Big island feral cat eradication campaigns: an overview and status update of two significant examples

D. Algar[1], M. Johnston[1] and C. Pink[2]

[1]Science and Conservation Division, Department of Biodiversity, Conservation and Attractions, Locked Bag 104, Bentley Delivery Centre, Western Australia, Australia 6983. <dave.algar@dbca.wa.gov.au>. [2]Christmas Island National Park, P.O. Box 867, Christmas Island, Indian Ocean, Australia 6798.

Abstract Feral cats have been known to drive numerous extinctions of endemic species on islands. Also, predation by feral cats currently threatens many species listed as critically endangered. Island faunas that have evolved in the absence of predators are particularly susceptible to cat predation. Australian islands, such as Dirk Hartog and Christmas, both formerly known to be high biodiversity islands, are no exception. In this paper we outline the techniques being used in the two eradication campaigns currently underway and provide an update on the status of the programmes on these islands that differ significantly in terms of climate, topography and habitation. Poison baiting and trapping are the methods used on both islands but have been managed differently to suit the local conditions.

Keywords: Christmas Island, Dirk Hartog Island, domestic cat, fence, land crab, planning, poison baiting

INTRODUCTION

There is extensive evidence that domestic cats (*Felis catus*) introduced to offshore and oceanic islands around the world have had deleterious impacts on endemic land vertebrates and breeding bird populations (e.g. Van Aarde, 1980; Moors & Atkinson, 1984; King, 1985; Veitch, 1985; Bloomer & Bester, 1992; Bester, et al., 2002; Keitt, et al., 2002; Pontier, et al., 2002; Blackburn, et al., 2004; Martinez-Gomez & Jacobsen, 2004; Nogales, et al., 2004; Ratcliffe, et al., 2009; Bonnaud, et al., 2010). Feral cats have been known to drive numerous extinctions of endemic species on islands and have contributed to at least 14% of all 238 vertebrate extinctions recorded globally by the IUCN (Nogales, et al., 2013). In addition, predation by feral cats currently threatens 8% of the 464 species listed as critically endangered (Medina, et al., 2011; Nogales, et al., 2013). Island faunas that have evolved for long periods in the absence of predators are particularly susceptible to cat predation (Dickman, 1992). Dirk Hartog and Christmas Islands, both documented as high biodiversity islands are no exception.

Dirk Hartog Island (DHI), an area of 620 km^2, is the largest island off the Western Australian coast (Abbott & Burbidge, 1995). Since the 1860s, DHI has been managed as a pastoral lease grazed by sheep (*Ovis aries*) and goats (*Capra hircus*). More recently, tourism has been the main commercial activity on the island undertaken by the former pastoralist family, the only permanent inhabitants on the island. Cats were probably introduced by early pastoralists and became feral during the late 19th century (Burbidge, 2001). Ten of the 13 species of native terrestrial mammals once present are now locally extinct (Baynes, 1990; McKenzie, et al., 2000) probably due to predation by cats (Burbidge, 2001; Burbidge & Manly, 2002; Algar, et al., 2011a). The house mouse (*Mus musculus*) has become established on the island, but other invasive species such as European rabbit (*Oryctolagus cuniculus*), red fox (*Vulpes vulpes*) and black rat (*Rattus rattus*) are not present.

Christmas Island (CI) occupies an area of 135 km^2 and is famous for the annual migration of tens of millions of red crabs (*Gecarcoidea natalis*) (Orchard, 2012; Misso & West, 2014). CI has a resident multi-cultural population of 2,239 residents (2015 records, <http://www.abs.gov.au/>), predominately Chinese, Malays and Europeans, who reside on the north-eastern tip of the island. Phosphate mining is a major economic driver on the island, with ecotourism becoming increasingly important. Cats were taken to CI at the time of first settlement in 1888 and a feral population established soon thereafter (Tidemann, et al., 1994). Four of the five mammal and two reptile species that were present on the island at settlement have since become extinct, with the introduction of cats playing a crucial role (Beeton, et al., 2010; Martin, et al., 2012). Two endemic rats, the bulldog rat (*Rattus nativitatis*) and Maclear's rat (*R. macleari*) disappeared shortly after black rats were introduced in 1900 (Green, 2014). In addition, several extant CI birds are listed as species likely to be adversely affected by cats (Beeton, et al., 2010).

Across Australia, cats have caused or contributed to population declines and extinctions on many offshore islands (Dickman, 1992; Dickman, 1996; Burbidge, et al., 1997; Burbidge, 1999). Today, the impact of cats is broadly acknowledged and control of feral cats is recognised as one of the most important fauna conservation issues in Australia. As a consequence of this, a national 'Threat Abatement Plan (TAP) for Predation by Feral Cats' has been developed (EA, 1999; DEWHA, 2008; DE, 2015). The TAP seeks to protect affected native species and ecological communities, and to prevent further species and ecological communities from becoming threatened. In particular, the first objective of the TAP is to "prevent feral cats from occupying new areas in Australia and eradicate feral cats from high-conservation-value islands".

DHI was established as a National Park in November 2009, and this now provides the opportunity to reconstruct the native mammal fauna (Algar, et al., 2011a). The island could potentially support one of the most diverse mammal assemblages in Australia and contribute significantly to their long-term conservation. Successful eradication of feral cats is considered to be a necessity prior to reintroductions. Similarly, the impact of cats on much of the biodiversity of CI has been of significant concern to island land management agencies and local residents. Eradication of cats on the island is necessary to mitigate the socio/health impacts and threat to those remaining extant species and to allow successful re-wilding of species such as the blue-tailed skink (*Cryptoblepharus egeriae*) that are currently restricted to captive breeding programmes.

The islands differ markedly in environmental and human factors but are linked in the agencies involved, that have iteratively resolved site-specific challenges associated with the removal of cat impacts on wildlife populations. In this paper we outline the cat eradication programmes currently underway on both islands, describe the strategies, techniques and application methodology and provide an update on the campaigns' progress.

