Research Article

Received: 19 November 2015 Revised: 12 February 2016 Accepted article published: 3 March 2016 Published online in Wiley Online Library: 1 April 2016

(wileyonlinelibrary.com) DOI 10.1002/ps.4263

Eradication of common mynas *Acridotheres tristis* from Denis Island, Seychelles

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Abstract

BACKGROUND: In Seychelles, the common myna has been shown to have a negative impact on endangered endemic birds on Denis Island, interfering with breeding attempts and attacking adult endemic birds at their nests. This stimulated an attempt to eradicate the island's mynas.

RESULTS: The eradication was undertaken in three phases, overall killing 1186 mynas and lasting 5 years. Decoy trapping was the most effective method for catching mynas, but the last birds were shot. Decoy trapping was compromised by catches of non-target species. Data collection from killed birds indicated that trapping did not favour either sex, and that most breeding occurred during the wetter season, November to March.

CONCLUSIONS: Eradication of mynas from small tropical islands is feasible. The Denis Island eradication was prolonged by difficulties in management and staffing. Using volunteers, the cost of the eradication was similar to that of eradicating rodents from the island. In future eradication attempts in Seychelles, possible food stress during the drier season (May to September) might facilitate trapping at this time. Habitat management, especially the removal of short mown grass, could enhance eradication progress. Continued monitoring is needed to confirm eradication and detect any immigration, and also to record responses in the endemic birds.

Supporting information may be found in the online version of this article.

Keywords: common myna; *Acridotheres tristis*; invasive alien species; eradication; Denis Island; island restoration; wildlife management

1 INTRODUCTION

Common mynas *Acridotheres tristis* (hereinafter referred to simply as 'mynas'), indigenous to southern Asia, have been introduced to many parts of the world, including southern Africa, south-eastern Australia, New Zealand and many tropical oceanic islands,[1] and they are regarded as one of the world's most serious invasive species.[2] Evidence for adverse effects on native fauna is, however, equivocal. Grarock *et al.*[3] found a negative correlation between myna numbers and the populations of cavity-nesting native species and non-native birds during a period of myna population expansion in south-eastern Australia and in New Zealand. Tindall *et al.*[4] found that reducing an island population of mynas by trapping large numbers led to significant increases in the populations of some other bird species. Pell and Tidemann[5] obtained circumstantial evidence that mynas depressed breeding success of native cavity-nesting parrots. Grarock *et al.*[6] confirmed a negative relationship between myna occupation of nestboxes and the numbers of two cavity-nesting parrot species at some study sites, but noted that the mynas and parrots had different habitat preferences. Lowe *et al.*[7] also concluded that differences in habitat utilisation by mynas and native cavity-nesting birds suggested that

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competition was minimal. Clark *et al.*[8] found that mynas are potential reservoirs of exotic avian pathogens that could impact native species.

In Seychelles, Komdeur[9] reported that mynas interfered with the breeding of endemic Seychelles magpie robins *Copsychus seychellarum*, which in the 1990s survived on only one island (Frégate) within the archipelago. Subsequently, mynas were observed competing for food and destroying eggs and chicks of Seychelles magpie robins during competition for nest sites.[10] This stimulated attempts to eradicate mynas from Frégate and other islands,[11] none of which were successful until Canning[12] eradicated the Frégate population by means of an intensive trapping programme. Small numbers of mynas have been eradicated from some Spanish islands,[13] but we are not aware of any other successful eradications of large populations of mynas to date.

On Denis Island, feral cats *Felis catus* and black rats *Rattus rattus* were eradicated in 2000 and 2002 respectively,[11] after which the island was considered to be suitable for the introduction of some of Seychelles' endangered endemic birds to increase their conservation status.[14,15] During an attempt to eradicate mynas in 2001, an unknown number were killed using the avicide Starlicide (also called DRC-1339; 3-chloro-*p*-toluidine hydrochloride), and 26 mynas were shot. The attempt was discontinued after black rats were discovered to have reinvaded.[11]

Seychelles fodies *Foudia sechellensis* and Seychelles warblers *Acrocephalus sechellensis* were introduced in 2004,[15] followed by Seychelles magpie robins and Seychelles paradise flycatchers *Terpsiphone corvina* in 2008. During post-translocation studies, Seychelles warblers, Seychelles fodies and a female flycatcher with severe head injuries and scars were observed, and a video observation confirmed that mynas can cause similar injuries (van der Woude J, Apperloo R and van Marrewijk M, Seychelles warbler population census on Denis Island, August–September 2013, unpublished report, 2013). Furthermore, reproductive success and population growth rates of the introduced endemic bird species were lower than expected based on previous translocations (the same unpublished report).

In view of these perceived problems, a myna eradication was begun in May 2010. This was continued, with varying intensity, until March 2015, when successful eradication was believed to have been achieved. This paper describes the eradication, the techniques used and their successes and weaknesses and the estimated costs, and discusses requirements to improve future eradication programmes. We also report data collected from killed mynas on the population structure and body condition of Denis Island mynas.

1.1 Common myna

Mynas are opportunist omnivores and to a large extent commensal with humans, but their main foraging adaptations are related to locating and procuring food on the ground in short vegetation.[1] Open areas of grassland and other low herb vegetation, such as grass airstrips and decorative lawns, are thus favoured feeding areas. They are also attracted to grazing livestock, which attract and disturb insects, and to refuse disposal sites, which also attract insects but additionally provide a wide variety of human food waste. Food waste often includes fruit, which mynas eat both as waste and when ripening on trees.

