The eradication of black rats (*Rattus rattus*) from Dog Island, Anguilla, using ground-based techniques

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Abstract Rat eradication techniques developed in New Zealand are a proven method for removing invasive rodents from islands worldwide. This technology moved rapidly from ground-based bait station operations to aerial application of rodenticides. Rat eradications on tropical islands using similar methods, have not always been as successful as those in temperate regions. As most previous eradications in the Caribbean have been on islands smaller than 50 ha, the eradication of black rats (*Rattus rattus*) from 207 ha Dog Island was a significant increase in size. Reptile and seabird populations on Dog Island had been in decline for a number of years and black rats were identified as the most likely factor. Following the feasibility study in 2007, the Dog Island Recovery Project was launched in 2011. This was a multiple-year project incorporating a ground-based eradication with establishment of biosecurity procedures to prevent reinvasion, alongside long-term monitoring of native species. Bait stations with cereal-based wax blocks containing brodifacoum at 0.005% w/w were established on a 30–50 m grid over the island. Interference with bait stations by non-target invertebrates, particularly crabs, was high and bait stations required moving or elevating to avoid this. However, there was no evidence of any non-target animals being killed or injured by the bait. Eradication success was confirmed in 2014.

Keywords: biosecurity, black rat, brodifacoum, Dog Island, eradication, monitoring, *Rattus rattus*

INTRODUCTION

Dog Island (207 ha) is located 13 km north-west of Anguilla (18.2783°N, 63.2533°W) in the north-east Caribbean and consists of one main island and three smaller offshore cays, East, Mid and West Cay (Sanders, 2006; Hodge, et al., 2008). Designated as an Important Bird Area, the Royal Society for the Protection of Birds (RSPB), Anguilla National Trust (ANT) and Fauna & Flora International (FFI) have monitored the seabird colonies on Dog Island for nearly 10 years and recorded that seabird populations, particularly sooty terns (*Onychoprion fuscatus*) and magnificent frigatebirds (*Fregata magnificens*), had been declining (Campbell, 1991; Sanders, 2006; Holliday, et al., 2007; Hodge, et al., 2008; Daltry, 2010). Dog Island also has a much reduced endemic reptile community consisting of the Anguilla Bank ground lizard (*Pholidoscelis plei*), the Anguilla Bank tree lizard (*Anolis gingivinus*), two species of dwarf gecko (Anguilla Bank dwarf gecko (*Sphaerodactylus parvus*) and Leeward Island banded gecko (*S. sputator*)), and the Anguilla Bank skink or slipperyback skink (*Spondylurus powelli*); surveys in 2009 failed to observe any dwarf geckos or skinks (Hodge, et al., 2003; Daltry, 2010; Hedges & Conn, 2012). Black (ship) rats (*Rattus rattus*) were identified as the most likely factor influencing this decline through predation on eggs, and young or small individuals. Rats are known to have devastating effects on seabird and reptile populations, causing extinctions on numerous islands worldwide (Moors & Atkinson, 1984; Atkinson, 1985; Towns, et al., 2006; Jones, et al., 2008, Harper & Bunbury, 2015). Many islands have been successfully cleared of rats, including more than 30 in the Caribbean, with a subsequent increase in bird and reptile populations (Day & Daltry, 1996; Daltry, 2000; Daltry, et al., 2001; Thomas & Taylor, 2002; Towns & Broome, 2003; Jones, et al., 2008; Varnham & Daltry, 2006; Howald, et al., 2007; Varnham, 2010).

The Dog Island Restoration Project partnership (consisting of Anguilla National Trust (ANT), Anguilla Department of Environment (DOE), Fauna & Flora International (FFI), the Royal Society for the Protection of Birds (RSPB) and the island owner, Anguilla Development Company) commissioned the development of an operational plan to eradicate black rats from Dog Island in 2011 (Bell, 2011) based on an earlier feasibility assessment (Varnham, 2007). Wildlife Management International Limited (WMIL) directed the eradication with the assistance of international volunteers and ANT, DOE, FFI and RSPB staff. The three-phase Dog Island Recovery Project (Phase I eradication of black rats; Phase II long-term monitoring of native species and Phase III biosecurity) began in January 2012.