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. 238–243. Occasional Paper SSC no. 62. Gland, Switzerland: IUCN.

MATERIALS AND METHODS

Site descriptions

DHI (25° 50' S, 113° 0.5' E) lies within the Shark Bay World Heritage Property of Western Australia, 1.5 km from mainland Australia. The island is approximately 79 km long and a maximum of 11 km wide with its long axis in a south-east to north-west direction. Detailed description of geology and vegetation is provided elsewhere (Beard, 1976; Payne, et al., 1987; Algar, et al., 2011a). The climate of the region is 'semi-desert Mediterranean' (Beard, 1976; Payne, et al., 1987). The mean annual rainfall for Denham, located 37 km to the east of DHI is 224 mm (Bureau of Meteorology, 2017; long-term records 1893–2016).

CI (10° 25' S, 105° 40' E) is located in the Indian Ocean, 360 km south of the Indonesian capital of Jakarta. The oceanic island is composed primarily of Tertiary limestone overlying volcanic andesite and basalt (Tidemann, et al., 1994; EA, 2002). The island consists of a series of fringing limestone terraces, separated by rugged limestone cliffs and scree slopes, rising to an internal central plateau at about 200 m and extending to 360 m above sea level. A National Park was established in 1980 and extended in 1986 and 1989 to include most of the rainforest; it now covers 63% of the island (EA, 2002). There are four main vegetation types described in detail by Claussen (2005). CI has a typical tropical, equatorial climate with a wet and a dry season. The wet season is from December to April when the north-west monsoon blows. For the rest of the year south-east trade winds bring slightly lower temperatures and humidity, and much less rain. The island has a mean annual rainfall of 2,183 mm, high humidity (80–90%) which varies little between months and consistent temperatures (mean daily temperature: 22.9–27.4° C) (Bureau of Meteorology, 2017).

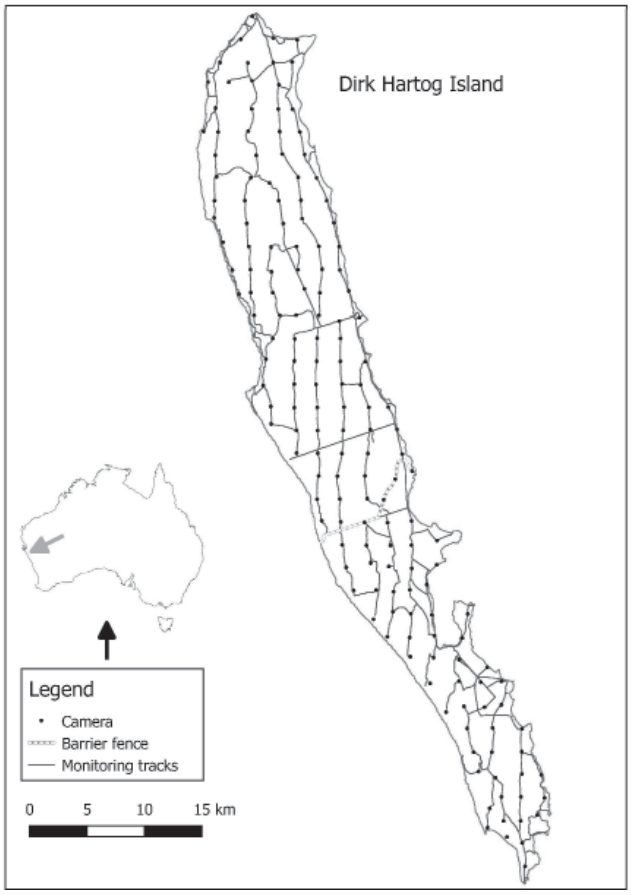


Fig. 1 Dirk Hartog Island.

Planning

To date, feral cats have been successfully eradicated from four Western Australian offshore islands: Serrurier Island (Moro, 1997); Hermite Island in the Montebellos (Algar, et al., 2002); Faure (Algar, et al., 2010) and Rottnest Islands (Algar, et al., 2011b) to enable reconstruction of the original fauna or protection of extant species. These successes and knowledge gained provide the confidence to tackle the more ambitious challenges of DHI and CI. There is a number of key elements used in the operational planning of a successful eradication strategy. The plan may include a pilot study that assesses the efficacy of proposed techniques as well as documenting the procedures to be used in the sequenced eradication phases, the monitoring programmes and the surveillance period prior to verifying eradication has been achieved. Plans for the DHI/CI eradication programmes build strongly on previous research conducted on both islands that examined eradication and monitoring techniques (Algar & Brazell, 2008; Algar, et al., 2010; Algar, et al., 2011a).

Central to the planning for DHI was the construction of a 13 km cat barrier fence. The island's size, in particular its length, poses logistical constraints on conducting an eradication campaign across the entire island simultaneously. It is not practical to monitor for cat activity over such a large area and therefore, the eradication campaign is being conducted in stages either side of the barrier fence. The fence was constructed with a 'floppy top' and electrical hotwires facing to the north to prevent reinvasion of the southern area once it had been cleared (see Fig. 1). Use of a barrier fence has been demonstrated to reduce the cost and increase the overall likelihood of successful eradication on the island (Bode, et al., 2013).

Crucial in the planning for CI was the presence of a domestic cat population. Key land management agencies initiated the preparation of a cat management plan as a critical first step. The plan (Algar & Johnston, 2010) was developed with these agencies, interest groups and the broader community. It was supported and endorsed by the various organisations and has been embraced by the public. Initially, local cat management laws were revised to include a prohibition on the importation of cats, promoting responsible cat ownership, compliance and enforcement of cat management laws. A staged approach to eradicate cats entirely from the island has been adopted, which is complemented by the gradual decrease of owned cats as the de-sexed domestic population dies out. The amended local legislation required all domestic cats to be neutered, micro-chipped and registered with the Shire (Stage 1). Surveys of domestic cats and veterinary programmes are outlined by Algar, et al. (2011c) and Algar, et al. (2014). Stage 2 requires the removal of all stray cats within the township. Without implementation of Stage 2 a significant source of cats, particularly natal recruits, would be available to disperse into or reinvade territories vacated across the rest of the island. Stage 3 involves the implementation of the island-wide (i.e. the national park, mine leases and Unallocated Crown Land) feral cat eradication programme.

