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Nesting success of a managed population of Mauritius Fodies *Foudia rubra* marooned on a partially restored island

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Summary

The marooning of populations on offshore islands can be used as a conservation technique for species threatened by introduced predators, but post-release breeding success is not always as high as expected. Following the release of Mauritius Fodies onto a partially restored islet of regenerating forest, supplementary food and control of nest parasites through the application of insecticide were used as precautionary measures to aid the establishment of a population. Nests were continuously monitored in the first three breeding seasons to inform future management decisions. The fodies built nests in taller, more mature vegetation and younger females were more likely to abandon nests before incubation started. Eggs were laid between July and February and nests made earlier in the season were more likely to fledge young. Treating nests with the insecticide carbaryl increased the probability of success, but the distance of the nest from the supplementary feeding aviaries had no effect. The number of young per female decreased each breeding season and nesting success was similar to that of fodies using exotic plantation trees on the mainland between 2002 and 2006. Future research using population models and adaptive management could lead to the withdrawal or reduction of support measures for the released population and/or the harvest of individuals to establish populations on other offshore islands.

Introduction

The marooning of populations of endangered birds on restored offshore islands has become an important strategy in the conservation of oceanic island species which are threatened by introduced predators, especially in New Zealand (Bell and Merton 2002, Castro *et al.* 2003, Taylor *et al.* 2005). The release of birds onto a predator-free island can lead to a period of rapid expansion with large numbers of young produced (Wanless *et al.* 2002, Richardson *et al.* 2006). However, some species have had lower levels of reproductive success on islands than in their original mainland populations despite an absence of predators (Bunin *et al.* 1997). Differences in climate and habitat between an island and the source population may contribute to this (Hooson and Jamieson 2004, Steffens *et al.* 2005). Other possible reasons include a lack of suitable food (Komdeur 1996, Castro *et al.* 2003) and the presence of nest parasites (Berggren 2005, Stamp *et al.* 2002). Conservation management can reduce the risks to a released population by the provision of supplementary food and control of parasites (Jones 2004).

The Mauritius Fody *Foudia rubra* declined from around 250 pairs in 1975 (Cheke 1987) to 104–120 pairs in 1993 (Safford 1997a). Since then, numbers have remained stable, but there have been changes in distribution as fodies have declined in areas of degraded native forest and increased in exotic forestry plantations, which are believed to provide some measure of protection from introduced mammalian nest predators (Cristinacce *et al.* 2009, Safford

1997b). Nest predation is a major threat to endangered Mauritian birds and the marooning of populations on offshore islands has been identified as one of three key strategies in their conservation (Safford and Jones 1998).

A project to establish a population of Mauritius Fodies on Ile aux Aigrettes, a partially-restored island, began in 2002–03 with trial harvests of nests from the mainland and captive rearing of chicks. The success of this programme (Cristinacce *et al.* 2008) led to the release of 93 fodies between November 2003 and March 2006, representing 14 territories from the mainland population. Sixty-one of these fodies were fledglings (under two months old) hand-reared in captivity for at least part of their time as nestlings. Twenty-five were fledglings reared by their parents in captivity and seven were adults that had been hand-reared and kept in captivity for 9–38 months. The first eggs were laid on the island in the 2004–05 season and the population contained 38 pairs by the end of the 2006–07 breeding season.

Precautionary management to aid the establishment of the population consisted of the provision of supplementary food and the treatment of nests with the insecticide carbaryl. This was initiated because a brood had died in captivity in the lowlands after being infested with nest parasites. Not all nests could be accessed to apply treatment and the distance between nests and the supplementary feeding aviaries differed, allowing an assessment of the effectiveness of these measures to be undertaken. This paper examines the factors affecting the selection of nesting habitat and the nesting success of fodies in the first three breeding seasons on the island to guide future management of the population.