METHODS

Study area

Dog Island is a low-lying (highest point: 29 m asl), rocky island with three small offshore islets (Mid Cay, West Cay and East Cay). There are several long, sandy beaches, two saline ponds and the rest of the coastline is rocky or has low cliffs (< 8 m high). The island lies within a Marine Protected Area, covering an area of approximately 10 km^2 around the island (Hodge, et al., 2008). The island is popular with visiting yachts and tourist vessels from Anguilla or Saint Martin/Sint Maarten.

Dog Island was originally covered in dry forest or woodland, with shorter vegetation in coastal areas exposed to salt spray, but today is dominated by low, thorny scrub (e.g. *Lycium americanum* and *Castela erecta*) and prickly pear cacti (*Opuntia* spp.) due to herbivory by feral goats (*Capra hircus*). Larger trees including manchineel (*Hippomane mancinella*), sea grape (*Coccoloba uvifera*), white cedar (*Tabebuia heterophylla*) and buttonwood mangrove (*Conocarpus erectus*) can be found around the coastline and occasionally inland.

The island is recognised as an Important Bird Area because it is globally significant for a large number of breeding seabirds, in particular sooty terns and magnificent frigate birds, (Sanders, 2006; Hodge, et al., 2008). Other

In: C.R. Veitch, M.N. Clout, A.R. Martin, J.C. Russell and C.J. West (eds.) (2019). Island invasives: scaling up to meet the challenge, pp. 162–166. Occasional Paper SSC no. 62. Gland, Switzerland: IUCN.

seabirds include brown boobies (*Sula leucogaster*), laughing gulls (*Larus atricilla*), masked boobies (*S. dactylatra*), brown noddies (*Anous stolidus*) and red-billed tropicbirds (*Phaethon aethereus*) (Holliday, et al., 2007; Hodge, et al., 2008; Daltry, 2010). The commonest land-birds on Dog Island are Caribbean elaenias (*Elaenia martinica*), bananaquits (*Coereba flaveola*) and black-faced grassquits (*Tiaris bicolor*). The island is also frequently used by migratory species travelling between North and South America (Holliday, et al., 2007; Daltry, 2010; Ross, 2011). A total of 48 resident and migratory bird species were confirmed on Dog Island by Richard Brown and Giselle Eagle from January to March 2012 (Bell, 2012).

Dog Island also has an important, albeit reduced, community of endemic lizards (Hodge, et al., 2003; Hedges & Conn, 2012). Notable missing reptiles are the globally threatened Anguilla racer (*Alsophis rijgersmaei*) and Lesser Antillean iguana (*Iguana delicatissima*), which were presumably present in the past. Dog Island would have been connected by a land bridge to Anguilla and indeed the rest of the Anguilla Bank well into the late Pleistocene, likely until 5,000 years ago. Three globally threatened species of marine turtles – hawksbill (*Eretmochelys imbricata*), green (*Chelonia mydas*) and leatherback (*Dermochelys coriacea*) – nest on and forage around Dog Island. Freshly dug holes have been recorded on many of the island's beaches (Hodge, et al., 2003; Daltry, 2010).

There have been few studies of the invertebrate fauna of Dog Island. Varnham (2007) collected samples using pitfall traps, but her specimens have not been identified to date (Daltry, 2010). Hermit crabs (*Coenobita clypeatus*) are present in high numbers, particularly around the coast.

Feral goats are present on the island; a remnant of more extensive grazing practices (Daltry, 2010). These goats are the property of the landowner but are hunted regularly, with or without permission. There are no known native mammals on Dog Island, but it could potentially support native bat species.

