the wild on Codfish Island where she has mated, nested and fledged a chick. Hand-rearing became a regular part of kakapo management with the introduction of an intensive nest management regime, including regular nestling health checks, in 1997. This identified nestlings that were ill, injured, or significantly underweight for their age, and since 1997 all such nestlings have been hand-reared in captivity. In addition, clutches have been removed from nests and artificially incubated whenever nests were considered likely to fail, and since 1999 some clutches have been removed to induce females to re-nest (Elliott *et al.* 2001). All chicks hatched from artificially incubated eggs were hand-reared. This paper describes the hand-rearing methods used for kakapo and the subsequent integration of hand-reared kakapo into the wild population.

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Table 1 Types of accommodation provided to captive kakapo chicks of different ages.

Chick age (days)	Accommodation
0 – 15	Enclosed brooder, thermostatically controlled
16 – 32	Open top tub in warm room
33 – 84	Open pen in cool room suitable for 3 birds
85	Outdoor enclosure with covered shelter and vegetation cover
131 – 163	Released from captivity

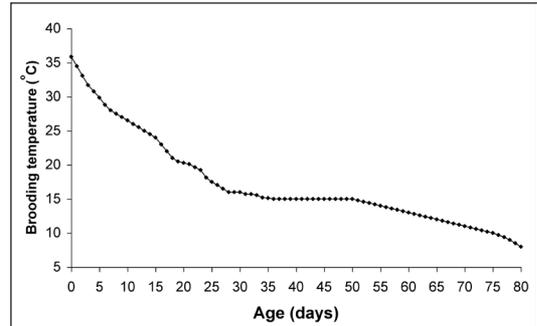
MATERIALS AND METHODS

Brooders, pens and enclosures

Chicks were transported from the nest to a temporary brooding facility in a portable incubator. Once their condition had stabilised they were transported by air to the main hand-rearing facility on the South Island mainland. Chicks less than two weeks old were kept inside thermostatically controlled, transparent plastic brooders (1 m x 0.5 m) in small plastic bowls or tubs, on a substrate of crumpled paper towels and tissue paper. This provided head support for young chicks and prevented chicks rolling onto their backs thereby reducing the risk of food aspiration. Paper towels and tissues were replaced regularly, usually after each meal, to maintain good hygiene. Chicks older than two weeks were brooded in a warm humid room in open top plastic tubs. Tubs were sufficiently large for chicks to lie spread-eagled at rest without touching each other. Deep tubs and brooders required ventilation grills in the base to maintain airflow and avoid a build-up of heat and stale air.

At approximately 33 days old, chicks were moved into a large plastic pen (2.4 x 1.2m x 0.6m high) on the floor of a cool (< 18°C) room. A brooding tub placed on its side with vegetation draped over the entrance, provided a familiar and secure refuge for chicks. An electric blanket (pet pad) under towels in the tub provided extra warmth for the chicks should they require it. The pen was large enough for three chicks, but could be divided in half or doubled in size depending on how many birds were being raised. Birds that had not previously been together were placed in adjoining pens where they could see each other through a perspex window, for a few days before being placed in the same pen. While penned, chicks were provided with solid food and other stimuli to prevent boredom and to encourage them to feed themselves. The variety of stimuli and food provided was increased as chicks developed and included fresh leaves, natural foods, branches to climb on, fruit, food pellets, nuts and seeds.

Tubs and pens were lined with green, woven, cotton towels crumpled to improve traction and avoid chicks splaying their legs when at rest. Towels were laundered daily to maintain a high standard of hygiene. Wood shavings were used as pen substrate in 1997, but were messy, unhygienic, obscured weaning food and made monitoring faeces and regurgitation difficult. Brooders, tubs and pens were cleaned daily with warm water and detergent and disinfected twice weekly with 1:200 Virkon S (Antec International) or TriGene (Ethical Agents Ltd).



► **Figure 1** Brooding temperature regime for hand-reared kakapo chicks

They were thoroughly cleaned and disinfected between every change of chicks.

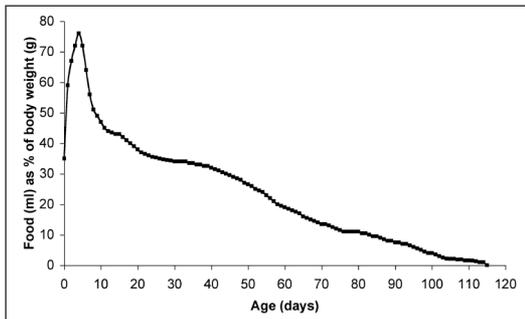
Hand-reared chicks were moved to an outdoor enclosure at between 75-101 days of age ($\bar{x} = 85$, $n = 16$). This involved a transfer from the mainland hand-rearing facility to an outdoor enclosure on the island where chicks would later be released into the wild. The outdoor enclosure on Codfish Island was approximately 600 m² with an enclosed area of 5 m² to provide shelter from the weather. Additional cover was provided by low shrubby vegetation and trees up to 4 m high. Initially the chicks were confined within the shelter for a few days until they had settled into their new surroundings. Sufficient weatherproof roost boxes were placed on the ground within the enclosure so that each bird could roost alone if it wanted to. Chicks were introduced to as many natural foods as possible by staking fresh 0.5 m branches of different kakapo food plants into the ground. In addition to browse, this vegetation provided chicks with additional shelter and security. The different types of accommodation provided to hand-reared chicks at different stages of development are summarised in Table 1.