Eradication effort

Baits and baiting application

Baiting is recognised as the most effective method for controlling feral cats on mainland Australia (Short, et al., 1997; EA, 1999; Algar & Burrows, 2004; Algar, et al., 2007; Algar, et al., 2013), and has been used as the primary technique for eradicating cats on islands (Algar, et al., 2002; Algar, et al., 2010). World-wide, cat eradications have been attempted on a number of islands with 82 successful campaigns that range in size from 5–29,000 ha (Campbell, et al., 2011). There have also been eradication attempts on a further 15 islands that have failed (ibid.). All successful campaigns on islands >2,500 ha used primary poisoning with toxic baits, with the exception of Santa

Catalina (3,020 ha). Interestingly, seven failed campaigns on the five largest islands (all >400 ha) did not use toxicants (Campbell, et al., 2011). A locally developed bait known as *Eradicat*® (Algar & Burrows, 2004) containing 4.5 mg of directly injected toxin '1080' (sodium monofluoroacetate) is used on both DHI and CI.

The primary eradication technique to be used in the DHI programme was aerial baiting. A pilot study conducted during March–May 2009 assessed the efficacy of this strategy (Johnston, et al., 2010; Algar, et al., 2011a). This achieved very positive results with 80+% of the feral cat population poisoned following bait consumption (ibid). These results demonstrated that a baiting programme, with the *Eradicat*® bait as the primary eradication technique, could be highly effective on DHI.

Deployment of baits from an aircraft was not considered feasible on CI at the commencement of this campaign due to the removal of baits by the abundant land crabs. However, targeted aerial baiting into discrete difficult to access areas is now being contemplated for late in the dry season when land crabs are less active (Johnston, et al., 2016). Preliminary baiting exercises on the island where baits were placed on the ground, highlighted the potential problem of non-target species removing ground-laid baits. Red crabs, robber crabs (*Birgus latro*), which dominate the forest floor, black rats and feral chickens (*Gallus domesticus*) readily removed baits laid on the ground. Bait removal by non-target species reduces bait availability to feral cats and therefore eradication efficacy. In a later trial, Algar & Brazell (2008) demonstrated a device to suspend baits above the ground that effectively reduced bait removal by non-target species yet provided ready access to feral cats. A key finding from this trial was that the bait suspension devices (BSD) would provide an effective primary cat eradication technique on the island. During the eradication campaign, BSD are located at 100 m intervals on both sides of the extensive 160 km road/track, staggered at 50 m intervals across the road/track. Each BSD suspends two *Eradicat*® baits tied at the link, considered a single bait for analysis purposes, at a height of about 550 mm using 6–8 lb fishing line. Baits are replaced when taken and as required to maintain palatability. Suspended baits were also deployed off-track throughout the forest at 50 m intervals in 2015 and, due to unprecedented rainfall, to a lesser extent in 2016.

The total number of toxic baits removed indicates the maximum number of individuals poisoned. The minimum number of individuals poisoned is calculated by ascribing bait removals from consecutive BSDs to the same animal. The actual number of feral cats poisoned would be between these two extremes. While one *Eradicat*® bait contains a lethal dose, it is likely that some cats would visit multiple BSDs given the delay between bait consumption and death.

Trapping

Trapping programmes are being used as the secondary eradication effort to remove those animals that survive the baiting programmes. On DHI, cats are being captured in padded leg-hold traps; (Victor 'Soft Catch'□ traps No. 3 (Woodstream Corp., Lititz, PA.; U.S.A.) using a mixture of cat faeces and urine as the lure. Trapped cats are destroyed using a 0.22 calibre rifle. All animals captured are sexed and weighed; a broad estimation of age (as either kitten, juvenile or adult) is recorded using weight as a proxy for age. The pregnancy status of females is determined by examining the uterine tissue for embryos. Stomach contents are removed for diet analysis and a sample of hair and tissue taken for DNA microsatellite profiling. Also, prior to the commencement of the two aerial baiting programmes, a number of cats were trapped and fitted with a GPS data-logger/radio-telemetry collar (Sirtrack Ltd, New Zealand). Mortality of radio-collared animals following the baiting programmes was used to provide a measure of baiting efficacy.

On CI, the trapping programme commenced in the township to remove stray cats. Initially, cage traps were used rather than padded leg-hold traps to minimise the risk of injury to domestic cats. Cats were captured using wire cage traps (60 × 20 × 20 cm) with treadle plates (Sheffield Wire Products, Welshpool, Western Australia). All traps were covered with a hessian sack to provide shelter and protection to the captured animals until they could be collected. The traps were usually baited with cooked chicken wings. Outside the township, elevated trap platforms (ETPs) – where trap sets are raised above ground level – are used to exploit cats' agility and ability to jump, while preventing trap interference from ground-dwelling non-target wildlife such as land crabs. Traps along roads and tracks are generally set on cleaned half 200 l fuel/oil drums in the same configuration and lured as ground sets on DHI.

Monitoring

Monitoring programmes use evidence of actual presence through camera trap images, spotlight records and sign, whether it be footprints, scats or hair, to detect the presence/absence of individuals in an area. In eradication campaigns, monitoring programmes provide information on where further effort is required and whether additional measures and/or resources are needed. A key component of these eradication campaigns is to employ monitoring methods that will provide quantitative estimates of the effectiveness of eradication operations; the techniques must also be capable of detecting animals at low density populations. The physical characteristics of DHI and CI differ significantly and required the adoption of a different suite of monitoring techniques across the two islands.

