ENVIRONMENTAL IMPACT ASSESSMENT

FOR THE ERADICATION OF

BLACK RATS *Rattus rattus*

FROM THE OUTER CHAGOS ARCHIPELAGO

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Cover image: Sooty terns *Onychoprion fuscatus* (G. Harper)

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EXECUTIVE SUMMARY

This Environmental Impact Assessment (EIA) evaluates the likely impact of a proposed eradication of black rats from 30 islands of the outer Chagos Archipelago, Indian Ocean, by utilising aerial application of brodifacoum-laced rat bait. The project has been justified by the evidence that rats have caused considerable degradation of the terrestrial ecosystem throughout the Chagos Archipelago, along with probable flow-on impacts in the marine environment, through significant predation on the native seabirds, invertebrates and flora over the past 200 years.

The background to the eradication operation is laid out, along with an outline of the operational plan to use helicopters to distribute bait, operating from a support vessel. Alternatives to the suggested techniques in the feasibility study, such as ground baiting or using a different toxin, are assessed and rejected. All possible impacts of the operation are then assessed, including impacts on native and introduced species, soil and water, humans, and wilderness values, or because of fuel spills, waste, possible biosecurity breaches or at more distant sites.

Assessment of the proposed operation's likely environmental impacts is undertaken and mitigation actions proposed where possible. The ethics of eradicating rats using a second-generation anticoagulant are evaluated, but more humane methods are, like ground-baiting, not feasible on a highly isolated archipelago such as the Chagos Archipelago. There are few non-target species likely to die through primary or secondary poisoning on the islands and there are no population level impacts on non-target species.

As brodifacoum is very insoluble in water toxic baiting will have ephemeral and very minor effects on soil, water and vegetation, which will result in the poison being degraded to its constituent components over the course of weeks to months by microorganisms in soil or sediment. What little bait that enters the ocean will be quickly broken up by wave action and disperse. The bait will again be quickly degraded in the marine ecosystem.

The operation of two helicopters will cause most of the physical disturbance and noise associated with the eradication, with some minor transitory effects where the few ground-baiting sites are. There is unlikely to be extended effects on what few nesting seabirds there may be on rat-infested islands during the operation, but care should be taken if seabird colonies are present.

Ship and helicopter operations will be the primary source of atmospheric emissions, along with possible fuel spills. There is little that can be done to reduce the atmospheric emissions to any large degree, but prompt and effective suppression of fuel spills will limit any impact from this source.

Management of waste is largely covered by the MARPOL convention as the operation is ship-based, and any non-biodegradable waste generated onshore will be returned to the ship

for processing. Current biosecurity procedures will require some additional improvement prior to the eradication proceeding.

From its inception this proposed operation has examined the potential environmental impacts and intends to incorporate these factors into future decision processes. Further development of this document will include assigning roles and responsibilities for managing environmental impacts and implementation of suggested mitigation measures. Monitoring, and responding to any environmental impacts, will be an integral part of the eradication programme, in order to maximise the benefits that will accrue from the project.

The EIA concludes that the overall predictable impacts of the eradication operation are likely to be transitory and minor in nature, particularly if suggested mitigation actions are acted upon.

Negative environmental impacts are likely to be ephemeral, particularly if impact mitigation measures are adhered to. Similarly, non-target species impacts should be very limited and transitory, with rapid recovery from any losses.

The anticipated ecological benefits of the operation, due to the complete removal of rats, are likely to be significant. Successful eradication is expected to result in restoration of ecosystem function. It is expected there will be a substantial increase in seabird abundance over time, associated nutrient deposition, improved native forest diversity and structure, increased marine turtle nesting success and numbers, with a corresponding improvement in the diversity and resilience of marine reef species.

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INTRODUCTION

This EIA sets out to determine the likely impact of a proposed rat eradication operation on the environment of the Chagos Archipelago. The assessment will introduce a description of the treatment area, the preferred eradication technique and a consideration of alternative techniques. The main body of the document will evaluate the likely environmental impacts and where possible suggest ways to mitigate these impacts. It should be acknowledged that this EIA is a living document and it is expected to be amended as the proposed operation develops.

This EIA will be subject to independent evaluation by eradication practitioners and specialists of the Island Eradication Advisory Group (IEAG; NZ) and Island Conservation (IC; USA).

The introduction of invasive black rats, along with habitat modification, has caused extensive damage to the ecosystem of the Chagos Archipelago, through predation of seabirds, chicks and eggs, and invertebrates including land crabs, consumption of native plants and propagules, and the flow-on effects to the adjacent marine environment through disruption of nutrient flows.

Black rats were probably introduced during European colonisation of the islands and only 4.7% of the terrestrial space on the entire Chagos Archipelago is now considered free of mammalian predators (Harper et al. 2019). They have caused significant declines in seabird distribution and abundance.

A proposed rat eradication project plans to remove all rats from the 30 rat-infested islands of the outer Chagos Archipelago. The rat populations are largely separated from each other on each island, so rats can be eradicated island by island through a 6-8 week operation. This document will be amended as the operational planning develops and if any additional information is forthcoming during the pre-operation trials.

Two aerial applications of pollard bait pellets laced with the second-generation anticoagulant brodifacoum will be undertaken by helicopters with under slung bait spreaders. Where required, areas of heritage buildings or mangrove forest will be treated by hand-baiting. Bait applications will occur at least 10 days apart to ensure all rats have access to bait over space and time.

It is proposed that the rat baiting will be conducted from a suitable support vessel, as there are few suitable landing sites for helicopters to operate from and many islands are separated by considerable distances. A team of about 15-20 personnel will undertake the operation.

Alternative toxins and methods were assessed. However, other aerial rat eradications have shown that brodifacoum is the most efficacious for rat eradication. Ground techniques for bait application were also assessed but at the envisaged scale were impractical, lengthy, expensive and caused significantly more localised damage than aerial bait application, especially at the scale involved. However, bait may be hand-laid on some small areas on a few islands where aerial techniques may result in bait not being readily available to rats, such as in mangrove swamps for example.

1. PURPOSE OF ERADICATION

Black rats (*Rattus rattus*) have been introduced to islands throughout the world as a stowaway during human exploration and colonisation. Their arrival, irruption, and predation of, and competition with, naive native island species has invariably caused a local collapse in ecological function (Harper & Bunbury 2015).

Damage by rats has been particularly heavy on tropical islands as they are particularly rich repositories of biodiversity wealth. Within the Chagos Archipelago, where seabirds are keystone species essential for ecosystem integrity, rats are present on 95% of the entire archipelago.

Rats have been present for about 200 years, but ecological damage has only been recorded relatively recently. For example, Symens (1999) recorded significant loss of tern species on rat-infested islands within the Chagos Archipelago and Carr et al. (*in review*) showed that red-footed booby were significantly more common on rat-free islands. The scale of these losses is partially explained by the high population densities black rats can attain on tropical islands where they can breed year round.

Declines in seabird numbers and colony size have far-reaching effects through alteration of nutrient flows into the adjacent ocean, with reductions in algae, plankton abundance, and reef fish diversity along with altering feeding sites of marine megafauna such as manta rays (McCauley et al. 2012, Graham et al. 2018). In the long-term, rats will also alter the composition and structure of forest through preferential consumption of seeds, seedlings and fruit (Harper & Bunbury 2015).

The purpose of the proposed eradication is to remove all black rats from the 30 islands of the outer Chagos Archipelago that they are present. This will allow native, invertebrates including land crabs, and plant species to recover, enabling the restoration of local terrestrial and marine biological diversity and ecological functioning.

Post-eradication monitoring will check that all islands are free of rats and record the response of native species to the rats' removal. If any rats survive on any islands they will be re-treated to ensure no rats remain to re-invade any neighbouring islands. Strict biosecurity will be essential to ensure the benefits of the proposed eradication will endure.

1.1 Summary of proposed eradication method

The eradication operation plans to remove all rats from 30 islands in the outer Chagos Archipelago through two aerial applications of brodifacoum-laced pollard baits at least 10 days apart. This is a successful and commonplace eradication technique and used been used to eradicate rodents on several hundred islands worldwide (Howald et al. 2007).

A few small areas of heritage value or where mangrove forest is present will have rat bait hand-laid. The operation will operate from a support vessel, which will transport the entire team and all the resources required for the operation to and from the islands.

It is proposed the operation is conducted in June as this is historically the driest month in the archipelago. The operation will be successful if there are no rats present on any of the 30 islands at least 12 months after the eradication is completed, as this allows rats time to recover to detectable levels on tropical islands (Keitt et al. 2015).

Figure 1. Map of the outer Chagos Archipelago showing its location and the atolls proposed for rat eradication (coloured).

2. BACKGROUND

2.1 Previous control and eradication efforts in the Chagos Archipelago

No rat control has been undertaken on the outer islands of the Chagos Archipelago in recent times. A bait-station rat eradication attempt using bait blocks on Eagle Island (252ha) in 2006 failed and was an object lesson in the challenges involved. Another eradication attempt in 2014 (Harper et al. 2019), using hand-broadcast of rat bait pellets was successful on Ile Vache Marine (Peros Banhos) and two small islands (Salomon). Further eradication trial work on at least one larger island at Peros Banhos is planned before the proposed whole archipelago operation begins.

2.2 Feasibility study
A feasibility study was recently completed (Harper 2020 [a]) to assess the likelihood of a rat eradication of the outer islands of the Chagos Archipelago being successful. It highlighted some issues, particularly the significant logistical challenges of undertaking an eradication operation at such a highly isolated location, but concluded if conducted in the driest month (June), using aerially applied rat toxin, it would have a very good chance of success.