It is not known when black rats became established on Dog Island; but this is likely to have occurred sometime after 1613 when rats were first recorded in the Caribbean region (Harper & Bunbury, 2015). There is a history of human habitation on the island (i.e. stone walls and ruins) and rats may have reached Dog Island during this occupation or when ships were wrecked along the shores. Rats have been implicated as causing major impacts on island biodiversity (Towns, et al., 2006; Jones, et al., 2008) and they are known to have effects on important species on Dog Island. House mice (*Mus musculus*) have never been recorded on Dog Island (Varnham, 2007; Hilton & Connor, 2008; Bell, 2011).

Eradication operation

The eradication operation was planned to take place in the dry season (between January and May), when natural foods for the rats are in short supply and when there was little, or no risk of the operation being interrupted by tropical storms or hurricanes. The eradication option adopted for this project was a ground-based poison programme using protective bait stations to reduce risk to non-target species, particularly the reptile and feral goat populations. The eradication programme ran from 8 February 2012 to 4 April 2012 and included establishing the bait station grid, poisoning, monitoring and biosecurity. Biosecurity monitoring ran monthly between April 2012 and February 2014. The final check, species monitoring, and rat-free declaration ran from 10 to 19 February 2014. A core team of ten people completed the eradication, six people completed the biosecurity monitoring and a four-person team completed the final check. Each operational task was undertaken and completed as follows:

Bait station grid

A series of parallel tracks was cut through the vegetation on Dog Island, by a local contracting firm from Anguilla, between 20 November 2011 and 10 February 2012. Three additional lines were completed between 27 February and 6 March 2012. The contracting firm used two mechanised tools; machetes and rakes, to complete the task. One third of the island (the north-eastern end) had lines that were 30 m apart where the scrub was lower and easier to cut and the rest of the island, where scrub was much denser and more difficult to clear, had lines that were 40 m apart; bait stations were placed every 30 m along these lines. Areas of manchineel were not cut by the contracting firm (under arrangement with ANT as they did not want to deal with the toxic plant) during the track cutting phase of the project, but the main areas of manchineel were completed by the eradication team over a one-week period (10–15 February 2012) during the grid establishment phase, and two smaller stands of manchineel were completed over two four-day periods during the baiting phase (2–6 and 12–16 March 2012). Protective gloves and clothing and full-face masks were worn by the team when cutting tracks through the manchineel to avoid the sap and fumes which can irritate or blister the skin and cause breathing issues.

The bait station grid was established between 8 February and 15 February 2012. Bait stations were made from 1.5-litre plastic bottles (with the top and bottoms removed) donated by the public on Anguilla. These stations were pegged to the ground with wire "legs" to prevent movement by wind and/or stabilised with rocks or other material to reduce interference by feral goats. Bait was placed in the centre of the station through either end of the bottle.

Bait stations were placed out on the baiting grid. Mid and East Cays (not shown in the figures) were baited, but bait was laid on the surface (i.e. under vegetation and rocks) as feral goats were not present on the cays and there were few other non-target species present on these offshore islets. Each station was marked with flagging tape to ensure visibility in thicker vegetation.

The entire grid of 1,714 stations was established before being individually numbered and mapped using GPS and added to a GIS-linked database (Fig. 1).

Poisoning

Brodifacoum was used in two formulations: Klerat® (Syngenta, UK), a 20 g, wax-based wax block containing the bittering agent Bitrex™, and Pestoff® (Animal Control Products, NZ), a 24 g grain-based block bait. Both had 0.005% active ingredient and were dyed blue (or green/

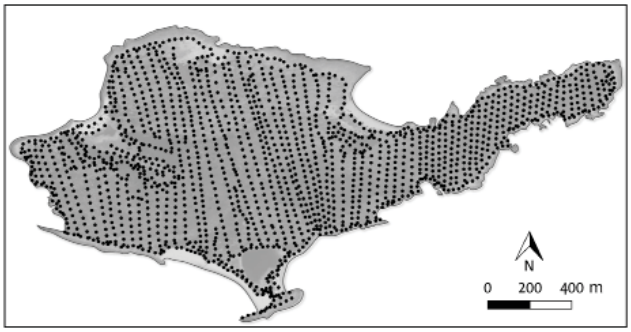

Fig. 1 Bait station grid on Dog Island, Anguilla (bait station positions are marked by a black dot).

blue), to be less attractive to birds (Caithness & Williams, 1971; Hartley, et al., 1999; Weser & Ross, 2013).

