

Management in Practice**Eradication of invasive common mynas *Acridotheres tristis* from North Island, Seychelles, with recommendations for planning eradication attempts elsewhere**

Chris J. Feare^{1,*}, Jeremy Waters², Sarah R. Fenn^{2,3}, Christine S. Larose⁴, Tarryn Retief², Carl Havemann², Per-Arne Ahlen⁵, Claire Waters^{2,6}, Maxine K. Little^{2,7}, Sarah Atkinson^{2,8}, Bethan Searle^{2,9}, Elliot Mokhobo², Arjan de Groene^{10,11} and Wilna Accouche¹⁰

¹WildWings Bird Management, 2 North View Cottages, Grayswood Common, Haslemere, Surrey GU27 2DN, UK

²North Island, Seychelles

³Present address: School of Biological Sciences, Zoology Building, University of Aberdeen, Aberdeen, UK

⁴WildWings Bird Management, Pointe au Sel, Mahe, Seychelles

⁵Swedish Association for Hunting and Wildlife Management, Öster-Malma, Nyköping, Sweden

⁶Present address: Cousin Island, Seychelles

⁷Present address: School of Biological Sciences, The University of Queensland, Brisbane, Australia

⁸Present address: Orkney Native Wildlife Project, H24 Garrison Road, Hatston Industrial Estate, Kirkwall, Orkney Islands, KW15 1PG, UK

⁹RSPB England, Exeter Office, 4th Floor (North Block), Broadwalk House, Southernhay West, Exeter, Devon, EX1 1TS

¹⁰Green Islands Foundation, Victoria, Mahe, Seychelles

¹¹Present address: WWF-NL, Zeist, The Netherlands

Author e-mails: feare_wildwings@msn.com (CJF), waters@gmail.com (JW), purplepostie@hotmail.co.uk (SRF), christine.larose@hotmail.co.uk (CSL), tarrynr@north-island.com (TR), carlh@north-island.com (CH), per-arne.ahlen@jagareforbundet.se (PAA), c.waters123@hotmail.co.uk (CW), maxineklittle@gmail.com (MKL), sarah.atkinson84@yahoo.co.uk (SA), bethan.searle@gmail.com (BS), arjandegroene@gmail.com (AG), gmg@gif.sc (WA)

*Corresponding author

Citation: Feare CJ, Waters J, Fenn SR, Larose CS, Retief T, Havemann C, Ahlen P-A, Waters C, Little MK, Atkinson S, Searle B, Mokhobo E, de Groene A, Accouche W (2021) Eradication of invasive common mynas *Acridotheres tristis* from North Island, Seychelles, with recommendations for planning eradication attempts elsewhere. *Management of Biological Invasions* 12(3): 700–715, <https://doi.org/10.3391/mbi.2021.12.3.12>

Received: 4 October 2020

Accepted: 10 February 2021

Published: 17 May 2021

Handling editor: Luis Reino

Thematic editor: Catherine Jarnevig

Copyright: © Feare et al.

This is an open access article distributed under terms of the Creative Commons Attribution License (Attribution 4.0 International - CC BY 4.0).

OPEN ACCESS**Abstract**

Introduced common mynas (*Acridotheres tristis*) can negatively impact native wildlife throughout the mynas' non-indigenous range, and in Seychelles myna eradication attempts have been attempted on some smaller islands to protect endemic and indigenous fauna. Initial attempts, relying on a quick knock-down of the population using toxicants, failed. Here we describe an eradication on North Island, Seychelles, that was accomplished by trapping, supported by shooting in the final stages. This eradication attempt was ultimately successful but took place in two stages spanning seven years and involved removing 1641 birds. During the second, successful, stage, morphometric data collected from caught mynas provided pointers to optimum times during the mynas' annual cycle to target control activities. During both stages the trapping of non-target species interfered with the capture of mynas. The six main conclusions from this eradication are (i) eradication of mynas from small islands is feasible and achievable by trapping and shooting, without recourse to the use of toxicants; (ii) provision of adequate resources for the life of an eradication attempt, especially ensuring continuity of funding and staffing, is essential for the efficient removal of the whole population; (iii) knowledge of myna phenology can be used to target the optimal timing of an eradication attempt, (iv) post eradication, vigilance and capacity for immediate action must be maintained to remove any immigrant mynas, (v) further research on trap design is needed to minimise the capture of non-target species, and (vi) introduced endemic bird populations should be monitored to assess their responses to myna removal.

Key words: introduced birds, invasive species, eradication methodology, seasonal vulnerability, island rehabilitation, economics

Introduction

Remote oceanic islands have historically provided opportunities for biota that reached them to evolve in environments different from those on the continents where they originated (e.g. Ashmole and Ashmole 2000; Steadman 2006; Cheke and Hume 2008). Divergence from the original stock was also facilitated by reduced species richness on isolated islands (MacArthur and Wilson 1967). Genetic drift and new selection pressures (Clegg 2010) led colonisers to follow new evolutionary pathways, leading to high degrees of endemism (Kier et al. 2009). Some of the evolved traits, such as lack of wariness of novel situations, and for birds the extreme condition of flightlessness (Sayol et al. 2020), rendered island endemics vulnerable to human activities, including the deliberate or accidental introduction of alien invasive species. This has exposed many small island endemics to levels of competition and predation to which they were not adapted (Duncan and Blackburn 2007). These have led to population declines and extinctions, with direct human predation and introduction of alien invasive species (especially mammalian) as significant causative agents.

BirdLife International (2020) estimates that 75% of extant island endemic birds are threatened by invasive species, compared with only 13% on continental land masses. These serious impacts of invasive species have led to requirements for interventions, with some alien bird species among the targets where sufficient evidence of adverse impacts has accrued (e.g. Veitch et al. 2019).

Human settlement of Seychelles in the late 1700s in tandem with invasive species introductions led to major ecological changes on most islands, and island extinctions and range contractions of some of the archipelago's endemic birds ensued (Stoddart 1984). Recognising the ongoing threat to some of Seychelles' endemic taxa, conservation organisations, island owners and government agencies commenced rehabilitation projects on some smaller islands from the late 1960s onwards (Feare 2017). Rehabilitation has included replacement of exotic vegetation with indigenous flora and eradication of invasive mammals (Rocamora and Henriette 2015). These projects aimed primarily to safeguard surviving populations, and later to establish insurance populations of some of the most threatened endemic birds on islands with restored habitats (Richardson et al. 2006; Rocamora and Henriette-Payet 2008; Burt et al. 2016).