Following anthropogenic development, some of Seychelles' smaller islands (<250 ha) contain all or most of these habitats and support high densities of common mynas. Four of these islands, Denis (143 ha), Bird (101 ha), Frégate (219 ha) and North (201 ha), supported densities of 644, >510, 340 and >>373 mynas km^{-2}, respectively, before eradication attempts[12] (van der Woude J, this paper; Feare CJ and Larose CS, unpublished). These values are much higher than reported in suburban areas of Australia [Canberra 3–189 mynas km^{-2} (Pell and Tidemann[5] and Tidemann C, private communication); Sydney 3–100 mynas km^{-2} (Pell and Tidemann[5] and New South Wales Government[16])] and on Ascension Island [South Atlantic 12 mynas km^{-2} (Hughes BJ, private communication)]. In Pretoria, South Africa, van Rensburg *et al.*[17] reported an average density of 325 mynas km^{-2} in suburban habitats, but lower values in urban (243 mynas km^{-2}) and semi-natural (59 mynas km^{-2}) areas. In three small (<0.15 km^{2}) suburban areas of Cairns (Queensland, Australia), however, Tidemann (private communication) recorded densities of <566 mynas km^{-2}, comparable with those on the foregoing Seychelles Islands. There appear to be no estimates of density from areas where mynas are indigenous.

1.2 Denis Island

Denis Island (3° 48′ S, 55° 40′ E) is a coralline sand cay lying on the northern rim of the Seychelles Bank, 53 km north of Praslin Island, the nearest source of large numbers of mynas, and 52 km east of Bird Island. Denis is largely wooded but has a luxury hotel, a farm and a 0.07 km^{2} grass airstrip. The farm includes vegetable crops and animal husbandry (cattle, pigs, goats and poultry). Most cattle grazing occurs in wooded grassland on the east coast, at the borders of the grass airstrip, in a 2 ha plot on the west coast and in a small grassy area in the middle of the island. These grazed areas are preferred foraging grounds for mynas.

Up to 2014, Papaya trees *Carica papaya* were widely distributed around the more open areas of the island. The fruits were widely exploited by mynas until 2013–2014, when most papaya trees on the island were killed by a mealy bug *Paracocus marginatus* infestation.

2 METHODS

Some potential methods for catching or killing mynas were deemed unsuitable for use on Denis Island. The avicide Starlicide was considered to pose a risk to non-target fauna,[18] especially some of the Seychelles' endemic species that had been introduced to the island. Multicatch netting techniques, such as cannon nets and elastic-powered 'whoosh' or 'zap' nets,[19] were excluded because mynas on Denis Island did not flock densely in any of the island's open habitats, even when bait was presented. Nooses placed in the entrance of nest boxes[11] were not deployed, as few mynas used the available nest boxes and thus this technique would have contributed little to the catch rate required for eradication.

Some catching techniques were trialled but found to be inadequate as part of an eradication. Mist netting was inefficient, as mynas seemed to detect nets easily and proved capable of climbing out when caught. After catching three birds to be used as live

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decoys (see below), mist nets were not used. Nylon nooses placed among bait on the ground failed to catch mynas. Live-catch rat traps (single-catch spring-operated door), drop-traps (ca 50 × 50 cm square wire mesh traps supported by a post that could be pulled away by an operator when birds were seen feeding on bait beneath the trap), a ladder trap[20] and a bob-wire trap (cage trap, bird entry through hanging wires that swing inwards to allow entry but will not swing back) caught too few mynas to be of value to the eradication. Funnel traps, made on the island, and also commercially made mini-myna traps (www.mynamagnet.com.au) similarly caught only few birds on Denis Island. Decoy traps proved most effective in catching mynas, and the major part of the eradication was achieved using these. Trapped mynas were killed by cervical dislocation and incinerated after examination (see below). After substantial population reduction, the remaining mynas were shot.

2.1 Decoy traps

Decoy traps, measuring 60 × 60 cm and 40 cm high, were constructed from 50 × 25 mm galvanised wire mesh. Each had a central compartment housing a live decoy myna, around which were four catching compartments. Each of the latter was fitted with a door that was released when an entering bird stood on a treadle; the door dropped under its own weight. The decoy and catching compartments each had a roof door for maintenance access for the decoy bird and to remove birds that had been caught. The decoy birds were individually marked with colour rings and were given food [mainly kitchen waste rice, meat, fish (animal protein proved essential for their survival) and fruit] and water twice daily; in phase 3, decoys had their primaries clipped to reduce the risk of escape. Covers, normally made from coconut leaves, were placed on top of the traps to shield birds from sun and rain. Traps were visited at least twice a day to remove birds that had been caught, but when large numbers were being trapped, traps were visited much more frequently (<6 times a day), as judged necessary to remove the birds and reset the doors for subsequent catches.

Initially, traps were deployed where mynas were most frequently and predictably seen, including the airstrip, wooded grassland along the east coast, the farm and an area that had been cleared for ground-nesting sooty terns *Onychoprion fuscatus*.[21] Within these areas, traps were moved periodically when catch rates fell or when catches of non-target species interfered with the catching of mynas (see below). When numbers of mynas visiting these sites declined, traps were moved to more wooded areas, sometimes targeting pairs that were observed at particular locations. The decision when and where to move traps was highly subjective but guided by the experience of the trappers.