Materials and Methods

Study site

Ile aux Aigrettes (20°42′S, 57°73′E) is a 26 ha coralline island located in Mahebourg Bay, 625 m off the southeast coast of Mauritius. It contains one of the last and best-preserved remnants of lowland ebony *Diospyros egrettarum* forest in Mauritius and has been subject to a continuous restoration programme since 1986 involving the planting of native species and the weeding of exotics. Ship Rats *Rattus rattus* and Feral Cats *Felis catus* were eradicated from the island by the early 1990s (Strahm 1993), allowing the establishment of a population of Pink Pigeons *Nesoenus mayeri*, which now numbers around 80 birds (Edmunds *et al.* 2008).

Management of fodies

Supplementary food was provided on an *ad libitum* basis to fodies through two adjoining aviaries in the northwest of the island. The food consisted of chopped fruit (apples, bananas, mango, papaya), grated boiled egg, grated carrots, insectivorous mix (Witte Molen Universal Food, Meeuwen, Netherlands) and whole oats until May 2006, when it was changed to a mixture of duck starter-crumbles, liquidised prunes, mixed small seed and honey, which was blended to a suitable consistency and mixed in a 1:1 ratio with insectivorous mix. Nectar (Avesnectar®, Avesproduct, Netherlands) was provided in the mornings (dawn until midday) in two plastic feeders attached to the side of the aviaries.

Accessible nests were treated with a mixture of 5% carbaryl and 95% talcum powder just after incubation started and again around the day of hatching. The mixture was rubbed into the lining of nests when females were away.

Vegetation survey

Ile aux Aigrettes is divided into 12.5 × 12.5 m grid squares to aid vegetation monitoring and restoration. Each square on the island is marked with a numbered metal peg in the northwestern corner. Between August 2005 and January 2006 the vegetation in each grid square was classified into different habitat types. Coastal areas are open or contain dense scrub < 3 m high. Transition areas contain scrubby coastal vegetation with occasional mature trees and canopy forest is dominated by larger trees with occasional gaps or smaller trees. The grid squares were also classified according to the most abundant plant species in the canopy and the average height of the canopy (groups of < 3 m, 3–4 m, 4–6 m and > 6m). All classifications were estimated by one observer (AC). A random selection of 50 squares was resurveyed in February 2006 and the classifications did not differ from the originals.

Finding and monitoring nests

Nests were monitored between the 2004/5 and 2006/7 breeding seasons. They were usually located by following pairs with nesting material, but some were discovered after incubation had begun. The grid square on the island in which the nest was located and the species of nest tree were recorded. Once a nest was found, it was monitored at least once every two days by watching the behaviour of the parents from a location at least 5 m from the base of the nest tree. During building, the nest was observed for one hour or until the stage could be determined. If no activity was seen at a nest for two weeks, it was classified as abandoned before incubation. Nests were not monitored further if they were unfinished or if the pair were found building a new nest. During incubation, the nest was observed until it could be confirmed that the female had spent at least 10 consecutive minutes in the nest. After hatching, the nest was observed until one of the parents fed the chicks. If no activity was observed at an accessible nest, the contents were checked, if possible, before it was classified as failed. Any damage to the nest or its contents was recorded. The contents of accessible nests were also checked daily when the female was off the nest around the time the eggs were expected to hatch. The chicks were ringed with a single plastic ring at five days old and again with an additional plastic and metal identification ring at eight days old.

Data analysis

The expected number of nests in grid squares containing vegetation of each habitat type was calculated using the proportion of squares of each habitat type found on the island and the total number of nests found. This was compared to the observed values using chi-squared tests. Similar analyses were carried out for the most abundant species in the canopy in grid squares and the height of the canopy. The expected number of nests in each tree species was calculated using the proportion of the island in which a species was the most abundant tree in the canopy and the total number of nests found. This was then compared to the observed number of nests in each tree species. As this method uses the dominant canopy species in a square as a measure of tree abundance, it may underestimate the total number of expected nests in species which are common in the understorey, but do not dominate areas of forest. A more detailed survey of species abundance was not attempted due to time constraints.