Of necessity, the monitoring of feral cat activity must be conducted across the entire island. CI has an extensive road/track network (see Fig. 2) whereas, on DHI, much of the former pastoral road network has regenerated, with many roads and fence lines being impassable. The monitoring programme on DHI is being conducted from All Terrain Vehicles (ATVs) which can traverse the entire island in a safe and efficient manner. Prior to implementing the monitoring programme, it was necessary to construct a network of survey tracks to allow monitoring of cat activity across the island. The spacing of these tracks

Fig. 2 Christmas Island.

needed to permit detection of any cat during the survey period (i.e. two weeks each month) and therefore provide confidence in the sensitivity of the survey technique. Information obtained from the GPS data-logger radio-collars during the pilot study (Algar, et al., 2011a) was used to determine the likelihood of detection and to optimise the proposed spacing of the survey tracks for the eradication programme. Track lines were parallel to the long axis of the island and the orientation of the dune system. This was the preferred course for survey tracks for logistic reasons and also to minimise disturbance and erosion to dunes. Analysis of daily movement patterns, pooled for all cats, suggested that placement of monitoring tracks at a width of approximately 2.0 km across the full length of the island (see Fig. 1) would be sufficient to enable detection of these animals within each survey period. Choice of this spacing for the monitoring tracks and separation of camera traps (see later) was further strengthened by data collected on home ranges (100% Minimum Convex Polygon) of the radio-collared cats in the pilot study which were 12.7 km^2 for males and 7.8 km^2 for females (Johnston, et al., 2010). Thus, every cat has a very high probability of its sign being observed over a 10-day monitoring period (Algar, et al., 2011a).

Camera trapping

Camera trap studies are useful in providing information on feral cat presence/absence and provide an ideal technique for monitoring the impact of eradication measures through the progression of the eradication campaign as they will allow remote monitoring of cats following each period. On DHI, camera traps were established at 2 km intervals along and overlooking the track network with 105 Reconyx HC600 (Reconyx, Wisconsin; USA) cameras north of the barrier fence and 64 cameras to the south (see Fig. 1). Additional cameras were installed at key locations such as fence ends and around the tourist resort on freehold land. A variety of visual, olfactory or audible attractants were used at camera sites, including no lure. On CI, 84 Scoutguard SG-560C (HCO Outdoors, Norcross, GA, USA) non-lured camera traps were located approximately 1.0 km apart in an island-wide array, with six spatially explicit transects nested within (see Fig. 2). Occupancy analysis and spatial mark/resight modelling was conducted to estimate density over time (The Analytical Edge Pty Ltd., Hobart, Australia).

Sign searches

The sandy surface on DHI enables the search and detection of cat footprints. The network of management tracks is searched daily by skilled observers riding ATVs over a 10-day period on a seasonal basis, that is, four times per year. Circuits ranging in length from 80–140 km, are ridden at a speed of <20 km/h which is adequate to identify footprints on the track surface. The observers alternate the direction of travel and the circuit they inspect on a daily basis. The track surface on CI is hard and does not lend itself to identification of footprints. Other sign monitoring techniques are currently being developed that will complement the use of camera traps to survey for cat activity.

Surveillance period and independent verification

The final phase of the campaign on DHI, an intensive and simultaneous island-wide surveillance period was initiated in October 2016 on the belief that that eradication had been achieved. Assuming no more cats are found, this third phase is expected to be of a two-year duration and will be used to confirm eradication success in October 2018.

On DHI, surveillance monitoring for cat activity is being conducted over a 10-day period in each of the southern and northern sectors every three months. Surveillance monitoring is employing both camera trap recording and cat sign searches. The cat sign searches are being conducted along the pre-existing tracks and the monitoring grid network. Opportunistic cat sign searches along beaches and other areas of interest (e.g. caves and seabird colonies) are also being conducted. The monitoring is undertaken across the entire zone the same day to avoid any issues associated with cat movement.

In addition, on DHI specialist detector dogs and their handlers (Latitude 42 Environmental Consultants Pty Ltd., Tasmania, Australia) have been contracted to further independently verify the absence of cats and corroborate that eradication has been successfully achieved. A team of six dogs and experienced handlers undertake the intensive search effort for cat sign during the winter when weather conditions are the most favourable.

On CI, surveillance monitoring, which is yet to commence, will primarily utilise the island-wide camera array with a range of lures as on DHI. Detector dogs are not being considered for use on CI because of quarantine regulations for re-importation back onto the mainland, the difficult terrain and cultural issues associated with the presence of dogs on the island. A community reporting system will be maintained as well as implementing an intensive and comprehensive spotlighting effort around the island.

Finally, independent verification of eradication success on both islands is to be undertaken by an impartial organisation using data summaries provided.

RESULTS

Dirk Hartog Island

Logistical issues associated with transport of fencing materials prevented construction of the fence on DHI until following the completion of baiting monitoring in 2014. As a result, most of the island (90%) was baited in 2014. However, once completed, the fence alignment has played a key role in restricting the ranging of cats on the northern side.

Data on cat home range size and degree of overlap from the 2009 pilot study were used to derive a best estimate of cat population size pre-eradication effort. This analysis, with multiple assumptions, suggested that a total of 439 cats (range 309–503) was likely present prior to the eradication campaign. Prior to the first baiting campaign in 2014, 17 cats were trapped and fitted with VHF/GPS collars in the southern zone during April 2014. Trapped cats were released at the location of capture. Of these, fifteen were known to be alive when *Eradicat*® baits were applied on the 27–28 May. Fourteen of these animals (>90%) died following bait consumption. The fate of the remaining cat is uncertain but as it was last detected alive in June 2014 and has not be relocated by VHF or photographed since this time. Five cats were trapped, fitted with VHF/GPS collars and released at the location of capture in the northern sector in April 2015 prior to the second baiting programme. All were alive when baits were applied on 25 May 2015. Only one of these cats died following consumption of an *Eradicat*® bait, the remaining four were recovered by trapping. The combined monitoring programmes have detected 36 individual cats that survived the baiting programmes and these animals have subsequently been trapped. January and April seasonal surveillance programmes have failed to detect the presence of any further cat activity. Detector dogs did not locate any fresh sign of cat activity south of the barrier fence in 2016 and examine the area north of the fence during July 2017.

