Radio-tracking Studies of Grey-headed Flying-foxes, *Pteropus poliocephalus*, from the Gordon Colony, Sydney

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Radio-tracking studies of hand-reared grey-headed flying-foxes (*Pteropus poliocephalus*) released at the Gordon colony in the northern suburbs of Sydney have shown that successful integration of hand-reared bats with a wild colony depends on timing of release. Complete integration occurred when release was timed to coincide with independent foraging behaviour of wild juvenile bats.

Radio-collared hand-reared bats were found to move between the colony at Gordon and colonies in the Royal Botanic Gardens Sydney and at Cabramatta Creek in the south of Sydney. Long distance movements of individuals along the coast as far as 310 km north and 279 km south of Gordon were recorded.

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INTRODUCTION

In recent years there has been a rapid growth in the number of wildlife rehabilitation groups, particularly along the east coast of Australia. The ultimate goal of such groups is to release rehabilitated and hand-reared native animals back into the wild. Indeed this is required by law in all Australian states.

In some states there are restrictions on conditions and sites of release, such as regulations prohibiting release in National Parks, but these criteria appear to be based on general conservation biology principles rather than data based on studies of individual species and specific sites. The few local studies that have been carried out to determine the fate of rehabilitated, captive-reared or relocated animals after release have provided only limited data (Gipps 1991; Hyman 1993; Kleiman 1989). The programs have usually been terminated by high rates of predation by foxes or other introduced carnivores. For example, in a release of captive-bred Parma Wallabies, 100% were killed by foxes shortly after release (Short et al. 1992). Similarly 26 out of 55 rufous hare wallabies released with radio transmitters in the Northern Territory were killed by cats, and the total was probably much higher as the fate of some of the other radio-collared wallabies could not be determined (Gibson et al. 1994). In a long-term study of the fate of hand-reared ringtail possums released into Ku-ring-gai Chase, Augee et al. (1996) found low levels of survival and high rates of predation by foxes and to a lesser extent cats. The only successful release programs have apparently been on islands, such as the establishment of brush-tailed bettongs (Delroy et al. 1986).

All the above studies of release programs in Australia have dealt with terrestrial mammals. However Australia has a diverse bat fauna, including six families of Microchiroptera with about 56 species and one family (Pteropidae, the flying-foxes) of Megachiroptera with 7 species. Because of their proximity to human habitation and the economic impact of their occassional attacks on fruit orchards, flying-foxes receive considerable human attention. The distribution of the grey-headed flying-fox, *Pteropus poliocephalus*, includes the major cities of Brisbane and Sydney, and to a lesser extent Melbourne, and therefore this is the bat species most commonly involved in rehabilitation and release programs. However the fates of hand-reared flying-foxes, their survival and behaviour after release remain unknown.

Here we report a study of radio-collared, hand-reared *P. poliocephalus* juveniles released at the periphery of a colony site in the northern Sydney suburb of Gordon. The four main objectives were to:

1) determine the degree to which released hand-reared juveniles integrated with the resident wild colony;
2) establish release procedures which maximise such integration;
3) track local movements within 50 km, which is the maximum range for nightly foraging flights determined for this species by Eby (1991); and
4) track long distance movements to other colony sites to the north and south of Sydney.

MATERIALS AND METHODS

The individuals radio-tracked in this study were orphans that had been hand-reared by trained carers belonging to the Ku-ring-gai Bat Conservation Society (KBCS). Several wild adults that were captured by C.R. Tidemann and the Cabramatta Bat Colony Committee at Cabramatta Creek were also fitted with radio transmitters.

Colony site

The colony is located in a narrow, steep-sided valley in the Sydney suburb of Gordon, 13 kilometres north of the Sydney Opera House, 33°45′16″S, 151°9′30″E. This valley is drained by Stoney Creek, a tributary of Rocky Creek, which flows into Middle Harbour, and which eventually runs into Sydney Harbour. The valley consists of tall open forest, much degraded with introduced vines and ground cover. The site is being regenerated by paid contractors and volunteers who have worked regularly on site since 1987.

Release protocol

The established procedure used by the Ku-ring-gai Bat Conservation Society for release of hand-reared flying-foxes is to place the animals in a large aviary (2.5 m high, 3.1 x 6.3 m base) near to the colony but well outside its perimeter. The colony can be heard from the cage but not seen. Wild juvenile and adult flying-foxes have been observed regularly visiting the aviary when the hand-reared animals occupy it.