For nests that were discovered before incubation began, a stepwise binomial logistic regression was used to test the effect of different predictors on whether the nest proceeded to incubation (Tabachnick and Fidell 2007). The least significant covariate was discarded at each step until only covariates with a probable significance of 0.05 or lower remained. The season the nest was found and the nest tree species were entered as categorical covariates in the initial model. The month the nest was found (July to February), age of male (in days) when nest was found, age of female (in days) when nest was found and the distance of the nest (in metres) from the supplementary feeding aviaries were used as continuous covariates.

For nests that were followed since the start of incubation a similar stepwise binomial logistic regression was used to test the effect of predictors on whether a nest produced at least one fledgling. The categorical covariates used in the initial model were the season, the nest tree species and whether the nest was treated with carbaryl. The continuous predictors were the month when incubation started (July to February), the age of the male (in days) when incubation started, the age of the female (in days) when incubation started and the distance of the nest (in metres) from the supplementary feeding aviaries. The Mayfield (1961) method was used to calculate nesting success for all nests that were monitored during incubation or feeding chicks (including those found after incubation had started) with confidence intervals calculated according to Johnson (1979). The number of fledglings per successful nest and the number of fledglings per adult female was calculated for each of the first three breeding seasons.

Results

Mauritius Fody nests were not found in proportion to the number of squares of each habitat on the island ($\chi^2_2 = 13.0$, $P = 0.002$). More nests were found in canopy habitats than expected and fewer were found in coastal habitats (Table 1). The number of nests found in squares with different dominant species was in proportion to the numbers found on the island ($\chi^2_4 = 8.2$, $P = 0.084$), but the nest tree species was not in proportion to the dominant species in each square ($\chi^2_4 = 108.6$, $P < 0.001$). More nests were found in *Tarenna borbonica*, *Eugenia lucida* and the 'other species' category than expected from the number of squares in which they were the dominant species, but fewer were found in *Hilsenbergia petiolaris* than expected (Table 2). Nests were not found in squares with different vegetation heights in proportion to their distribution on Ile aux Aigrettes ($\chi^2_3 = 44.4$, $P < 0.001$). More nests were found in squares with the height categories of 4–6 m and > 6 m and fewer in squares with vegetation < 3 m and 3–4 m (Table 3).

Two hundred and forty-nine nests were found before incubation started and 128 (51%) of these reached incubation. Seventy-five nests were unfinished and 40 were completed but were then abandoned intact. One egg was laid in six nests, but no incubation was observed and the apparently incomplete clutches were deserted. The final binomial logistic regression showed that the age of the female had a significant effect, with nests built by pairs containing older females more likely to reach incubation, whereas the age of the male had no effect (Table 4). The habitat type in the square in which the nest was found also had a significant effect with fewer nests reaching incubation in transition habitats (Table 4).

The earliest eggs were laid in mid-June and the latest in mid-February. At least one chick fledged from 34 (27%) of the 128 nests that reached incubation. A further 27 nests were found after incubation started and 11 of these were successful. The signs left at the 110 nests that failed were: the contents disappeared and there was no obvious damage to nests on 69 occasions, 14 nests were inaccessible but appeared undamaged, one nest fell out of the tree, broken eggshells were found under five nests, six nests had infertile clutches, three nests containing intact fertile clutches were deserted, six single eggs were deserted when after the other eggs in the clutch disappeared, dead chicks were found in two nests, three nests were ripped open with their contents missing, one nest was destroyed during a cyclone and two nests containing eggs were seen to be predated by female Mauritius Fodies from adjacent territories.

Table 1. Expected and observed numbers of Mauritius Fody nests in each habitat type on Ile aux Aigrettes.

Habitat type	Percentage of squares covered by habitat	Expected number of nests in habitat	Number of nests found in habitat	Difference between observed and expected number of nests found in habitat
Coastal	11.7	32	14	−18
Transition	52.0	143	145	2
Canopy	36.3	100	116	16

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Table 2. Expected and observed numbers of Mauritius Fody nests in tree species on Ile aux Aigrettes.

