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Post-release survival of hand-reared pipistrelle bats (Pipistrellus spp)

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Abstract

*There is very little known about the post-release survival of hand-reared pipistrelle bats (*Pipistrellus *spp). We radio-tracked 12 pipistrelle bats, hand-reared and released under three different protocols: i) limited pre-release flight training and over-wintering (n = 5); ii) prolonged pre-release flight training, but with limited space (n = 2) and iii) prolonged pre-release flight training in large flight cage (n = 5). Of the five bats reared under the first protocol, four were recovered, grounded, within 48 h and the signal from the fifth bat lost on day two, due either to tag failure or from the bat flying out of the study area. Both bats in the second group flew strongly on the night of release but on the second and third nights only one emerged and flew briefly. The signals from both bats remained stationary on subsequent nights. In contrast, bats from the third group were tracked for between five and ten nights, indicating that they were able to survive independently following release. These preliminary results suggest that post-release survival depends on extensive pre-release conditioning in a large flight cage, rather than the limited flight opportunities traditionally provided within domestic houses by bat carers. Other factors that may affect post-release survival are discussed and further work is encouraged to determine whether rehabilitated bats integrate with the local population.*

Keywords: *animal welfare, pipistrelle bat, radio-tracking rehabilitation, survival, wildlife rehabilitation*

Introduction

Large numbers of captive-bred animals are released into the wild annually, either as part of a conservation strategy (eg water voles [*Arvicola terrestris*] in the UK [Moorhouse 2004; Mathews *et al* 2005, 2006], golden lion tamarin [*Leontopithecus rosalia*] in Brazil [Kierulff & Rylands 2003]), or as part of translocation programmes (eg Wolf *et al* 1996). In addition, the rehabilitation of sick, injured or orphaned wildlife is a growing source of large numbers of wild animals being released into the wild. Each year in the UK, Royal Society for the Prevention of Cruelty to Animals (RSPCA) wildlife centres admit many thousands of wildlife casualties and orphans requiring hand-rearing of which between 40 and 50% are released back into the wild (Molony *et al* 2007). However, such releases receive very little attention from conservation biologists as they are seen to have little conservation value.

The reintroduction of captive-bred animals back into the wild does not generally have a high level of success (Beck *et al* 1994; Ginsberg 1994; Mathews *et al* 2005; Jule *et al* 2008), and we might expect hand-reared animals to fare even poorer than those raised by their parents in captivity. Potential reasons for this could include the less appropriate nutritional composition of milk replacers, the lack of opportunity to learn social and other skills and the possibility that the orphans were already in poor condition, compared with their peers, when they were abandoned. Additionally, captivity and related factors, such as handling, can result in increased stress (Moorhouse *et al* 2007) thereby negatively affecting the health and welfare of the subject animals. Despite this, very few translocation, reintroduction or wildlife rehabilitation programmes consider the cumulative importance of stress during captivity (Teixeira *et al* 2007).

The release of captive-bred animals, in particular those that are hand-reared orphans, therefore raises important animal welfare issues (Cayford & Percival 1992; International Academy of Animal Welfare Sciences 1992; International Wildlife Rehabilitation Council 2005).

The population of pipistrelle bats (*Pipistrellus* spp) in the UK has been estimated to be in excess of three million (Bat Conservation Trust 2006). It has only recently emerged that this population comprises roughly of equal numbers of two cryptic species: *Pipistrellus pipistrellus* (common pipistrelle) and *P. pygmaeus* (soprano pipistrelle) (Barratt *et al* 1997).

Each year in the UK, hundreds of injured or orphaned bats (mainly common and soprano pipistrelles) are taken into care by specialist bat carers or general wildlife rehabilitators and many of these are ultimately released back into the wild. However, many carers equate release with success and very little is known about the survival or behaviour of hand-reared bats post-release.

Over a ten-year period (1997–2006), a total of 748 pipistrelle bats (557 adults and 191 juveniles) were admitted to RSPCA Stapeley Grange Wildlife Centre in north-west England, of which 33 and 54% were released, respectively (A Kelly, unpublished data). The decision to rehabilitate and release or euthanase was based on the condition of the bats on admission which was assessed via an extensive triage protocol developed over a number of years. Given the numbers involved, it is probably the case that the release of hand-reared bats will have little or no effect on the population of bats in the UK. However, there are serious implications for the welfare of the individual bats that are hand-reared and released. From the point of view of animal welfare, it is imperative that carers demonstrate that the bats are capable of surviving independently, otherwise the welfare of the animals will be compromised. For example, an inability to hunt and feed on insect prey may result in starvation; a previously-cited reason for not attempting the rehabilitation of orphaned bats (Walsh & Stebbings 1988). In this study, we report our research into the post-release survival of pipistrelle bats, hand-reared in a domestic environment in Wiltshire, UK and at the RSPCA Stapeley Grange Wildlife Centre in Cheshire, UK. The first two studies utilised methods at the disposal of most bat rehabilitators while the third had the additional element of pre-release conditioning in a large flight cage at the RSPCA centre.