Temperature and humidity

An effective temperature regime was perfected in 1999 after a sufficient number of chicks had been hand-reared. Ambient temperature was reduced daily (Fig. 1) so that by the time chicks were about one month of age it was 15°C. Optimum temperature decrements for each day of nestling age were determined by observing chicks' behaviour and skin colour; chicks suffering from heat stress were restless, vocal, had a respiration rate of >30 breaths per minute and visible skin was usually dark pink. Chicks older than

Table 2 Hand-rearing formula and concentration provided to hand-reared kakapo.

Age (days)	Formula type and concentration (% solids)
0-1	1st 1-2 meals Hartmann' solution, then 10% Kaytee Exact® original hand-feeding formula mixed with Hartmann's
2	12%
3	14%
4	16%
5	18%
6 - 7	20%
8 - 9	22%
8 - 10	Convert Hartmann's to water, by ¼ daily
10 - 55	24%
50 - 53	Convert diet to Pretty Bird 19/12® hand-rearing formula, by ¼ daily
53 - 67	26%
68 - 110	28%



► **Figure 2** Daily food intake of hand-reared kakapo chicks as a proportion of chick body weight

one month occasionally became heat stressed when the ambient temperature rose above 18°C, particularly when in a confined space such as a transport box. Air conditioning was used to keep older chicks cool; however, because this dried the air two to three steam vaporisers were used to maintain humidity. In order to preserve humidity, heating was provided by a thermostatically controlled oil-filled column heater rather than the air conditioner. In order to acclimatise older chicks to typical early winter temperatures of southern New Zealand, the ambient brooding temperature was gradually reduced to 10°C or less prior to transferring them to an outdoor enclosure. Humidity was maintained at 80% until chicks were transferred to the outdoor enclosure.

Diet

The diet of wild kakapo nestlings is primarily podocarp fruit, particularly rimu (*Dacrydium cupressinum*) (Powlesland *et al.* 1992; Cottam *et al.* 2006). Rimu fruit contains 15 - 23% fat (James *et al.* 1991; Cottam *et al.* 2006) and nestlings quickly develop substantial subcutaneous fat reserves on this diet. Because it was impractical to collect sufficient rimu fruit to feed captive chicks, these were fed a variety of proprietary hand-rearing diets between 1997 and 1999.

Two of these products, Kaytee Exact Original Hand-Feeding Formula® (Kaytee Products, Inc. Wisconsin, USA) and Pretty Bird 19/12® (Pretty Bird international, Inc. Minnesota, USA), eventually proved to be the most suitable and consequently were the only hand-rearing formulae used after 1999. About four hours after hatching chicks were fed warm Hartmann's solution; an electrolyte solution comprised of compound sodium lactate, to which powdered *Lactobacillus acidophilus* had been added. Thereafter, if the chick defecated normally, it was fed 10% Kaytee Exact® formula mixed with Hartman's solution over the next two days. The concentration of formula was then gradually increased, and when chicks were 8 - 10 days old, Hartman's solution was gradually replaced with water. When chicks were 50 - 53 days old Kaytee Exact® was gradually replaced with Pretty Bird 19/12®. The final formula concentration of 28% solids was used from 68 days post hatching until weaning (Table 2).

Mixing food

All proprietary hand-rearing diets were mixed to the manufacturers specifications. The water used to dissolve the dry food was filtered (0.5 microns) and UV light treated or boiled for 20 minutes, then cooled. Food of chicks aged less than seven days or those that were ill was mixed with Hartmann's solution instead of water. A water bath was used to keep food at the correct temperature between preparation and feeding; mixed formula was fed to chicks when it was 40 - 43°C. Mixed food was not kept longer than 20 minutes.

Diet conversion

The transition from one diet to another was done over three days, increasing the proportion of the new formula by a quarter of the volume fed each day. This was a precaution to avoid potential digestive complications that might arise from an abrupt change in diet. The same gradual transition was usually used when switching from Hartmann's solution to water for mixing the food (Table 2).

Table 3 Feeding schedule of captive kakapo chicks. *Average weaning age 111 days (range 94 - 127 d).

Age (days)	Meal interval (hours)	Meals daily	Hours of feeding
0-2	2	10	6 am – 12 am
3-4	2½	8	6 am – 12 am
5-7	3	7	6 am – 12 am
8-55	4	5	7 am – 11 pm
56-70	5	4	7 am – 11 pm
71-85	8	3	7:30 am – 10:30 pm
86-100	12	2	7:30 am – 7 pm
101 to weaning*	24	1	7:30 am (before dawn)

Meal size

Feeding frequency and number of meals were progressively reduced as chicks aged (Table 3). A daily feeding regime based on the chick's age and weight (with an empty crop) at the beginning of each day was used to determine the appropriate meal size with the volume of formula fed (ml) each day calculated as a proportion of the chick's weight (Fig. 2). Chicks significantly lighter than average were given extra food unless they began to regurgitate or resist feeding. When the number of daily meals was reduced to three during weaning; the first meal of the day remained the largest with subsequent feeds progressively decreasing in volume. This gave birds the incentive to forage at night and accept food after roosting if required.