In 1995, the first year of the study, the procedures for release used in previous years were followed and the hand-reared flying-foxes were placed into the aviary in late February. The aviary remained closed for a period of 28 days to allow the animals to become accustomed to the wild surroundings and to give them an opportunity for flight practice. Buckets of fruit with protein supplement were provided daily. On 18 March, a hatch in the aviary was opened and the animals were allowed to freely move in and out of the cage. Food was available from buckets hanging on the outside of the aviary for a further eight weeks.

In 1996 the flying-foxes were placed in the release aviary in late January, a month earlier than in 1995. The release hatch was opened 30 days later, on 26 February. Support feeding ceased after six weeks. In 1997, the earlier release time was repeated and the hatch opened on 21 February. Support feeding was gradually reduced, terminating completely after four weeks.

Radio transmitters

Radio transmitters were specially made for this project by Biotelemetry Tracking Australia, Kent Town, South Australia. A prime consideration for a radio-tracking system with flying-foxes is that there is virtually no prospect of recapturing the bat in order to remove expired transmitters. Therefore in 1995 transmitters were designed to be glued to the back of the animal so that they would fall off after a short period. The transmitters weighed 7 g and had a 26 cm trailing antenna. The range of the transmitters was good, at least 5 km line-of-sight, but after 20 days almost all of the transmitters had fallen off or were possibly removed by grooming.

In 1996 transmitters weighing 16 g with a shorter trailing antenna were attached to collars made from surgical tubing. This type of collar was designed for use on small marsupials (Soderquist 1993) where both stretch and limited life of the collar are required. Ultraviolet light destroys the rubber tubing, and in our experience the transmitter and collar fell off within 3–4 months. Prior to the 1996 release, prototypes of the collar were tested on captive flying-foxes and proved to be tolerated extremely well by the bats. The same system was used again in 1997.

Location techniques

The position of individual flying-foxes was determined by triangulation from three vantage points on the rim of the valley, above the colony. Bearings were determined using directional antennas and surveyors' (magnetic) compasses and plotted onto a "radio map" (Gibson et al. 1994) of the resident colony which was established by multiple bearings taken on transmitters placed at various spots on the outer limits of the colony.

Several aerial surveys were made from a NSW National Parks and Wildlife Service fixed-wing aircraft along the coast to the north and south of Sydney. Directional antennas (Telonix, Mesa, Arizona, USA) were fixed to the wings and transmitter frequencies were scanned using a multichannel Telonix scanner.

Exit counts

The size of the Gordon colony was estimated by counting the number of bats flying out at sunset over points located below the three major exit routes (Rosedale Bridge to the W of the colony, Maytone Ave. to the SE, and Warandoo St. to the NE). Counts were carried out by trained volunteers using hand-held counters.

RESULTS

Integration

The only criterion for a "successful" release capable of quantitative assessment by the technique outlined above is integration into the resident colony. Locations of bats in the Gordon Valley determined by triangulation for the three year period of this study are shown in Fig. 1. As data could only be obtained for the first 20 days after release in