2.3 Project management structure

The project will be overseen by a coalition of stakeholders with management provided by the Chagos Conservation Trust. A financial controller and a steering group will have overall financial and governance oversight of the project. A Project Manager will coordinate the detailed logistical management and planning with an Operations Manager running the field component encompassing the bait application and staff management. A team of experienced eradication professionals, including pilots and associated staff, will provide the personnel to undertake the operation.

2.4 Description of the proposed activity

This technique is a proven method and is in accordance with best practice worldwide (Holmes et al. 2015). Aerial broadcasts take substantially less time to carry out than other options. However, they involve considerable time for planning and can very costly, particularly where helicopter(s), suitable pilot(s) and associated equipment needs to be shipped in, which will be the case for the Chagos Archipelago. This operation will also require the input of highly skilled technical expertise.

Species vulnerable to secondary poisoning (either by eating bait or by eating other animals that have eaten poison bait) will need particular attention. Monitoring of native species before and after the operation will assess the impacts and biological response of the operation.

The field operations would involve a support ship transporting the helicopters and staff to the Chagos Archipelago, where the helicopters would be made operational. The support vessel would also transport the rat bait. It would steam to points off the various target islands or within the atolls to conduct the operation across the nearby islands.

At the recommended time of year for the eradication the prevailing weather during the operation is likely to be windy – 15-25kt, mainly from the southeast, with medium sea conditions (2-2.5m SE swell) so bait loading and helicopter operations will have to be done in the lee of the islands or within the atolls to enable safe operating conditions.

The support vessel will be required to provide live-aboard accommodation for the operation crew and will have the facilities (communications, cleaning, cooking facilities, aircraft support equipment, air conditioning etc.) to support the operation. The daily operation would involve running repeated loading of the bait buckets slung under the helicopter(s) during each day as flying conditions allow.

The aerial bait application will require that the helicopters carry under-slung bait buckets, which deliver bait pellets across a 50m wide swath as they follow parallel lines pre-loaded into the helicopter's GPS. Once the bait bucket is empty the helicopters return to the ship, where 20-25kg bait bags are loaded into it by a baiting team. The number of bait bags loaded into the bait buckets depend on the size of the bait bucket and the load the helicopter can carry. This can vary from ~300kg to 1 tonne.

Additional ground baiting of mangrove forest at two small sites will be carried out by a ground team. This is to ensure bait is available at these sites, which are consistently inundated, by attaching bait to trees, above the high-tide line.

The current quarantine procedures for island visits would remain in force for the operation with respect to checking clothing for weeds and seeds, bringing food and water on to the island and disposal of human waste. Where ground baiting is done only enough food/water for a day's operation would be taken to the islands and any remaining rubbish removed at the end of the day's operation. For refuelling the helicopter(s) will refuel on the ship. Permits to operate the helicopters will need to be obtained from British Indian Ocean Territory Administration (BIOTA) before the operation commences (Refer to Section 2.3).

The expected duration of the operation is up to three weeks with 10-14 days transit in each direction to/from the port of departure. Once the operation is complete the operation team would depart on the support vessel to the port of departure and would take all rubbish and any remaining bait with them.

2.5 Project documentation

A draft Feasibility Study and draft Operational Plan for proposed rat eradication project have been prepared and have been reviewed by the IEAG and IC. The reviewed documents will be amended where required before acceptance as completed documents for project implementation.

3. ALTERNATIVE OPTIONS

3.1 Do nothing

Rats on the Chagos Archipelago are a threat to the existence of seabirds, invertebrates including land crabs, and forest diversity and structure. Without their control or removal ecosystem degradation will continue. Furthermore, their existence also risks possible incursions occurring on other rat-free islands within the archipelago, particularly on Peros Banhos and Salomon atolls.

Delaying an eradication in order to wait for the development of less toxic, or cheaper eradication tools increases these risks without any guarantees the tools will reach 'field deployment' stage in the foreseeable future and their inherent risks are overcome (Kym et al. 2018, Manser et al. 2019).

At present this globally important island ecosystem continues to deteriorate with rats present and it is only luck that has prevented rats from invading new islands within the archipelago. Not proceeding with rat eradication does also mean that "The terrestrial and marine biodiversity and ecological integrity of BIOT is protected, enhanced and restored where possible" as the current British Indian Ocean Territory Administration priorities require and is inconsistent with the obligations of international agreements such as the Convention for Biological Diversity.

3.2 Rat control

On-going control or reduction in the rat population on all the islands, or eradication on some more isolated islands (e.g. Eagle or Egmont Islands) would likely have some local benefits. However, ground baiting is very time consuming, labour intensive and costly, and organising periodic control using helicopters would cost a significant portion of a single all-encompassing eradication operation.

Furthermore, benefits to native fauna and flora would only last as long as funding and logistical support is available. Prolonged control also adds the risk that rats may eventually avoid or develop a tolerance to anticoagulant bait, which would compromise control efforts or risk failure of any future eradication attempt. Moreover, there is also additional continued risk of secondary poisoning of native wildlife and likely accumulation of poison in the food chain.

Research on the costs and benefits of control versus eradication clearly showed that eradication was more beneficial in terms of seabird breeding success, environmental impact and cost (Pascal et al. 2008). In the long term, rat *control* means that the ecological goals for the islands' management as outlined in the BIOTA priorities would always be at risk.

3.3 Ground-based rodent eradication

Ground based eradication will be required in a few small areas on some islands where aerial application may results in bait not being available for rodents. This includes old settlements and mangrove swamps, where bait may fall into standing water or onto roofs for example.

3.3.1 Trapping

Trapping involves the use of persons to establish, set and check traps (be they kill-traps, live traps, self-resetting traps, etc.). They do have the advantage of avoiding toxin use. To be an effective tool for rat eradication on 30 islands over 1700 ha, traps would need to be set on a grid of at least 25m x 25m, or some 27,000 traps for all the islands.

In order to service the traps on at least a daily basis would require a person to check about 100 traps per day which would require some 270 people requiring accommodation and regular servicing to provide food and associated supplies with an associated environmental impact due to ship traffic and establishment of field camps.

Moreover, establishing traps require a grid of tracks which create a significant environmental impact in itself, which would include non-target deaths of native species such as land-crabs or seabirds. Trapping is also not an effective method for eradication in itself and would require at least several months of effort to achieve any degree of reduction in rat populations.

Trapping is simply not tenable as a method for the reasons of its likely failure, the large amount of resources and staff required to undertake the operation, the risk of non-target deaths, the substantial and prolonged environmental impact and likely high cost.

3.3.2 Bait stations or hand-laying bait.

Bait station use has several advantages in that bait could be kept dry in the wet conditions prevalent in the Chagos Archipelago, a lower non-target risk to native species, un-used bait can be removed, and more toxins could be used in bait stations. However, it has most of the disadvantages associated with trapping, including the large number of personnel required with the prolonged environmental impact of tracks, field camps and servicing this infrastructure and the associated high cost. Hand-laying bait also has these disadvantages but few of the advantages of bait stations as it essentially mimics aerial bait application.

Ground-based methods would be prolonged operations with a high environmental and monetary cost. They are also not cost-effective over 30 islands covering some 1700ha and the option is rejected as an efficacious or practical tool.

3.4 Alternative poisons

To use rodent toxins effectively in an eradication operation, additional criteria to the eradication planning principles outlined in Section 1.1 need to be addressed in order that all rats consume a lethal dose. These criteria are (after Howald et al. 2007, Keitt et al. 2015):

i. All individual animals must be exposed for sufficient time, and be susceptible, to toxic bait.

ii. Toxic bait should be highly palatable.

ii. Toxic bait should be applied using a method that precludes bait aversion.

Several rodent toxins are available for rodent control, they include:

A. Zinc Phosphide. This is the second most common rodent control toxin used after anticoagulants. It is an acute poison, which requires pre-feeding to overcome bait shyness and its effectiveness is also degraded when wet (Eason & Ogilvie 2009). It is highly toxic to birds so is a significant risk to non-target species on the outer islands of the Chagos Archipelago. Moreover, there are no formulations suitable for aerial delivery. It is not a practical option for an eradication on the Chagos Archipelago.

B. Sodium monofluoroacetate (1080). This toxin is used in New Zealand and Australia and has highly effective against rats (Innes et al. 1995). It is an acute toxin so bait aversion is an issue (Morriss et al. 2008), as is its water solubility (Eason and Wickstrom, 2001). Although there are formulations for aerial application these constraints preclude it as an option for this eradication operation.

C. Cholecalciferol (Vitamin D_3). This is also an acute poison, causing death. It's mode of action is through mobilisation of calcium stores into the bloodstream resulting in calcification of the cardiovascular system and other internal organs. Death is usually by heart failure (Eason & Ogilvie 2009). Unfortunately it is not currently available in a formulation for aerial application and also readily degrades when exposed to the elements (Mason and Litton, 2003). It is not a practical poison for an eradication on the Chagos Archipelago.

D. Bromethalin. This is a neurotoxicant that causes death through reduced nerve impulse conduction leading to paralysis (Eason & Ogilvie 2009). Although it can be very effective against rodents it is also highly toxic to birds and is not currently available in a formulation suitable for aerial application.

E. Anticoagulants. The primary method for eradicating rodents from islands is the use of anticoagulants combined into a highly palatable cereal or wax baits, distributed across every rat territory (i.e. across the whole island) in a methodical and comprehensive manner (Howald et al. 2007). This method has been developed and refined over many years and in many different eradication projects.