Feeding

The first meal of the day was given when the crop was empty, and subsequent meals when the crop was less than a quarter full. A feeding response was elicited by gently touching the corners of the mouth with the left thumb and forefinger, while allowing the chick to tilt its head as far back as it preferred. The other fingers supported, but did not restrain, the head. Small chicks (usually less than three days old) were fed under a lamp to keep them warm. Chicks less than 12 days old were fed with a teaspoon or 1 - 5 ml luer-tip syringe, dispensing formula directly into their mouth as they swallowed. After 15 days of age, chicks ceased begging and tilted their head too far back to safely deposit food in their mouth. Prior to this behaviour change, which occurred when chicks were c. 180 g (12 - 15 days old), chicks were fed directly into the crop, via a soft plastic tube (5.3 mm diameter) inserted down the oesophagus. The tube was attached to 20 - 100 ml syringes and exceeded the length of the crop and oesophagus (9.5 - 16 cm). A human urethra catheter (5 - 8.5 cm), warmed to soften the plastic, was used to feed weak chicks younger than 12 days.

Tubes entered the chick's mouth from their left, passing obliquely across it to enter the oesophagus on the right side. After 2 - 3 meals, the tube was readily accepted and slid easily into the crop. The tube was rinsed in warm water to remove any adhering food particles and lubricate it prior to feeding.

Establishment of normal gastrointestinal flora

The digestive tract of newly-hatched parrots is sterile but is quickly colonised by beneficial micro-organisms from the parent via regurgitated food resulting in the rapid establishment of a healthy gastrointestinal flora, predominantly bacteria. As well as aiding digestion, this gut flora plays an important role in suppressing the growth of pathogenic bacteria and micro-organisms in the digestive tract (Gerlach 1994b; Ritchie & Harrison 1994). In order to establish a normal gastrointestinal flora in chicks hand-reared from hatching or to re-establish it in those that had been treated with antibiotics, small portions of the faeces of healthy adult kakapo were added to the chicks' hand-rearing formula. The fresh faeces had previously been screened for aerobic and anaerobic bacteria, mould, yeast and parasites, and were then frozen until required. The hand-rearing formula was inoculated with faeces once a day for five days following hatching or immediately after antibiotic medication. Approximately 1g of faeces was mixed with 5 ml of warm water, stirred with a sterile swab and the same swab was stirred through the formula just prior to feeding. Older chicks taking larger meals received 0.1 - 0.3 ml of diluted faeces added directly to their food.

Weaning

Small quantities of solid food was provided to chicks after they were 30 days of age, e.g. apple and kumara slices, walnuts, almonds, kakapo pellets and fresh native berries, especially *Coprosma* spp., *Astelia* spp., rimu, totara (*Podocarpus totara*), and kahikatea (*Dacrydium dacrydioides*). The variety and quantity of solid food was increased as the chicks' began tasting and eating increasing amounts of it. The variety of natural food provided was progressively increased to improve the chicks' knowledge of natural foods and foraging skills.

The average age at weaning was 111 days (range = 94 - 127, $n = 16$). Weaning chicks less than 100 days old proved a little too early, whereas slower developing or problematic chicks needed to be hand-fed for a longer period. When chicks aged less than 90 days refused food, this was invariably a symptom of illness rather than an indication that they were ready to be weaned.

Data collection

Captive chicks were weighed daily prior to their first meal each morning (6 - 7 a.m.) when their crop was empty. Small chicks that were being spoon-fed small volumes of food were also weighed before and after each meal to record the amount fed. Brooding temperature and humidity and the volume of formula fed were recorded at every meal. In addition, anything out of the ordinary such as, coughing, sneezing, wheezing, rapid or heavy respiration involving movement of the wings, tail or mouth, dark pink or red skin, food in nostrils, foul odours or breath, unformed faeces and regurgitation was noted.

Parent-reared chicks were weighed daily in the first two weeks after hatching, then every other day until fledging. Weights were normally collected in the early evening during the mothers' first foraging trip when the chicks typically had little food in their crop. After fledging, parent-reared chicks were weighed during the day at 4 - 14 day intervals until they were 150 days old.

Sexing kakapo chicks

All chicks were sexed using DNA collected from either residual blood in egg shells after hatching or from blood samples taken from chicks after they were a few weeks old (Robertson 2006). By the age of two weeks, morphological differences were usually sufficiently pronounced to reliably indicate sex; female chicks had a smaller skeletal frame than males and a longer, narrower face. The lower mandible was noticeably wider in males than female chicks of the same age. Behavioural differences were also apparent, especially before chicks reached fledging age (72 days); males tended to be calm and somnolent, whereas females were active, vocal and easily agitated, particularly when held. As noted by Sibley (1994), the sexual dimorphism apparent in the primary feathers of adult kakapo (Powlesland 1989) was not a reliable indicator of the sex of chicks. The outer five primaries of first-year females frequently had cream markings on the tips of their inner webs, a characteristic of adult males.