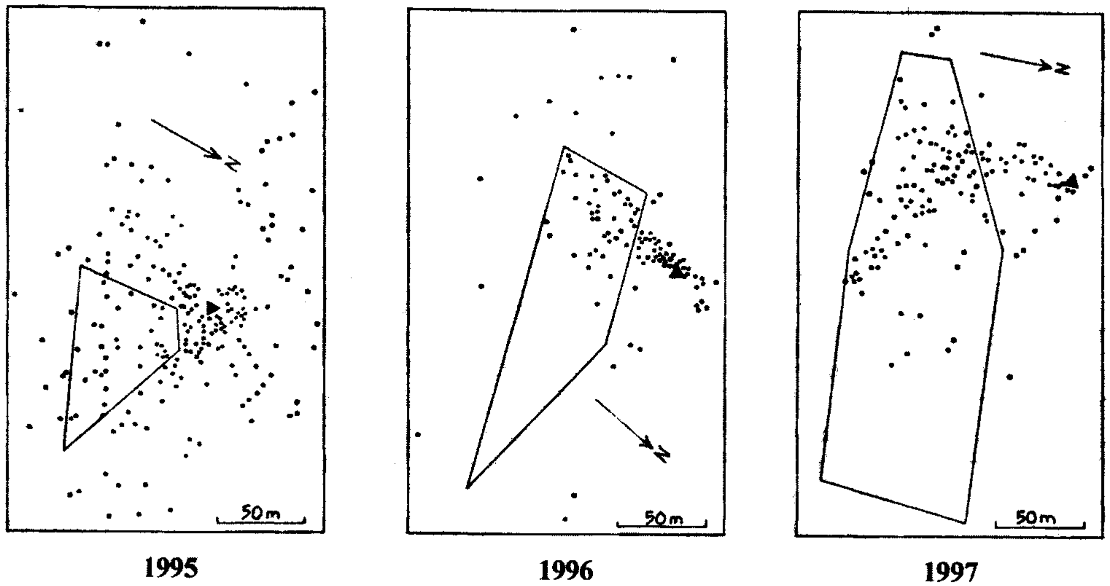

Figure 1. All roost sites determined by triangulation of signals from radio-collared grey-headed flying-foxes in the Gordon valley. The outline represents the maximum boundary of the resident, wild bat colony. The solid triangle indicates the position of the release cage.

1995, due to the subsequent shedding of the glued-on transmitters, Table 1 compares the location of daytime roost sites for all three years over that time period. In 1997, under conditions of relatively early release and cessation of post-release support feeding, integration was 100% by Day 20. By Day 20 in 1997 all the radio-collared bats were flying out from the valley with the nightly exit of the colony.

TABLE 1.

Summary of conditions and integration over three years of study. Integration is the percentage of total roost sites determined that lay within the resident colony site.

Year	Release date	Number of hand-reared bats	Number of wild bats	Support feeding	Mean Wt. (g)	Integration (Day 20)
1995	18 Mar.	28	2	Long Term	463	45%
1996	26 Feb.	48	4	Long Term	402	67%
1997	21 Feb.	31	4	Short Term	384	100%

Local and long distance movements

Unfortunately interference within the scientific research UHF band (150–152 MHz) is so great in the Sydney urban area that signals from the radio-collars could only be picked up at very close range or on the city outskirts.

Local movements of radio-collared flying foxes are shown in Table 2. In 1995 several radio-collared bats which had not roosted within the colony left the valley and were found in nearby backyards or neighbouring suburbs. Bats that had roosted within the colony site and had departed with the rest of the colony at dusk, were found in 1996 and

1997 in the Royal Botanic Gardens, next to the Sydney Opera House (Table 2). On 26 March 1997 a male bat was shot while feeding in a cumquat orchard at Glenorie, about 28 km from the Gordon site. During a tracking flight in 1997 a signal was detected in Bankstown from a transmitter that had been attached to a bat at the Cabramatta colony, about 9 km away.

TABLE 2.

Local movements of radio-collared flying-foxes

Date	Sex	Location	Distance and direction from release cage	Notes
21 Mar. 95	M	Maytone Ave	0.8 km SE	
24 Mar. 95	M	Warandoo Ave	0.4 km NE	remained for one week
7 Apr. 95	F	Roseville	5.1 km S	electrocuted on power line
20 Apr. 95	M	Hornsby	11 km NW	also in Hornsby 27 Apr.
27 Apr. 95	M	Hornsby	11 km NW	many stamens on fur
27 Apr. 95	M	Hornsby	11 km NW	
10 Mar. 96	F	Botanic Gardens	13 km S	feeding
1 Apr. 96	F	St. Ives	3.1 km N	
26 Mar. 97	M	Glenorie	28 km NW	feeding on cumquats
28 Mar. 97	F	Crows Nest	9.6 km SE	electrocuted (overhead wires), banded but not radio-collared
8 Apr. 97	F	Botanic Gardens	13 km S	collared at Cabramatta colony
13 Apr. 97	F	Botanic Gardens	13 km S	feeding
18 Apr. 97	F	Bankstown	9 km NE of Cabramatta	collared at Cabramatta colony
24 Nov. 97	F	Ryde	7.8 km SW	electrocuted (overhead wires), banded but not radio-collared

Individuals or small groups of grey-headed flying-foxes are frequently seen to roost for one to several days at various sites throughout metropolitan Sydney during summer, especially in large fig trees. During this study radio-collared bats were found to be absent from the Gordon colony for periods of one to 11 days before returning to it.