Materials and methods

Hand rearing

All the bat pups were hand-reared according to a protocol widely used by bat rehabilitators in the UK (Brown & Brown 2006). Esbilac® (PetAg Inc, USA) was used as a milk-replacer at a dilution of 1:3–1:1 (w:v) in water, the concentration being increased as the pups matured. At approximately 3–4 weeks of age (based on an assessment of body size, fur length and colouration, and activity levels) pups were gradually weaned onto mealworms. To begin with, these were offered by hand but once bats fed proficiently the mealworms were placed in a dish to allow self-feeding. The bats were kept in an incubator (27–31°C) until approximately four weeks of age and were later transferred to an unheated, wooden bat box. All bats were ringed on their forearm, for the purposes of identification, with individually-numbered, 2.9 mm (internal width when fitted) aluminium bat rings. In all cases, the weight of the bats was recorded (to the nearest 0.1 g) and the length of the forearm measured with callipers (to the nearest 0.1 mm) prior to release. Bodyweight was divided by forearm length to give a body condition score. Individual bats were considered ready for release once they were capable of prolonged and sustained flight of at least 15 min duration.

Release and follow-up protocols

Limited pre-release flight training

The first study involved 11 bats, all of which originated from the same abandoned roost. Once the juvenile bats began to exercise their wings they were given daily opportunities to fly indoors (approximately 20 min per bat) in an enclosed room. The time available for flight was limited by the need for the bats to be watched at all times to prevent individuals becoming lost in the domestic environment available; typically a room in the bat carer's house. The flight practice was provided at dusk, the normal emergence time for the species. When the bats had learned to fly, the six animals with the greatest flight ability (> 15 min continuous strong flight, showing agility in avoiding objects), three males and three females, were taken in their bat box to the release site. The box was erected adjacent to a known pipistrelle roost, and the bats were given four days to habituate, during which time mealworms were made available and weights checked daily. During the habituation period, bats were weighed on day one and again on day four to check for changes in bodyweight. The bat box was then unblocked on 1 September (autumn) in good weather and the bats allowed to emerge at will. At this time the bats were approximately nine weeks old. Mealworms were placed in the box for a further week after the bats had departed.

The bat box was checked daily for 14 days for signs of bat activity. In addition, seven sessions of harp trapping and mist netting were conducted close to the roost in the month following the release. The harp trap consisted of a light but strong frame, approximately 3 × 2 m (length × breadth) supporting two parallel arrays of taut monofilament threads, one slightly overlapping the other. The elasticity of the threads cushions the impact of the bat which is then trapped in a collection bag. Mist nets were used to trap any bats that evaded the harp net.

As the six ringed bats that were initially released were never re-sighted, the decision was taken to radio-track the remainder of the cohort (five bats), together with a wild-caught juvenile as a control. These bats had to be over-wintered prior to release because licensing authority from English Nature (now Natural England) was only provided in mid-September and by this time the juveniles had acquired high fat reserves (in preparation for hibernation) which meant they were not able to fly effectively when fitted with the additional burden of a radio-tag.

Each bat was fitted with a 0.35 g radio-tag with a whip-antenna (Titley Electronics, Australia) by a licenced batworker (FM). The tags were attached using Skin-Bond® adhesive (Smith and Nephew, UK); the antenna projecting beyond the tail membrane. They were sited on a plaque formed from matted fur and adhesive (which formed a stable base for attachment) between the scapulae. This method was used in order to avoid having to trim the fur and attaching the transmitter directly to the skin, which could be potentially more stressful and is difficult in small bats. The transmitters weighed between 6.5 and 7.8% of the bodyweight of the bats (7.3 [± 0.7%]).

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The bats were habituated to the presence of the tag for one day before transportation to the release site and, again, they were kept in the bat box that had been used in captivity and placed adjacent to a known roost. The short life span of the radio-tags meant they were only habituated for one further night at the release site before being allowed to emerge.

A wild pipistrelle bat from the release site was captured in a harp trap under license from English Nature, and was radio-tagged using the same methodology.

The bats were tracked using a combination of two receivers – R-1000 telemetry receivers (Orange Comms, California, USA), and Mariner 57 receivers (Mariner, Lowestoft, UK), which are no longer manufactured – in order to provide the best combination of range and directionality. The receivers were fitted with Yagi 3-element directional antennae (Biotrack Ltd, Wareham, UK).

Prolonged pre-release flight training, but with limited space

In this segment of the study, six bats were placed in an indoor polythene covered enclosure measuring 3 × 2 × 1.8 m (length × width × height). The inside of the enclosure was lined with soft cloth to provide roosting and landing opportunities, and the wooden bat box was fixed to one wall. Mealworms were provided daily, as were fruit-flies, in an effort to provide foraging opportunities.