Release from captivity

On Maud Island, five hand-reared birds were released directly from the outdoor enclosure that they had occupied since weaning. The enclosure, about 600 m² was on the periphery of kakapo habitat and close to neighbouring birds. The birds were trained to use a cat door, which allowed them, but not other kakapo, access to the enclosure and the supplemental food within it. On Codfish Island, ten birds were released from smaller enclosures (30 - 500 m²) situated in habitat used by free-ranging kakapo. The birds were kept in these enclosures from 4 - 38 days before being released which was achieved by either opening the side of the enclosure (seven birds) or via a cat door (three birds). The size of the pre-release pen, duration of time chicks spent in it and the number of chicks held in the same pen did not appear to influence the speed or distance of dispersal of released

chicks. Two birds were successfully released directly into the wild to avoid harassment by neighbouring birds while in a pre-release pen.

Sixteen birds hand-reared between 1997 and 2005 were released into the wild aged from 131 - 275 days (\bar{x} = 173 days). Hoki, a female hand-reared in 1992, was released after 4.7 years in captivity. All released chicks were competent at feeding from lidded hoppers and had ceased losing weight after weaning. It was considered advisable to release birds from captivity before they became bored and restless within their outdoor enclosure.

Post-release support

Supplementary food was provided to chicks for varying lengths of time after their release but by the time they were one year old 76% (n = 13) of chicks had either ceased taking it or were no longer provided with it. Initially supplementary food was provided to newly released chicks for a relatively long period, but, as more chicks were released the duration of supplementary feeding was progressively reduced so long as they weren't underweight for their age. Ten chicks who were no longer provided with supplementary food by the time they were one year old had had access to this for an average of 132 days (range = 8 - 220 days).

RESULTS AND DISCUSSION

Temperature and humidity

Appropriate temperature, humidity and ventilation are essential for the normal development of hand-reared parrot nestlings (Flammer & Clubb 1994). In kakapo, preventing overheating by progressively reducing the brooding temperature has proven essential to chicks' health and survival; ambient temperatures above 18°C have caused heat stress, impaired digestion and death. Keeping humidity at 80%, similar to the 80 - 90% humidity measured within kakapo nest sites (D. V. Merton pers. comm.), appeared important to maintain normal respiration, skin hydration, digestion and clear sinuses in chicks.

The susceptibility of kakapo nestlings to overheating suggests that they are adapted to cold conditions. Kakapo nests are situated at or below ground level in natural cavities in logs, tree stumps, the ground, or under dense vegetation (Powlesland *et al.* 1992). Nestlings are confined to the nest cavity for about 70 days throughout the southern autumn (late February - late June) when temperatures in southern New Zealand are relatively cool. For example, during the 2002 nestling season (19 February - 24 June) the average temperature on Codfish Island at 2 m.a.s.l was 10.9°C (range 0.4 - 22°C), however, since nests were in forest between 100 - 240 m.a.s.l they are likely to be significantly cooler than this. Chicks must be able withstand relatively prolonged exposure to such temperatures because brooding female kakapo leave the nest to forage for periods of 1-4 hours, 2-7 times each night soon after their first chick hatches (Elliott *et al.* 2001). Nine mothers left the nest an average of five

Table 4 Gross nutrient content (%) of five commercial hand-rearing formulae fed to kakapo chicks

Formula	Lake's	Kaytee Original	Kaytee Macaw	Pretty Bird 19/8	Pretty Bird 19/12
Protein	18	22	19	19	19
Fat	6.5	8	12	8	12
Fibre	5	5	5	2.5	3.4
Moisture	10	10	10	10	10

times a night (range = 3 - 7) when their oldest chick was 35 days of age, spending an average of 599 minutes (range = 426 - 710) away from their nest. The longest single absence averaged 194 minutes (range = 151 - 208) (Fig. 3).

Kakapo nestlings do display several apparent adaptations that may help them survive such periodic prolonged exposure to cold and predispose them to overheating in captivity. Unlike other parrot species in which chicks hatch virtually naked, kakapo chicks are well covered with white down about 1cm long at hatching. A second coat of dense grey down that emerges between these white down follicles from about 17 days of age is retained as a permanent down layer beneath the contour feathers. In addition to this permanent down layer, further insulation is provided by copious subcutaneous fat deposits that accumulate, with adequate nutrition, a few days after hatching.

Diet

Because so few chicks were hand-reared at any one time it was not possible to use a rigorous experimental approach to determine the optimum diet for chicks. The most suitable diet was, therefore, developed by trial and error. The results apply only to kakapo and do not imply the superiority or inferiority of any particular product with respect to other species.

Lake's Special Needs Hand-Rearing Formula® (Lake's Unlimited, Inc. Minnesota, USA) proved an adequate diet for chicks less than 50 days of age but older chicks were lighter on this diet than parent-reared chicks of the same age, probably because of its relatively low fat content (6.5%, Table 4). For example, the growth rate of one hand-reared male chick (Sirocco) at 50 to 75 days of age was 11% below that of the average parent-reared male chick of the same age. The only female chick hand-reared on this diet remained sickly and stunted and eventually died at 80 days of age. In 1998, a male chick (Sinbad) was fed Lake's formula until 45 days old, then gradually converted over a three day period to a higher (12%) fat formula; Pretty Bird 19/12® Hand-Rearing Formula. The transition to the new diet was uneventful, and this chick was 5% below the average growth curve of parent-reared males at 55 - 75 days of age. Use of Lake's® formula was subsequently discontinued because its fish protein content was considered potentially unsuitable for a herbivorous species.