Introduced invasive bird species included common mynas *Acridotheres tristis* (Linnaeus, 1766) (hereafter “mynas”). They are native to south-east Asia but were widely introduced to tropical islands in the expectation of controlling insect pests (Feare and Craig 1998). Where mynas are indigenous they are commensal with humans and introduced birds readily adapt to human-modified habitats in their new environments (Blackburn et al. 2009). On small islands, however, human settlements are inevitably close

to less disturbed areas that might support remnant endemic bird populations, putting the endemics at risk. Mynas are recognised as a major threat to endemic and indigenous birds through predation of eggs and chicks, disturbance to and injury of breeding adults, and food and nest site competition (Komdeur 1996; van der Woude and Wolfs 2009; Feare et al. 2015; Hughes et al. 2017). Several attempts have been made to eradicate mynas from some small Seychelles islands (< 200 ha, with estimated populations of *ca.* 750–1000 mynas) using toxicants applied to rice or bread bait to quickly reduce numbers (Millett et al. 2004; Rocamora and Henriette 2015), but this approach failed and was not followed by alternative methods. Opportunistic shooting on Frégate (Millett et al. 2004) and North Island (G. Wepener *unpublished*) was insufficient to achieve eradication. More recently, trapping has proved more effective in reducing myna numbers but the efficacy of different trapping techniques varied between islands or habitats (Canning 2011; Feare et al. 2016).

North Island (201 ha, 4°23'S; 55°14'E) is privately-owned and managed as a high-end tourism resort with strong conservation interests. Black rats *Rattus rattus* (Linnaeus, 1758) and cats *Felis catus* Linnaeus, 1758 (Rocamora and Henriette 2015) and domestic farm animals (recommended by Hill et al. 2002) were removed from the island between 2003 and 2005, and the initiation of a vegetation rehabilitation programme was begun in 2002. In 2012 island conservation staff decided that a concerted effort should be made to eradicate the breeding population of mynas, estimated to have been *ca.* 890 birds (Rocamora and Henriette 2015). The longer-term aim of these initiatives was to provide suitable habitat for the (re)introduction of some of Seychelles' endangered endemic bird species. Seychelles white-eyes *Zosterops modesta* E. Newton 1867 had already been introduced in 2007, despite the presence of mynas (Rocamora and Henriette-Payet 2008).

Here we document the eradication of mynas from North Island as part of a broader island rehabilitation project coordinated by Seychelles NGO Green Islands Foundation (GIF). We identify problems that must be confronted prior to the initiation of similar eradications, including lack of continuity of trapping effort and interference through the capture of non-target species. We also used this opportunity to (i) investigate habitat differences in trap efficiency, (ii) examine seasonal variation in body condition and (iii) identify times of year that might optimise trapping in relation to breeding and moult.

Materials and methods

Eradication techniques

The primary method used to capture mynas was live trapping, mainly decoy-trapping. Apart from small numbers that were retained for subsequent use as decoys, trapped birds were humanely euthanised by cervical dislocation



Figure 1. A decoy trap with a decoy myna in the central decoy compartment, three birds captured in outer catching compartments and two mynas attracted to the trap vicinity (Arjan de Groene/GIF).

soon after capture (Feare et al. 2016). In the later stages, when trapping efficiency declined, shooting was introduced.

We made no attempts to locate nests in order to destroy them, along with eggs and chicks. Favoured nest sites in Seychelles are in the crowns of coconut trees (*personal observations*) and are very difficult to access for control. During his successful eradication of mynas on Frégate Island, Canning (2011) only destroyed nests and their contents when these had been built in nest boxes erected for endangered Seychelles magpie robins *Copsychus sechellarum* A. Newton, 1865, which contributed little to the eradication. So far, nest boxes have not been erected on North Island.

Twenty decoy traps, made of 50 mm × 25 mm wire mesh, were deployed. Four catching compartments surrounded a central compartment that housed a live decoy myna (Figure 1, Feare et al. 2016). Each catching compartment had an entry aperture measuring *ca.* 8 cm × 8 cm which was closed by a drop-door triggered by an entering bird. Three birds caught in a mist net along with the first mynas to be trapped were retained as decoys for future trapping. Decoys were provided with food (restaurant waste, primarily boiled rice with fish and meat) and water twice daily and a small amount of food was placed in the catching compartments as bait. The traps were placed on the ground in most of the island's habitats where mynas fed: grassland, marsh, coconut and broadleaved woodland, beach crest vegetation, and organic waste disposal sites. When catch rates declined or when birds changed preferred feeding areas, traps were moved (usually within 2–4 days) to target places where mynas were observed feeding. In addition, other traps trialled were: four commercially made “Mini Myna Magnet” traps

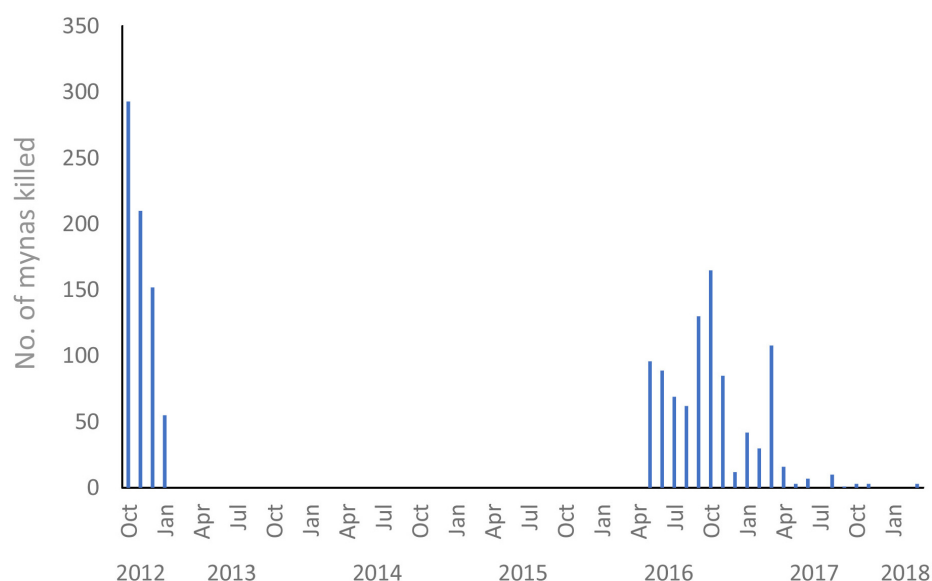


Figure 2. Number of mynas euthanised/month during the eradication on North Island, Seychelles. Phase 1, October 2012–January 2013; Phase 2, May 2016–March 2018.