The poisoning programme commenced on 16 February 2012 and continued through to 30 March 2012. Baits were present in each station throughout the poisoning programme and replaced as required. Two bait blocks were constantly available in each main island bait station throughout the programme. Klerat® was used as the main bait (16 February–20 March and 26–30 March). Pestoff® was only used for checks 20 and 21 (21–25 March) to target any surviving or rats that had avoided Klerat® for any reason.

The bait stations on Dog Island were checked and serviced every 1–4 days. However, the stations on the offshore cays were only checked twice, during suitable weather, on team changeover days when the boat was available. Thus, they had more bait per station (10 blocks) than on the main island. To present the data on bait-take gained from these varied bait station checks we grouped the data into 25 periods or checks (mean (±SEM) = 1.44 ± 0.14 days between checks, range 1–4 days) shown as days from baiting (Fig. 2).

Bait take was recorded in field notebooks by bait station number and the species believed to have consumed or removed the bait as confirmed by sign in and around the bait station (i.e. pieces or fragments with rat teeth marks or crab claw marks, etc.). These data were entered into a database and large-scale maps showing active stations were produced in real-time to enable the team to effectively monitor bait take activity and target any "hot spots". All rat carcasses found were collected and returned to base for incineration to reduce risk for non-target scavengers.

Mitigation measures such as using bait stations to prevent access by goats to the bait, moving bait stations if crabs interfered with the stations and raising the bait stations into vegetation were used to reduce the risk of primary and secondary poisoning to non-target species.

Monitoring

Three distinct periods of monitoring were undertaken as the project progressed. Monitoring points consisted of materials attractive to rats (e.g. chocolate flavoured wax or resin, candles and soap) and tracking tunnels. Intensive monitoring using 3,428 points at 15–20 m spacing was carried out from 12 March 2012 to 4 April 2012 to detect any surviving rats. This was followed by a 22-month period of long-term monitoring using 167 commercial lockable plastic bait stations (placed around the coastline of Dog Island as long-term biosecurity stations) from 5 April 2012 to 9 February 2014. These biosecurity stations were established at high risk areas on the island; around the coast and at seabird breeding sites (Bell, 2012). The final check, using 626 monitoring points and biosecurity stations, was carried out between 10 and 19 February 2014. WMIL, FFI and ANT staff and volunteers carried out the intensive and final checks and ANT staff and volunteers maintained the long-term monitoring. All stations were individually numbered and any evidence of activity (e.g. teeth marks or foot prints) was recorded in field notebooks by number and the species believed to have consumed the wax or soap or marked the tracking plate.

Monitoring items were placed inside and outside each biosecurity station as well as halfway between each biosecurity station. Sand traps smoothed out to detect rat foot prints were established on beaches and inner island tracks. Checks for active rat runs and activity (i.e. identifying evidence of predation or scavenging on carcasses, chews on plants, droppings, etc.) at high-risk sites (i.e. ruins, seabird colonies, etc.) were also undertaken.

Each monitoring site was checked regularly, either separately, or during the poisoning phase, together with the poisoning bait station grid. Any rat and non-target species sign found on detection devices was recorded and added to the database.

RESULTS

Bait take was high over most of the island. Green/blue rat droppings appeared within three days and rats consumed 189 kg of bait. The bait take pattern was typical of other bait station rat eradication campaigns (Thomas & Taylor 2002). It was very high in the days immediately after the first bait loading (checks 1–3) and dropped to a relatively low level 20 days after initial baiting (check 10). A small increase was recorded at day 22 after initial baiting (check 12) but dropped away, reaching zero bait take on day 26 after the initial baiting (check 15) (Fig. 2).