At the end of phases 1 and 2, remaining decoys were killed. In order to provide a supply of decoys for the commencement of phase 3 (see below) of the eradication in May 2014, 20 mynas (16 adults, four juveniles) were caught in a decoy trap on Seychelles' main island, Mahe (15 500 ha), where large numbers of mynas occur. They were transported to Denis Island by air.

2.2 Shooting

To avoid the risk of mynas becoming averse to shooting and associating people with weapons or threatening circumstances, shooting was deferred to the very end of the eradication process. By this time the numbers of remaining mynas were low, they were proving difficult to trap, they were no longer associating in flocks and individuals could be targeted out of sight of other mynas. The weapons used were a .22 rim fire rifle fitted with a silencer, using subsonic hollow-point ammunition, and a 12-gauge shotgun with US No. 7 cartridges. The hunter initially mapped the locations of feeding birds and selected sites from which they could be shot. Mynas normally feed in pairs,[1] and when selecting a bird to be shot he waited until the second member of the pair was out of sight before shooting the target. He later returned to seek and shoot the remaining member of the pair. Birds were shot from hides (usually buildings), by stalking in a vehicle (electric buggy) and by drive-by shooting from a moving vehicle. Shooting from hides and stalking in the vehicle were supplemented by baiting at specific sites, and mynas were sometimes attracted by calling devices (that mimic bird distress calls when blown into). Shooting of all known surviving mynas was completed in 3 weeks.

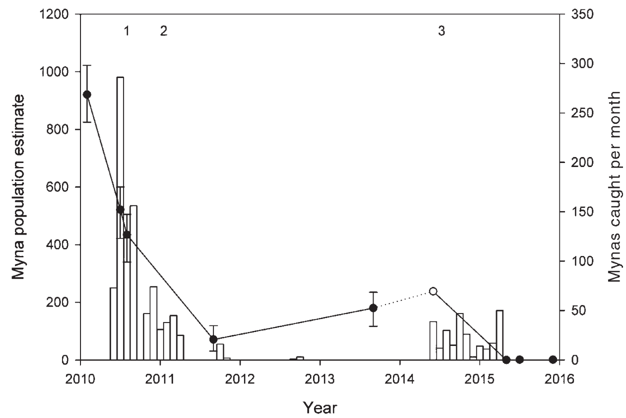

Figure 1. Estimated myna population size (left-hand *y*-axis) and the monthly number of mynas caught during the eradication on Denis Island (right-hand *y*-axis). The three phases of the eradication are indicated above the columns. Population size estimates (black dots) were based on 20 m radius point counts along thirty 200 m transects. The first population estimate was conducted before the start of the eradication of the mynas. The estimated population size at the start of phase 3 (May 2014, white dot) was calculated from the annual, undisturbed population growth rate between August 2011 and August 2013. The last two columns represent birds that were shot at the end of the eradication.

2.3 Timescale of the eradication

The eradication was undertaken in three phases of intensive eradication, separated by periods when mynas were undisturbed and were able to reproduce (Fig. 1): phase 1 – 20 May to 21 August 2010 (weeks 1 to 14); phase 2 – 30 October 2010 to 30 March 2011 (weeks 24 to 45); phase 3 – 19 May 2014 to 18 March 2015 (weeks 209 to 252).

The project was staffed largely by volunteer graduate students after appropriate training on the island. For phases 1 and 2, and at the initiation of phase 3, volunteers were trained by CJF. In the later stages of phase 3, however, new volunteers were trained by their immediate predecessors. Difficulties in recruiting, volunteer retention and periods of inadequate management input were largely responsible for the intervals during which no eradication was undertaken (Fig. 1).

2.4 Myna biology

Little is known of myna population dynamics,[22] especially on small tropical islands that support high densities.[23,24] We collected basic information on the birds' biology from the dead birds, including population parameters that might change in response to the eradication process.

Killed mynas were aged as adult or juvenile (juveniles distinguished by an all-grey iris and dull brownish feathers, especially on the head when very young, and by the lack of a dark mark at the base of the lower mandible in older but still immature birds[24]). Body mass (Pesola balance to nearest g), head + bill length (Vernier callipers to nearest mm) and wing length (flattened chord using stopped rule) were measured. An index of body condition (mass/head + bill length) was calculated to make allowance for differences in body size. Birds were sexed by dissection.

Body mass and head + bill length of the mynas caught on Mahe at the beginning of phase 3 were measured, but they were not sexed.

2.5 Non-target fauna

During trapping, a variety of non-target animals, mainly birds, were caught. These closed doors to catching compartments of decoy traps and thus prevented entry of mynas. The larger species, Madagascar turtle doves *Nesoenas madagascariensis* (introduced into Seychelles), common moorhens *Gallinula chloropus* (indigenous) and in the final phase of the eradication free-ranging chickens *Gallus domesticus* additionally damaged the trip mechanisms of the traps, necessitating frequent repair or replacement. This interference imposed considerable constraints on the myna trapping programme. This was appreciated throughout phase 1, but numbers of non-target species were not recorded. During phase 2, numbers of non-target species trapped were recorded throughout. In phase 3, numbers of Madagascar turtle doves were recorded throughout, while numbers of other non-target captures were recorded up to August 2014, when the volunteer staff changed.

By clipping some tail feathers of the Madagascar turtle doves, we discovered that the same individuals repeatedly returned to traps. To reduce interference with the myna trapping programme, the decision was taken with island management to kill trapped turtle doves in the final phase of the eradication. Moorhens are protected under Seychelles legislation, and they had to be released unharmed, thereby continuing to interfere with myna trapping. In the final phase of trapping, however, many trapped moorhens were temporarily held in a large cage until the completion of the eradication.