(www.pestit.com.au); three small home-made walk-in traps; a ladder trap (a wooden-framed wire mesh cage *ca.* 2 m × 1.5 m × 1.5 m, with V-shaped roof and ladder-type openings at the base of the V); and a 4 m × 3 m wooden-framed drop-trap built to cover pits at the organic waste site and operated by an observer hidden *ca.* 30 m away with a pull release.

The eradication took place in two phases (Figure 2):

Phase 1. On 5 October 2012, the decoy and Mini Myna Magnet traps were deployed and baited until 9 January 2013, when island staff designated to undertake the eradication did not have the time required to maintain trapping operations.

Phase 2. New administration within GIF and new environment management staff on North island facilitated the recruitment of dedicated eradication staff, mainly graduate volunteers, who were employed on 6-month contracts. GIF ensure continuity of staffing and decoy trapping resumed on 13 May 2016 (the Mini Myna Magnet traps were no longer serviceable). Decoy traps were the main technique used until 24 March 2017, when falling catches (Figure 2) led to the initiation of intensive shooting by two professional hunters. Most birds were killed using a silenced .22 rifle with subsonic hollowpoint ammunition, but a .25 air rifle and 12-gauge shotgun were also used. This continued until 3 April 2017 and was followed by more opportunistic shooting by island staff (trained by the marksman) using the .25 air rifle. Decoy trapping continued throughout the shooting until what was believed to be the last bird was killed on 10 February 2019.

Two constraints to the project had to be addressed, relating to non-target species entering traps and the risk of mynas habituating to shooting.

All captures of non-target birds, apart from Madagascar fodies *Foudia madagascariensis* (which were small enough to enter and escape through the trap mesh), resulted in the closure of a trap door and thereby limited myna access to the traps. Most snail and crab captures similarly closed trap doors. The larger non-target birds additionally risked damaging the trap mechanism, especially Madagascar turtle doves *Nesoenas picturatus* (Temminck, 1813) and common moorhens *Gallinula chloropus* (Linnaeus, 1758). Even the presence of one of these species in a trap deterred entry by a myna (S.R. Fenn and B. Searle *unpublished*). Madagascar turtle doves are non-native to Seychelles and are not protected, while common moorhens are indigenous and protected under Seychelles legislation. During Phase 2 some trapped individuals of both species were individually marked by clipping remiges and/or rectrices, revealing that these individuals repeatedly re-entered traps. Subsequently, Madagascar turtle doves were humanely dispatched, but moorhens and the other bird species and invertebrates were released.

Most shooting was done from golf buggies, the main mode of transport on the island. To avoid mynas associating the buggies with shooting activities, the hunters used their buggies as a “taxi” service to island staff so that much of their use on the island was not shooting-related.

Data collection

During both Phases, the daily number of mynas trapped (and shot in Phase 2) were recorded. Breeding and the annual moult involve elevated energy and nutrient demands (e.g. Freed and Cann 2012) and thus might increase the attraction of bait in traps to mynas. To procure more precise information on the timing of these events for mynas in Seychelles, the ages (adult or juvenile as per Feare et al. 2016) of trapped birds were recorded to identify when most juveniles entered the population. Morphometric data collected included body mass (Pesola balance) and head-bill length (Vernier calliper), from which an index of body condition was derived (body mass/head + bill length) (Gosler et al. 1998). Primary moult score (Ginn and Melville 1983) was recorded to identify the main period of annual moult. Sex was determined by dissection. Breeding status of adult males was assessed by measuring left testis length (mm), and ovarian development in adult females was coded as 1, ovary small with indistinguishable follicles; 2, follicles visible but < 1 mm diameter; 3, follicles < 5 mm diameter; 4, one or more follicles > 5 mm.

During Phase 1, data were recorded from the start of trapping on 5 October until 12 December 2002; thereafter data collection ceased as island staff were diverted to non-eradication duties. Data were collected throughout Phase 2.

Non-target species

The number of non-target captures in the decoy traps was recorded during Phase 2.

Table 1. The number of mynas euthanised during the two phases of the eradication, broken down by capture method and age (adult or juvenile).

Phase	Age class	Method					Total
		Decoy	Mini Myna	Drop	Other*	Shot	
Phase 1	Adult	433	220	–	28	–	681
	Juvenile	6	3	–	4	–	13
	Not aged	2	0	–	10	–	12
	Total	441	223	–	42	–	706
Phase 2	Adult	683	–	30	1	87	801
	Juvenile	96	–	1	3	16	116
	Not aged	3	–	4	5	6	18
	Total	782	–	35	9	109	935

* “Other” includes birds caught by hand (trapped inside buildings or unhealthy), caught in a mist net or in other trap types trialled for a short time.

Post-eradication vigilance

As North Island lies only 7 km from much larger Silhouette Island (*ca.* 1995 ha), which supports a large myna population (Greig-Smith 1986), there is a risk of re-colonisation. Post eradication, 12 months of intensive searches for sightings or vocalisations of mynas were undertaken. This involved one of the original myna eradication staff or a trained observer walking regular tracks throughout the island searching for any signs of mynas. Between two and six island walks per week were undertaken during four periods of the day (dawn, before 0700 h; morning, 0700–1200 h; afternoon, 1200–1630 h; and evening, after 1630 h). In addition, island maintenance and hotel staff were instructed to report any possible sightings of mynas.