Christmas Island

One hundred and eighty-four domestic owned cats have been registered on CI since 2010, with only 74 domestic

cats remaining at the conclusion of the 2017 domestic cat survey. Deregistered cats had either died from natural causes or road fatalities, or were euthanised as the owners had moved off-island. Although the programme on CI commenced in late 2010, funding to commence the island-wide eradication effort (Stage 3) was not secured until 2015. Short-term control programmes were conducted around the township in 2013 and 2014 to protect the significant investment and gains achieved in controlling stray cats until a new source of funding could be obtained. Over the period 2011 to 2015, 336 stray/feral cats were trapped within the township and a further 216–311 were poisoned along roadsides/tracks that surrounded the area. From 2015 to 2017, cage trapping removed 46 stray cats within the township, outside the township limited ETP leg-hold trapping resulted in the removal of (12), shooting (11) and roadside BSDs a further (158–216) cats. An unknown number of cats was removed from forest baiting in 2015 and 2016 due to uncertainty in determining bait uptake by cats. Based on the upper and lower estimation method of baits taken on BSD, between 779–932 stray/feral cats have been removed since 2010. Preliminary results from the 2016 island-wide array camera monitoring estimated that a population of 225 (SE=23) feral cats remains across the island.

DISCUSSION

Globally, the Dirk Hartog project will become the largest island feral cat eradication campaign attempted to date and Christmas Island is a relatively large island with significant human inhabitation. The restoration of former species richness on DHI and recovery of the threatened wildlife populations on CI has required management of feral and domestic cats. The strategies used to achieve the reduction in cat populations have been tailored to suit the specific circumstances applicable to each island. Perhaps the largest challenge on DHI was to ensure that the monitoring tools were sufficiently sensitive given the scale of the island. Removal of cats from Christmas Island is characterised by improving the management of owned cats as well as mitigating the impact of land crabs on poison baiting operations. The guiding principles for successful eradication (Bomford & O'Brien, 1995) have been successfully met in both of these island programmes, although it is worth noting that maintaining the appropriate socio-political environment has been an ongoing and time-consuming component of both programmes. The eradication programmes on both islands have followed a logical progression of intensiveness that aimed to reduce the population rapidly from base levels and then use follow-up trapping to target remaining cats, that is, initial population knockdown with a low cost/broad-scale method followed by high cost/labour intensive mopping up. The monitoring programmes suggest that the cat populations have been reduced to low (CI) or non-detectable (DHI) levels bearing out the prescriptions provided in the operational plans.

Residents on CI have been involved in the development and maintenance of the owned cat population. This has also involved a compliance programme and importation ban that was necessary to maintain the closed population. Maintaining quarantine on DHI has been a more straightforward process given that one family is involved who are invested in the ecological restoration of the island given the anticipated benefits to their tourism enterprise.

Poison baiting has formed a critical part of the eradication tools on both islands but the variable results achieved in these programmes should be noted in preparation for similar programmes in the future. A low baiting efficacy consequently leads to a requirement for greater follow-up control with respect to investments in time and labour. A probable explanation for the observed differences in baiting success in 2014 and 2015 on DHI relates to the meteorological factors at the time of baiting. Just prior to 2014 baiting, a pulse of cooler weather was recorded which would have had the effect of reducing the availability of alternative prey such as small reptiles and mammals. In contrast, the 2015 season was characterised by a rodent irruption that may have been triggered by rainfall associated with Tropical Cyclone Olwyn. On CI, unprecedented rainfall in 2016 reduced baiting efficacy significantly and prompted the development of alternative trap sets that were effective under wet conditions. Alternative removal tools, such as different trap sets, must be ready to implement in situations where baiting is less successful (Robinson, et al., 2015). Project governance and budgeting would ideally include sufficient contingency to adapt or permit operational flexibility to account for environmental factors that influence on-ground outcomes (Springer, 2016).

Ultimately, the success of these programmes will be measured by the response of native wildlife species. On CI, there has been a dramatic increase in the nesting success rate in the red-tailed tropicbird (*Phaethon rubricauda*) populations following improvement in the management of urban cats (Algar, et al., 2012) as well as anecdotal reports of a positive response in forest birds such as the Christmas Island emerald dove (*Chalcophaps indica natalis*). It is premature to make claims about the recovery of extant species on DHI other than to note detections of species on cameras which were not detected in 2014. These include the little long-tailed dunnart (*Sminthopsis dolichura*), painted button quail (*Turnix varius)* and bush stone curlew (*Burhinus grallarius*). The wildlife response on DHI will be intensively monitored in subsequent years during the ecological restoration of the island.

ACKNOWLEDGEMENTS

The Dirk Hartog Island Ecological Restoration Project is funded by the Gorgon Barrow Island Net Conservation Benefits Fund. The DHI cat team comprises Gary Desmond, Jason Fletcher, Neil Hamilton, Mike Onus and Cameron Tiller. The Christmas Island Cat Eradication Project is currently funded by the Director of National Parks, the Threatened Species Commissioner and an environmental mining offset acquired from Phosphate Resources Ltd (Christmas Island). Funding has also been provided by Department of Infrastructure and Regional Development, the Shire of Christmas Island, Christmas Island Phosphates and Border Force. The CI cat team comprises Neil Hamilton, Jason Fletcher, and Cameron Tiller together with the island-wide survey baiting team Dion Maple, Rob Muller, Samantha Flakus, Matt Hudson, Tanya Detto, Jol Muller, Trent Lane, Joanna Chan, Simone Richardson, Brendan Tiernan, Renata de Jonge, Jason Turl, Sean White, Simon Pahor and John Jaycock. The Department of Biodiversity, Conservation and Attractions Animal Ethics Committee approved protocols 2009/35, 2012/41 and 2015/39 which describe activities undertaken in this project.