Nest tree species	Percentage of squares in which dominant species	Expected number of nests in tree species	Number of nests found in tree species	Difference between observed and expected number of nests found in tree species
Hilsenbergia petiolaris	34.0	93	23	−70
Tarenna borbonica	18.5	51	64	13
Diospyros egrettarum	22.5	62	60	−2
Eugenia lucida	10.8	30	52	22
Others*	14.2	39	76	37

*Other nest tree species were *Passiflora suberosa, Ficus reflexa, Leucaena leucocephala, Scutia myrtina, Dracaena concinna, Margaritaria anomala, Ludia mauritiana, Dodonea viscosa, Albizia lebbeck, Ficus rubra, Premna serratifolia, Thespesia populnea, Gastonia mauritiana, Scaevola taccada, Tylophora coriacea, Hibiscus tiliaceus* and *Dendrolobium umbellatum.*

The final binomial regression showed that the month in which eggs were laid was the best predictor of success, with nests from earlier in the season having a greater likelihood of success (Table 5). The use of carbaryl also had a significant effect on success with 33% (27/54) of nests producing fledglings when the carbaryl was used and only 15% (7/47) when it was not used. The daily probability of nest survival for all nests on Ile aux Aigrettes was 0.959 (95% CI 0.951–0.967, 145 nests, 2,526 exposure days). The number of days taken from the start of incubation to fledging was known exactly for 27 nests and the mean (± SE) was 28.4 ± 0.4. This gives an estimated nesting success of 30.3% (95% CI 24.0–38.3). The number of fledglings per adult female decreased each season, but the number of fledglings from each successful nest remained similar (Table 6).

Discussion

Mauritius Fodies nested in more mature, taller forest, appearing to avoid the more scrubby coastal areas. Younger females were more likely to abandon a nest before starting incubation. Nests were more likely to fledge chicks if they had been treated with carbaryl to control parasites, but the distance to the supplementary feeding aviaries had no effect on success. It is difficult to assess the effect of the extra food on the fodies as all the breeding birds used it on a daily basis, but the energetic costs of flying to the aviaries did not decrease the probability of a nest fledging chicks.

Mauritius Fodies nested in *Hilsenbergia petiolaris* less often than in other species even though they often built nests in squares where it was dominant. Pink Pigeons on Ile aux Aigrettes also rarely nest in this species (Swinnerton 2001). More nests may have been found in *Tarenna borbonica, Eugenia lucida* and the others category of nesting tree than expected because of the

Table 3. Expected and observed numbers of Mauritius Fody nests in height categories on Ile aux Aigrettes.

Height category (m)	Percentage of squares falling into height category	Expected number of nests in height category	Number of nests found in height category	Difference between observed and expected number of nests found in height category
<3	17.4	48	20	−28
3–4	45.2	124	110	−14
4–6	34.2	94	124	30
>6	3.2	9	21	12

Table 4. Final binomial logistic regression model for predictor variables on whether a Mauritius Fody nest found on Ile aux Aigrettes during building reached incubation stage (Nagelkerke $R^2 = 0.078$, 59% of datapoints classified correctly by final model). Canopy was used as a reference for the Habitat type category.

Covariate	Coefficient	SE	Wald statistic	df	*P*	Odds ratio
Age of female	0.002	0.001	8.92	1	0.003	1.002
Habitat type			6.27	2	0.044	
Habitat type (Coastal)	−0.382	0.658	0.34	1	0.561	0.682
Habitat type (Transition)	−0.680	0.272	6.27	1	0.012	0.506
Constant	−0.449	0.339	1.76	1	0.185	0.638

Discarded covariates were: season, month nest was found, age of male, distance from supplementary feeding aviaries and nest tree species.

way abundance was calculated in this study. These trees are often found in the understorey of the ebony forest so their actual abundance may have been underestimated by using the number of squares in which a species was dominant.

The Mauritius Fodies on Ile aux Aigrettes are all descended from pairs that nested in *Cryptomeria japonica* or pine *Pinus* plantations and they may show preferences for taller trees because their mainland ancestors nested in mature trees. The nesting sites of the Mauritius Fodies on the island may change in future seasons as the population increases, less optimal habitat is available and more individuals fledge from nests in scrubby habitats. The vegetation on certain parts of Ile aux Aigrettes may become more suitable for nesting fodies as areas that have been cleared of exotic vegetation and replanted with natives start to mature.