In 1999 eight chicks hatched in captivity provided an opportunity to evaluate different hand-rearing formulae. The first five chicks were fed Pretty Bird 19/8® from hatching,

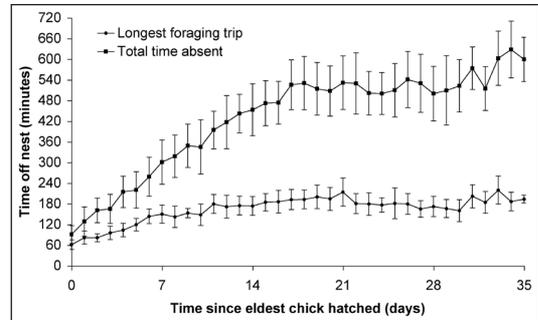


Figure 3 Average time (minutes) per night that kakapo nests ($n = 15$) were unattended by the mother when rimu fruit was abundant on Codfish Island (late summer-autumn 2002). The total time absent and the longest foraging trip per night are shown with 95% C.L. bars

but this was discontinued after they developed digestive problems after 6 - 27 days; chicks occasionally excreted dense, unformed faeces that had the appearance of damp undigested food. These abnormalities may have been due to the relatively low fibre content of this product (Table 4) and usually appeared when chicks were eight days old at which time their diet contained 22% solids or higher. The abnormal faeces were associated with slow digestion, dehydration and constipation. Digestion, hydration and faeces returned to normal within 24 hours of feeding a new diet; Kaytee Exact® which has twice as much dietary fibre as Pretty Bird 19/8® (Table 4).

In an attempt to mimic the relatively high fat content of rimu fruit, the first two chicks hatched in 1999 were fed a comparatively high-fat formula (Pretty Bird 19/12®) at the ages of three and six days. The eldest chick died after 11 days; the primary necropsy result was fatty liver disease (hepatic lipidosis) consistent with a metabolic and/or dietary problem. This chick was 24% below the average weight of parent-reared male chicks and its enlarged liver reduced the space available to its lungs and air sacs, which probably contributed to it aspirating food four days before it died. Occasional respiratory discomfort, lethargy, restlessness, and reduced digestion were the only symptoms observed five days before death but respiratory distress and crop shut-down were acute on the day of death. The second chick developed similar symptoms, but in light of the necropsy results for its older sibling, its diet was changed to a lower fat formula after which its health returned to normal within five days. Fatty liver disease is common in hand-raised chicks of some species of macaws (Arini) and cockatoos

Table 5 Mixed-effects ANOVA comparing hand-reared (HR) and parent-reared (PR) kakapo growth rates (% increase per day) for three age groups (days) of male and female chicks (* = significant difference in growth rate).

Age (days)	Female 0-40	Female 1-70	Female 71-150	Male 0-40	Male 41-70	Male 71-150
HR %/day	8.4	1.2	0.2	9.2	1.4	0.2
PR %/day	11.2	1.4	0.4	11.9	1.2	0.2
P	0.000*	0.37	0.16	0.002*	0.40	0.98

(Cacatuini) which are easily overfed (Flammer & Clubb 1994). Although it seemed unsuitable for young chicks, Pretty Bird 19/12® could be fed to chicks over 50 days of age with no ill effects.

In 1997 an underweight chick (Gromit) was hand-reared from 12 to 21 days of age, then fostered to a female with infertile eggs for a further nine days. Despite being hand-fed in the nest for four days it continued to grow slowly requiring it to be taken into captivity once again. Beginning in the foster nest, this chick was fed food mixed at a higher concentration than normal (32%) and fortified with nuts to increase the fat content to 21%, similar to the fat content of the natural diet, for a total of six days. This high-fat diet appeared to cause slow digestion, dehydration and weight fluctuation. Resuming Lake's formula at the normal concentration (25%) corrected these problems.

A relatively high-fat hand-rearing formula designed for macaw chicks was fed to three of the six chicks reared in 1999 from 50 days of age. The growth rate and condition of these chicks was very similar to that of the three chicks reared on Pretty Bird 19/12® but its use was discontinued after chicks tended to develop mild diarrhoea and smelly faeces. Therefore, after 1999 all kakapo chicks have been reared on just two proprietary hand-rearing diets; Kaytee Exact® for chicks less than 50 days of age and Pretty Bird 19/12® for older chicks.

Therefore, although several commercial hand-rearing diets are suitable for kakapo some are only suitable for chicks at a certain stage of development. For example, low fibre (2.5%) in the diet was the probable cause of digestive complications and constipation in chicks less than one month old and excessive fat content probably caused fatty-liver disease in chicks less than three weeks old. Hand-rearing formula mixed at higher concentrations, or fortified with nuts to increase the fat content, have also caused slow digestion, dehydration and weight fluctuation. All hand-rearing diets fed to kakapo chicks contain about nine times less fibre than rimu fruit, the principal food of kakapo nestlings in the wild (Cottam *et al.* 2006).