In addition to the above, by the start of phase 3 of the eradication, chickens were increasingly allowed free range from the farm in the northern part of the island. Here, smaller chickens repeatedly entered decoy traps, even when no bait was placed inside them. Their interference was so severe that they effectively prevented the trapping of mynas in this area.

2.6 Censuses of mynas

In order to estimate myna population size on Denis before and during the eradication, we conducted fixed-radius point counts along 200 m line transects. Thirty line transects were set at random across the whole island in each vegetation type. During 2 min observations at each of five equidistant points along each transect, the number of birds within a 20 m radius, their behaviour and the distance from the observer were recorded. This radius was determined by the high density of the vegetation, to ensure that we were able to detect all birds within the radius. Mynas are relatively conspicuous and are not cryptic in their behaviour. They are very vocal, producing a large variety of loud calls. However, birds aurally detected had to be confirmed visually to determine the number of birds present within the fixed radius. Mynas that were flying were not recorded unless the flights started or ended within the transects. During each population census, all transect counts were performed within 8 days and under similar weather conditions. Counts were conducted twice in the morning (between 9 and 11 a.m.) and twice in the afternoon (between 3 and 5 p.m.) in random order. As analyses showed no effect of the time of day on the number of birds observed, the number of counts along each transect was reduced from four to two in the years 2011 and 2013, when both counts were performed in the morning. Except for 2013, when a census was performed by van der Woude only, the observations within each period were done by two observers. The pre-eradication population census was performed in January 2010. Thereafter, myna counts were performed in June 2010 (during phase 1), July 2010 (during phase 1), August 2011 (after phase 2) and August 2013 (more than 2 years after the end of phase 2).

Population size was estimated using the formula $P = s \times A/a$, where P is the population estimate, s is the average number of mynas per transect observed over the replicated counts within a survey, A is the total area of the island and a is the sampled area. Total area was defined as the total size of Denis Island excluding the surface area of the beaches, as the beach is rarely used by mynas. We used ArcGIS 10.3 to determine the size of the total area (m^2). To estimate the number of mynas at the beginning of phase 3, we calculated the undisturbed population growth rate using the formula

$$\text{Population growth rate} = \frac{\left[\left(N_{t_2} - N_{t_1}\right)/N_{t_1}\right] \times 100}{t_2 - t_1}$$

where N_{t_1} is the population estimate in August 2011 and N_{t_2} is the estimated population size in August 2013.

At the end of phase 3, the hunter regularly traversed the entire island to locate mynas over a 3 week period. Following the removal of the last-known myna on 18 March 2015, a post-eradication monitoring programme was put in place, consisting of island-wide surveys with no fixed route but all including the main myna habitats: farm, airstrip and hotel. Surveys were conducted twice a day until 19 April, and 3 times a week from 30 April. This decreased to twice-weekly surveys in June and monthly surveys from June to November. Following the confirmed sighting of a myna in November (during an annual bird census, not a myna survey), four daily visits to that location and to main myna habitats were undertaken, followed by three visits a week until 12 December, after which surveys reverted to the monthly schedule. In addition to these dedicated myna surveys, vigilance for mynas is maintained on daily, weekly and annual whole-island surveys targeted at other biota.

2.7 Cost of the eradication

Costs were estimated from records held by Green Islands Foundation, the NGO that administered the project. Two costs were prepared, one detailing basic costs of consultant fees, transport and equipment, the other including overheads incurred by the island.

2.8 Statistical analyses

Myna detections were initially analysed in DISTANCE v.6.2[25] in order to estimate detection probability and population density. However, no models were successfully fitted with the key functions and expansions available in the program. Our data violate one of the assumptions of DISTANCE: the graph of the detection function should have a shoulder around or near the point.[25] The detection in our study did not decrease with distance from the observer, probably owing to the relatively small radius in

Table 1. Number of trap days for which each trap type was employed, number of mynas caught by each trap and the catch rate (CR: number of birds trap^{-1} day^{-1})

	Phase 1			Phase 2			Phase 3		
Trap type	Trap days	Number of birds	CR	Trap days	Number of birds	CR	Trap days	Number of birds	CR
Decoy	1234	625	0.506	2567	260	0.101	5962	175	0.029
Mini-myna							1202	10	0.008
Funnel	122	4	0.033	No data	2				
Bob wire				72	0	0.000			
Ladder							210[a]	8	0.038
Drop							81	4[b]	0.056
Rat	39	8	0.205						
Mist net	No data	3	–	–	–	–	–	–	–

[a] Although the ladder trap was available for catching for 210 days, it was not baited for all of this time, and the number of days for which bait was provided was not recorded. The calculated catch rate is therefore an underestimate.
[b] Four drop traps were constructed, but as each required an observer to watch a trap and release the support when a myna entered, no more than two traps could be operated at one time. The calculated catch rate is therefore based on two traps.