Two female bats were selected as being the strongest fliers according to the same criteria as previous treatments and were fitted with 0.35 g PIP3 radio-transmitters (Biotrack Ltd, Wareham, UK). The bats weighed 6.3 and 6.4 g, respectively, with the transmitters contributing 5.5% of the bodyweight of each bat. The protocol for fitting the tags and habituating the bats was identical to that used in the standard pre-release flight, with the one exception being that on the night of release the animals were placed directly into the known bat roost, in an effort to integrate them with the wild population, as opposed to being allowed to emerge from a bat box.

Prolonged pre-release flight training in large flight cage

In this part of the study, 14 bats (including 13 hand-reared orphans and one grounded juvenile) were placed in a bat box inside an outdoor flight cage (7 × 4 × 2.3 m), at Stapeley Grange Wildlife Centre. The cage consisted of a double-skinned, fine (1 cm^2) tri-weld mesh, with a solid floor. Mealworms continued to be provided in the bat box and the flight cage hosted two photocell ultraviolet lights to attract flying insects. In addition, insect-attracting shrubbery (eg honeysuckle) was planted in and around the bat flight cage, and bins containing decomposing/composting vegetable waste and food matter were placed inside the bat flight cage to attract insects through the mesh.

The bats were allowed to fly freely within the enclosure for approximately 21 days and their flight observed on a regular basis. Towards the end of this period, five bats (three females and two males) considered to be the strongest flyers (in accordance with the criteria described earlier) were fitted with 0.35 g PIP3 radio-transmitters as in the previous treatments. Due to a change in the formulation of Skin-Bond®, Ostomy Adhesive Solution® (Salts Healthcare Ltd, Birmingham, UK) was used to attach the transmitters. The transmitters weighed an average of 6% of the bats' body weight (5.1–6.7%), similar to that of Davidson-Watts and Jones (2006).

Staggered release

Once the transmitters had been fitted, the bats were observed in the bat flight cage to look for any obvious effects on flight performance. Once satisfied there were no detrimental effects caused by the transmitters, the bats were transferred in groups in their box to the outside of the bat flight cage before being allowed to leave the box. The first group of three bats with transmitters (Z3300, Z3298 and Z3296) was moved to the outside of the bat flight cage on 9th September 2006 (autumn). Z3300 left on the first night and Z3298 and Z3296 on the second night. The second group of eight bats, including one tagged bat (Z3299), was moved in their box to the outside of the bat flight cage on 12th September 2006 and all eight left the bat box on the first night. The final group of three bats, which included the last radio-tagged bat (Z3297), was moved to the outside of the flight cage on 14th September 2006. All three left the bat box that night. All bats were tracked using a Sika receiver (Biotrack Ltd, Wareham, UK) and a Yagi 3-element directional antenna. The tagged bats were tracked continuously during the night until 48 h after the last radio contact was made with each bat. Daytime positioning was used to confirm the bats' roost sites.

Statistical analysis

Data were analysed using SPSS v11.0. The data conformed to the assumptions of parametric tests, and the differences between means were examined using *t*-tests.

Results

The characteristics of all bats used in this study at the point of release can be seen in Table 1.

Standard pre-release flight training

These bats had a mean (± SD) weight of 5.0 (± 0.5) g and a forearm length of 31.3 (± 0.87) mm when the first individuals were selected for release (1st September 2001); (Table 1). The bats selected for the first release, on the basis of being the strongest fliers, tended to be thinner, ie had a lower body condition score; weight:arm ratio (g/mm) was 0.139 for released bats versus 0.159 for those that were subsequently over-wintered; $t = -2.06$, df = 9, $P = 0.069$). All of the bats in the first release gained weight during the four-day habituation period (mean increase of 0.23 g; $t = 3.18$, df = 5, $P = 0.028$) and therefore had a corresponding increase in their condition index (mean increase of 0.007 g/mm), giving a final mean (± SD) condition index of 0.154 (± 0.014). For comparison, morphometric data from wild juveniles caught at the release site during the same timeperiod are also shown (Table 2). The condition index of these bats was 0.156 (± 0.0091). In the wild, juvenile bats emerge from the roost earlier in the season than the release dates in our studies (captive-reared bats appear to develop more

Table 1 Characteristics of bats ready for release.