REFERENCES

Abbott, I. and Burbidge, A.A. (1995). 'The occurrence of mammal species on the islands of Australia: a summary of existing knowledge'. *CALMScience* 1(3): 259–324.

Algar, D., Burbidge, A.A. and Angus, G.J. (2002). 'Cat eradication on the Montebello Islands'. In: C.R. Veitch and M.N. Clout (eds.) *Turning the tide: the eradication of invasive species*, pp. 14–18. Occasional Paper SSC no. 28. IUCN SSC Invasive Species Specialist Group. IUCN, Gland, Switzerland and Cambridge, UK.

Algar, D. and Burrows, N.D. (2004). 'Feral cat control research: Western Shield review, February 2003'. *Conservation Science Western Australia* 5(2): 131–163.

Algar, D., Angus, G.J., Williams, M.R. and Mellican, A.E. (2007). 'Influence of bait type, weather and prey abundance on bait uptake by feral cats (*Felis catus*) on Peron Peninsula, Western Australia'. *Conservation Science Western Australia* 6(1): 109–149.

Algar, D. and Brazell, R.I. (2008). 'A bait-suspension device for the control of feral cats'. *Wildlife Research* 35: 471–476.

Algar, D., Angus, G.J., Brazell, R.I., Gilbert, C. and Withnell, G.B. (2010). 'Eradication of feral cats on Faure Island, Western Australia'. *Journal of the Royal Society of Western Australia* 93: 133–140.

Algar, D. and Johnston, M. (2010). *Proposed Management Plan for Cats and Black Rats of Christmas Island*. Western Australian Department of Environment and Conservation. 63 pp.

Algar, D., Johnston, M. and Hilmer, S.S. (2011a). 'A pilot study for the proposed eradication of feral cats on Dirk Hartog Island, Western Australia'. In: C.R. Veitch, M.N. Clout and D.R. Towns (eds.) *Island invasives: eradication and management*, pp. 10–16. Occassional Paper SSC no. 42. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB.

Algar D, Angus G.J. and Onus M.L. (2011b). 'Eradication of feral cats on Rottnest Island, Western Australia'. *Journal of the Royal Society of Western Australia* 94: 439–443.

Algar, D., Hilmer, S., Nickels, D. and Nickels, A. (2011c). 'Successful domestic cat neutering: first step towards eradicating cats on Christmas Island for wildlife protection'. *Ecological Management and Restoration* 12(2): 93–101.

Algar, D., Hamilton, N., Holdsworth, M. and Robinson, S. (2012). 'Cat removal implicated in improved nestling success in iconic red-tailed tropicbird rookery'. *Landscope* 27(4): 43–47.

Algar, D., Onus, M.L. and Hamilton, N.A. (2013). 'Feral cat control as part of 'Rangeland Restoration' at Lorna Glen (Matuwa), Western Australia: the first seven years'. *Conservation Science Western Australia* 8(3): 367–381.

Algar, D., Hamilton, N., and Pink, C. (2014). 'Progress in eradicating cats, *Felis catus*, on Christmas Island to conserve biodiversity'. *Raffles Bulletin of Zoology* Supplement No. 30: 44–52.

Baynes, A. (1990). 'The Mammals of Shark Bay, Western Australia'. In: P.F. Berry, S.D. Bradshaw and B.R. Wilson (eds.) *Research in Shark Bay—Report of the France-Australe Bicentenary Expedition Committee,* pp. 313–325. Perth, WA: Western Australian Museum.

Beard, J. (1976). *Vegetation Survey of Western Australia*, *Sheet 6. 1:1 000 000 Map Sheet and Explanatory Notes*. Perth, Australia: UWA Press.

Beeton, B., Burbidge, A., Grigg, G., Harrison, P., How, R., McKenzie, N. and Woinarski, J. (2010). *Final Report of the Christmas Island Expert Working Group to Minister for the Environment Protection, Heritage and the Arts*. Canberra: nt of the Environment, Water, Heritage and the Arts.

Bester, M.N., Bloomer, J.P., Van Aarde, R.J., Erasmus, B.H., van Rensburg, P.J.J, Skinner, J.D., Howell, P.G. and Naude, T.W. (2002). 'A review of the successful eradication of feral cats from sub-Antarctic Marion Island, Southern Indian Ocean'. *South African Journal of Wildlife Research* 32(1): 65–73.

Blackburn, T.M., Cassey, P., Duncan, R.P., Evans, K.L. and Gaston, K.J. (2004). 'Avian extinction and mammalian introductions on oceanic islands'. *Science* 305: 1955–1958.

Bloomer, J.P. and Bester, M.N. (1992). 'Control of feral cats on sub-Antarctic Marion Island, Indian Ocean'. *Biological Conservation* 60: 211–219.

Bode, M., Brennan, K.E.C., Helmstedt, K., Desmond, A., Smia, R. and Algar, D. (2013). 'Interior fences reduce cost and uncertainty when eradicating invasive species from islands'. *Methods in Ecology and Evolution* 4(9): 819–827.

Bomford, M. and O'Brien, P. (1995). 'Eradication or control for Vertebrate Pests'? *Wildlife Society Bulletin.* 23(2): 249–255.

Bonnaud, E., Zarzosa-Lacoste, D., Bourgeois, K., Ruffino, L., Legrand, J. and Vidal, E. (2010). 'Top-predator control on islands boosts endemic prey but not mesopredators'. *Animal Conservation* 13(6): 556–567.

Burbidge, A.A. Williams, M.R. and Abbott, I. (1997). 'Mammals of Australian islands: factors influencing species richness'. *Journal of Biogeography* 24: 703–715.

Burbidge, A.A. (1999). 'Conservation values and management of Australian islands for non-volant mammal conservation'. *Australian Mammalogy* 21: 67–74.

Burbidge, A. (2001). 'Our largest island'. *Landscope* 17(2): 16–22.

Burbidge, A.A. and Manly, B.F.J. (2002). 'Mammal extinctions on Australian islands: causes and conservation implications'. *Journal of Biogeography* 29: 465–473.