The rate of nest abandonment was 51% on Ile aux Aigrettes, which is slightly higher than the 30–40% recorded on the mainland, but this varies considerably between pairs (Safford 1997c). There may be more disturbance from high levels of human activity or increased interference from other fodies at the greater densities on Ile aux Aigrettes. There will probably be a higher proportion of younger females on Ile aux Aigrettes as the population has only been recently established and they are more likely to abandon nests before incubation. The effect of habitat is puzzling, with the nests more likely to be abandoned in transition habitats than in the most and least mature areas. However, sample sizes are small in coastal habitats, as Mauritius Fodies do not nest there very often. The percentage of the variance in whether Mauritius Fodies abandon their nests before incubation explained by the final model is very low (7.8%) and there may be other factors operating.

The nesting success on Ile aux Aigrettes is similar to figures from *Cryptomeria* trees on the mainland (Safford 1997b, Cristinacce *et al.* 2009). Safford (1997b) found much lower success in pine, eucalyptus and native trees, although more recently Cristinacce *et al.* (2009) found similar success in pine trees, but were unable to calculate success in native or eucalyptus trees because very few pairs nested in these habitats. Carter and Bright (2002) used cameras and eggs placed in weaver bird nests to show that nest predation by Ship Rats and Crab-eating Macaques *Macaca*

Table 5. Final binomial logistic regression model for predictor variables on whether at least one Mauritius Fody fledged from a nest that reached incubation stage after being found during building on Ile aux Aigrettes (Nagelkerke $R^2 = 0.326$, 76.6% of datapoints classified correctly by final model).

Covariate	Coefficient	SE	Wald Statistic	df	*P*	Odds ratio
Month eggs were laid	−0.74	0.17	19.39	1	< 0.001	0.477
Use of carbaryl	−1.12	0.53	4.49	1	0.035	0.325
Constant	2.15	0.66	10.67	1	0.001	8.610

Discarded covariates were: season, age of male, age of female, habitat type, distance from supplementary feeding aviaries and nest tree species.

Table 6. Number of adult Mauritius Fody females, fledglings and successful nests in each of the first breeding seasons on Ile aux Aigrettes.

Season	Number of adults females	Total number of fledglings	Number of fledglings per female	Number of successful nests	Number of fledglings per nest
2004–05	2	6	3	3	2
2005–06	19	40	2.11	18	2.22
2006–07	38	47	1.24	24	1.96
Total	—	93	—	45	2.07

fascicularis was higher in native trees than in *Cryptomeria* plantations. The view that exotic plantations provide some measure of protection from mammalian predators is supported by the similar nesting success on Ile aux Aigrettes.

The only confirmed predators of Mauritius Fody nests on Ile aux Aigrettes are female Mauritius Fodies, but there may be others. Three nests were found ripped open and mammals would have been suspected if this happened on the mainland. Indian Mynahs *Acridotheres tristis* were observed predating a Red-whiskered Bulbul *Pycnonotus jocosus* nest on Ile aux Aigrettes (A. Cristinacce, pers. obs.) and are suspected of reducing the nesting success of the Tahiti Flycatcher *Pomarea nigra* (Blanvillain *et al.* 2003) and Seychelles Magpie-robin *Copsychus sechellarum* (Komdeur 1996). These large birds would have to damage a domed fody nest to gain access to the contents. Other potential predators include Red-whiskered Bulbuls, Striated Herons *Butorides striata*, agamid lizards *Calotes versicolor*, Indian Wolf Snakes *Lycodon aulicus* and Asian Musk Shrews *Suncus murinus*. Shrews and bulbuls are abundant on Ile aux Aigrettes and could potentially affect breeding success if they predated large numbers of nests. Direct methods such as placing clay or plasticine eggs in unused fody nests and checking any marks made on them, or using cameras around active nests would be required to identify important predators.