Cost

The financial outlay of the eradication process in 2012–2013, and from 2015 to 2019, were recorded by Green Islands Foundation. This covered staff and international travel, equipment, and accommodation and subsistence costs for volunteers.

Results and discussion

Number of mynas trapped/shot

During Phase 1, 706 mynas were euthanised during the 3.5 months of the eradication attempt. During Phase 2, 935 mynas were euthanised or shot during the 34 months of trapping and shooting (Figure 2, Table 1).

In both phases, trapping accounted for the majority of captures, but the efficacy of the main traps used differed between habitats (Table 1). In Phase 1, the four Mini Myna Magnet traps failed to catch mynas in grassland, beach crest vegetation, woodland habitats or among hotel or workers’ accommodation. However, they did catch where mynas concentrated in foraging flocks at the organic waste site, where organic waste from the hotel and workers’ restaurants was deposited daily in pits dug in the sand. At this site, the drop-trap successfully caught mynas in October 2016.

Table 2. Percentage of females with oocytes with diameter > 1mm during Phase 2, from May 2016 to April 2017. n = the total number of females whose ovary was assessed each month.

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
% Oocyte >1	0	0	0	0	0	2.5	19.1	0	18.2	0	20.1	0
n	38	35	38	35	68	79	47	2	11	1	39	0

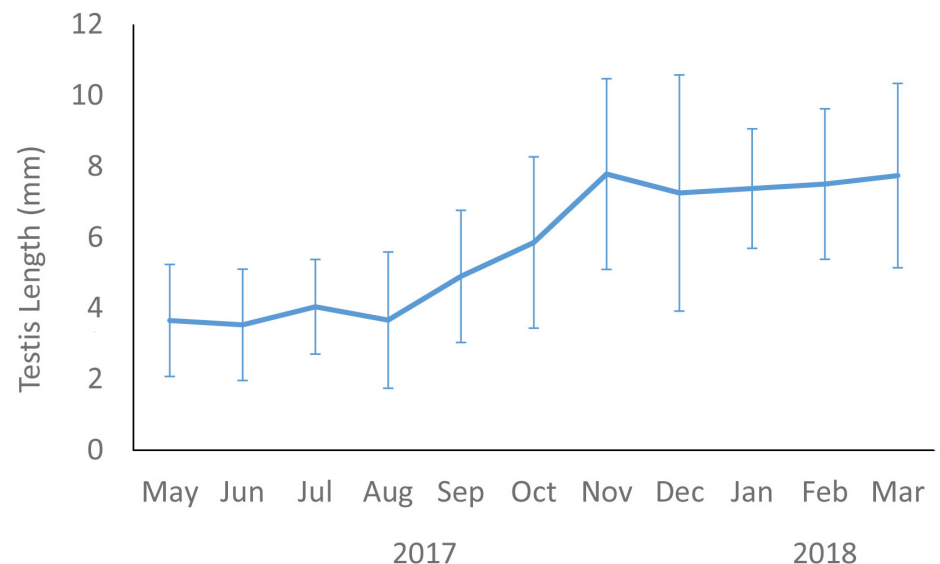


Figure 3. Monthly mean (\pm standard deviation) testis length in male mynas trapped or shot in Phase 2, from May 2016 to March 2017.

Table 3. The percentage of juvenile mynas in monthly catches during Phase 2 from May 2016 to April 2017. n = number of individuals aged.

	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
% juvenile	13.5	6.7	1.4	1.6	2.3	4.2	2.3	0.8	55.8	80.6	23.5	25.0
n	96	90	70	63	131	166	86	12	43	31	101	16

During both phases of the eradication, catches of adults greatly outnumbered those of juveniles (Table 1). Phase 1 coincided with a breeding season but data collection ended before most juveniles would have fledged (see below), whereas Phase 2 extended over a complete myna annual life-cycle.

Annual cycle of mynas on North Island

The duration of data collection in Phase 1 was too short to provide information on seasonal trends in breeding state or body condition.

In Phase 2, females were found with enlarged oocytes (> 1 mm) in October, November, January and March; sample sizes in December and February were too small to assess breeding status (Table 2).

Males with large testes (> 6 mm) were recorded in all months, suggesting some reproductive capacity year-round, but mean testis length increased from its lowest level in May–August to its highest from November to March (Figure 3).

The proportion of juveniles in the euthanised samples rose sharply in January, peaked in February and declined thereafter (Table 3). By deduction, nest-building, laying, incubation and chick rearing will have occurred mainly

Table 4. Mean indices of body condition, standard deviation (Stdev) and sample size (n), for mynas trapped or shot between May 2016 and April 2017.

Sex	Month	M	J	J	A	S	O	N	D	J	F	M	A
Female	Mean	1.92	1.86	1.89	1.82	1.85	1.86	1.86	1.66	1.64	1.97	2.04	–
	Stdev	0.16	0.12	0.16	0.19	0.11	0.14	0.16	0.16	0.14	–	0.18	–
	n	38	35	38	35	68	79	47	2	11	1	39	0
Male	Mean	1.99	2.00	2.01	1.95	1.95	1.98	1.97	1.69	1.78	1.70	2.20	2.12
	Stdev	0.19	0.18	0.18	0.24	0.15	0.16	0.15	0.19	0.21	0.51	0.21	0.20
	n	35	30	24	27	59	78	37	8	8	2	23	8

Table 5. The number of non-target species caught in decoy traps throughout Phase 2 of the eradication: Madagascar turtle dove (MTD), common moorhen (CM), Madagascar fody (MF), barred ground dove *Geopelia striata* (Linnaeus, 1766) (BGD), green-backed heron *Butorides striatus* (Linnaeus, 1758) (GBH), ruddy turnstone *Arenaria interpres* (Linnaeus, 1758) (RT), Eurasian whimbrel *Numenius phaeopus* (Linnaeus, 1758) (EW), land snail *Achatina fulica* (Ferussac, 1821) (LS), hermit crab *Coenobita* Latreille, 1829 sp. (HC), land crab *Ocypode* Weber, 1795 sp. (LC).

Species	MTD	BGD	CM	GBH	RT	EW	MF	LS	HC	LC
n	1237	3158	3595	13	32	1	9	690	24	50

through November–January (supported by direct observations of main nest building activity in November–December).