Study	Year	Ring number	Sex	Bodyweight (g)	Forearm length (mm)	Condition index (bodyweight/forearm)
1[a]	2001	U3450	M	4.0	31.5	0.12
1[a]	2001	U3452	F	5.3	32.6	0.14
1[a]	2001	U3455	M	4.1	29.4	0.14
1[a]	2001	U3456	M	4.5	31.6	0.14
1[a]	2001	U3457	F	5.2	31.7	0.16
1[a]	2001	U3462	F	4.5	31.4	0.14
1[b]	2002	U3453	F	5.1 (4.5)	30.1 (30.1)	0.17 (0.15)
1[b]	2002	U3454	M	5.5 (4.9)	31.8 (31.8)	0.17 (0.15)
1[b]	2002	U3458	M	4.6 (4.5)	31.5 (31.8)	0.15 (0.14)
1[b]	2002	U3460	F	4.9 (5.4)	31.1 (32.0)	0.16 (0.17)
1[b]	2002	U3461	M	4.2 (4.9)	31.3 (31.2)	0.13 (0.16)
2	2005	Y3084	F	5.6	32.0	0.18
2	2005	Y3085	F	5.5	30.9	0.18
3	2006	Z3300	F	6.1	33.3	0.18
3	2006	Z3299	F	5.2	31.6	0.16
3	2006	Z3298	M	5.8	30.6	0.19
3	2006	Z3297	M	6.9	31.6	0.22
3	2006	Z3296	F	5.6	31.2	0.18

[a] Released without radio-tags in first season. [b] Released with radio-tags after over-wintering (data are from initial assessment in 2001, with over-wintered values shown in parenthesis).

Table 2 Mean (± SD) bodyweight, forearm length and body condition index of wild juvenile bats caught at release site 13/9–20/9/2001.

Sex	Mean bodyweight (g)	Mean forearm length (mm)	Condition index (bodyweight/forearm)
Male	4.3 (± 0.2)	30.8 (± 0.5)	0.14 (± 0.01)
Female	4.8 (± 0.2)	31.7 (± 0.6)	0.15 (± 0.01)

slowly). Therefore, we gathered another data series for newly-emerged juveniles at the release site the following year (6th August 2002), to provide further comparisons with our captive-reared animals. Twenty-one bats were measured at the release site and their mean condition index was 0.147 (± 0.0096).

None of the ringed, hand-reared bats released without radio-transmitters in August were recaptured, either in the bat box or in mist nets and harp traps at the site. There were also none recaptured during annual trappings at the site over three years and no evidence, in the form of fresh droppings or consumption of mealworms, to suggest that the bats ever returned to their bat box. In comparison, recapture rates for ringed, wild bats from the known maternity roost at the site was high (> 75%) (F Mathews, unpublished data).

After over-wintering, the bats were very similar in their bodyweight, arm and body condition index measurements, with the following exceptions. U3453, which was previously one of the heaviest individuals, reduced its weight from 5.1 to 4.5 g. In contrast, two of the lightest bats increased their weights: U3460 increased from 4.9 to 5.4 g, and U3461 increased from 4.2 to 4.9 g. Four of the five bats released with radio-tags were observed flying strongly on the night of their release, and showing apparently normal types of flight for the species. The remaining individual was taken back into captivity (U3461). Although bat echolocation calls and feeding buzzes were heard on heterodyne bat detectors (BatBOX III, Stag Electronics, UK), it was not possible to determine whether the calls came from the released bats or from wild bats emerging from the nearby roost.

Two bats (U3458 and U3460) were found grounded and dehydrated during the next day. They were within 500 m of the release site. These animals were taken back into captivity. A further bat (U3454) was identified flying for approximately 20 min on the second evening (its daytime roost was not located but it was not with the wild bat colony). On the next day it was found grounded, underweight and dehydrated within 750 m of the release site. The radio signal from the final individual was lost on day two and could not be retraced despite an extensive search from

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Table 3 The number of days the bats were tracked following self release from the prolonged flight conditioning treatment. The transmitters were fitted on 6/9/06 and the bats placed outdoors to self-release from 9/9/06. The battery life of the transmitters ranged from 11-14 days, in line with manufacturers predictions.

Bat (ring number)	Date left bat box	Last date tracked	Number of days tracked	Battery life (days)
Z3300	10/9/2006	19/9/2006	10	14
Z3299	12/9/2006	17/9/2006	6	12
Z3298	10/9/2006	16/9/2006	7	11
Z3297	14/9/2006	18/9/2006	5	13
Z3296	9/9/2006	16/9/2006	8	11

high ground. The loss of signal resulted either from tag failure, or from the bat flying out of the study area. The wild-caught individual flew extensively for each night of tracking before the battery failed, travelling up to 2 km from the roost. It returned to the roost each night.

Prolonged pre-release flight training, but with limited space

The two bats were both slightly heavier and had a better condition index (higher weight/arm ratio) than those in the previous study (see Table 1). They were observed flying strongly on the night of release (7th September 2004). They appeared to forage around trees and were heard to emit echolocation calls (Duet Bat Detector, Stag Electronics, UK). These calls were judged by an experienced bat worker (FM) to be atypical of pipistrelle bats, due to the lack of a constant-frequency component. Although increasing repetition rates were detected, no feeding buzzes could be linked, with any degree of certainty, to the bats being tracked.