Meal size

The first six hand-reared kakapo chicks were fed to capacity, up to 18% of their body weight per meal, until they were 30 days old. From then until weaning the maximum meal size was 10% of body weight. Regurgitation was common among these chicks, particularly after they were one month old, and they regularly regurgitated or resisted

feeding between 26 and 80 days of age. Regurgitation of food (1 - 10 ml) often occurred immediately after feeding but sometimes up to an hour later. Chicks regurgitated suddenly with no preceding symptoms usually while they were standing or lying down. Occasionally a chick would appear uncomfortable and stand trembling until it had regurgitated. Chicks typically relaxed and fell asleep immediately after regurgitating. Two siblings (Trevor, a male, and Boomer, a female) were fed reduced meal sizes and total daily food volumes. The fact that these chicks displayed normal growth without regurgitation suggests that regurgitation was due to over-feeding.

Gastrointestinal bacteria

Attempts to establish beneficial bacteria in the gastrointestinal tract of hand-reared chicks by adding dried *Lactobacillus acidophilus* bacteria to chicks' food, or feeding hand-rearing formulae containing *Lactobacillus*, *Bacillus*, *Bifidobacterium* and *Streptococcus* species, were unsuccessful. These bacteria are not part of the normal kakapo gastrointestinal flora and did not colonise chicks' digestive tracts. Crop and cloacal cultures confirmed that the addition of small amounts of adult faeces to chicks' food was followed by the rapid establishment of the normal kakapo gastrointestinal flora with no ill effects. This appeared to improve the health of hand-reared kakapo chicks while knowledge of the constituents of normal kakapo gastrointestinal flora obviated unnecessary medication for bacteria that are a normal part of this flora, for example, *E. coli* is pathogenic in other parrot species but a normal part of the gastrointestinal flora of kakapo.

An anaerobic bacterium, *Clostridium perfringens*, was a temporary resident of the gastrointestinal tract of all hand-reared chicks but has not been recorded in adult kakapo or parent-reared chicks. This is a potentially pathogenic species that usually appears when gastrointestinal motility is reduced, which can occur as a result of enteritis, low dietary fibre and following the administration of some medications (Gerlach 1994a). It did not cause any adverse effects in hand-reared chicks and was not detected after weaning. Its source and the reason for its appearance are unknown. The presence of *Clostridium* is associated with low dietary fibre in other bird species and the hand-rearing formulae on which kakapo chicks were reared are significantly lower in dietary fibre than the diet of chicks in the wild. *Clostridium* was no longer detected in hand-reared kakapo after the amount of dietary fibre in their diet was increased.

Growth

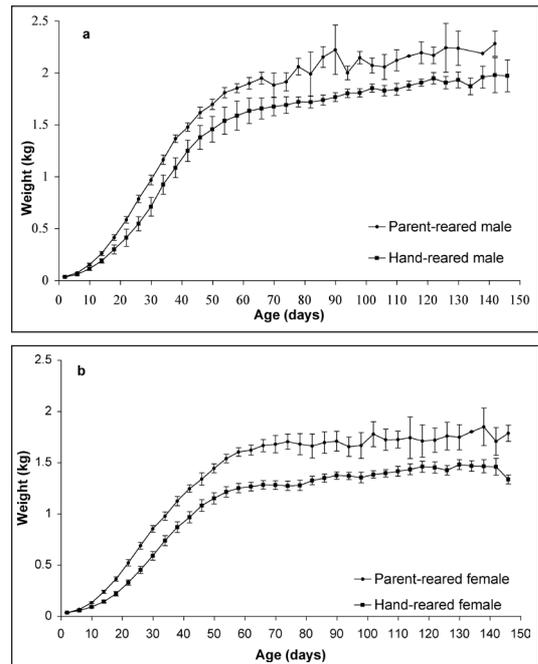
Hand-reared chicks gained weight daily until they were approximately 45 days old after which their growth rate slowed. Chicks 45 - 55 days old did not always increase in weight each day and occasionally lost a small amount of weight over 24 hours. Chicks' weights eventually stabilised at 50 - 60 days, usually several days earlier in females than males. The mean weight \pm 95% C.L. at weaning (110 days) was 1839 ± 57 g for male chicks and 1413 ± 49 g for females, compared to 2118 ± 101 g and 1722 ± 82 g for parent-reared males and females respectively (Fig. 4).

Hand-reared chicks grew significantly slower than parent-raised chicks during their first 40 days of life, but thereafter growth rates were not significantly different. (Mixed-effects ANOVA; female $P = 0.000$, male $P = 0.002$) (Table 5). The slower initial growth rate of hand-reared compared to parent-raised chicks is not surprising since chicks were usually hand-reared because they were either malnourished (Elliott *et al.* 2001), suffering from ill health, or both.