Primary moult was first detected in samples euthanised in March. Most individuals of both sexes were actively replacing remiges from May to July, with the majority having completed moult by August.

In both Phases, and across all months of Phase 2, the mean body mass of adult males was consistently greater than that of adult females; (Phase 1, females $98.79 \text{ g} \pm 12.48 \text{ [sd]}$, males $106.73 \text{ g} \pm 10.03$, $t_{490} = 7.75$, $p < 0.01$; Phase 2, females $101.86 \text{ g} \pm 9.38$; males $110.76 \text{ g} \pm 11.38$, $t_{717} = 11.48$, $p < 0.01$).

Likewise, the body condition index of adult males was consistently greater than that of females (Table 4), (Phase 1, females $1.83 \pm 0.23 \text{ [sd]}$, males 1.92 ± 0.17 , $t_{492} = 5.08$, $p < 0.001$; Phase 2, females $1.87 \pm 0.16 \text{ [sd]}$, males 1.98 ± 0.20 , $t_{730} = 7.80$, $p < 0.001$).

From the gonad and moult data we identified three stages of the annual cycle: pre-breeding (September–October), breeding (November–February) and moult (May–August). Body condition indices did not differ significantly between pre-breeding and breeding stages, or between pre-breeding and moult, but in both sexes body condition index was higher during moult than during breeding (females, breeding 1.82 ± 0.18 , moult 1.88 ± 0.16 , $t_{205} = 2.34$, $p = 0.02$; males, breeding 1.89 ± 0.21 , moult 1.99 ± 0.16 , $t_{169} = 2.86$, $p = 0.005$).

Non target species caught during trapping

In Phase 2, between 13 May 2016 and 18 March 2018, there were 8809 non-target animal captures in the decoy traps (Table 5).

Post-eradication monitoring

On 29 June 2019, four months after the intensive monitoring began, a myna was seen by a staff member. This bird was unwary and was shot and

Table 6. Estimated costs (US\$) of the two phases of the myna eradication.

Item	Phase 1 (2012–2013)	Phase 2 (2015–2019)
Equipment	33,200	7,700
Consultant fees + travel	10,250	43,500
Volunteer accommodation, subsistence, boat travel, admin.	4,750	16,400
Project management	5,000	14,800
Total	53,200	82,400

killed on 11 July from a hide erected for the purpose. There have been no other reported occurrences of mynas on the island since then.

Cost

The combined cost of the two eradication phases came to an estimated US\$ 135,600 (Table 6). Costs for Phase 1 are however likely to be an underestimate, as the time spent by island staff on myna-related activities was not calculated, and project management was undertaken as part of a wider Protected Areas project. Equipment included purchase of traps/trap-building materials and tools. Project management by Green Islands Foundation included staff time for budget procurement, cost monitoring, volunteer and hunter recruitment, negotiation for firearms permissions and liaison with island management.

Discussion

The eradication of mynas from North Island marks the third successful eradication of mynas from small islands in Seychelles, following those on Frégate (Canning 2011) and Denis (Feare et al. 2016). However, like the Denis eradication, the North Island eradication suffered from inadequate resourcing at the outset. During planning of the attempt, C. Feare (CF) and C. Larose (CL) had emphasised that two dedicated staff would need to be trained and maintain necessary trapping intensity, but at the initiation of training, two existing island staff had been allocated part-time, with hotel guest duties taking priority. It soon became apparent that these island staff could not manage their workload and that the trainers (CF and CL) were doing the bulk of the work. After the trainers' departure from the island on 4 November 2012, weekly reports showed that the number of mynas caught dropped rapidly (Figure 2) and in mid-January island staff were removed from trapping duties. No further staff were recruited and this phase of the eradication attempt was abandoned.

Following management changes in Green Islands Foundation and on North Island, the eradication attempt resumed in 2016, leading to the success of the eradication seven years after the initiation. In total, 1641 mynas were killed on North Island. However, without the break in the eradication, fewer birds would have to have been killed, and the cost of the eradication would have been lower. The myna population was not censused before control began in 2012, but the three breeding seasons that

elapsed before the start of Phase 2 most likely allowed some population recovery. If Phase 2 is considered as an independent eradication, an overall cost of c. US\$ 85,000 (Table 6) may be realistic for a *ca.* 200 ha island supporting *ca.* 1000 mynas (some of the equipment procured for Phase 1 was used in Phase 2). This cost is based on the use of volunteers to undertake most of the trapping, however, and allowance for additional labour costs must be made in the absence of volunteer availability when planning future eradications.

The Frigate, Denis and North Island eradications demonstrate that eradication of mynas from small islands can be achieved without attempting to catch adults at nests or destroy clutches; these time-consuming procedures contribute little to eradication attempts (Millett et al. 2004; Canning 2011). Additionally, success on these islands has shown that the use of toxicants, which have potential adverse environmental risks and whose contribution to eradication is difficult to quantify (Feare 2010), was unnecessary. On larger islands with small human populations, toxicants might help to accelerate eradication (G. McCormack *pers. comm.* on Atiu, Cook Islands), but further information on non-target risks on tropical islands is needed.

The gonad cycle on North Island confirmed that breeding was concentrated during the wetter north-west monsoon, November–March, with moult during May–August. Body condition during breeding was significantly lower than during moult, possibly associated with the higher energy and nutrient demands of breeding (Norberg 1981). Nevertheless, the annual moult imposes further nutritional demands (Lindström et al. 1993) during the dryer season when invertebrate foods, representing a source of essential animal protein (Machovsky-Capuska et al. 2015), are less abundant (Hill et al. 2002). This potential limitation of dietary protein was not reflected in a reduced body condition, however, suggesting that our simple index is inadequate for indicating stressors that might impact susceptibility to trapping where food baits are used. In planning future myna eradications, commencement early in the breeding season and continuation through to moult completion might offer the optimal trapping efficiency through attraction to baited decoy traps, as both life stages involve elevated energy/nutrient demands.