Throughout the poisoning phase, 89% of bait stations were visited by rats, with 58% active within nine days of the initial baiting. The high number of active bait stations during the first two bait rounds shows that the rats quickly accepted the bait over most of the island.

The average number of blocks removed was 6.18 (± 0.07) blocks per station (Range: 0–16.05). As shown by Fig. 3, bait take was not evenly distributed over the entire island, with the greatest level of bait take at the eastern end where the main sea bird colony was situated, and the centre of the island. Bait take was also recorded on all the offshore stacks. Rats were also quickly eradicated from the cays as bait was still present when the second baiting visit was undertaken.

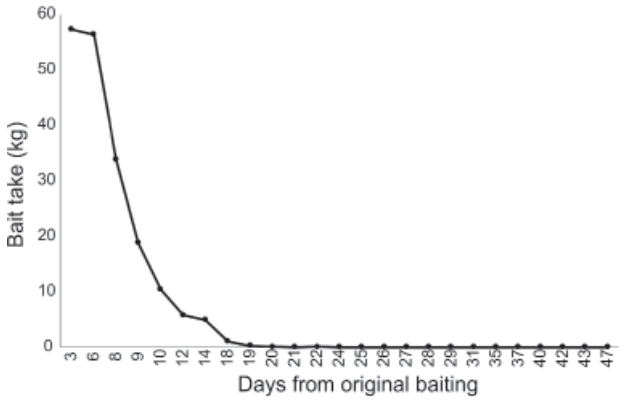

Fig. 2 Amount (in kg) of bait consumed by black rats (Rattus rattus) at each bait check (marked by black dot) during the black rat eradication on Dog Island, Anguilla (Day 1 was 16 February 2012).

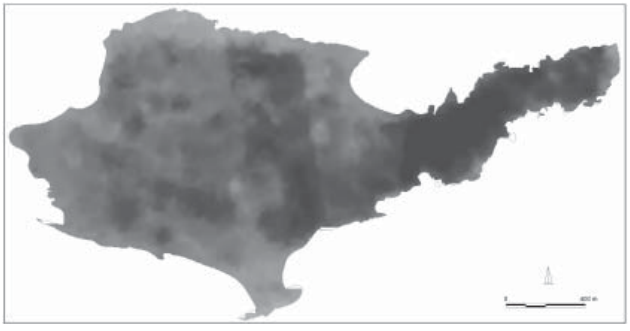

Fig. 3 Distribution of total bait take by black rats (*Rattus rattus*), as bait blocks consumed per station, during the black rat eradication on Dog Island, Anguilla. Darker shading indicates higher levels of bait uptake by rats.

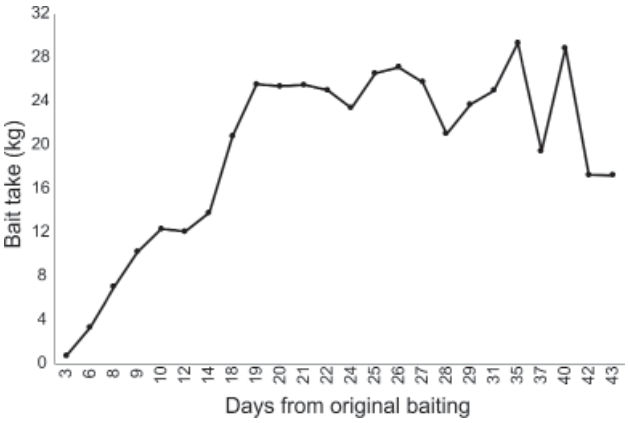

Fig. 4 Amount of bait (in kg) consumed by hermit crabs (*Coenobita clypeatus*) at each bait check (marked by black dot) during the black rat (*Rattus rattus*) eradication on Dog Island, Anguilla.