Bureau of Meteorology (2017). 'Climate data online'. <http://www.bom.gov.au/climate/cdo/about/cdo-selecting-data.shtml>. Accessed July 2017.

Campbell, K.J., Harper, G., Algar, D., Hanson, C.C., Keitt, B.S. and Robinson, S. (2011). 'Review of feral cat eradications on islands'. In: C.R. Veitch, M.N. Clout and D.R. Towns (eds.) *Island invasives: eradication and management*, pp. 37–46. Occassional Paper SSC no. 42. Gland, Switzerland: IUCN and Auckland, New Zealand: CBB.

Claussen, J. (2005). *Native Plants of Christmas Island*. Perth: Success Print.

DE (Department of the Environment) (2015). *Threat Abatement Plan for Predation by Feral Cats*. Commonwealth of Australia. 47 pp.

DEWHA (Department of the Environment, Water, Heritage and the Arts) (2008). *Threat Abatement Plan for Predation by Feral Cats*. Canberra: Department of the Environment, Water, Heritage and the Arts.

Dickman, C.R. (1992). 'Conservation of Mammals in the Australasian Region: the Importance of Islands'. In: J.N. Coles and J.M. Drew (eds.) *Australia and the Global Environmental Crisis*, pp. 175–214. Canberra: Academy Press.

Dickman, C.R. (1996). *Overview of the Impact of Feral Cats on Australian Native Fauna*. Report to Australian Nature Conservation Agency.

EA (Environment Australia) (1999). *Threat Abatement Plan for Predation by Feral Cats.* Environment Australia, Biodiversity Group, Canberra.

EA (Environment Australia) (2002). *Third Christmas Island National Park Management Plan*. Environment Australia, Canberra.

Green, P. (2014). 'Mammal extinction by introduced infectious disease on Christmas Island (Indian Ocean): The historical context'. *Australian Zoologist* 37: 1–14.

Johnston, M., Algar, D., Onus, M., Hamilton, N., Hilmer, S., Withnell, B. and Koch, K. (2010). *A Bait Efficacy Trial for the Management of Feral Cats on Dirk Hartog Island*. Arthur Rylah Institute for Environmental Research Client Report. Heidelberg, Victoria: Department of Sustainability and Environment.

Johnston, M., McCaldin, G. and Rieker, A. (2016). 'Assessing the availability of aerially delivered baits to feral cats through rainforest canopy using unmanned aircraft'. *Journal of Unmanned Vehicle Systems* 4(4): 276–281.

Keitt, B.S.; Wilcox, C.; Tershy, B.R.; Croll, D.A. and Donlan, C.J. (2002). 'The effect of feral cats on the population viability of black-vented shearwaters (*Puffinus opisthomelas*) on Natividad Island, Mexico'. *Animal Conservation* 5: 217–223.

King, W.B. (1985). 'Island Birds: Will the Future Repeat the Past'? In: P.J. Moors (ed.) *Conservation of Island Birds*, pp. 3–15. International Council for Bird Preservation Technical Publication No. 3. Cambridge, England.

Martin, T.G., Nally, S., Burbidge, A.A., Arnall, S., Garnett, S.T., Hayward, M.W, Lumsden, L.F., Menkhorst, P., McDonald-Madden, E. and Possingham, H.P. (2012). 'Acting fast helps avoid extinction'. *Conservation Letters* 5: 274–280.

Martinez-Gomez, J.E. and Jacobsen, J.K. (2004). 'The conservation status of Townsend's shearwater *Puffinus auricularis auricularis*'. *Biological Conservation* 116: 35–47.

McKenzie, N.L., Hall, N. and Muir, W.P. (2000). 'Non-volant mammals of the southern Carnarvon Basin, Western Australia'. *Records of the Western Australian Museum Supplement No. 6*: 479–510.

Medina, F.M., Bonnaud, E., Vidal, E., Tershy, B.R., Zavaleta, E.S., Donlan, C.J., Keitt, B.S., Le Corre, M., Horwath, S.V. and Nogales, M. (2011). 'A global review of the impacts of invasive cats on island endangered vertebrates'. *Global Change Biology* 17: 3503–3510.

Misso, M. and West, J. (2014). 'Conservation management of the terrestrial biodiversity of Christmas Island: challenges and perspectives'. *Raffles Bulletin of Zoology Supplement* No. 30: 17–23.

Moors, P.J. and Atkinson, I.A.E. (1984). 'Predation on Seabirds by Introduced Animals, and Factors Affecting its Severity'. In: J.P. Croxall, P.J.H. Evans and R.W. Schreiber (eds.) *Status and Conservation of the World's Seabirds*, pp. 667–690. International Council for Bird Preservation Technical Publication No. 2. Cambridge, England.

Moro, D. (1997). 'Removal of a feral cat from Serrurier Island'. *Western Australian Naturalist* 21: 153–156.

Nogales, M., Martin, A., Tershy, B.R., Donlan, C.J., Veitch, D., Puerta, N., Wood, B. and Alonso, J. (2004). 'A review of feral domestic cat eradication on islands'. *Conservation Biology* 18(2): 310–319.

Nogales, M., Vidal, E., Medina, F.M., Bonnaud, E., Tershy, B.R., Campbell, K.J. and Zavaleta, E.S. (2013). 'Feral cats and biodiversity conservation: the urgent prioritization of island management'. *BioScience* 63(10): 804–810.

Orchard, M. (2012). *Crabs of Christmas Island*. Christmas Island Natural History Association. Christmas Island, Indian Ocean, Australia.

Payne, A.; Curry, P. and Spencer, G. (1987). 'An Inventory and Condition Survey of Rangelands in the Carnarvon Basin, Western Australia'. *Technical Bulletin No.73.* Perth, Australia: Western Australian Department of Agriculture.