Interchange between the Cabramatta and Gordon colony sites was shown by the appearance of two female bats radio-collared at Cabramatta (weighing 375 and 490 g) at Gordon (9 April and 6–19 April respectively).

Bats detected more than 50 km from the Gordon colony site are listed in Table 3.

In 1996 signals from radio-collars that had been put on hand-reared bats were located north and south of Sydney. A signal from a radio-collar that had been put on a wild bat which was released at Gordon on 24 April 96 was found on 30 April at the same site near Raymond Terrace where signals were detected from two radio-collars that had been put on hand-reared animals (Table 3).

In 1997 several radio-collar signals were detected south of Sydney (Table 3), but flights to the north of Sydney on 18 April and 29 May 1997 failed to detect any signals. However a radio-collar from a female was found on the ground on 28 May 1997 at Sea Acres Reserve in Port Macquarie (310 km north of Sydney, Table 3), a known *P. poliocephalus* colony site.

TABLE 3.

Radio-collared, hand-reared flying-foxes from the Gordon colony located by aerial survey, except (W) indicates a wild bat, (C) indicates a bat caught in the Cabramatta colony.

Date	Animal number	Sex	Weight at release	Location	Distance and direction from Sydney (km)
28 Mar. 96	1.504	M	354	Raymond Terrace	123 N
28 Mar. 96	1.616	F	423	Raymond Terrace	123 N
28 Mar. 96	1.042	M	405	Nowra	130 S
30 Apr. 96	1.616	F	423	Raymond Terrace	123 N
30 Apr. 96	1.676W	M	453	Raymond Terrace	123 N
30 Apr. 96	1.042	M	405	Nowra	130 S
18 Apr. 97	1.239	F	670	Batemans Bay	230 S
18 Apr. 97	1.013C	F	375	Dalmeny	279 S
18 Apr. 97	1.217	F	681	Batemans Bay	230 S
>28 May 97	0.907	F	669	Port Macquarie	310 N
29 May 97	1.013C	F	375	Dalmeny	279 S
29 May 97	1.573C	F	890	Fisherman's Paradise	182 S
29 May 97	1.246C	F	520	Moruya	256 S
29 May 97	1.380C	F	500	Nowra	130 S

Exit counts

The total number of bats counted exiting the colony at sunset in the years 1995–1997 are shown in Fig. 2. An increase in the number of bats exiting the colony shown in the period mid-Dec. to Feb. each year corresponds to the time at which young were first observed to fly independently from the site. Flightless juveniles remain at the colony site for about three months, usually November–January (Parry-Jones 1987).

The number of bats in the colony drop dramatically in June and July, although in most years a small group of bats remain over winter.

DISCUSSION

Integration

The degree of integration (Table 1) is taken from data shown in Figure 1. In evaluating Figure 1 it is important to note that the lines drawn as the colony boundary are based on signals from transmitters placed at the extreme edges when the colony was at its furthest expansion in each year during the study. Not only does the colony size and shape vary yearly as shown in Figure 1, but there is also some variation within each year. Points outside the boundaries in Fig. 1 can be taken with confidence as representing non-integrated roost sites, and the value "% integration" represents the minimum number of bats that did not integrate. Points within but close to the boundaries could represent sites that were not integrated.

Another feature of Figure 1 is that points outside the boundaries are concentrated in the vicinity of the release cage which was also the supplementary feeding station. This obervation lead to the decreased period of supplementary feeding in 1997.