There was substantial interference by hermit crabs (Fig. 4). The average number of blocks eaten by crabs was estimated at 14.7 (± 0.3) blocks per station (Range 0–48.3). Crabs took a few days to become habituated to the bait, but then crab activity levels remained high (i.e. from days 19–41 over 50% of the stations were visited by crabs each round) (Fig. 4). There were 1,586 (92.5%) bait stations that had crab activity during the poisoning phase and only 128 stations were not affected. Crabs ate an estimated 467.4 kg of Klerat® bait throughout the eradication. There was no evidence that crabs were adversely affected by the bait. Anticoagulants are considered unlikely to affect invertebrates, as most have an open circulation system and have different physical and chemical clotting systems compared to vertebrates (Pain, et al., 2000).

Other non-target species had interfered with the bait to lesser amounts; goats consumed 0.04 kg (2 blocks) of Klerat® bait, ground lizards 0.26 kg (10.8 blocks) of Pestoff® bait, ants 10.9 kg of Klerat® bait and other insects 0.33 kg of Klerat® bait.

No animals, other than rats, exhibited signs of poisoning and no suspicious mortalities were recorded over the 11-week operation. The team was trained to observe non-target behaviour and collect any carcasses. There were 160 rat carcasses collected on the surface during the operation. These carcasses were collected and incinerated on the island to prevent availability to non-target species.

Monitoring for rat presence continued island-wide for two years after the end of the poisoning operation. The last rats were detected on 13 March 2012 during the overlap between the poisoning and intensive monitoring phases and these rats were successfully targeted using Klerat® by 30 March 2012. No rats or sign were detected during any phase of the long-term or final check monitoring. Dog Island was declared rat-free in May 2014.

DISCUSSION

The success of the Dog Island black rat eradication shows that a well-planned, adequately resourced, well-executed programme, supported by the landowner and directed by experienced operators and completed during the dry season can eradicate black rats from a large, arid, tropical island using a ground-based bait station operation. Dog Island is now the largest Caribbean island to be cleared of invasive rats and we believe that similar techniques could be utilised on other, even larger, islands in the Caribbean region.

Once the poison grid was established, the island was cleared of rats within four weeks (25 days from initial baiting). Bait-take showed that the rat population was not evenly distributed across the island. Apparently high concentrations of rats where the seabird colonies are present suggests rats were likely to have been having an effect on these nesting seabirds.

Importantly there were no known non-target species affected by this operation despite intensive searches for carcasses and a high level of interference by land crabs and to a lesser degree by ground lizards, invertebrates and, on one occasion, a goat which ate two blocks of bait. This stands in marked contrast to other operations that have inadvertently poisoned a variety of birds and other native wildlife (e.g. Howald, et al., 2007, Fisher, et al., 2011, Pitt, et al., 2015). Our choice of bait was a critical factor to this success; the primary bait used was Klerat® which was consistently untouched by any vertebrate other than rats (whereas the goat and lizards ate Pestoff® bait only). Klerat® has been equally successful in almost all the previous rat eradications in the Caribbean completed or managed by the authors and others (Day & Daltry, 1996; Daltry, 2000; Garcia, et al., 2002; Varnham, 2003; Varnham & Daltry, 2006; Witmer, et al., 2007; Varnham, 2010).

Ecological surveys conducted prior to the rat eradication operation identified a suite of ecological indicators on Dog Island that were consistent with the impacts of black rats, including the suppressed diversity and abundance of land birds, lizards and plants (Daltry, 2010). Audubon's shearwaters (*Puffinus lherminieri*) were first confirmed nesting on the island in 2012, within a few weeks of eradicating the rats (Bell, 2012). Preliminary surveys in 2014 found significant increases in a number of native species since the rats were eradicated; a two-fold increase in the density of ground lizards, three-fold increase in abundance of land-birds and a three-fold increase in burrow occupancy of Audubon's shearwaters (Bell & Daltry, 2014). Further increases were recorded during routine monitoring in 2016 and are predicted to continue over the next 10–20 years. Birds, lizards, goats, vegetation and invertebrates should be monitored for the next 20 years to detect and assess longer-term changes to the Dog Island ecosystem.