Anticoagulants cause death in rats by preventing blood clotting and hence, causing internal haemorrhaging (Eason et al. 2002). The effects of the anticoagulants are not felt by the rats until a few days after consumption and hence, are unlikely to associate the symptoms with the bait and cause them to cease eating it (i.e. bait avoidance or shyness) before they received a lethal dose.

First and second-generation anticoagulant rodenticides (FGAs & SGAs) have both been used to successfully eradicate rodent on islands. First-generation anticoagulants (warfarin, diphacinone, chlorophacinone, coumatetralyl) are less potent and less persistent but require multiple feeds over several days to reach a lethal dose, so would require multiple applications during about a week in order to be effective.

An additional toxin, Cholecalciferol + Coumatetralyl (C+C), comprising a mix of a first generation anticoagulant with Cholecalciferol, has shown promise. It is less persistent in the environment but with similar effectiveness as second generation anticoagulants. It is also more humane as animals will die more quickly than by SGAs (Eason & Ogilvie 2009). Although it has several advantages such as low toxicity to birds and reduced secondary poisoning risk, there is no formulation available for aerial application at present.

In contrast to the FGAs, second generation anticoagulants (brodifacoum, bromadiolone, difenacoum, flocoumafen) are more potent and more persistent but do not require multiple feeds, a lethal dose can be attained through a single feed of bait. This latter characteristic makes them better suited to tropical environments where competition for bait by land crabs and other bait consumers (e.g. ants) can be high and natural food can be available all year around. Bromodialone is also not as toxic to rats as brodifacoum so would require higher doses or application rates to be effective (Đpakauskas et al. 2005).

Although they act in the same way as brodifacoum, bromadiolone, difenacoum, and flocoumafen are not registered for aerial broadcasting, which is the preferred method for this eradication (Eason and Ogilvie, 2009). Moreover, brodifacoum has a long and well-recorded history of success as a rodent eradication toxin on islands (Howald et al. 2007).

Although second-generation anticoagulants break down in soil relatively quickly (<6 months Fisher et al. 2011) they can persist in the blood and livers of non-target species, particularly mammals and birds (Hoare & Hare 2006, Pitt et al. 2015). Invertebrates, including land crabs appear to be little affected due to differences in their blood physiology (Pain et al. 2000, Brooke et al. 2013). Anticoagulant accumulation generally occurs where pest control operations are of long duration with multiple bait deployments and is much less of a concern in short-term applications, particularly on isolated islands (Hoare & Hare 2006).

Poison	Poison type	Half-life in blood/tissue	Persistence in the environment	Available for aerial application?
Zinc phosphide	Acute toxin		12-24 hrs.	N
1080	Acute toxin	<11 hrs.	7 days	Y
Cholecalciferol	Acute toxin	10-68 days	12 weeks	N
Bromethalin	Neurotoxin	6 days	-	N
C+C	Calcium mineralisation	-	-	N
Coumatetryl	FGA	50-70 days	16 weeks	N
Diphacinone	FGA	3 days	6 weeks	Y
Pindone	FGA	2.1 days	4 weeks	Y
Difenacoum	SGA	<100 days	-	N
Bromodialone	SGA	170 days	<24 months	N
Brodifacoum	SGA	130 days	<24 months	Y

3.5 Summary of alternatives

Do nothing	This alternative is rejected as will not fulfil the objectives of the BIOTA environmental priorities or remove the predominant agent of decline of many terrestrial native species on the Chagos Archipelago.
Rat control	This alternative will be expensive, of unknown duration, cause substantial damage to the islands and subject to the vagaries of budget re-allocations, without removing rats. For these reasons it is rejected.
Ground-based eradication techniques	Similar to rat control, ground-based eradication techniques will be expensive, of long duration, cause substantial damage to the islands and have a much lower chance of success.
Alternative poisons	There are no alternatives to brodifacoum that were as effective with a correspondingly extensive and proven

	record of success in rodent eradications utilising aerial bait distribution.

4. SITE DESCRIPTION

Located in the middle of the Indian Ocean the Chagos Archipelago comprises the largest atoll in the world, the Great Chagos Bank, alongside four additional atolls (Carr 2011). On the atolls' rims 55 small islands comprise the terrestrial portion of the territory at some 21km^2 (Harper et al. 2019).

Diego Garcia, the largest island and holds a military facility in the Chagos Archipelago, is on the southern boundary of the archipelago (Fig. 1). Low-lying and geologically young these remote islands have not had the speciation that has developed on similarly isolated archipelagos such as Hawaii and the Seychelles. The atolls are largely formed from marine sand deposits with some raised rock formations.

The islands were discovered in about 1500 by Portuguese explorers but were not permanently settled until the late 18th century. A substantial copra and coconut oil operation was developed across the entire archipelago and thrived until the middle of the 20th century. Coconut oil and copra production facilities were initially established at Diego Garcia using slave labour and were soon replicated on the outer islands of the Chagos Archipelago (Stoddart 1971b).

Virtually all the target islands have had the native forest removed and replaced with a dense monoculture of coconut palms (*Cocos nucifera*). As several seabird species preferentially nest in native trees, this destruction of nesting habitat was probably the first major impact on the previously large seabird colonies that existed there. The settlers also supplemented their diet with seabirds, seabird eggs, turtles and their eggs, and introduced invasive mammals, which hastened the decline in native bird numbers and degraded native forest.

The outer islands of the Chagos Archipelago are the wettest of all the atolls in the Indian Ocean. The mean rainfall for the Peros Banhos atoll (data from 1950-1966) is approximately 4000mm, distributed bio-modally, with a slightly drier period through the austral winter (Stoddard 1971a). During the summer season approximately 400mm falls each month (range: 40-800mm), whereas in June is the driest month with a monthly average of about 150mm (range: 05-270mm).

4.1 Native flora and fauna

Although there are no endemic plant species in the outer islands of the Chagos Archipelago a few islands that were not converted to coconut plantations reveal what the native flora on the islands must have looked like before being settled.

In general a sand or boulder beach rises to a crest dominated by coastal species like *Scaevola taccada, Heliotropium arboretum Argusia (Tournefortia) argentea, Guettarda speciosa, Morinda citrifolia and some coconuts. Behind the crest is either a forest comprised of large* *trees; e.g. Coedes (Pisonia) grandis, Neisoperma (Ochrosia) oppositifolia, Calophyllum inophyllum, Barringtonia asiatica* and *Cordia subcordata*, or bare ground and low grasses. The structure of some of the native forest trees allows arboreal nesting by lesser noddies *Anous tenuirostris* and red-footed boobies *Sula sula*, whereas the open areas are used by species such as brown noddies *Anous stolidus* and sooty terns *Onychoprion fuscatus*. Small areas of *Pemphis acidula* and a single mangrove species occur in brackish lagoons on a few islands (Stoddart 1971b).

Birds are the predominant vertebrate fauna of the Chagos Archipelago and it holds seabird populations of international importance, with 38 species being recorded and 18 proven as breeding (Carr et al. 2013).

The most numerous species, sooty terns, number in the many 10's of 1000s. The archipelago has c. 300,000 pairs of breeding seabirds, comprised of 18 species, of which ~ 94% nest solely on rat-free islands. Because of the numbers and diversity of seabirds, nine designated and two proposed IUCN IBAs (Important Bird and Biodiversity Areas) exist in the Chagos Archipelago outside of Diego Garcia (the southernmost atoll) and 17 islands are strict nature reserves (Carr 2015). Due to its isolation and young geological history, the only native land birds present in the archipelago is the local sub-species of green-backed heron (striated heron) (*Butorides striata albolimbata*). Numerous vagrants and migrant species have been recorded (Carr 2011).

Like other tropical islands, land crabs are the dominant invertebrates, with the coconut crab (*Birgus latro*) being the most obvious, but in much larger numbers due to a lack of harvesting. Along with coconut crabs, smaller hermit crab species are present on all islands. The burrowing land crab *Cardisoma carniflex* are also present, but mainly on islands with wetlands or mangroves present (Stoddard 1971c).

No native mammals, including bats, exist on the islands. There are populations of endangered green turtles (*Chelonia mydas*) and critically endangered hawksbill turtles (*Eretmochelys imbricate)* that nest on some islands and their populations are slowly recovering since harvesting ceased (Cole 2009).

4.2 Alien species

Black rats, feral cats (*Felis catus*), dogs (*Canis familiaris*) and pigs (*Sus scrofa*) were likely to have had the most severe effect on the Chagos Archipelago's ecosystem in the past. Of these species only rats are now confirmed as present.

Feral chickens and a possibly a single donkey remain on few islands along with numerous introduced plant species. There is one widespread introduced landbird species, the red fody (*Foudia madagascariensis)*. Numerous vagrants and migrant bird species have been recorded (Carr 2011). Two gecko species (Common house gecko *Hemidactylus frenatus*, Mourning gecko *Lepidodactylus lugubris*) have been introduced to the outer islands of the Chagos Archipelago (Cole 2009).

4.3 Current usage

For the past 40-plus years the outer islands of the Chagos Archipelago have had no human settlement. Indeed, there is no permanent population in the entire Chagos, but Diego Garcia, the southernmost and largest of the archipelago, hosts a joint UK-US military facility. Occasional yacht visits to Peros Banhos and Salmon atolls occur, along with regular patrols by the BIOT Patrol Vessel 'Grampian Frontier'. On-going scientific research is regularly conducted on the islands, with a focus on coral reef resilience and marine species diversity, seabirds, tuna, sharks and mantas.