In 1999, four healthy female chicks were successfully hand-reared from hatching to fledging. This provided the opportunity to compare the growth rates of these healthy, hand-reared chicks to those of whose growth, or health, was compromised before hand-rearing began. This comparison indicates that poor growth or health in the nest explains 50% of the difference in growth rate between hand-reared and parent-reared chicks. The growth rate of the four healthy hand-reared females (9.6%/day) was significantly greater than that of other hand-reared female chicks (7.5%/day, mixed-effects ANOVA, $P = 0.02$) and was not significantly less than that of healthy, parent-reared females (11.2%/day) ($P = 0.09$; Fig. 4). This comparison was not possible for male chicks because only one was hand-reared from hatching without developing health problems.

Although parent-reared (PR) kakapo initially grew faster and were heavier at fledging age (72 days) than hand-reared (HR) kakapo ($\sigma\sigma$: PR $\bar{x} = 1912 \pm 88$ g, HR $\bar{x} = 1688 \pm 80$ g; ♀♀ : PR $\bar{x} = 1702 \pm 73$ g, HR $\bar{x} = 1271 \pm 47$ g), there was no significant difference in the femur or shoulder-sternum length (the length from the mid-point of the posterior end of the sternum to the distal end of either clavicle) between these groups of chicks after the age of 150 days. An ANOVA indicates significant sexual size dimorphism in these parameters (Table 6) (shoulder-sternum length $P < 0.0001$, femur: $P < 0.0001$) but no significant hand-rearing effect (shoulder-sternum length $P = 0.66$, femur: $P = 0.13$).

Although insufficient data were collected to allow statistical analysis there was evidence of sexual size dimorphism developing relatively early. The mean width of the lower mandible of four 15-day-old hand-reared female chicks was 17.8 mm (range = 16.1 - 18.6mm) compared to 21.4 mm for a male chick of the same age. By 30 days of age lower mandible width had increased to 20.0 mm (range 18.4 - 21.0mm) in the females and 25.7 mm in the male chick.



► **Figure 4** Growth rate of parent-reared and hand-reared (a) male and (b) female kakapo chicks (mean \pm 95% C.L.)

Survival to weaning

Since 1997, 16 of 22 hand-reared chicks (73%) have been successfully weaned and returned to the wild, all of which remained alive at January 2006 (Table 7). Another bird hand-reared in 1992 (Hoki) has been free-living since 1997. These 17 hand-reared birds (7 $\sigma\sigma$, 10 ♀♀) comprise 40% of all kakapo fledged since 1990 ($n = 43$) and 20% of the total population.

Thirteen (59%) of the 22 chicks hand-reared since 1997 were taken into captivity because they appeared malnourished, injured or ill, and, apart from a 75-day-old fledgling that had been abandoned by its mother, all were taken into captivity < 36 days of age ($\bar{x} = 24 \pm \text{se } 5.3$ d). Of these 13 chicks, nine were underweight ($\geq 20\%$ below the average weight for their age) and five of these were evidently ill; two had upper respiratory infections of unknown cause, one (Sinbad) had a gastrointestinal yeast (*Candida albicans*) infection and later developed a severe sinus infection, one had hepatitis and the last had a congenital deformity of the pyloric sphincter. All survived except the last two chicks which died at 46 and 62 days of age, respectively. Another two nestlings were successfully hand-reared; one had been injured by a sub-adult male kakapo, and the other abandoned by its mother after she was harassed by an adult male kakapo.

Six hand-reared chicks (38%) have died before weaning, three because of health problems contracted in the nest (see above) and three as a direct result of the hand-rearing process; one from fatty-liver disease after being fed a relatively high-fat diet, and one from food aspiration that

Table 6 Comparison of the skeletal size of parent-reared (PR) and hand-reared (HR) kakapo ($\bar{x} \pm 95\%$ C.L. (n)).

Length (mm)	PR female	HR female	PR male	HR male
Shoulder-sternum	109.8 \pm 2.2 (34)	108.0 \pm 3.2 (10)	128 \pm 2.0 (40)	126.5 \pm 3.6 (6)
Femur	93.7 \pm 2.4 (33)	89.0 \pm 4.2 (10)	101.0 \pm 1.8 (40)	101.1 \pm 5.9 (6)

Table 7 Survival of hand-reared (HR) kakapo chicks and their proportion of the total population at the end of each breeding year, 1990-2005.

Nest year	Number hand-reared	Number weaned	% of total population	Kakapo population size
1991	1	0	0	51
1992	3	1	2	52
1993	0	0	2	51
1997	2	1	4	54
1998	1	1	5	56
1999	8	6	15	62
2002	5	4	15	86
2005	6	4	20	86
Total	26	17	20	86

was probably induced by heat stress. Lack of information on the normal kakapo gastrointestinal flora led to unnecessary medication of one chick for a bacterium subsequently found to be a normal component of this (*E. coli*). The chick died at 80 days of age due to chronic kidney failure, possibly the result of antibiotic (enrofloxacin) treatment, compounded by dehydration and a long illness.

Another nine chicks (69%) were successfully hand-reared from hatching following the artificial incubation of 13 eggs (Elliott *et al.* 2001; Eason *et al.* 2006). Eight of these hatched from 10 viable eggs collected in 1999 on Pearl and Little Barrier Islands to protect them from the possibility of predation by rats (*Rattus* spp.), or weka (*Gallirallus australis*). Another two eggs were artificially incubated on Codfish Island in 2005 after they rolled out of the nest and had been without incubation for 12 - 24 h. One hatched, but the chick had an acute necrotised umbilicus, was weak, difficult to feed and died 36 hours later from acute bacterial bronchopneumonia, probably due to food aspiration. The ninth chick hatched from an egg artificially incubated in 2005 to correct inadequate weight loss during natural incubation.