Unfortunately, as long as goats remain on Dog Island, some of the benefits of removing rats may be significantly reduced or fail to occur at all (Daltry, 2010). By preferentially eating all but the most spiny and toxic plants, the goats are maintaining an artificial, plagioclimax vegetation of thorny scrub across most of the interior of the island, which has low diversity and supports relatively few animals. Our cross-island transects, for example, revealed these interior areas had an extremely low density of lizards (Bell & Daltry, 2014). Another major concern about the goat herd is that it attracts parties of hunters who pose a biosecurity risk because their vessels and gear could provide pathways for rodents and other pests to invade the island.

While eradicating rats from Dog Island is a considerable achievement, it is important to stress that keeping this island rodent-free will require constant vigilance and commitment from all agencies, interested parties and the Anguillan community to prevent, detect and respond to any incursions. Prevention of rat re-infestation should be the primary aim. The greatest risk of reinvasion by rats reaching Dog Island is with private vessels, charter boats and fishing boats, particularly those that moor overnight, from Anguilla or the other nearby islands such as the Prickly Pear Cays and Saint Martin. This is especially so when equipment and food are brought to the island. Permanent biosecurity stations have been established on Dog Island and these will be maintained indefinitely by trained ANT staff. An incursion response plan has also been developed by ANT to deal with any rats that may be detected in the

future. This shows that the local conservation agencies are totally committed to the restoration of this important Caribbean island.

ACKNOWLEDGEMENTS

This project was carried out with funding from National Fish and Wildlife Foundation (Grant No. 2011-0002-000000 to FFI Inc.) and the Governor's Discretionary Fund (awarded to ANT). The Klerat™ bait was donated by Syngenta Crop Protection AG. We would like to thank Alan Gumbs (Anguilla Development Company, owner of Dog Island), Jacqueline Cestero (Project Manager), Clarissa Lloyd, Janeczka Richardson, Kim Gumbs, Louise Soanes, Devon Carter and Michael Matthew (ANT staff), Jenny Bright and James Millett (RPSB), Robert Bensted-Smith, Sara Calçada, Nav Dayanand, A.E. Lovett and Mary Rider (FFI), Scott Hall (NFWF Seabirds Keystone Initiative), Judy Pierce (US Fish & Wildlife Service), Kirsty Swinnerton and Richard Griffiths (Island Conservation), Mark Birchmore, Alan Buckle, Andy Bywater and Alex Cornish (Syngenta), Bill Simmons (Orillion, previously Animal Control Products, New Zealand), Keith Broome (Island Eradications Advisory Group, Department of Conservation, New Zealand), Sharrine Gumbs (Uneek Supplies), Lee Brooks (Ashley & Sons), Marshall Mitchell (Safe Cargo), Maximo Hodge and Marvin Carty (Trucking), Linda Bottlik (Sunfish Design), Jackie Pacsher (Island Dream Rental), Kathy Haskins, Rachel Haskins-Brodie and Kieron Brodie (Sandy Feet Car Rental) and Hon. Othlyn Vanterpool (Anguilla Scouts). Special thanks to all of the volunteers (Thomas Aveling, Luke Banse, Richard Brown, Chris Clarke, Giselle Eagle, Paul Garner-Richards, Melissa May, Tegan Newman, Matthew Rogers and Sophie Thomas) who worked on Dog Island during the eradication. Emile Lloyd, Rumple Lloyd and Irwin Lloyd provided boat transport to Dog Island. Neville Carty, Ashton Richardson, Khaloni Richardson, Giovani Hughes, Leopold Reid, Clayton Reid, Andrew Brooks, Wells Allwalters, Paul Gillis, Peter Liddie, Movis Connor, Evan Hodge, and Desmond Brooks cut tracks across Dog Island to establish the bait station grid. Kelvin Floyd (WMIL) designed the GIS-linked database and provided Figs 1 and 2.

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