Table 2. Catches of non-target animals in decoy traps during phase 2 (October 2010–March 2011) and phase 3 (May 2014–March 2015). Catch rates (number of birds trap^{-1} day^{-1}) in phase 2 are based on 2567 trap days. In phase 3, data for Madagascar turtle doves are based on 5962 trap days, but catches of the other species were recorded for only 82 trap days

	Phase 2		Phase 3	
Species	Number caught	Catch rate	Number caught	Catch rate
Madagascar turtle dove	3362	1.310	876	0.147
Barred ground dove	690	0.269	25	0.305
Moorhen	572	0.223	323	3.939
Chicken	1	0.000	46	0.561
Turnstone	13	0.005	1	0.012
Seychelles magpie robin	21	0.008	4	0.049
Madagascar fody	14	0.005	3	0.037
Seychelles fody	1	0.000	0	0.000
Hermit crab	542	0.211	2	0.024
Land crab	55	0.021	12	0.146

which the counts were performed, together with the conspicuous behaviour of the mynas. We therefore used non-parametric bootstrapping to produce estimates of population size and corresponding 95% confidence intervals.[26] For each transect–census combination, we resampled the data 1000 times, with replacement. The gained average numbers of birds and intervals were extrapolated to the total size of Denis Island excluding the surface area of the beaches (the beach provides no suitable habitat for mynas).

We used ArcGIS 10.3 to determine the size of the island. To estimate the number of mynas at the beginning of phase 3 (August 2013), we calculated the monthly population growth rate based on the undisturbed population growth between August 2011 and August 2013.

Statistical analyses were performed in R (v.3.2.2). We used an alpha level of 0.05 for all statistical tests. In the analyses of body mass and body condition, we fitted a linear model using generalised least squares with a constant variance function using package nlme (v.3.1-121). In both analyses, phase, month and sex and their interactions were included as predictors. Additionally, we analysed the change in body mass and condition within phase 3 separately and included sex, month and the interaction in the model. Sex ratio of trapped mynas within each phase of the eradication was analysed using binomial tests and a chi-square test. A linear regression was used to test the correlation between the number of mynas killed and the decrease in population size.

3 RESULTS

During the eradication, 1186 mynas were killed (in phase 1, 640 were killed; in phase 2, 260 were killed; in phase 3, 264 were killed; a further 22 were caught in August and September 2011 and 2012, outside the main trapping phases). Of the total killed, 1120 were trapped and 66 were shot at the end of the project.

3.1 Trap success

The various trap types used during the eradication were employed for different lengths of time, depending on their success. By far the most successful on Denis Island were decoy traps, which achieved a higher catch rate trap^{-1} day^{-1} than all other traps employed throughout the eradication (Table 1). During the latter stages of phase 3, however, the catch rate of decoy traps declined to the extent that in some weeks no birds were caught, and at this time the catch rates of ladder and drop traps exceeded those of decoy traps, but this is based on very small samples.

Throughout the eradication, trapping success of mynas was compromised by the catching of non-target species, especially in decoy traps (Table 2). Madagascar turtle doves were the most significant problem (Table 2).

Some non-target species were extensively caught in some of the other traps used. For example, 1495 Madagascar turtle doves were caught in a bob-wire trap in January–March 2011 (catch rate 9.9 birds trap^{-1} day^{-1}). While mynas may have been discouraged from entering these traps with large numbers of non-target birds, they were not physically excluded by the closure of access entrances.

3.2 Shooting

Of the 66 mynas shot, 62 were killed using a .22 rifle, and four using a shotgun; the latter was not used until the end of the shooting phase to minimise the risk of other mynas being present in the vicinity and learning to avoid the hunter and associated noise. Fifty-six of the shot birds were retrieved; of these, 31 were aged, with 23 adults and eight juveniles.

Most (52) of the mynas were shot by stalking, while 11 were shot from hides and three from a moving vehicle; all of the latter were killed using the shotgun.

3.3 Censuses of mynas

In total, 1432 mynas were recorded during the five population censuses. Myna population size before eradication (January 2010) was estimated at 921 individuals (Fig. 1). It decreased by over 50% to 434 in July, within 2 months of the start of the eradication. By August 2011 the population had decreased to only 71 birds, at which time 919 birds had been killed. In 2013, over 2 years after the end of phase 2, the myna population was estimated at 180 birds. The annual population growth rate in this period without any disturbance of catching was approximately 77 birds year^{-1}. Unfortunately, no myna population census was performed before the onset of phase 3 of the eradication; however, from the population growth rate we estimated the population size in May 2014 to be approximately 238 birds (Fig. 1). The decrease in the estimated population size over the course of the eradication correlated strongly with the number of birds caught ($R^2 = 0.896$, $P = 0.01$).

No mynas have been discovered during post-eradication monitoring. On 23 June, however, one myna was seen opportunistically. It was monitored for 1 month to see if it attracted others. It did not and was shot on 25 July. The bird was ringed, having been a decoy that had escaped despite having had its primaries cut to render it flightless; when shot, the primaries had regrown. On 10 November 2015, a myna was reported by non-experienced island staff, and during an annual bird census on 24 November, conservation staff reported a confirmed sighting. Despite continuing monitoring and intensive searches, using callback of myna vocalisations, this bird has not been seen or heard since (as at 19 January 2016). Whether it is still present and whether it was a bird remaining from the original population or a new arrival are unknown.

3.4 Myna population structure

3.4.1 Sex ratio

The overall sex ratio of the 901 trapped adults that were sexed was 0.998 males per female, indicating a population sex ratio of unity. There was no indication of any change in sex ratio over the phases of the eradication [χ^2 (4, $N = 901$) = 6, $P = 0.19$] (Table 3).