Integration of hand-reared birds into the wild population

Minor fights leading to the establishment of a dominance hierarchy, particularly among male chicks, were frequently observed after they were 120 days of age. Such behaviour may be important to subsequent male performance on the lek. Chicks became predominantly nocturnal as soon as they were placed in an outdoor enclosure and, after weaning, were generally inactive during daylight hours and reluctant to leave the cover of vegetation until after dark.

Three of the four chicks released in 2002 stopped taking the supplemental food provided to them after they moved to new home ranges distant from their feeding stations. The condition of these birds remained comparable to those birds

still taking supplemental food. All hand-reared chicks ceased associating with their surrogate siblings within 57 days of release (\bar{x} = 25 d, range = 1 - 57 d, n = 13) when their mean age was 177 days (range = 157 - 201, n = 13). This is somewhat earlier than the age at which parent-reared chicks became independent from their mothers (\bar{x} = 246 d, range = 183 - 350 d, n = 25) (Eason *et al.* 2006). Seventeen hand-reared birds have now been released, however, only three have so far reached sexual maturity. The oldest hand-reared female (Hoki), bred for the first time at 10 years of age after having spent the first 4.7 years of her life in captivity, isolated from other kakapo since she was 10 weeks of age. She copulated with two males and laid one egg which died within four days of development. She subsequently hatched and fledged a foster chick which she abandoned after repeated harassment by an adult male at the nest site.

The two sexually mature hand-reared males (Sirocco) and (Sinbad) display different degrees of sexual attraction to humans. Both these birds were raised in isolation from other kakapo after they were 10 and three weeks old, respectively, and both spent a total of 8.5 months in captivity. Although, predominantly nocturnal, both will approach people they detect near (c. 20 m) their day-time roost. Since he was 4.8 years old, Sirocco has visited the hut on Codfish Island (1.6 km from his normal home range), for increasingly longer periods each summer and autumn. Attempts to discourage him by chasing, throwing water and returning him to his usual home range have been ineffective at deterring this behaviour. During his seventh summer he began booming from a track and bowl system he established on the path between the hut and toilet, the only site regularly visited by humans at night, and would attempt to copulate with anyone that approached his bowl. Sirocco has shown no interest in establishing a track and bowl system near other kakapo, however, he returns to his winter home range at the end of each booming season.

The other human-imprinted male kakapo, Sinbad,

occasionally visited the houses on Maud Island during his first two years of life, but normally lived c. 800 m from these. He was moved to Codfish Island at two years of age where he established a home range 2.3 km from the hut. Although he hasn't visited the hut, after he reached four years of age he regularly visited people camped near kakapo nests at night, and after he reached seven years of age he was sometimes stimulated to boom by the close proximity of people and would occasionally attempt to copulate with them. Other aspects of his behaviour appear normal; like most adolescent male kakapo (Powlesland *et al.* 1992; Eason *et al.* 2006) he visited booming males before he began booming, and although he has not yet established his own track-and-bowl system, he has on several occasions boomed in close proximity to other booming males.

The different degrees of sexual attraction these two males display towards humans probably reflect differences in their treatment in captivity. While in captivity, Sirocco was encouraged to climb and play-fight with people for about an hour each night. In contrast, Sinbad was not encouraged to play with people and his daily contact with humans was relatively brief.

No other hand-raised birds so far show any sign of sexual attraction to humans; four (two males, two females) are no longer approachable, while another six (two males, four females), although approachable, prefer to remain at arm's length. The only male chick that has heard others booming when three years old or older (Ariki) displayed normal juvenile male behaviour by visiting booming males. All of these birds

were hand-reared in the presence of two or three other chicks and were released from captivity within 165 days.

In 2005, a wild, sub-adult male kakapo entered a pen on Codfish Island and attacked two hand-reared female chicks within it. One chick (Yasmine) sustained only minor injuries and was able to be released four weeks later but the second (Pounamu) sustained serious head and neck wounds requiring surgery and a 3.5 month convalescence before she could be released into the wild.

CONCLUSION

The ability to hand-rear underweight, ill, or injured kakapo nestlings has made a significant contribution to the species' conservation; most such chicks can now be successfully hand-reared and returned to the wild, as can most chicks hatched from artificially incubated eggs. Important factors in hand-rearing kakapo are daily reduction of the brooding temperature, use of an appropriate hand-rearing formula for the chick's age, avoiding overfeeding, establishment of natural gut flora, and the socialisation of chicks with other kakapo. Although no hand-reared males have yet fathered young, the inequality of male mating success in kakapo is such that many adult males have also yet to mate (Eason *et al.* 2006). The only hand-reared female that has so far reached sexual maturity has mated and fledged a chick. Although two male chicks hand-reared in isolation from other kakapo are sexually attracted to humans, all other hand-reared chicks, apart from varying degrees of tameness, display normal kakapo behaviour.

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