4.4 Environmental Management

At approximately 640,000 km^2, the 10 year-old BIOT Marine Protected Area (MPA) is one of the largest, no-take marine reserves in the world and encompasses the 55 islands and five atolls of the Chagos Archipelago. The Chagos Archipelago may be one of the largest contiguous tracts of largely un-impacted coral reefs in the world.

Not surprisingly, environmental management by BIOTA has a strong focus on management of the MPA, especially as illegal fishing by ships from Sri Lanka and India, along with some pelagic fishing activity, is the most pressing issue (Spalding 2015, BIOT 2018).

A dedicated BIOT Patrol Vessel is active within the MPA that also provides support for research programmes. There are strong linkages between the fishery protection work and the outcomes of the proposed rat eradication. Illegal fishing vessels in the MPA pose a significant biosecurity risk to the outer islands of the Chagos Archipelago, as they could carry invasive species. This risk is highlighted by the occasional wreck that has occurred (Spalding 2015, pers. obs.) and evidence of past illegal landings on islands. This threat and suitable responses need to be highlighted as part of the MPA management actions and be an integral part of biosecurity protocols.

Management of the 30-40 yachts that visit the Chagos Archipelago each year is also a priority and there are dedicated anchorages are available at Peros Banhos and Salomon atolls. All visitors require a permit before accessing the northern Chagos, and are checked by regular patrols by the BIOTA fisheries patrol vessel.

Terrestrial environmental management is tied strongly to island restoration, with the principal tool at this stage being the eradication of the remaining invasive mammal, the black rat, alongside removal of 'coconut chaos' on islands and replacement with native habitat.

As such, the management actions strongly support eradication planning activities. As part of this, biosecurity is gaining importance within the management framework but needs further development and investment in biosecurity infrastructure and protocols, along with increasing the focus on the outer islands of the Chagos Archipelago and the threats to these islands. This is especially pertinent if invasive mammals are to remain absent from these islands after the proposed rat eradication.

Further research on the terrestrial and marine environment is encouraged within the BIOTA environmental priorities, along with dealing with waste management and removal of marinederived waste, the vast majority of which is from countries on the periphery of the Indian Ocean. Responses to climate change mainly focus on the monitoring changes in environmental measures including coral health, climate, sea level and temperature and managing coastal vegetation.

4.5 Heritage sites

Several islands have remnants of settlements, with the largest number of ruins being on Boddam Island, Salomon atoll. All are in poor condition with, at most, only remaining concrete walls of buildings, a decaying jetty and a railroad remaining. The historic graveyards at Coin and Boddam receive some periodic maintenance.

4.6 Baseline monitoring information and on-going research

Current research within the archipelago will provide some baselines against which the response of native species and ecosystems to the rat removal can be measured. The Bertarelli Foundation is funding a large and comprehensive science programme which includes research on seabirds, turtles, manta rays and sharks within the MPA. Alongside this work research on the resilience of coral reef species and habitats is being conducted, which has been tied to the presence or absence of seabirds due to rat impacts at the Chagos Archipelago (Graham et al. 2018). Additional monitoring is planned to provide baselines for flora and land crab abundance and diversity (Harper 2020.[b]), over and above the current seabird monitoring work (P. Carr, pers. comm.).

4.7 Future environmental reference state in the absence of the proposed activity

Without rat eradication rats will probably eventually invade additional islands, especially in the Peros Banhos and Boddam atolls, where constituent islands are relatively close and the internal waters comparatively benign for a rat rafting on flotsam.

On rat-infested islands continued degradation in native plant diversity and forest structure will occur alongside on-going declines in seabird abundance and diversity and an associated reduction in nutrient transfer and enhancement the adjacent marine ecosystem.

Marine turtle nests will continue to be subject to predation by rats and there is likely to be reductions in numbers and possibly species of land crabs and other invertebrates.

5. ASSESSMENT, MINIMISATION AND MITIGATION OF LIKELY IMPACTS

This section presents the probable positive and negative environmental impacts of the proposed eradication operation as previously described above. The likely duration and degree of harm caused by negative impacts are described, with recommended minimisation or mitigation actions outlined in a summary table. The suggested measures will be implemented via actions set out in the Operational Plan (Harper 2020[b])

5.1 Potential positive effects of the proposed operation

Where seabirds have been reduced in numbers or extirpated by rats, rat eradication has resulted in an increase in seabird numbers (Le Corre et al. 2015, Croll et al. 2016, Newton et al. 2016) leading to significantly improved marine diversity through nutrient transfer from seabirds and their colonies (McCauley et al, 2012, Graham et al. 2018) and may promote coral reef recovery following bleaching events (Benkwitt et al. 2019). Recovery of seabird populations will significantly increase the area within the Chagos Archipelago where marine diversity and ecosystem resilience is improved. However, this will also depend on substantial changes to the flora on most islands, which are currently dominated by *Cocos nucifera*. As no seabirds nest in abandoned plantations and only two species nest in native trees additional significant modification of the current forest cover is required in order that a beneficial increase in the area of potential seabird nesting sites becomes available. Planned re-afforestation with native species on the Chagos Archipelago is part of the restoration planning for the archipelago.

Responses to rat eradication are highly likely to include marked increases in the numbers, and changes in the species composition, of land crabs, turtle hatchlings and land birds, with increased breeding success of seabirds, particularly tern species, with a consequent expansion in the number and size of their colonies (Harper & Bunbury 2015).

Indeed, the current presence of black rats affect seabird colonisation, as seabird population density in the Chagos Archipelago is approximately 760 times higher on the rat-free islands (Graham et al. 2018), which also have flora that encourages seabird nesting. Higher seabird abundance will also lead to increased nutrient deposition (Caut et al. 2012).

Over time, native forest structure and composition is also likely to change as fruit, seeds and seedlings previously preferentially eaten by rats become increasingly common (Wolf et al. 2018, Shiels & Ramírez de Arellano 2019). This will be particularly true for islands with remaining native forest and previous plantations being re-afforested with native trees.

Rats are highly likely to be depredating marine turtle nests and this will cease with rat eradication, likely leading to increased breeding success and abundance of both of these threatened turtle species (Caut et al. 2008, Gronwald et al. 2019).

5.2 Ethical considerations of poisoning

Rat eradication operations on islands overwhelmingly use poisons, mainly anticoagulants, to achieve success, because they are highly efficacious (Fisher et al. 2011). However anticoagulants cause prolonged deaths in rats over several days by haemorrhaging, which is highly likely to cause varying degrees of pain (Mason & Littin 2003). Symptoms of poisoning by brodifacoum include internal and external haemorrhaging, un-natural posture, increased inactivity, and during the final stages before death were un-moving but conscious. Study animals took between 5.6 - 8.5 days to die but in the field generally die within 3-5 days (Littin et al. 2000, pers. obs.). Relative to fast acting toxicants e.g. cyanide, anticoagulants are not considered very humane. However, currently no other options for the scale of restoration planned exist.

In addition to apparent pain and suffering caused to the target animals, rats, there is also a risk of primary and secondary poisoning for non-target animals, particularly vertebrates such as birds, with similar symptoms to rodents and likely similar suffering (Murray 2017). In contrast, there is little evidence that invertebrates, including land crabs, are affected, probably due to their different blood physiology (Pain et al. 2000).

In the case of this proposed eradication, consideration of animal welfare concerns relating to the stress and pain caused to the target and non-target animals exposed to anticoagulants needs to be weighed against the impact of the prolonged rat presence in the Chagos Archipelago.

Rat predation and or competition has resulted in significant declines in native species abundance and distribution for many years mainly through direct predation and the suffering this causes at all life stages, which in the case of the predominant terrestrial vertebrates, seabirds, includes eggs, chicks, and adults.

Without rat eradication this harm will continue indefinitely. Indeed, rat control, as discussed above, would also not arrest this process, as some rats would always remain and be subject to periodic suffering during control operations in perpetuity.

In contrast, rat eradication would result in a very short duration of pain and distress to the existing rat population, and possibly some non-target species animals. The ongoing distress that rats have brought to native species through predation (Morgan et al. 2006, , Fea & Hartley 2018, Gronwald et al. 2019) would then cease. The enduring positive native animal welfare outcomes over many generations into the future that accrue from this eradication far outweigh the very short-term suffering of an invasive predator.

5.3 Potential effects of operation on human health

Brodifacoum is as toxic to humans as it is for other vertebrates and as little as 1-2 mg can result in detectable effects to blood clotting in adult humans. However this is at the lowest end of the range of effects and usually significant exposure to brodifacoum is required to cause death. For example, a small adult (60kg) would need to consume 750g of rat bait dosed with 0.2g/kg of brodifacoum in one meal to have a 50% chance of death (Broome et al. 2015). There is an effective antidote through long-term administration of Vitamin K.

The humans most at risk from brodifacoum during the proposed eradication operation are the eradication staff, and especially the bait loaders as they will be directly handling toxic bait and bait containers. However, if they wear suitable PPE and follow correct handling procedures the risk of exposure is very small.

Numerous eradications have been conducted using brodifacoum and there have been no recorded incidences of death or harm to staff handling the bait. Health monitoring of staff members that each loaded many tonnes of aerially applied rodent bait during two large eradication operations at Macquarie Island and South Georgia revealed no detectable effects of the poison in their bloodstream (Doube 2019).