On North Island, the breeding and moult periods were identified by examination of birds trapped or shot. When planning future eradications in other parts of the world where less knowledge of myna annual cycles is known, a simpler method of identifying these events could be used. The onset of the breeding season is characterised by many birds visiting potential nest cavities and the carrying of nest material; both of these are conspicuous behaviours. Following the breeding season, birds in active wing moult can be identified when flying overhead by a conspicuous gap in the trailing edge of the open wing, where an old feather has been lost and has yet to be replaced by the growth of a new feather. Where an eradication

attempt is deemed necessary, local conservation staff could be asked to report nest-building and moult prior to the planning of the eradication in order to determine the timing of these life stages.

During moult, in addition to increased energy and nutrient requirements (Lindström et al. 1993), birds experience flight impairment due to missing wing feathers and tend to reduce activity, including vocalisation, likely as a response to increased vulnerability to predation (Barta et al. 2006). This general low-profile during moult can lead to increased wariness and a reluctance to take flight (Rivera et al. 1998; observed but not quantified in mynas in Seychelles, CF and CL *pers. obs.*), but once a myna has been located, its reticence to move might render it easier to shoot. On this basis, commencement of an eradication with intensive trapping at the start of the breeding season, accompanied by shooting during the annual moult, might be a more efficient and economic approach than control at other times during the annual cycle.

The capture of non-target species, especially Madagascar turtle doves and common moorhens, constrained and possibly prolonged the decoy trapping programmes. Both species are common on Seychelles' smaller rat-free islands and are likely to interfere with myna eradication attempts on similar islands in the archipelago. Although larger than mynas, these species are capable of squeezing through the entrances designed for mynas. Trials of decoy traps with entry apertures of different sizes are needed to determine whether smaller entrances could mitigate non-target catch without compromising catches of mynas.

Shooting was delayed until as late as possible due to aversion that mynas can develop to people with weapons (Fox and Madsen 1997), but we cannot predict at what stage in a myna eradication shooting should be introduced. We do not know whether "trap shyness" is inherent in some individuals in a myna population or whether aversion to trapping is a trait learned during the course of a trapping programme. Although the Frigate eradication was achieved without resort to shooting (Canning 2011), on North and Denis Islands most of the birds that failed to be caught during the trapping stage were relatively quickly shot by professional hunters with a sound knowledge of bird behaviour. Necessary authorisations should thus be sought during the earliest stages of planning an eradication. Seeking permissions from government departments and police for the import and use of firearms, including rifle, air rifle and shotgun, can be prolonged (years rather than months) and time-consuming.

Most small islands in the Seychelles archipelago are within *ca.* 50 km of islands that support large numbers of mynas and are thus potential sources of immigrants. We do not yet know when or how far mynas will fly over sea. All three islands from which mynas were eradicated have had single incidents of immigration. On Frigate, a group of 14 birds was discovered in August 2015 (nearest possible source 25 km); seven of these birds were

shot, one remained on the island until at least October 2016, but the other six disappeared (J. van de Crommenacker *pers. comm.*). On Denis Island (nearest source 52 km) a group of three birds were discovered in May 2018; all were subsequently shot. One bird found on North Island (nearest source 7 km) in June 2019 was shot. These occurrences highlight the necessity to maintain vigilance for reinvasion, and the tools and staff to facilitate immediate removal of new arrivals.

Myna eradications were undertaken primarily to benefit the conservation status of endemic taxa, especially endangered birds (see Evans 2021). These eradications have enabled existing endemic species populations to recover (Frégate) and provided suitable habitats into which endemic species can be introduced to establish insurance populations (Denis and North). In these objectives the myna eradications, all preceded by the removal of rats and cats and by on-going habitat rehabilitation/creation, have been highly successful. Frégate's population of Seychelles magpie robins increased from its nadir in the 1960s of *ca.* 12 birds (then the total world population) following mammal eradications and habitat improvement. However, myna eradication (Canning 2011) led to a more rapid increase, with the island's population reaching over 130 birds by 2015. The population of magpie robins on Frégate is now used to (re)populate other islands in Seychelles (Burt et al. 2016). On Denis, four species of endemic birds, Seychelles warbler *Acrocephalus sechellensis* (Oustalet, 1877), Seychelles fody *Foudia sechellarum* E. Newton, 1867, Seychelles magpie robin and Seychelles paradise flycatcher *Terpsiphone corvina* (E. Newton, 1967) were released on the island in 2004 and 2008 and populations of all have increased (Bristol and Gamatis 2017; Bristol and Accouche 2019; Doblas et al. 2015; van de Crommenacker and van Dinther 2015). Monitoring of endemic bird responses to myna removal continues on these islands.

On North Island, Seychelles white-eyes were introduced in 2007, despite the presence of mynas, and underwent a slow but steady increase up to 2014 when the population appeared to have stabilised at this level. Subsequently, a rapid population increase coincided with removal of most of the mynas (Pietersen 2017). Now that mynas have been eradicated, proposals to introduce more endemic bird species are under way, to further increase the security of Seychelles' endemic avifauna. Following myna eradication, monitoring of the responses of endemic bird populations will provide valuable information for decision makers contemplating invasive bird eradications where these are considered to pose threats of predation and disturbance.

Having confirmed that the combination of trapping and shooting can be efficient means of eradicating mynas from small islands with few people (< 150), trials are now needed to determine the feasibility and efficiency of scaling up this approach to tackle myna populations on larger islands, and islands with more people. One successful eradication has been achieved,

over a period of c. 9 years, on 2,900-ha Atiu island (Cook Islands, south Pacific). There, *ca.* 26,000 mynas were killed by trapping, shooting and using a toxicant (Lieberman et al. 2018, G. McCormack *pers. comm.*) but Atiu has only limited human occupation. In all cases it will be essential to ensure the full support of the human population to avoid interference with traps, both by people and domestic animals. Additionally, high human density raises safety issues regarding shooting, although on Mahe, Seychelles (*ca.* 15,700 ha, human population *ca.* 90,000) ring-necked parakeets *Psittacula krameri* (Scopoli, 1769) were eradicated almost entirely by shooting (Bunbury et al. 2019). Limited experience suggests that other capture techniques, such as intensive mist-netting, can be more effective with some species in some circumstances (Bunbury et al. 2019). The trapping and shooting approach adopted for mynas is thus unlikely to be applicable to all other invasive bird species, and prior investigation is needed to establish the techniques most appropriate for each species and the environment that the invasive species inhabits.