The bats roosted close together, approximately 300 m from the roost they had been released into, under stone roofing tiles. On the second and third nights, only one bat emerged and flew briefly and, on subsequent nights, signals from both bats remained stationary.

Prolonged pre-release flight training in large flight cage

These bats had a higher average bodyweight and a higher body condition index than the bats in the previous two treatments (Table 1). The bats were tracked for up to 10 days and were all recorded actively flying on each night tracked (see Table 3). Including the number of days following transmitter attachment, this amounted to the battery life of the transmitters.

Two of the tagged bats (Z3298 and Z3296) settled in a residential area of Crewe, Cheshire, 4.6 and 4.7 km, respectively from the release site, but approximately 1 km apart. Z3300 settled in Nantwich Church steeple, about 2.7 km from the release site. Z3299 was located in buildings adjacent to the release site and Z3297 remained on the release site, returning to a bat box on the outside of the bat flight cage which it used from 16th September until it left again on the 18th September.

Discussion

Our results provide evidence that hand-reared pipistrelle bats are capable of surviving independently following release, at least in the short-term. However, this survival appears to depend on extensive pre-release conditioning in a large, flight cage, rather than by the limited flight opportunities traditionally provided within rehabilitation centres and domestic houses by bat carers. In the first two studies, the seven bats that were radio-tracked all either had to be rescued and taken back into captivity or appeared to have died (it is possible that the stationary signals were due to the tags having become detached, but this is a rare occurrence). None of the six bats released without radio-tags have ever been recaptured despite three years of follow-up trapping.

In contrast, the bats released following conditioning in the flight cage were tracked for between five and ten nights, post-release. According to the manufacturers, the expected battery life of the transmitters was 10–14 days. Taking into account the number of days following transmitter attachment that the bats remained in the flight cage, the number of days tracked corresponded to the battery life of the transmitters. The signals were therefore most likely to have been lost due to battery failure as, in all cases, the signal was lost 11–14 days after activation (Table 3). This demonstrates that all five bats must have been able to catch the insect food upon which they depend. This skill was attained despite being deprived of any 'training' that they may have been exposed to in a natural roost situation. Anecdotally, rudimentary 'feeding buzzes' were recorded in two hand-reared pipistrelle bats flown in our bat flight cage earlier in 2006 (M Brown personal communication 2006). However, it should be pointed out that the five bats radio-tracked in this part of the study were considered to be the best flyers within a group of 14 bats. That these five bats were tracked for between 5 and 10 consecutive nights does not mean that all hand-reared bats are likely to survive. This finding occurs despite the fact that all of the bats involved in this study went through an intensive triage process on admission, which removed bats that were unlikely to survive due to their poor condition or untreatable injuries.

There are a number of alternative explanations for the observed difference in the number of days the bats were radio-tracked between treatments. Firstly, the transmitters may have contributed a larger burden to the bats in the first two treatments. It has been recommended that tags should weigh less than 5% of the bodyweight of flying animals (Aldridge & Brigham 1988). In the current study, transmitters accounted for an average of 7.3% (n = 5) of the body mass of the over-wintered bats (standard pre-release flight training), 6.35% (n = 2, prolonged pre-release flight training, but with limited space) and 6% (n = 5) of the bodyweights of bats in the prolonged flight conditioning cage. The additional burden of radio transmitters on flying animals is likely to have implications for both manoeuvrability and energetic costs (Caccamise & Hedin 1985) as has been shown to be the case in pregnant bats (Norberg & Rayner 1987; Hughes & Rayner 1991). Aerodynamics may also play a role in the ability of flying animals to carry loads. For example, small bat species may be able to carry larger loads, relative to their body mass, than larger species and species with a low wing loading (eg lesser horseshoe bat [*Rhinolophus hipposideros*]) may be able to carry larger loads (Norberg & Rayner 1987). Bontadina *et al* (2002) successfully tagged and tracked eight female lesser horseshoe bats ranging in weight from 4.7 to 7.4 g, with tags adding between 4.5 and 8.1% of the bats' bodyweight. Davidson-Watts and Jones (2006) successfully tagged and tracked 23 *P. pipistrellus* and 23 *P. pygmaeus* over a three-year period, with tags that weighed between 4.9 and 7% of the body mass of both species (average = 6%). Nicholls and Racey (2006) radio-tracked 14 *P. pipistrellus* and 12 *P. pygmaeus* over a three-year period using transmitters that never exceeded 7% of bodyweight, with an average of 6.1%. Some of the bats in our study were carrying tags that were in excess of the 5% recommended by Aldridge and Brigham (1988), but were within the range of these other studies. However, the body mass of small bats may vary by much more than 5% and so bats may be able to compensate for this extra load. The bodyweight of small bats may fluctuate widely following feeding and during pregnancy. For example, Hughes and Rayner (1993) demonstrated that the mean weight of pipistrelle bats can vary by up to 17% following feeding and foetuses may account for up to 40% of the body mass of pregnant bats (Kurta & Kunz 1987).