There is a very small possibility of poisoning of visitors on yachts, or researchers, and only if they visit within a few weeks of the operation and they either eat many bait pellets or land crabs, particularly coconut crabs, which are highly likely to have consumed toxic bait on the target islands. This risk will be reduced by the placement of warning signs at the landing sites and information for permit applicants. This risk is further diminished as killing coconut crabs is illegal in the Chagos Archipelago, but it could be virtually eliminated by closing the area to visitors for six months post-eradication (i.e. until December following the operation). The bait pellets themselves pose little risk and are likely to have decomposed or been consumed by land crabs within a few weeks of the operation, which is particularly likely given the high rainfall experienced in the archipelago.

The likely effects of the eradication operation on human health are very low.

5.6 Potential for primary or secondary poisoning of non-target species

On the outer islands of the Chagos Archipelago, most of the native animals (seabirds) source food directly from the ocean and are therefore highly unlikely to consume pollard bait. On Palmyra atoll, no brodifacoum residues were found in any seabirds despite particularly heavy bait applications during a successful rat eradication there (Pitt et al. 2015). There are few terrestrial animals, namely land birds, two gecko species, a few land crab species and other invertebrates that are most likely to encounter and possibly consume bait pellets (Table 2).

5.6.1 Seabirds

There is virtually no record of brodifacoum causing mortality in seabirds, even at locations with large and diverse seabird populations (Pitt et al. 2015). There has been one study that recorded a single sooty tern chick pecking at and possibly ingesting a non-toxic bait pellet but it was an extremely rare incident (Sztukowski & Kesler 2013).

5.6.2 Land birds

Many bird species are at risk of primary or secondary poisoning by anticoagulants (Vyas 2017), with scavenging and predatory birds, such as gulls and raptors, usually at most risk (Ebbert & Burek-Huntington 2010, Fisher & Campbell 2012, Sánchez-Barbudo et al. 2012). However, as these species are largely absent from the Chagos Archipelago, it leaves wader species that hunt invertebrates at most at risk in this archipelago. An assessment of risk for land was undertaken through a literature review, to inform a table of likely species present, their foraging behaviour and their risk of primary and secondary poisoning as a result (Table 2).

Of the land bird species present visiting or vagrant wader species are probably the most common (Carr 2011) and wader deaths from secondary poisoning through consumption of invertebrates have been recorded (Dowding et al. 2006, Pitt et al. 2015). However, the likelihood of significant mortality in this group is virtually eliminated by undertaking the eradication operation during their breeding season when they are absent (austral winter = northern summer) and has been a risk-reduction method for this guild in other tropical rat eradications (Wegmann et al. 2012). Nonetheless, there are a few individuals of the wader species that remain over winter and will be at risk of secondary poisoning (Table 2). The whimbrel and turnstone are probably at greatest risk as they forage across more habitats than other species and have a catholic diet. Moreover, some individuals (e.g. non breeders) are likely to remain during the operational period

5.6.3 Reptiles

There is generally little concern for populations of lizards during rodent eradications (Hoare & Hare 2006), with little evidence of reptiles being susceptible to brodifacoum (Weir et al. 2016). However, at an individual level there are a few reports of reptile species being adversely affected by brodifacoum.

A few Round Island or Telfair's skinks *Leiolopisma telfairi* died after a rabbit eradication on Round Island, Mauritius, possibly due to an inability to thermoregulate during particularly hot weather post-anticoagulant consumption (Merton 1987). This may also have been the explanation for the deaths of about 5% of a Galapagos land iguana *Conolophus subcristatus* population on Seymour Norté Island some weeks after a rodent eradication using brodifacoum bait (Harper et al. 2011), as well as a few Wright's skinks *Mabuya wrightii*, on Frégate Island, Seychelles (Thorsen et al. 2000).

In contrast, Bungaras *Varanus gouldii* ate dead rats until their droppings were green from the bait dye during an eradication on an island off the northwest Australian coast, but no deaths were recorded (Burbridge 2004). Similarly Herrera-Giraldo et al. (2019) found no evidence of population level impacts on two endemic lizard species after a rat eradication using aerially-applied brodifacoum bait on Desecheo Island, Caribbean, in 2012.

There is some evidence for prolonged retention of anticoagulant residues in lizards (Rueda et al. 2016), which suggest that although the risk of reptile populations being adversely affected by brodifacoum is very low, they do pose a significant, and possibly prolonged, secondary poisoning risk to their predators (Hoare & Hare 2016).

Although a few samples of marine turtles have been taken during rat eradications on tropical islands no records of mortality from anticoagulants were recorded (Pitt et al. 2015), as there is no real pathway considering their diet. Similarly, terrestrial tortoises appear to be at little risk of poisoning through consumption of brodifacoum bait (Fisher 2011).

Table 2. Mortality risk from exposure of Chagos Archipelago terrestrial species to brodifacoum pollard bait.

Species	IUCN status.	Individuals affected	% of world population	Estimated global population	Potential pathways: 1° or 2° poisoning	Risk of individual mortality	Risk to archipelago population total	Risk to species	Mitigation
Red junglefowl *Gallus gallus*	LC	**~200**	**<0.001**	Millions	Primary & secondary	High	Medium	Nil	None
Green-backed heron *Butorides striata albolimbata*	LC	**~50**	**<0.01**	100,000+	Secondary	Medium	Low	Nil	None
Cattle egret *Bubulcus ibis*	LC	**<30**	**<0.001**	5 million	Secondary	Medium	Low	Nil	None
Indian pond heron *Ardeola grayii*	LC	**<30**	**<0.001**	100,000+	Secondary	Medium	Low	Nil	None
Red fody *Foudia madagascariensis*	LC	**~200**	**<0.001**	500,000+	Primary & Secondary	High	Low	Nil	None
Ruddy turnstones *Arenaria interpres*	LC	**<200**	**<0.001**	1 million	Secondary	Medium	Low	Nil	None
Greater sand plover	LC	**<200**	**<0.001**	1 million	Secondary	Medium	Low	Nil	None

Charadrius leschenaultii									
Whimbrel *Numenius phaeopus*	LC	**<100**	**<0.001**	1 million	Secondary	Low	Low	Nil	None
Grey plover *Pluvialis squatarola*	LC	**<200**	**<0.001**	1 million	Secondary	Medium	Low	Nil	None
Bar tailed godwit *Limosa lapponica*	NT	**<200**	**<0.001**	1 million	Secondary	Medium	Low	Nil	None
Curlew sandpiper *Calidris ferruginea*	NT	**<100**	**<0.001**	1 million	Secondary	Medium	Low	Nil	None
Other wader species	LC	**<100**	**<0.001**	100,000+	Secondary	Medium	Low	Nil	None
Gecko spp. *Hemidactylus frenatus, Lepidodactylus lugubris*	LC	**~200,000**	**<0.001**	10 Million	Secondary	Medium	Low	Nil	None
Coconut crab *Birgus latro*	DD	**~20,000**	**<0.05**	500,000	Primary & Secondary	V. low	Nil	Nil	None
Hermit crab *Coenobita* spp.	LC	**250,000+**	**<0.001**	20 Million	Primary & Secondary	V. low	Nil	Nil	None

5.6.4 Invertebrates.

Land crabs will ingest brodifacoum-laced pollard bait and indeed pose a risk to operational success due to the amounts of bait they consume (Samaniego et al. 2019). However, they have a different blood clotting system, so are not susceptible to anticoagulant poisons and show no adverse effects at an individual or population level from rat eradication operations using these toxins (Pain et al. 2000).

Similarly, insects will consume toxic rodent baits but are not affected (Booth et al. 2003, Bowie & Ross 2006, Brooke et al. 2013). Terrestrial molluscs will also consume bait. There are mixed reports about its effects on molluscs, with some recorded deaths from brodifacoum consumption (Gerlach & Florens 2000). On Frégate Island, Seychelles, two snail species, *Pachnodus silhouettanus* and the introduced giant African land snail *Achatina fulica*, apparently died as a result of exposure to relatively low doses of brodifacoum, and may have adversely affected another snail species *Pachystyla bicolor* in Mauritius (Gerlach & Florens 2000; Booth et al. 2001).

This is in contrast to research noting no effects at an individual or population level (Brooke et al. 2011). Any impacts, positive or negative, of an eradication operation on terrestrial molluscs in the Chagos Archipelago will be difficult to assess, as virtually nothing is known about them, aside from a short species list from Diego Garcia (Peake 1971).

5.7 Potential environmental effects

5.7.1 Effects of brodifacoum bait on fresh water quality and soil

Brodifacoum is almost insoluble in water and binds to sediment, which means it is also largely immobile in soil (Eason and Wickstrom 2001). Monitoring for brodifacoum residues in fresh water immediately after several rat eradication operations on islands using bait containing brodifacoum at 20 or 25 parts per million has not detected any residues, including a tropical operation with a very heavy application rate, and an accidental spill resulting in a large point-source application of bait into a lake (Morgan et al. 1996, Ogilvie et al. 1997, Fisher et al. 2011, Fisher et al. 2012, Pitt et al. 2015).

In soil brodifacoum breaks down relatively quickly as it binds with soil and is eventually broken down by soil organisms (Fisher et al. 2011). On tropical atolls baits containing brodifacoum at 25ppm can be undetectable within a few weeks on various soil types (Alifano et al. 2012) and on temperate islands, undetectable within 3-6 months (Fisher et al. 2011).

5.7.2 Effects of brodifacoum bait on the marine environment

Some bait pellets are likely to enter the marine environment. Aerial bait spreading across islands will include a coastal swath to ensure all areas are covered and even with a deflector to constrain spreading landward some pellets will drop onto beaches and roll into the surf zone. Wave action on saturated pellets will cause them to break up quite quickly and what little toxin is in a pellet will be diluted in seawater. It is possible that intertidal marine animals will consume small amounts of toxin, particularly filter feeders, but also some fish whilst pellets are still relatively intact.