Acknowledgements

The myna eradication project received wide support from a number of sources. Initiation and administration for Phase I was provided by Linda Vanherck, North Island conservation officer and Markus Ultsh-Unrath of Green Islands Foundation. North Island Company Ltd. provided logistical support, including accommodation, meals and boat transfers to consultants, staff and volunteers. In addition to the volunteers among the co-authors, Jennifer Appoo, Patricia A. Gonzalez, Terence Mahoune, Ellie Moulinie, Alusia Malinowska, Rebekah Mulder, Krystal d'Offay, Dillys Pouponeau and Lynsey Rimbault, provided voluntary assistance for short periods. Mikael Paavola and Pete Haverson, professional hunters, visited North Island at different times during the project to shoot mynas and also remained involved in providing advice to staff working on the project. North Island management and staff remained committed to the project by providing oversight to the volunteers and remained on the look-out for mynas. We are grateful to Anna Zora for information on the myna reinvansion of Frégate Island in 2016, and to Gerald McCormack for providing details of the myna eradication process on Atiu Island. We are also grateful to two reviewers for their valuable comments on the manuscript.

Funding declaration

The project was funded from 2012 to 2015 by the Government of Seychelles-UNDP-GEF “Strengthening Seychelles’ protected area system through NGO management modalities” project. From 2016 The myna eradication project was funded by North Island, and Green Islands Foundation through the CSR tax paid by North Island. During the baiting period, Thai Union company kindly donated canned tuna to the project. Finally, we are grateful to the Swedish Association for Hunting and Wildlife Management for covering publication costs.

Ethics statement

The eradication of common mynas from North Island was a component of the North Island Environmental Management Plans 2011–2015 and 2016–2020 and was approved in its entirety by the Seychelles Ministry of Environment, Energy and Climate Change.

References

- Ashmole P, Ashmole M (2000) St Helena and Ascension Island: a natural history. Anthony Nelson, Oswestry, 475 pp
- Barta Z, Houston AI, McNamara JM, Welham RK, Hedenström A, Weber T, Fero O (2006) Annual routines of non-migratory birds: optimal moult strategies. *Oikos* 112: 580–593, <https://doi.org/10.1111/j.0030-1299.2006.14240.x>
- BirdLife International (2020) The state of the world’s birds. https://www.birdlife.org/sites/default/files/attachments/BL_ReportENG_V11_spreads.pdf (accessed 23 December 2020)

- Blackburn TM, Lockwood JL, Cassey, P (2009) Avian invasions. Oxford University Press, Oxford, 305 pp, <https://doi.org/10.1093/acprof:oso/9780199232543.001.1>
- Bristol RM, Accouche W (2019) Seychelles Magpie Robin population census and ringing of unringed individuals on Denis Island, December 2018. Report to Seychelles Magpie Robin Recovery Team, Mahe, Seychelles, 13 pp
- Bristol RM, Gamatis I (2017) Seychelles paradise flycatcher population census on Denis Island, June 2017. Report to Green Islands Foundation, Mahe, Seychelles, 5 pp
- Bunbury N, Haverson P, Page N, Agricole J, Angell G, Banville P, Constance A, Friedlander J, Leite L, Mahoune T, Melton-Durup E, Moumou J, Raines K, van de Crommenacker J, Fleischer-Dogley F (2019) Five eradications, three species, three islands: overview, insights and recommendations from invasive bird eradications in the Seychelles. In: Veitch CR, Clout MN, Martin AR, Russell JC, West CJ (eds), Island invasives: scaling up to meet the challenge. Occasional Paper SSC no. 62. Gland, Switzerland: IUCN, pp 282–288
- Burt AJ, Gane J, Olivier I, Calabrese L, de Groene A, Liebrick T, Marx D, Shah N (2016) The history, status and trends of the Endangered Seychelles Magpie-robin *Copsychus sechellarum*. *Bird Conservation International* 26: 505–523, <https://doi.org/10.1017/S0959270915000404>
- Canning G (2011) Eradication of the invasive common myna, *Acridotheres tristis*, from Frégate Island, Seychelles. *Phelsuma* 19: 43–53
- Cheke A, Hume J (2008) Lost land of the Dodo. Poyser, London, 464 pp
- Clegg S (2010) Evolutionary changes following island colonization by birds. In: Losos JB, Ricklefs RE (eds), The theory of island biogeography revisited. Princeton University Press, Princeton, NJ, 476 pp
- Doblas LL, McClelland S, van der Woude J, van de Crommenacker J (2015) Seychelles warbler population census on Denis Island: August - October 2015. Report to Green Islands Foundation, Mahe, Seychelles, 14 pp
- Duncan RP, Blackburn TM (2007) Causes of extinction of island birds. *Animal Conservation* 10: 149–150, <https://doi.org/10.1111/j.1469-1795.2007.00110.x>
- Evans T (2021) Quantifying the global threat to native birds from predation by alien birds on small islands. *Conservation Biology*, <https://doi.org/10.1111/cobi.13697>
- Feare CJ (2010) The use of Starlicide® in preliminary trials to control invasive common myna *Acridotheres tristis* populations on St Helena and Ascension islands, Atlantic Ocean. *Conservation Evidence* 7: 52–61
- Feare C (2017) Orange omelettes and dusky wanderers. Calusa Bay Publications, Seychelles, 326 pp
- Feare C, Craig A (1998) Starlings and mynas. Helm, London, 285 pp
- Feare CJ, Lebarbenchon C, Dietrich M, Larose CS (2015) Predation of seabird eggs by common mynas *Acridotheres tristis* on Bird Island, Seychelles, and broader implications. *Bulletin of the African Bird Club* 22: 162–170
- Feare CJ, van der Woude J, Greenwell P, Edwards H, Taylor JA, Larose CS, Ahlen P-A, West J, Chadwick W, Pandey S, Raines K, Garcia F, Komdeur J, de Groene A (2016) Eradication of common mynas from Denis Island, Seychelles. *Pest Management Science* 73: 295–304, <https://doi.org/10.1002/ps.4263>
- Fox AD, Madsen J (1997) Behavioural and distributional effects of hunting disturbance on waterbirds in Europe: implications for refuge design. *Journal of Applied Ecology* 34: 1–13, <https://doi.org/10.2307/2404842>
- Freed LA, Cann, RL (2012) Changes in timing, duration, and symmetry of molt of Hawaiian forest birds. *PLoS ONE* 7: e29834, <https://doi.org/10.1371/journal.pone.0029834>
- Ginn HB, Melville DS (1983) Molt in birds. British Trust for Ornithology, Tring, 112 pp
- Gosler AG, Greenwood JJD, Baker JK, Davidson NC (1998) The field determination of body size and condition in passerines: a report to the British Ringing Committee. *Bird Study* 45: 92–103, <https://doi.org/10.1080/00063659809461082>
- Greig-Smith PW (1986) The distribution of native and introduced landbirds on Silhouette island, Seychelles, Indian ocean. *Biological Conservation* 38: 35–54, [https://doi.org/10.1016/0006-3207\(86\)90018-2](https://doi.org/10.1016/0006-3207(86)90018-2)
- Hill MJ, Vel TM, Holm KJ, Parr SJ, Shah NJ (2002) North Island. *Atoll Research Bulletin* 495: 176–199, <https://doi.org/10.5479/si.00775630.495-10.177>
- Hughes JH, Martin GR, Reynolds SJ (2017) Estimating the extent of seabird egg depredation by introduced common mynas on Ascension Island in the South Atlantic. *Biological Invasions* 19: 843–857, <https://doi.org/10.1007/s10530-016-1294-z>
- Kier G, Kreft H, Lee TM, Jetz W, Ibisch PL, Nowicki C, Mutke J, Barthlott W (2009) A global assessment of endemism and species richness across island and mainland regions. *Proceedings of the National Academy of Sciences* 106: 9322–9327, <https://doi.org/10.1073/pnas.0810306106>
- Komdeur J (1996) Breeding of the Seychelles Magpie Robin *Copsychus sechellarum* and implications for its conservation. *Ibis* 138: 485–498, <https://doi.org/10.1111/j.1474-919X.1996.tb08069.x>
- Lieberman A, McCormack G, Rideout B, Malcolm R (2018) Translocation and re-establishment of the Rimatara Lorikeet from Rimatara Island, Austral Islands, French Polynesia to Atiu