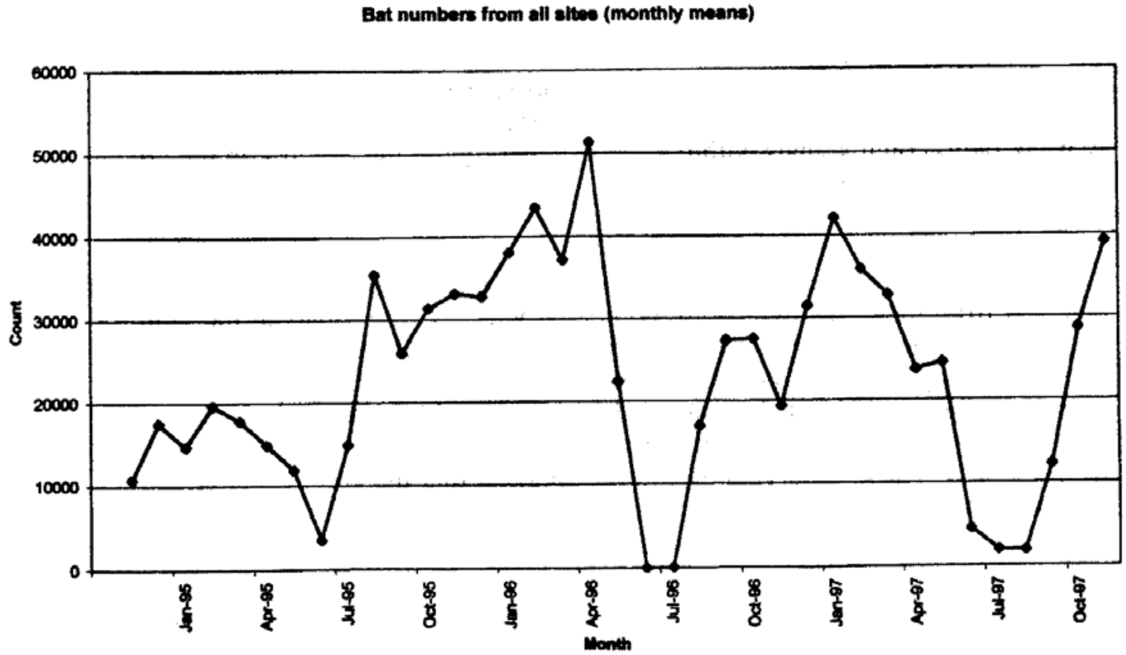

Figure 2. Total numbers of bats counted exiting the Gordon valley over the three years of this study.

Each year is of course different, and we were unable to control variables such as weather, food supply, and colony size. Integration clearly increased from 1995 to 1996, and from 1996 to 1997. We conclude that this is likely to have been the result of altered release procedures, but we also acknowledge that it is impossible to rule out uncontrollable or even unknown environmental factors.

Local movements

In 1995 several radio-collared animals were recovered from backyards of houses at the edges of the colony (eg Maytone and Warandoo Avenues in Table 2). This did not occur in subsequent years and is most likely to be the result of failure of the juveniles to integrate into the wild colony in 1995.

Movement of individuals between the Gordon colony and the Royal Botanic Gardens Sydney have been demonstrated in this study (Table 2). The number of flying foxes in the Royal Botanic Gardens Sydney has increased from several hundred in 1991 to more than 4,000 in 1999. They are reported to be remaining for longer periods, and a "reasonably large number" was observed in the Royal Botanic Gardens Sydney throughout the winter of 1998 (Botanic Gardens Staff, pers. comm.). Due to the fact that the numbers present vary from day to day, it has been assumed that the Royal Botanic Gardens Sydney "colony" is simply an aggregation of bats from the Gordon Colony with continuing interchange. However the exact relationship remains uncertain and may be changing.

The Cabramatta colony site is different in that it is much further from Gordon than the Royal Botanic Gardens Sydney and contains far more bats than the latter; up to 30,000 (G.L. Newman, ANU, pers. comm.). The Cabramatta Creek site is continuously occupied from September through May (C.R. Tidemann and G.L. Newman, ANU, pers. comm). The numbers of bats recorded at this site and the persistence of the colony through the mating season indicate it is a separate colony from the one at Gordon, even though there is an interchange of individuals.

Other tracking results simply confirm that bats from the Gordon Colony forage throughout the Sydney metropolitan area, including fruit growing regions to the NW (Table 2). The small number of foraging locations fixed over the three years of the study is due to the immense area to be covered and the impossibility of sorting out the relatively weak radio-collar signals within a cacophony of radio interference in the urban area.