Secondly, temporal and geographical variation may contribute to the observed difference in survival between the groups. The first two treatments were carried out in Wiltshire in 2001, 2002 and 2004. The third treatment group was released in Cheshire in 2006. We can not rule out climatic effects between the years as having an effect on the bats' ability to survive. Insect abundance may have varied between years and between sites, with a small reduction in fitness resulting in increased selection pressure. In addition, the final group was acclimatised to external environmental conditions for three weeks prior to release, compared to four days in the other bats.

Thirdly, the condition scores of the radio-tracked bats differed between the three groups. The five over-wintered bats in the first group had a condition score (weight:forearm) of 0.14–0.17, compared to 0.16–0.22 in the prolonged pre-release flight conditioning group (Table 1). It is possible that the latter group had greater fat reserves than the over-wintered bats and therefore had a buffer that allowed them to survive over the crucial first few days of release. The condition indices of the bats released without prolonged pre-release flight conditioning were very similar to those observed in wild-caught juveniles. Indeed, heavier bats were not selected at all for release because they had poor flight abilities. In contrast, higher weights were attained in conjunction with good flight abilities in the prolonged flight-conditioning group.

Finally, the five bats over-wintered and radio-tracked came from the same roost and were therefore not independent of each other, in contrast to the bats in the prolonged pre-release flight conditioning group, which all came from four different roosts. The bats in the second treatment also came from different roosts. It is possible that the bats that all came from the same roost were in a state of poor fitness relative to the other bats.

Although we have concluded that pre-release flight conditioning in a large, flight cage improved the post-release survival of hand-reared pipistrelle bats, a number of other possible contributing factors arose and it is possible that a combination of these factors may explain the observed differences in post-release survival. The use of a large, flight cage for captive bats is not a new idea. Bat researchers have learned that in order to keep captive bats in good health, good flight facilities are a necessity. Although the design of a flight cage has been available to researchers for several years (Racey 1999), many bat carers have failed to make use of such a facility, due either to lack of knowledge or lack of funds.

It is important that studies of the release of captive-bred animals also investigate longer-term survival. For example, the average post-release survival time of orphaned red fox (*Vulpes vulpes*) cubs has been found to be 94 days (Robertson & Harris 1995) and ring recoveries of hand-reared tawny owls (*Strix aluco*) indicated post-release survival of one to 2,246 days (median = 123 days) (Leighton *et al* 2008). Measuring long-term survival is difficult for rehabilitated bats, however extensive ringing and surveys of roosts through local bat conservation groups could yield long term survival data.

In some generalist bat species, it has been demonstrated that there may be a learning aspect involved in developing the ability to forage within different habitat types (Wund 2005). It is not clear whether this behaviour is driven either by the bats experiencing different habitats and developing their echolocation to differentiate between habitat types or learning from other related or non-related bats. The development of echolocation skills in bats may be affected by being captive-reared inside a closed space. It has been demonstrated that the echolocation calls of *Myotis lucifugus* and *M. leibii* differed between bats recorded inside a closed space (indoor flight room) and bats flying freely outside. Calls produced inside were of shorter duration and were produced at shorter inter-pulse intervals than bats flying

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freely outside (Mukhida *et al* 2004). One way to measure the fitness of captive-reared bats would be to assess their echolocation skills prior to release. However, since captive-reared bats are generally kept indoors and flown in a limited space, it may be very difficult for bat carers to accurately assess the calls of rehabilitated bats under such conditions. Very little is known about the ontogeny of echolocation in neonatal bats. It is not clear whether echolocation calls are learned or innate (Jones *et al* 1991). Young bats must not only use echolocation to navigate and hunt, but they may also need to modify it when hunting with conspecifics (Fenton 2003). Echolocation is also used for socialisation — young bats use both auditory and olfactory signals to establish the bond with their mother so the rudiments of echolocation must be present at birth. A study of the components of these isolation calls (I-calls) in the greater spear-nosed bat (*Phyllostomus hastatus*) implied a genetic component (Bohn *et al* 2007) and these I-calls are thought to be the precursors of true echolocation in many species of bat (Swift 1998). Esser and Schmidt (1989) suggested that acoustic signals used in communication were learnt (at least to some extent) in the lesser spear-nosed bat (*Phyllostomus discolor*) since individual characteristics of social calls from the mothers were also present in the offspring. Jones and Ransome (1993) showed that the echolocation calls of bats are influenced by maternal effects and change over the bats' lifetime.