Table 3. Total numbers of mynas identified as adults broken down by sex, and the sex ratio in each of the phases of the eradication

	Phase 1	Phase 2	Phase 3
Total	528	179	194
Male	259	94	97
Female	269	85	97
Sex ratio M:F	1:0.96	1:1.12	1:1

3.4.2 Proportion of young

The proportion of juveniles caught during each calendar month throughout the eradication suggested that most young entered the population from January to March (supporting information Fig. S1). This implies that most breeding occurs during the wet season, which extends from November to April. However, the presence of juveniles in all months raises the possibility that limited breeding could occur throughout the year.

3.4.3 Body size, mass and condition

On average, males were significantly heavier than females ($N = 439$, 104.09 ± 0.48 g and $N = 445$, 96.73 ± 0.51 g respectively, df = 880, t =1.96, $P < 0.001$) (Fig. 2). Furthermore, body mass differed significantly with phase of eradication ($F = 52.3$, $P < 0.001$), month ($F = 6.08$, $P < 0.014$) and the interaction between phase and sex ($F = 14.24$, $P < 0.001$) and between phase and month ($F = 7.39$, $P < 0.001$). Male mynas caught during the final phase of the eradication were significantly heavier than males caught during the first phase of the eradication (phases 1 to 3, df 110, $t = 1.98$, $P = 0.025$; phases 2 to 3, df = 165, $t = 1.97$, $P = 0.08$). In females, the body mass of birds caught during phase 3 was significantly higher compared with birds caught during phases 1 and 2 (df = 131, $t = 1.98$, $P < 0.001$ and df = 176, $t = 1.97$, $P < 0.001$ respectively). Consequently, females caught during phase 3 did not differ in weight from males caught during each phase of the eradication (phase 1, df = 132, $t = 1.98$, $P = 0.60$; phase 2, df = 186, $t = 1.97$, $P = 0.74$; phase 3, df = 173, $t = 1.97$, $P = 0.18$). Within phase 3, body mass increased significantly with time ($F = 4.84$, df = 10, $P < 0.001$).

Both wing length and head-bill length of adult males ($N = 445$) caught during the eradication were significantly larger compared with the females [male $N = 445$, wing = 143.23 ± 0.21 cm (SE), female $N = 444$, wing = 137.58 ± 0.22 cm, $t_{885} = 18.26$, $P < 0.001$, male head-bill length = 55.60 ± 1.10 cm, female head-bill length = 53.10 ± 0.10 cm, $t = 2.21$, $P = 0.028$].

Body mass corrected for size was used as an index of body condition (mass (g)/head + bill length (mm)]. As with body mass, body condition varied with phase of eradication ($F = 37.38$, $P < 0.001$), sex ($F = 69.25$, $P < 0.001$) and interaction between phase and sex ($F = 12.3$ $P < 0.001$) and between phase and month ($F = 4.35$, $P = 0.037$). Male condition was significantly higher compared with females in phases 1 and 2 (df = 169, $t = 1.97$, $P < 0.003$ and df = 523, $t = 1.96$, $P < 0.001$ respectively), but this difference disappeared in phase 3 (df = 175, $t = 1.97$, $P = 0.41$). As with body mass, females caught during phase 3 had a significantly higher body condition compared with females caught during phases 1 and 2 (phases 1 to 3, df = 130, $t = 1.98$, $P < 0.001$; phases 2 to 3, df = 170, $t = 1.97$, $P = 0.002$). Male condition, however, did not change with phase of eradication (phases 1 to 3, df = 113, $t = 1.98$, $P = 0.08$; phases 2 to 3, df = 168, $t = 1.97$, $P = 0.23$). Within phase 3 there was a significant effect of time (month, $F = 5.95$, df = 1, $P < 0.016$).

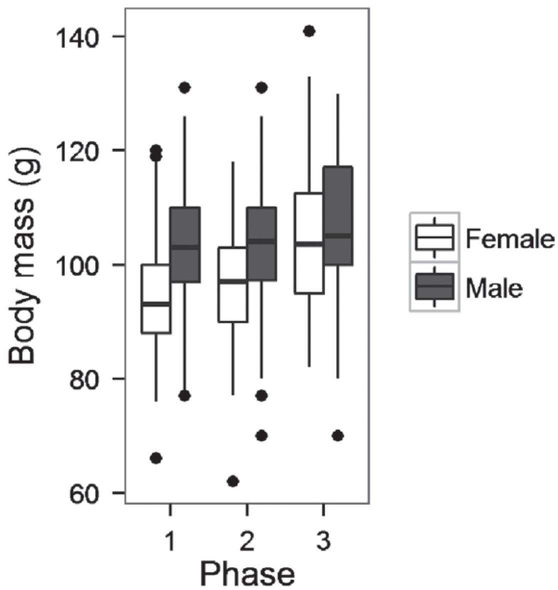

Figure 2. Body mass of male and female mynas caught during each phase of the eradication. Sample sizes: during phase 1, females = 261 and males = 264; during phase 2, females = 81 and males = 91; during phase 3, females = 95 and males = 83.

The mynas that were caught on Mahe before the start of phase 3 (May 2014) proved to be significantly heavier than their Denis Island counterparts that were caught in the following week [adults, Mahe 115.0 ± 3.0 g (SE), $N = 16$, Denis 104.9 ± 2.1 g, $N = 34$, $t_{48} = 2.52$, $P = 0.015$; juveniles, Mahe 110.0 ± 4.8 g, $N = 4$, Denis 92.2 ± 3.8 g, $N = 9$, $t_{11} = 2.70$, $P = 0.021$]. This was reflected in significantly higher body condition scores of Mahe adults ($t_{48} = 2.24$, $P = 0.030$) and juveniles ($t_5 = 2.79$, $P = 0.038$).