- Island, Cook Islands. In: Soorae PS (ed), Global reintroduction perspectives: 218: Case studies from around the world. IUCN/SSC Reintroduction Specialist Group, Gland, Switzerland and Environment Agency Abu Dhabi, pp 110–114, <https://doi.org/10.2305/IUCN.CH.218.08.en>
- Lindström Å, Visser GH, Daan S (1993) The energetic cost of feather synthesis is proportional to basal metabolic rate. *Physiological Zoology* 66: 490–510, <https://doi.org/10.1086/physzool.66.4.30163805>
- MacArthur RH, Wilson EO (1967) The theory of island biogeography. Princeton University Press, Princeton NJ, 203 pp
- Machovsky-Capuska GE, Senior AM, Zantis SP, Barna K, Cowieson AJ, Pandya S, Pavrd P, Shiels S, Raubenheimer D (2015) Dietary protein selection in a free-ranging urban population of common myna birds. *Behavioural Ecology* 27: 219–227, <https://doi.org/10.1093/beheco/arv142>
- Millett J, Climo G, Shah NJ (2004) Eradication of the common myna *Acridotheres tristis* populations in the granitic Seychelles: successes, failures and lessons learned. *Advances in Vertebrate Pest Management* 3: 169–183
- Norberg A (1981) Temporary mass decrease in breeding birds may result in more fledged young. *American Naturalist* 118: 838–850, <https://doi.org/10.1086/283874>
- Pietersen D (2017) Assessment of the Seychelles White-eye *Zosterops modestus* Newton, 1867 population on North Island, Seychelles. Report for the period 5 to 21 October 2017, North Island, 12 pp
- Richardson DS, Bristol R, Shah NJ (2006) Translocation of the Seychelles Warbler *Acrocephalus sechellensis* to establish a new population on Denis Island, Seychelles. *Conservation Evidence* 3: 54–57
- Rivera JHV, McShea WJ, Rappole JA, Haas CA (1998) Pattern and chronology of prebasic molt for the Wood Thrush and its relation to reproduction and migration Departure. *Wilson Bulletin* 110: 384–392
- Rocamora G, Henriette E (2015) Invasive alien species in Seychelles. Island Biodiversity and Conservation Centre, University of Seychelles, and Muséum national d'Histoire naturelle, Paris [Inventaires & Biodiversité series], 384 pp
- Rocamora G, Henriette-Payet E (2008) Conservation Introductions of the Seychelles White-eye on predator-free rehabilitated islands of the Seychelles archipelago. In: Soorae PS (ed), Global re-introduction perspectives. Case studies from around the world. Environment Agency, Abu Dhabi, pp 121–128
- Sayol F, Steinbauer MJ, Blackburn TM, Antonelli A, Faurby S (2020) Anthropogenic extinctions conceal widespread evolution of flightlessness in birds. *Science Advances* 6: eabb6095, <https://doi.org/10.1126/sciadv.abb6095>
- Steadman DW (2006) Extinction and biogeography of tropical Pacific birds. University of Chicago Press, Chicago, IL, xiv + 594 pp
- Stoddart DR (1984) Impact of man in the Seychelles. In: Stoddart DR (ed), Biogeography and ecology of the Seychelles islands. Dr W Junk Publishers, The Hague, Netherlands, pp 641–654
- van de Crommenacker J, van Dinther M (2015) Denis Island environment department annual report, 2015. Report to Green Islands Foundation, Mahe, Seychelles, 41 pp
- van der Woude J, Wolfs P (2009) Monitoring and studying the Seychelles Warbler. Denis Island field report 2009. Report to Green Islands Foundation, Mahe, Seychelles, 7 pp
- Veitch CR, Clout MN, Martin AR, Russell JC, West CJ (eds) (2019) Island invasives: scaling up to meet the challenge. Occasional Paper SSC no. 62. IUCN, Gland, Switzerland, xiv + 734 pp