Similarly, immediately after application of rodent bait containing 25ppm brodifacoum at both Palmyra atoll in 2011 and Wake Atoll in 2012, sampling for residues revealed brodifacoum in some marine species. At Wake Atoll, 12.5% of sampled bluefin trevally (n = 8) and all blacktail snapper (n = 4) had low but detectable levels of brodifacoum residues. Later sampling in 2015 revealed no detectable residues in any sampled fish species, including the species sampled in 2012 (Siers et al. 2016).

The eradication operation at Palmyra atoll applied bait containing 25ppm brodifacoum at a very high combined application rate of 155kg/ha. Post-eradication sampling immediately after the operation recorded detectable brodifacoum in most fiddler crabs (n=40) 2.5 months later and in nine of 10 blackspot sergeant fish a month post-eradication.

All mullet (n=24) found dead over the following month (n=24) had detectable brodifacoum, with residue concentrations declining over the period from an initial high value (Pitt et al. 2015). It is apparent that short-term application of rodent bait for eradication purposes does not result in long-term persistence of this toxicant. Sampling for brodifacoum in these identical species at Palmyra three years later revealed no detectable residues (Wegmann et al. 2019).

This project should aim to monitor for brodifacoum residues in invertebrates including land crabs, coastal fish, reptiles and land birds for at least one year post-eradication to add to the limited available data on residue persistence post-eradication, particularly for tropical islands (Pitt et al., 2015)

Like freshwater, brodifacoum is almost insoluble in seawater, so is almost always undetectable in the water column after a rat eradication (Pitt et al. 2015). An exception was during an accidental spill resulting in an extraordinarily large point-source application of bait into a tidal coastal area. Approximately 20 tonnes of bait containing brodifacoum at 20ppm discharged into a 100 x 300m (> 6600 kg/ha) site after a truck accident at Kaikoura, New Zealand (Primus et al. 2005). Brodifacoum was detectable in the water column directly above spill site for between 36hrs and nine days after the accident. Of sediment samples at, and near, the spill site for the next nine days, only one had detectable levels of brodifacoum.

Almost all fish and crustacean species sampled in the immediate area over the subsequent two weeks did not have residues over the Mean Level of Detection (MLD) of 0.020 ppm. Residues persisted the longest in filter feeders and molluscs, with mussels, limpets and paua (abalone) still having detectable MDLs brodifacoum for up to a year later, but Maximum Residue Limits (MRL) for human consumption, in mussels, that persisted for over 2.5 years.

This case is an extreme example of brodifacoum loadings at a single point and would not occur at anywhere near this concentration during a rodent eradication. Monitoring of marine life during rodent eradications on islands has detected much lower residues and persistence than recorded at Kaikoura.

At Ulva Island, New Zealand, an aerially applied rat-bait operation using bait containing brodifacoum at 20ppm, at a combined application rate of 11.5kg/ha, again resulted in some mussels and limpets retaining brodifacoum for a few months. In mussels brodifacoum was still detectable at low levels in a small portion of samples for up to 6 months, and in limpets, brodifacoum was again detectable in a 1/3 of samples but for only 3.5 months (Masuda et al. 2015). Brodifacoum was also detected in two out of five samples of blue cod, a sedentary predatory fish at 1.5 months days post-eradication, but not at 3.5 months. All sampled species were alive at the time of sampling.

5.7.3 Potential effects of the operation on vegetation

As brodifacoum is largely insoluble in water there will be no uptake of the toxin by plants. There will be no impact on plant growth.

As the operation will be primarily conducted as an aerial application of rat poison, there will be little requirement for any work to take place on land. The exception will be for hand-application of bait in the mangrove and/or *Pemphis* forest on 3 islands and some possible hand-broadcast of bait in or under any remaining structures.

In the latter case no effect on vegetation is likely besides personnel walking through forest to distribute bait. In the case of the mangrove/*Pemphis* forest, this will may involve cutting lines through this dense vegetation to allow field staff access to baiting points. It is expected that this vegetation will re-grow and the cut lines should be undetectable within 2-3 years. Note that it is an offence to cut vegetation on the islands of the outer Chagos Archipelago, so this activity will require a permit (BIOTA 2018).

5.7.4 Physical disturbance and noise

As the operation will be ship-based almost all physical disturbance by helicopters will be restricted to the helideck when landing, taking off and loading. However, as 30 islands will require treatment these islands will all be subject to noise disturbance, the level of which will depend on the frequency of flights and aircraft type during the initial coastal mapping runs and the bait application swaths.

Of note is that the vast majority of seabird colonies are on rat-free islands in the outer Chagos Archipelago so the risk of both disturbance or bird strike is very small as these islands will not be subject to bait applications. Moreover, pilots will be briefed to avoid any seabird nesting areas on rat-free islands and to not fly near any colonies in the early morning or late evening when seabirds are in transit between colonies and feeding grounds. Moreover, the pilots will be actively avoiding the possibility of bird strike. However the risk of birdstrike will be present to a small degree in any case.

In general terms, helicopters flying relatively close to birds (<200m) will usually elicit a reaction from nesting ducks and raptors, sometimes leading to flight (Larkin et al. 1996). There is little published data recording the reaction of terns or boobies to helicopters. There is an indication that some individual boobies may move off their nest for up to 15 minutes if there is helicopter activity (landing) within about 100-150m (Lusk et al. 2000). A co-generic species, gannets (*Sula* spp.) can be disturbed by light aircraft closer than 200m (Hoang 2013).

An additional operational risk is bird strike. However, separate analyses of the altitude of seabirds flying over the sea in the north Atlantic determined that virtually all of them flew below 20m above sea level and this included the northern gannet, a co-generic of booby species (Jongbloed 2016, Cook et al. 2018).

The only two species that are likely to fly or hover above this altitude are the frigate birds (pers. obs.). Although these species do not breed on any of the target islands (Carr 2011) some individuals are likely to loiter near booby breeding colonies when harassing returning boobies for food. At this stage the limited information available suggests that over-flights should be at least 100-150m (300-500 feet) above ground level when applying bait over or near seabird roosting sites or breeding colonies.

As most islands with rats have few seabird colonies the affect or helicopter noise or over-flights will be very limited. It is likely that at least some colonial seabird species will be breeding in June, particularly the various tern and booby species. Frigatebirds mostly breed on rat-free islands so are unlikely to be unduly affected. Short term absences from a nest by an adult are not a danger to eggs or chicks, but they may suffer heat stress or death if the parent is absent for too long.

It is unlikely that falling pellets will cause undue disturbance to wildlife as pellets are light (2gm) and will arguably be much less disturbance than a heavy rain shower (pers. obs.). It will likely only happen for a few seconds during each application and less than 4-6 times during the entire operation, as the helicopter flies over an island distributing bait.

5.7.5 Atmospheric emissions

The support vessel and helicopters will be the principal sources of atmospheric emissions during the operation. The ship will mainly be producing emissions during manoeuvring and steaming between islands or atolls, but to a lesser degree when at anchor. Helicopters will produce emissions during bait application and mapping island boundaries (Table 3).

A ship capable of carrying two helicopters and bait for the operation is likely to consume approximately 4 tonnes/day of fuel for the 60 days of the operation. This is an overestimate as it is unclear at this stage how much time will be spent anchored. Helicopter operations will require 12,000L of Jet A1 (60 x 200L drums) (Harper 2020. [b])

Table 3. Emissions from the support vessel and helicopters during the operation.

Source	Estimated fuel consumption (tonnes)	Conversion factor (UK National Atmospheric emissions inventory www.naei.org.uk)	Carbon dioxide emissions (tonnes CO_2)
Ship	240	3.2	128
Helicopters	10	3.15	31.5
Total			159.5

In addition to the main emission sources there will be small amounts of emissions from the use of the ship's tender(s), along with lubricating and hydraulic oils. These emissions will be minimal compared with the support vessel and helicopter operations.

Besides the carbon emissions, various other atmospheric pollutants will be emitted, including carbon monoxide, nitrous oxide, particulates etc. These emissions, along with fuel vapour during re-fuelling or spills, will be quickly dispersed into the local atmosphere and will not adversely affect air quality or wildlife to any degree.

These emissions will certainly comprise a fraction of the atmospheric contaminants emitted from Diego Garcia in the south, where large diesel generators power the military base there, all waste paper and cardboard is incinerated and aircraft movements number several each week (Spalding 2015).

5.7.6 Fuel and oil spills

Fuel will be stored within the support vessel to power its engines and generators, and for the helicopters, either internally (bunkered) or as 200l fuel drums. Fuel spills are most likely to occur during either loading at the port of departure or when re-fuelling helicopters and are unlikely to be more than 10L before detection. Spills could also occur by leakage, from fuel tanks for the ships tender or if the support vessel is holed. Jet A1 is relatively volatile and any remaining residues after a clean-up will likely evaporate. Fuel for a ship is more dense and may require specialised equipment to retain and recover it, especially if it enters the sea.

5.7.7 General waste

All ship board rubbish will need to be retained as per Annex V (Regulations for the Prevention of Pollution by Garbage from Ships) of the MARPOL Convention in 1998. This should be a standard procedure for any chartered ship and waste management will be part of the induction by the ship's crew for the operational team.

Any waste generated by field teams will need to be retained and returned to the ship for processing. Any remaining bait will need to be returned to the port of departure for disposal into a waste management facility. It is an offence to leave waste on the islands (BIOTA 2018).