3.4.4 Costs

The basic cost of the eradication was estimated to be $US 62 250. Of this, $US 27 600 went on fees and transport for specialist consultants, training and the hunter, and $US 9000 on equipment, with a further $US 16 800 on project management in Seychelles. When overheads (volunteer accommodation and subsistence on the island, administration costs incurred by GIF, etc.) were added, the overall cost was estimated to be $US 156 950.

4 DISCUSSION

The Denis Island project demonstrated the feasibility of eradicating small populations of mynas. The process provided lessons on eradication methodology and planning and also produced new insights into myna biology on small tropical islands.

4.1 Eradication

On Frégate Island, Seychelles, mynas were eradicated using Mini-myna (funnel) traps.[12] These were ineffective on Denis Island, where decoy traps, backed up by shooting, proved to be the most effective eradication method. On North Island (Seychelles), decoy traps were most successful in grassed areas and gardens, but where flocks assembled at an organic waste site funnel traps were more effective (Feare CJ and Larose CS, unpublished). We do not understand the factors underlying these differences, but planning future eradications should take account of this behavioural flexibility.

The prolonged duration of the eradication on Denis Island was due to two factors. Firstly, it lacked adequate management to ensure continuity of funding and of volunteer staff and their training; this resulted in long gaps in the project, during which mynas were able to breed and equipment deteriorated. It might also have contributed to the trap shyness that was suspected towards the end of the eradication. It was only when a much more proactive management structure was put in place that the third phase of trapping and shooting was initiated with the determination to complete the eradication. Secondly, the catch rate was retarded by intensive interference from non-target species, notably Madagascar turtle doves, common moorhens and, in the third phase, free-ranging domestic chickens. Decoy traps were particularly susceptible to this interference because, once a non-target bird was caught, that trap compartment was no longer available to catch a myna.

In the Denis Island eradication the use of volunteer graduate students raised problems of staff recruitment and retention, which contributed to some extent to the long duration of the eradication. Repeated staff changes also raised issues with respect to training. Throughout phases 1 and 2, and during phase three until August 2014, the volunteers were trained by CJF. Thereafter, new incumbents were trained by their immediate predecessors. Inconsistencies discovered in some data recording, e.g. catches of non-targeted fauna, were likely due to inconsistency in training. Employment of more professional and experienced staff for the duration of a myna eradication would have obviated these problems but would have been more expensive.

The eventual success of the third phase of eradication might have been assisted by ecological features pertaining at the time. Although highly adaptable and opportunistic, common mynas are specialised primarily to forage on the ground for surface and subsurface invertebrates.[1] The creation of open grassland, in the form of mown airstrips and lawns around hotels, might contribute to the high densities of mynas on some of Seychelles' smaller islands. During phase 3 of the eradication, the grass of the airstrip margins was left to grow tall to provide grazing for cattle. This practice temporarily deprived mynas of former short-grass feeding areas that had been heavily utilised by them, especially in early morning and late evening (personal observation). In addition, the mynas' main fruit source, papaya, had almost disappeared from the island following killing of trees by an invasive mealy bug in 2015. These two events would certainly have deprived mynas of formerly available food sources.

Although the Denis Island eradication took over 4 years, the duration of the phases of intensive knockdown lasted in total only about 21 months. Half of the initial population was caught within the first 2 months of eradication, and if continuity of the project had been assured throughout, eradication could probably have been achieved within 21 months.

In order to inform proposals to eradicate mynas elsewhere, it is important to record the costs. Our estimates of $US 62 250 basic cost, or $US 156 950 including island overheads, are the first available for a myna eradication. Martins *et al.*[27] provided estimated costings for mammal eradications on islands, but in insufficient detail to know what cost components were included. Within Seychelles, their figures suggest that rodent eradications on three islands cost similar amounts to our basic cost.

4.2 Monitoring

Our pre-eradication myna census produced an estimate much larger than the 300–350 individuals estimated in 2001,[28] but this estimate was not based on a standardised census technique. Initial population size and number of birds killed during the first eradication attempt in 2002 were not accurately known, and the reported surviving population of 40–60 birds[11] did not allow for possible aversion to feeding areas where Starlicide had been presented.[18] The high population estimate in 2010 correlated well with the numbers subsequently killed, highlighting the importance of accurate pre-eradication estimates to guide planning and management of the eradication programme and estimation of likely timeframe and costs.

A common reason for unsuccessful eradications is the failure to detect the last remaining animals[29] or to detect reinvasions by small numbers.[30] Denis Island's post-eradication monitoring has so far failed to discover further mynas. However, incidental observations revealed a decoy that had escaped earlier and was shot, while a second myna was seen on only on two occasions in the same location, and was assumed to have been the same bird. Whether it survived the eradication or was a new arrival, and its fate, are unknown. The closest large populations are ca 50 km distant. Most of the transport to and from the island goes by air, but a supply boat arrives monthly. The presence of a myna on the boat is unlikely to go unnoticed, but boat transfer is a possible pathway for reinvasion. Mynas are normally sedentary[31] but they have been seen at sea 80 km from land.[32] So, although Denis is relatively isolated, there is a risk of reinvasion. In South Africa, where mynas have been introduced,[33] females are the main, more dispersive sex.[34]