Long distance movements

If the dates of release (Table 1) and the dates when radio-collar signals were detected from the air (Table 3) are compared with counts of bats at the Gordon colony (Fig. 2), it is clear that the radio-collared bats did not leave the colony site at times of mass migration. In 1996 the radio-collared bats left during a period when colony numbers were increasing, not decreasing. Movements of bats from the Cabramatta colony into and out of the Gordon colony likewise do not correlate with mass movements to or from Gordon. These observations strongly suggest that the colony site at Gordon is in a constant state of flux, with individual bats coming and going continuously. The colony cannot be seen as a fixed population of individuals, moving in mass in response to conditions of food availability or requirements of reproduction. These factors no doubt determine the number of bats that are present at any one time in a colony site such as Gordon, but they do not lead to mass movements such as the migrations of many bird species. One animal (1.042, Table 2) was located at Nowra, 130 km south of Sydney, on 28 March but had returned to Gordon by 4 April. By 30 April he was in Nowra again. The constant movement of individuals or possibly small groups, rather than movement of a population as a unit, observed in this study, and also observed in a radiotracking study carried out in northern NSW (Eby 1991), provides a likely answer to the frequently raised question "How do flying-foxes know when and where an outbreak of blossom occurs?" If individual bats are always moving about within the core of the range, they will begin to congregate where food resources are plentiful. There is no need to postulate complex communication or super sensory capacities.

The opportunistic nature of movements and feeding congregations of *P. poliocephalus* is shown in 1996 by the fact that some bats flew north to an area around Raymond Terrace where *Melaleuca quinquinerva* was flowering while others went south to the Nowra region where *Eucalyptus longifolia* was flowering. In 1997 bats flew to several locations along the coast south of Sydney (Table 3) where *Corymbia gummifera* was flowering and where there was heavy but patchy flowering of *C. maculata*.

Unlike the irregular flowering cycles of food resources other than figs, the reproductive cycle of *P. poliocephalus* is regular and annual. The regularity of occupation of the Gordon site reflects this regularity of the reproductive cycle, with an early peak starting in September when the colony begins to function as a maternity site, and a later peak during the mating season in April-May (Fig. 2). Unfortunately the need to balance radio transmitter (battery) weight with signal strength, and transmitter life, limited the above study to a period of three months after release, and no data on bat movements could be related to reproductive behaviour. However this will be the subject of further radiotelemetry studies of flying-foxes.

Release management

Based on evidence from the exit counts (Fig. 2) that wild juvenile bats were flying independently from the colony at sunset from as early as mid-December, the release date was moved forward from 18 March to 21 February. By the criterion used in this study (the degree of integration of hand-reared grey-headed flying-foxes with the resident, wild colony), this earlier release of hand-reared animals combined with decreased post-release support was highly successful. As shown in Table 1, animals released on 21 February integrated completely while most of those released 18 March remained outside the resident colony over a comparable time span. The animals released earlier weighed less (mean 384 g) than those released later (mean 483 g), which is in contrast to the widely accepted principle within wildlife care groups that the larger a bat is on release, the greater its chances of survival. In our interpretation of the above findings, body weight is not the important factor; behaviour and natural cycles have a much greater influence on survival. In this study we chose to release earlier than the traditional mid to late March period because observations of the colony over a number of years showed that resident juveniles begin to undertake independent foraging flights from the colony in January or early February; sometimes as early as December (Fig. 2). Before this time, the juveniles remain in the colony at night and are suckled by the mothers after the latter return from foraging flights for a period of about 3 months (Parry-Jones 1987). During this time they are scattered throughout the area occupied by the adult bats. However from late February and March juveniles have been observed in the Gordon colony (KBCS, unpublished observations) to begin to segregate into separate roosting trees at the outer edge of the colony. Although there is clearly a great deal of work that needs to be done in order to understand the social behaviour of *P. poliocephalus*, it seems likely that at the start of the mating season (from early March), there would be minimal tolerance of new juveniles at the colony site and even territorial exclusion due to mating behaviour.

Other factors that might contribute to the success of earlier release are reduced exposure to human contact, to a restricted environment and to an unnatural diet.

The reduction in support feeding in 1997 might also have contributed to the rapid integration of the released animals into the wild colony. In 1996 radio-collared bats were still observed at the support feeding station (the release cage) at night for six weeks after release. Within two days of stopping support feeding (17 April 96) this behaviour had ceased.

In summary, we propose that release of hand-reared juvenile *P. poliocephalus* should be done as near as possible to the time when wild juveniles are starting to make independent foraging flights and that support feeding be reduced to less than 4 weeks after release.

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