In the prolonged, pre-release flight conditioning group, although the five bats stayed together throughout the three-week period in the batbox contained within the bat flight cage (with another nine bats), the releases from the flight cage were staggered over a number of days. Following release, the bats dispersed, with two travelling approximately 4.5 km, one travelling approximately 2 km and the other two less than 0.5 km. All five bats roosted in separate locations and it is not known whether they had joined other roosts or roosted on their own. This raises further questions of whether the bats are able to integrate with the local population. Pipistrelles are known to be able to identify members of their own colony through olfactory cues (de Fanis & Jones 1995) and they also use a variety of social calls to protect food patches or attract mates (Barlow & Jones 1997). Although we have demonstrated that hand-reared pipistrelle bats are capable of independent survival (at least in the short-term), it is unclear whether they are able to show normal behaviour.

Animal welfare implications

The release of captive-reared animals into the wild has important implications for animal welfare. Many wildlife rehabilitators equate release with success and very few post-release survival studies have been conducted. Animals that are unable to survive independently in the wild will become dehydrated, starve and ultimately die. This follows time in captivity which is, in itself, stressful. Post-release monitoring can be used by wildlife rehabilitators to identify rearing practices that are most likely to result in post-release survival success. These practices could then be adopted by other rehabilitators in order to optimise the chances of survival.

Although we have demonstrated that orphaned pipistrelle bats, born in the wild but raised in captivity, can survive independently in the wild for a short period, we can not be sure that they are able to integrate back into the population, exhibit normal behaviour or acquire sufficient fat reserves to survive hibernation. An inability to select appropriate roosting sites or to integrate into the population has implications for reproductive success, social facilitation of feeding and raises the possibility of aggression from members of established roosts. Therefore, we recommend further work to investigate the post-release roosting and foraging behaviour of hand-reared and rehabilitated bats. Comparing echolocation development of hand-reared, orphaned bats with that of post-natal bats in natural roosts would provide useful information on whether echolocation development is innate or requires some degree of learning from parents or other roost members. Increased complexity of the flight enclosure could assist development of echolocation and allow more opportunity for muscle development and flight training.

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References

Aldridge HDJN and Brigham RM 1988 Load carrying and manoeuvrability in an insectivorous bat: a test of the 5% 'rule' of radio-telemetry. *Journal of Mammalogy 69*: 379-382

Barlow K and Jones G 1997 Function of pipistrelle social calls: field data and a playback experiment. *Animal Behaviour 53*: 991-999

Barratt EM, Deaville R, Burland TM, Bruford MW, Jones G, Racey PA and Wayne RK 1997 DNA answers the call of pipistrelle bat species. *Nature 387*: 138-140

Bat Conservation Trust 2006 *National Bat Monitoring Programme, Annual Report, 2005*. Joint Nature Conservation Committee: London, UK

Beck BB, Rapaport LG, Price MRS and Wilson AC 1994 Reintroduction of captive-born animals. In: Olney PJS, Mace GM and Fiesnte ATC (eds) *Creative Conservation: Interactive Management of Wild and Captive Animals*. Chapman and Hall: London, UK

Bohn KM, Wilkinson GS and Moss CF 2007 Discrimination of infant isolation calls by female greater spear-nosed bats, *Phyllostomus hastatus*. *Animal Behaviour 73*: 423-432

Bontadina F, Schofield H and Naef-Daenzer B 2002 Radio-tracking reveals that lesser horseshoe bats (*Rhinolophus hipposideros*) forage in woodland. *Journal of Zoology 258*: 281-290

Brown M and Brown B 2006 *Bat Rescue Manual: Rescue and First Aid for Grounded Bats and General Bat Care*. Bat Care News: Otley, West Yorkshire, UK

Caccamise DF and Hedin RS 1985 An aerodynamic basis for selecting transmitter loads in birds. *Wilson Bulletin 97*: 306-318

Cayford J and Percival S 1992 Born captive, die free. *New Scientist 1807*: 29-33

Davidson-Watts I and Jones G 2006 Differences in foraging behaviour between *Pipistrellus pipistrellus* (Schreber, 1774) and *Pipistrellus pygmaeus* (Leach, 1825). *Journal of Zoology 268*: 55-62

de Fanis E and Jones G 1995 Post-natal growth, mother-infant interactions and development of vocalisations in the Vespertilionid bat *Plecotus auritus*. *Journal of Zoology 235*: 85-97

Esser KH and Schmidt U 1989 Mother-infant communication in the lesser spear-nosed bat *Phyllostomus discolor* (Chiroptera: Phyllostomidae) evidence for acoustic learning. *Ethology 82*: 156-168

Fenton MB 2003 Eavesdropping on the echolocation and social calls of bats. *Mammal Review 33*: 193-204

Ginsberg JR 1994 Captive breeding, reintroduction and the conservation of canids. In: Olney PJS, Mace GM and Fiesnte ATC (eds) *Creative Conservation: Interactive Management of Wild and Captive Animals*. Chapman and Hall: London, UK