Pontier, D., Say, L., Debias, F., Bried, J., Thioulouse, J., Micol, T. and Natoli, E. (2002). 'The diet of cats (*Felis catus* L.) at five sites on the Grande Terre, Kerguelen archipelago'. *Polar Biology* 25: 833–837.

Ratcliffe, N., Bell, M., Pelembe, T., Boyle, D., White, R.B.R., Godley, B., Stevenson, J. and Sanders, S. (2009). 'The eradication of feral cats from Ascension Island and its subsequent recolonization by seabirds'. *Oryx* 44(1): 20–29.

Robinson, S., Gadd, L., Johnston, M. and Pauza, M. (2015). 'Long-term protection of important seabird breeding colonies on Tasman Island through eradication of cats'. *New Zealand Journal of Ecology* 39(2): 316–322.

Springer, K. (2016). 'Methodology and challenges of a complex multi-species eradication in the sub-Antarctic and immediate effects of invasive species removal'. *New Zealand Journal of Ecology* 40(2): 273–278.

Short, J., Turner, B., Risbey, D.A. and Carnamah, R. (1997). 'Control of feral cats for nature conservation. II. Population reduction by poisoning'. *Wildlife Research* 24: 703–714.

Tidemann, C.R., Yorkston, H.D. and Russack, A.J. (1994). 'The diet of cats, *Felis catus*, on Christmas Island, Indian Ocean'. *Wildlife Research* 21: 279–286.

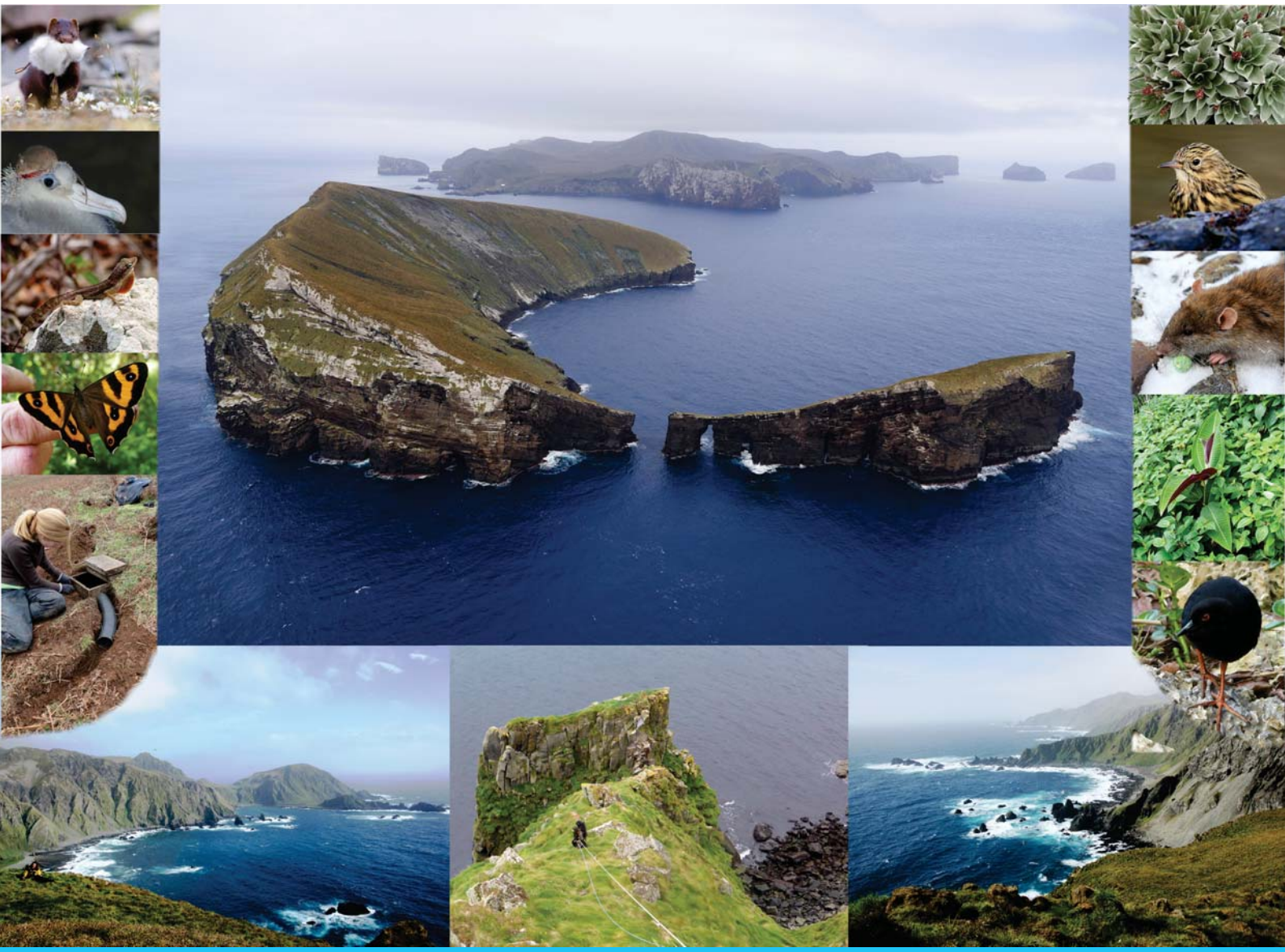
Van Aarde, R.J. (1980). 'The diet and feeding behaviour of feral cats, *Felis catus*, on Marion Island'. *South African Journal of Wildlife Research* 10: 123–128.

Veitch, C.R. (1985). 'Methods of eradicating feral cats from offshore islands in New Zealand''. In: P.J. Moors (ed.) *Conservation of Island Birds*, pp. 125–141. International Council for Bird Preservation Technical Publication No. 3. Cambridge, England.

Island invasives: scaling up to meet the challenge

Proceedings of the international conference on island invasives 2017

Edited by C.R. Veitch, M.N. Clout, A.R. Martin, J.C. Russell and C.J. West



Occasional Paper of the IUCN Species Survival Commission N° 62

SSC
Species Survival Commission