5.7.8 Sewage and waste water

As most of the operational activities will take place aboard the support vessel, sewage and grey water will be treated by the ship's on-board facilities and disposed of as per the Annex IV of the MARPOL Convention 1998.

Any human waste produced during the field operations on the 2-3 islands should be buried to a depth > 500mm to allow it to decompose undisturbed by local scavengers (land crabs).

The effect of sewage and waste water will be minimal to local wildlife if managed as per the above conventions.

5.7.9 Light pollution

The most likely effect of light pollution is bird strike on a ship at night, particularly if the visibility if poor (mist or fog). There have been no reports of bird strike on the BIOT patrol vessel in recent years, so the impact of light pollution is likely to be very minor. A nocturnal 'blinds-down' policy would reduce the risk further.

5.7.10 Aesthetic and heritage values

The chosen method for delivery of rat toxin will have virtually no effect on heritage values (remaining buildings), although any field work to apply bait by hand will have to be carried out in such a way that there is no localised effect through trampling, damage or marking at heritage sites.

Helicopter activity may reduce the wilderness values of the islands during the operation for any visiting visitors on yachts. It is noted that most visits take place from April to June (i.e. during the operational period). These visits average about 34 each year (BIOTA 2018).

There is a possibility that permits for visits could be cancelled for the duration of the operation in the Chagos Archipelago (~ 1 month) to remove this impact.

5.7.11 Introduction of alien species and translocation of diseases

Any operation in the Chagos Archipelago poses a risk of alien species or pathogens being introduced to the islands. There are several pathways for introductions of alien species and pathogens but for this operation they will all have to be via the support vessel. They can include the introduction of soil, seeds, and invertebrates via shoes, clothing, dirty equipment, or rubbish.

To counter this, the equipment for all field teams, the helicopters and bait spreaders will need to be carefully inspected and cleaned before commencing operations on or over the islands. This can be done during the voyage to the islands and repeated between visits to islands within the Chagos Archipelago.

Ballast water and the ship's hull will need to be clean and free of possible marine invasive species before leaving the port of departure.

A Chagos Archipelago biosecurity plan will provide guidance for the procedures to be adhered to, to reduce biosecurity risks to the islands and wildlife, both on the ship and when undertaking field work. It should include an incursion response plan.

5.7.12 Adjacent and associated ecosystems

Of the activities discussed in this assessment the activities most likely to affect associated ecosystems are the atmospheric emissions and solid waste removal, including un-used toxic bait. Atmospheric emissions are likely to be very small, certainly when compared to the many airline flights overflying the Chagos Archipelago every day.

Similarly the waste produced by about 25 personnel and ship's crew over a two month period is dwarfed by all the islands or continents within the Indian Ocean and its periphery. Of the waste, only any remaining bait will have any degree of impact, as it will need to be disposed of at a suitable waste facility at the port of departure. Careful planning should remove the need to return any bait to the port of departure. Overall impact on associated ecosystems is therefore likely to be miniscule.

A likely increase in seabird numbers will have spill-over effects to other archipelagos, with probable increases in nesting attempts elsewhere in the Indian Ocean.

5.7.13 Indirect and cumulative impacts

Indirect impacts are most likely to accrue during the planning and initial operational portion of the operation. These include the need to fly senior personnel to countries for planning purposes, flying personnel to the port of departure and any associated impacts such as use of hotels, taxis etc. These can be mitigated by video conferencing as much as possible, off-setting carbon emissions.

Similarly, re-positioning of the support vessel to and from the port of departure will likely require movement of crew nationally or internationally, emissions from steaming to / from the port of departure and the need for fuel for these voyages.

The production of the toxic bait will also have indirect impacts at the country of manufacture, including the transport of goods to the factory.

Cumulative impacts include the accumulation of any possible contaminants within the ecosystem, likely from emissions and possible fuel spills and will add to any contamination that may have occurred in the past. Toxin accumulation from the rat bait is unlikely as discussed in Section 5.7.1. and any unused bait or contaminated containers will be disposed at the Port Of Departure as per the MSDS.

5.7.14 Impact matrix

A matrix of the impact activities, the degree of impact severity and possible mitigation actions are outlined in Table 5. The impact parameters are given in Table 4.

Table 4. Impact matrix parameters for the proposed rat eradication operation.

Activity	Type of activity.
Result	Description of potential results of activity that may cause impact.
Predicted impact	Description of what is directly, indirectly and cumulatively impacted by the activity.
Probability	Likelihood of impact occurring: Unlikely (<5%), Low (<25%), medium (25– 75%), high (>75%), certain (100%).
Extent	Geographical area affected: Local (directly in area of impact), Regional (whole of the Chagos Archipelago), Global.
Persistence	Period of time during which changes in the environment are likely to occur: Short (minutes–hours), Medium (days–weeks), Prolonged (months–years), Very prolonged (decades to centuries), Unknown.
Intensity	Severity of impact: Low, Medium, High.

Significance	Severity & importance of the impacts on the environment: Very low (negligible impacts), Low (less than minor or transitory impacts), medium (minor or transitory), high (greater than minor or transitory), very high (major or irreversible changes).
Mitigation	Suggested measures that will be put in place to mitigate or prevent the impacts from occurring.

Table 5. Summary of predicted impacts of the proposed rat eradication operation, the impact severity, and suggested mitigation.

Activity	Result	Predicted Impact	Probability	Extent	Persistence	Intensity	Significance	Mitigation
Ship, tender, & helicopter operations	Atmospheric emissions	Minor, but cumulative addition of gaseous pollution to atmosphere. Particulate matter & heavy metals.	Certain	Local - global	Prolonged	Low	Very low	Maintain engines to high standard including filter replacement. Keep ship movements to a minimum. Anchor ship as close to target islands as possible to reduce helicopter flight times.
Ship and eradication operations on ship or land	Waste production (grey water, sewage, rubbish)	Nutrient enrichment, faecal bacteria, organic and heavy metal pollutants	Certain	Local: ship's route	Short	Low	Low	Adhere to the MARPOL requirements with regard to waste at sea. Return all field waste to ship for on-board processing. Bury human waste on land to a minimum of 500mm.
Ship & helicopter operations	Fuel spills	Contamination of seawater or soil	Medium	Local	Medium	High	Low	Fuel handling & transfer kept to a minimum. Correct fuel transfer equipment available and staff trained in its use. Fuel booms and absorbents available to deal with spills. Staff trained in fuel spill procedures. Safe storage of fuel, esp. drums.

Helicopter operations	Noise & physical disturbance	Disturbance to roosting or nesting birdlife. Temporary nest abandonment leading to reduced breeding success.	Certain	Local	Short	High	Medium	Contract experienced helicopter pilots. Fly at a minimum altitude above any colonies or roosting sites (>300 ft?). Avoid landings or sudden manoeuvring near seabird aggregations.
Helicopter operations	Bird strike	Damage to helicopter. Delay or stoppage of eradication operation	Medium	Local	Short	High	High	Contract experienced helicopter pilots. Fly at a minimum altitude above any colonies or roosting sites (>300 ft?). Avoid landings or sudden manoeuvring near seabird aggregations. Have sufficient spares to repair likely damage.
Ship operation	Light pollution	Seabird disorientation, landing on ship, possible impact deaths	Low	Local	Short	Low	Very low	Minimise lights at sea or when anchored, particularly in poor visibility conditions.
Ship & helicopter operations	Noise & physical disturbance	Impact on wilderness experience	Low	Local	Short	Low	Very low	Cancel or restrict yacht / research visits during the operational period. Allow yacht / research visits at non-target islands (e.g. Nelson Island).

Ship & helicopter operations	Physical disturbance	Impact on heritage sites	Low	Local	Short	Low	Very low	Keep field team small. Brief field teams on minimising impact at heritage sites. Minimise marking and line cutting.
Ship, tender, & helicopter operations	Introduction of alien species	Reduction or extinction of native species populations. Flow-on ecosystem effects.	Low	Low - regiona l	Short - prolonged	Low - high	Low -high	Inspect and clean all clothing and equipment going ashore with field teams. Inspect and clean the helicopters and equipment (bait spreaders) before arrival at the Chagos Archipelago. Clean the hull and ballast tanks of the ship before departure to the Chagos Archipelago. Adhere to protocols of the Chagos Archipelago Biosecurity Plan
Eradication operation	Primary poisoning of rats	Eradication of black rats	High	Region al	Permanent	High	Very high	Significant beneficial impacts.
Eradication operation	Primary poisoning of non-target species	Reduction in colony sizes. Extinction of native species	Low	Local	Short	Medium	Medium	Monitoring after first bait application to assess effect on possibly impacted species.
Eradication operation	Secondary poisoning of non-target species	Reduction in colony sizes. Extinction of native species	Low	Local	Short	Medium	Medium	Monitoring after first bait application to assess effect on possibly impacted species.

Eradication operation	Effects on soil and water.	Contamination of soil, fresh water or salt water. Mortality in marine species. Reduction in populations of terrestrial or marine species through poisoning	Unlikely	Local	Short - prolonged	Low	Very low	Use differential GPS to ensure accurate bait dispersal. Ensure bait spreaders and linkages are in working order to avoid accidental spillage. Use bait deflectors on coastal bait applications. Apply bait at application rates that are adequate, but not excessive, to ensure rat eradication.
Eradication operation	Cutting / marking of plants for ground baiting operation	Damage to native plants	Low	Local	Medium	Medium	Low	Keep track / access cutting to the minimum required ensure adequate bait distribution. Remove all markings and non-biodegradable baiting fixings after the operation.
Eradication planning & staff movements	Atmospheric emissions from planes	Minor, but cumulative addition of gaseous pollution to atmosphere	Certain	Global	Prolonged	Low	Very low	Offset aircraft carbon emissions. Maximise the efficiency of aircraft and ship movements. Undertake video conferencing where possible

6. MONITORING AND VERIFICATION

6.1 Baseline monitoring in preparation for rodent eradication

At present there is a significant amount of biological science being conducted in the Chagos Archipelago, with funding from the Bertarelli Foundation, which will provide some baseline data prior to rat eradication. Additional data, on vegetation response and the recovery in land crab abundance and diversity will be gathered before the operation commences.