The other essential component of monitoring is that of the indigenous fauna that the eradication was aimed to protect. Although full eradication has only recently been achieved, monitoring during and following the recently completed project has already revealed increases in populations of Denis Island's Seychelles magpie robins, Seychelles paradise flycatchers and Seychelles warblers (van der Woude J, Apperloo R and van Marrewijk M, Seychelles warbler population census on Denis Island, August–September 2013, unpublished report, 2013; Aperloo R, van Marrewijk M and van der Woude J, Seychelles magpie robin population assessment on Denis Island, Seychelles, 4/8/2013–26/9/2015, unpublished report, University of Groningen, 2013), and some breeding seabirds might also have benefited.[35]

4.3 Myna biology

Throughout the eradication, the sex ratio of the killed birds remained approximately 1:1. Mynas live in pairs throughout the year, when feeding, resting or preening in daytime and when commuting to and from night roosts,[1,36] and are believed to pair for life.[37] At times, members of a pair were known to have been caught at the same time,[36] but on many occasions it is likely that only one member of a pair was caught. The lack of a skewed sex ratio among trapped birds during all phases of the eradication suggests that the catching method did not favour either sex.

Although incomplete, the seasonal changes in the proportion of young in the population (supporting information Fig. S1) supports the conclusion, from a previous study on moult and gonad size in phases 1 and 2 of the eradication,[26] that the main breeding period is January to March, during the north-west monsoon. However, it seems that limited breeding can occur throughout the year, but the relative success of breeding attempts at different times of year has not been studied. During the drier south-east trade wind season from May to October, aridity is combined with desiccation from the almost constant salt-laden winds, leading to reduction in plant growth and, in some species, defoliation.[38,39] These factors likely influence the abundance of insects and fruit, providing suboptimal conditions for breeding. However, this is the main period of moult, which imposes nutritional demands,[40] and if the foods containing the required nutrients have restricted availability, mynas may have to devote more time, and more energy, to foraging. If this scenario is correct and the birds experience more stress during the south-east trades, this could be the most effective time to undertake eradications: juvenile mortality could be at its highest and recruitment low. Stresses at this time might be augmented if food availability were limited further by interventions, such as restricting the mowing of grassed areas, allowing it to grow to 15–20 cm, which reduces myna foraging, and ensuring that mynas are excluded from feeding areas for domestic stock and from access to organic waste or other sources of food, especially animal protein,[35] associated with human activity.

However, birds had significantly higher body mass in 2015 compared with 2010, especially in females. Two factors might have contributed to this apparently anomalous finding: (1) reduced myna numbers in 2015 might have reduced intraspecific competition for food,[41,42] which could be advantageous for smaller, possibly subordinate, females; (2) provision of bait to attract mynas to specific areas where they could be shot (WC, who processed these birds, noted that some were exceptionally heavy and on dissection they proved to have full gizzards, unlike many birds caught in traps).

The finding that Denis Island mynas had significantly lower body mass and body condition index than birds caught using the same technique on Mahe, a much larger island with greater ecological diversity, could imply that small coralline islands represent poorer habitats for mynas. However, the high densities found on these islands suggest differently and show that this is not the full story. This warrants further study.

5 CONCLUSIONS

Methodology for eradicating rodents from islands is now well established,[43] its development having benefited from decades of research due to their public health and agricultural impacts. Bird eradication methodology lags far behind. Too few bird eradication attempts have so far been successful to provide experience, and attempts on Denis, Frégate and North Islands in Seychelles suggest that myna behaviour and thus the techniques needed to eradicate mynas differ between islands. We clearly need to know much more about the biology of mynas on small tropical islands, especially their population dynamics. The apparent uniqueness of island myna populations in terms of their behaviour in relation to traps, possibly reflecting the species' flexibility in utilising different habitats, poses difficulties in eradication planning.

The durations of the Denis and Frégate Island[12] eradications (ca 21 and ca 8 months respectively) demonstrate that removal of populations of several hundreds of mynas from small islands is feasible. Importantly, it requires a long period of sustained effort with total dedication of island owners and project managers and dedicated, well-trained practitioners. Difficulties of predicting duration pose problems for funding and staffing, both of which require flexible approaches. Duration might be reduced by appropriate environmental management before and during eradications and by timing the initial knockdown to coincide with predictable periods of food shortage for mynas; ways of achieving these warrant investigation. Post-eradication monitoring, education and vigilance of all island staff and maintenance of capacity for rapid action if new incursions are discovered are essential and require open-ended commitment and funding.

Finally, documentation, and its dissemination, of all attempted bird eradications and their successes and failures will help in the formulation of protocols for wider use in future.

ACKNOWLEDGEMENTS

This project was funded by UNDP/GEF as part of the project 'Strengthening Seychelles protected area system through NGO management modalities', and was administered by Green Islands Foundation. We thank former GIF administrator Michelle Etienne for initiating the project. On Denis Island, owners Mickey and Kathy Mason gave the project their full support, and Mr Prasad and his staff provided logistic support to assist with the construction and transport of traps. The Seychelles Police Department granted the firearms permit, without which the final stage of the eradication would have been impossible. Jildou van der Woude's research was funded by a NWO-VICI grant (86503003) awarded to J Komdeur (a grant provided by the Netherlands Organisation for Scientific Research). We are grateful to Janske van de Crommenacker for helpful comments on the manuscript, and to her and Martijn van Dinther for discussion and reports during the writing of the paper. Constructive comments of three reviewers helped to improve the manuscript.

SUPPORTING INFORMATION

Supporting information may be found in the online version of this article.

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