Hughes PM and Rayner JMV 1991 Addition of artificial loads to long-eared bats, *Plecotus auritus*, handicapping flight performance. *Journal of Experimental Biology 161*: 285-298

Hughes PM and Rayner JMV 1993 The flight of pipistrelle bats, *Pipistrellus pipistrellus* during pregnancy and lactation. *Journal of Zoology 230*: 541-555

International Academy of Animal Welfare Sciences 1992 *Welfare Guidelines for the Reintroduction of Captive-Bred Mammals to the Wild.* The Universities Federation for Animal Welfare: Wheathampstead, Herts, UK

International Wildlife Rehabilitation Council 2005 <http://www.iwrc-online.org/>

Jones G, Hughes PM and Rayner JMV 1991 The development of vocalisations in *Pipistrellus pipistrellus* (Chiroptera: Vespertilionidae) during post-natal growth and the maintenance of individual signatures. *Journal of Zoology 225*: 71-84

Jones G and Ransome RD 1993 Echolocation calls of bats are influenced by maternal effects and change over a lifetime. *Proceedings of the Royal Society of London, Series B, Biological Sciences 252*: 125-128

Jule KR, Leaver LA and Lea SEG 2008 The effects of captive experience on reintroduction survival in carnivores: A review and analysis. *Biological Conservation* doi:10.1016/j.biocon.2007.11.007, in press

Kierulff MCM and Rylands AB 2003 Census and distribution of the golden lion tamarin (*Leontopithecus rosalia*). *American Journal of Primatology 59*: 29-44

Kurta A and Kunz TH 1987 Size of bats at birth and maternal investment during pregnancy. *Symposium of the Zoological Society of London 58*: 79-106

Leighton K, Chilvers D, Charles, A and Kelly A 2008 Post-release survival of hand-reared tawny owls, *Strix aluco*, based on radio-tracking and leg band return data. *Animal Welfare 17*: 207-214

Mathews F, Orros M, McLaren G, Gelling M and Forster R 2005 Keeping fit on the ark: assessing the suitability of captive-bred animals for release. *Biological Conservation 121*: 569-577

Mathews F, Moro D, Strachan R, Gelling M and Buller N 2006 Health surveillance in wildlife reintroductions. *Biological Conservation 131*: 338-347

Molony SE, Baker PJ, Garland L, Cuthill IC and Harris S 2007 Factors that can be used to predict release rates for wildlife casualties. *Animal Welfare 16*: 361-367

Moorhouse T 2004 Factors affecting the success of reintroduction as a species tool for the water vole (*Arvicola terrestris*). *Environment Agency Science Report W1-040/TR*. Environment Agency: Bristol, UK

Moorhouse T, Gelling M, McLaren GW, Mian R and MacDonald DW 2007 Physiological consequences of captive conditions in water voles (*Arvicola terrestris*). *Journal of Zoology 271*: 19-26

Mukhida M, Orprecio J and Fenton MB 2004 Echolocation calls of *Myotis lucifugus* and *M. leibii* (Vespertilionidae) flying inside a room and outside. *Acta Chiropterologica 6*: 91-97

Nicholls B and Racey PA 2006 Habitat selection as a mechanism of resource partitioning in two cryptic bat species *Pipistrellus pipistrellus* and *Pipistrellus pygmaeus*. *Ecography 29*: 697

Norberg RM and Rayner JMV 1987 Ecological morphology and flight in bats (Mammalia: Chiroptera): wing adaptations, flight performance, foraging strategy and echolocation. *Philosophical Transactions of the Royal Society of London, Series B, Biological Sciences 316*: 335-427

Racy PA 1999 Bats. In: Poole TB (ed) *The UFAW Handbook on the Care and Management of Laboratory Animals, Volume 1: Mammals, Seventh Edition.* Blackwell Science Ltd: Oxford, UK

Robertson CPJ and Harris S 1995 The behaviour after release of captive-reared fox cubs. *Animal Welfare 4*: 295-306

Swift S 1998 *Long-eared Bats*. Poyser: London, UK

Teixeira CP, Schetini de Azevedo C, Mendl M, Cipreste CF and Young RJ 2007 Revisiting translocation and reintroduction programmes: the importance of considering stress. *Animal Behaviour 73*: 1-13

Walsh ST and Stebbings RE 1988 *Care and Rehabilitation of Wild Bats.* The Robert Stebbings Consultancy Ltd: Peterborough, Cambridgeshire, UK

Wolf CM, Griffith B, Reed C and Temple SA 1996 Avian and mammalian translocations: update and reanalysis of 1987 survey data. *Conservation Biology 10*: 1142-1154

Wund MA 2005 Learning and the development of habitat-specific bat echolocation. *Animal Behaviour 70*: 441-450