The highest densities of Mauritius Fodies on the mainland are 1.33 pairs ha^{-1} (Cristinacce *et al.* 2009) whilst the 38 pairs on the 26 ha Ile aux Aigrettes are at a density of around 1.5 pairs ha^{-1} although this varies throughout the island. Interference by non-breeding birds at high densities can reduce nesting success on islands (Komdeur 1996) and resources for breeding may be limited even with the provision of supplementary food. There may also be a shortage of some essential nutrients on Ile aux Aigrettes that are not provided by the additional food. Hatching success may have been affected by the higher temperatures on Ile aux Aigrettes compared to upland areas on the mainland as the chicks are more likely to dehydrate during the hatching process. In New Zealand, Takahes *Porphyrio hochstetteri*, Kakapos *Strigops habroptila* and South Island Saddlebacks *Philesturnus corunculatus corunculatus* all had lower hatching success when they were translocated from cooler southern areas to islands in warmer regions (Hooson and Jamieson 2004). The effect of nest parasites on the mainland is unknown because it is difficult to access nests, but the use of carbaryl on Ile aux Aigrettes had a positive effect on nesting success, suggesting parasites could become a problem on the island if management is withdrawn. Numbers of parasites could rise as density increases, which could lead to an outbreak of pathogens with the potential to cause a crash in a population of birds on a small island (Hale and Briskie 2009).

The nesting success of Mauritius Fodies on Ile aux Aigrettes was much lower towards the end of the breeding season. This pattern is commonly seen in bird species (Hochachka 1990, Norris 1993) and has also been recorded in the mainland population of Mauritius Fodies (Safford 1997b). Safford (1997b) suggested that the decline in breeding success throughout the season on the mainland may be due to changes in the foraging activities of omnivorous mammalian predators as the availability of other food items fluctuates. On Ile aux Aigrettes this is not thought to affect breeding success, so the decline over the season could be related to climatic factors. Temperature and humidity increase throughout the breeding season in southeast Mauritius, whilst rainfall is relatively low until December or January when there is a marked increase (unpubl. data from the

Mauritian Meteorological Service). These changes could affect nest parasites, hatching success or the levels of insect prey available to Mauritius Fodies. Female Mauritius Fodies have been observed to lay up to nine clutches during a season and later clutches are less successful than earlier ones. The first clutches in a season of Hihis *Notiomystis cincta* are more than 10 times more likely to fledge chicks as the second clutches (J. Ewen, pers. comm.). We did not test the direct effect of clutch number on the nesting success of Mauritius Fodies as we could not be sure that all clutches had been found.

The productivity per female decreased each season on Ile aux Aigrettes as the population grew, and will presumably continue to decrease as it reaches carrying capacity and the females start to age. The potential density of an unmanaged population of Mauritius Fodies is unknown as the remnant upland population on the mainland may have been forced into sub-optimal habitat by nest predation. Rodrigues Fodies *Foudia flavicans* were found at densities of 14.29 birds ha^{-1} in a monoculture of *Araucaria cunninghamii* (Impey *et al.* 2002) and the Seychelles Fody persists without management in numbers of 458–614 on Cousine (26 ha) (Kraaijeveld and Komdeur 2003) and around 1,000 birds on Cousin (29 ha) (Birdlife International 2008), both similar sizes to Ile aux Aigrettes (26 ha).

The nesting success of Mauritius Fodies on Ile aux Aigrettes is sufficient to support a viable population with current management practices. For sustainability reasons, it would be preferable to reduce the support provided through supplementary food and placing carbaryl in nests. Adaptive management using population models as used by Armstrong *et al.* (2007) would allow a reduction in management without jeopardising the survival of the population. These models could also be used to predict a sustainable harvest of Mauritius Fodies from Ile aux Aigrettes for release on to other offshore, predator-free islands (Dimond and Armstrong 2007). Supplementation of the offshore populations from the mainland may also be required as inbreeding can cause problems for populations with few founders (Jamieson and Ryan 2000). The continued monitoring of survival and reproduction on Ile aux Aigrettes is vital to inform management decisions, as patterns may change in the first few years after release (Armstrong and Ewen 2002).

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