Seabird distribution and abundance is currently being determined along with their connections with other charismatic megafauna, including turtles, tuna, sharks and mantas. The researchers are examining how these species use the Chagos Archipelago and how the BIOT Marine Protected Area works to protect this biodiversity.

Alongside this work, researchers are establishing the resilience of coral reef species and habitats within the BIOT MPA, particularly as a baseline comparison for more heavily impacted reefs elsewhere. This research will be able to compare the coral reef health before and after rat eradication and the expected increase in seabird abundance and numbers of seabird colonies.

6.2 Monitoring during and after the eradication programme

Initial monitoring during the operation trial stage will focus on confirmation of efficacy of the bait application rates at selected islands, and will include a ground-based rat eradication operation on one island to assess possible bait formulations, bait off-take by non-target species such as land-crabs and any non-target species impacts that may not yet have been determined.

One year post-operation a field expedition will visit each treated island to search for rat sign to confirm operational success. Tools should include wax gnaw-sticks, coconut meat as lures for camera traps, peanut butter wax tags, traps set up trees, spotlight searches, etc. Vegetation recovery should be assessed on islands with significant native forest remnants and include seedling counts. The survey should also search and map any introduced plant species expansion or new incursions. There is a possibility of using trained dogs also, but their effectiveness is limited by the tropical climate.

The Bertarelli-funded research will provide baseline information on the larger scale ecosystem changes that will occur following rat eradication, including the likely improvement in coral reef health and resilience with increases in seabird abundance (www.marine.science).

6.3 Gaps in Knowledge and Uncertainties

The status and development of a biosecurity and incursion response plan is not clear at present. A fully developed and reviewed plan will be required before proceeding with the eradication.

6.4 Environmental Management

At present the environment management of the Chagos Archipelago as outlined by 11 environmental priorities. These focus on control of illegal fishing activity, invasive species, managing waste and plastic pollution and mitigating and understanding climate change (BIOTA 2021) as this is the most urgent management requirement but does also provide protocols for the conduct of visiting yachts and research teams.

A focus has been placed on biosecurity as this needs significant strengthening to ensure enduring benefits of a rat eradication. A draft biosecurity plan for the Chagos Archipelago (Harper 2017) provides a guide for any voyages departing from Diego Garcia.

BIOTA has employed two Environmental Officers to manage the environmental issues in the BIOT.

6.5 Policies and procedures

All BIOTA policies and procedures relating to the Chagos Archipelago will be followed, which includes the BIOTA's environmental priorities or any documents that supersede these.

An endorsed biosecurity plan for the BIOT is required before the operation proceeds and its protocols should also be adhered to. An incursion response plan should be a part of this and be deployed in case of shipwrecks or suspected illegal landings.

6.6 Roles and responsibilities

Effective management of all the environmental risks associated with the proposed rat eradication will require the cooperation of all the personnel involved. Liaison with the BIOTA with regard to permitting, along with compliance and mitigation management will be the ultimate responsibility of the Project Manager. Some of these actions and responsibilities will, of necessity, be devolved to the ship's captain, the Chief Pilot, the Operations Manager, and leaders of field crews.

6.7 Implementation of mitigation measures

The Project Manager will manage the operational team to ensure that environmental risks are minimised or mitigated where possible (Table 5). As the eradication operation planning develops and additional pertinent information is forthcoming this EIA will be reviewed and updated by the Project Manager.

6.8 Environmental reporting

The operational report will include details of any environmental incidents and restorative actions taken. Environmental monitoring outcomes will also form a portion of the report as part of the assessment of the success and benefits of the eradication. Recommendations for environmental management of similar operations on other tropical atolls and for future work in the Chagos Archipelago should also be included as part of the conclusions.

7. CONCLUSIONS

When contemplating costs and benefits of a proposed rodent eradication, it is useful to have pertinent foundations with which to appraise the likely outcomes against. Cowan et al. (2011) set out useful criteria for assessment of pest removal operations utilising toxins to reduce outcome uncertainty, namely;

(1) Do the perceived benefits actually justify the eradication of the pest species?

(2) Is the risk of failure too high?

(3) Will perverse outcomes result in minimal benefits?

(4) Will the management fail because of unforeseen technical problems?, and;

(5) Will the benefits of successful management be lost if reinvasion cannot be minimised?

In order to assess these criteria it is necessary to restate the current and likely situation in the Chagos Archipelago with regard to rats. The removal of rats from the outer islands of the Chagos Archipelago will have a profound, positive impact on the terrestrial environment of the islands, especially when combined with the management of invasive vascular plants and the restoration of abandoned coconut plantations to native habitats.

Since black rats invaded over 200 years ago they have precipitated significant disruption in ecosystem function within the archipelago by causing declines in seabird numbers and colony distribution, likely reduction in the numbers and diversity of keystone species such as land crabs, and deleterious reduction in nutrient pathways to the surrounding ocean with a subsequent decline biodiversity and resilience in coastal reefs. There is now compelling evidence for the benefits that accrue when rodents are eradicated, mainly through the ensuing recovery of previously degraded populations of native fauna and flora and the flow-on effects through the ecosystem.

The eradication operation has a high chance of success on most, if not all, the islands and if any eradications on single islands fail they can be dealt with as small units post-operation.

There may be some negative environmental effects arising from a rodent eradication on the outer islands, including possible impacts on some predatory birds such as herons and wader species. However, on a population level, any losses should be quickly replaced as the ecosystem recovers, with all non-target species likely to recover to similar abundances post-eradication. The suggested steps to reduce or mitigate adverse effects of the operation should minimise any prolonged environmental impacts including non-target species loss or disturbance from aerial or ground-baiting.

Consequently when assessed against the criteria set out by Cowan et al. it is obvious that significant ecosystem benefits will likely arise from the proposed eradication, with a very good chance of success. It is unlikely that many, if any, significant perverse outcomes will occur as a result of a rat eradication, and with careful planning and management the operation should be able to secure sufficient funding and achieve its goals.

Due to the highly isolated location of the archipelago rat incursions are much less likely to occur and with effective monitoring and biosecurity protocols in place these will further reduce the possibility.

In essence the benefits of the proposed eradication of black rats from the many islands within the Chagos Archipelago far outweigh any discernible costs or losses and the opportunity to restore ecosystem function within an entire tropical archipelago should be pursued.

8. REFERENCES

Alifano A, Wegmann A, Puschner B, Howald G. (2012) Migration of brodifacoum and diphacinone from bait pellets into topsoil at Palmyra Atoll National Wildlife Refuge. *In*: Proceedings of the 25th Vertebrate Pest Conference (R. M. Timm, Ed.) Published at University of California, Davis. Pp. 139-143.

Benkwitt CE, Wilson SK, Graham NAJ. (2019) Seabird nutrient subsidies alter patterns of algal abundance and fish biomass on coral reefs following a bleaching event. *Global Change Biology* 25: 2619–2632.

Bowie MH, Ross JG. (2006) Identification of weta foraging on brodifacoum bait and the risk of secondary poisoning for birds on Quail Island, Canterbury, New Zealand. *New Zealand Journal of Ecology* 30: 219-228.

British Indian Ocean Territory Administration. (2021) Website: https://biot.gov.io/environment/

Brooke de ML, Cuthbert RJ, Mateo R, Taggart MA (2011) An experimental test of the toxicity of cereal pellets containing brodifacoum to the snails of Henderson Island, South Pacific. *Wildlife Research* 38: 34 –38.

Brooke de ML, Cuthbert RJ, Harrison G, Gordon C, Taggart MA. (2013) Persistence of brodifacoum in cockroach and woodlice: Implications for secondary poisoning during rodent eradications. *Ecotoxicology and Environmental Safety* 97: 183-188.

Broome KG, Fairweather AAC, Fisher P. (2015) Brodifacoum Pesticide Information Review. Version 2015/1. Unpublished report docdm-25436, Department of Conservation, Hamilton, NZ. 115p.

Booth LH, Fisher P, Heppelthwaite V, Eason CT. (2003) Toxicity and residues of brodifacoum in snails and earthworms. DOC Science Internal Series 143. Department of Conservation, Wellington. 14 p.

Burbridge AA. (2004) Montebello Renewal: Western Shield Review – February 2003. *Conservation Science West Australia* 5: 194-201.

Carr P (2011) A guide to the birds of the British Indian Ocean Territory. Information Press, Oxford, UK.

Carr P. (2013) Factors influencing breeding island selection of red-footed booby *Sula sula* (Linn. 1766) in the Chagos Archipelago, central Indian Ocean, and the implications for future island management plans. MSc Thesis, University of Warwick, UK.

Carr P. (2015) Birds of the British Indian Ocean Territory, Chagos Archipelago, central Indian Ocean. *Indian Birds* 10: 57–70.

Carr P, Hillman JC, Seaward MRD, Vogt S, Sheppard CRC. (2013) Coral Islands of the British Indian Ocean Territory (Chagos Archipelago). *In*: CRC Sheppard (ed.). Coral Reefs of the United Kingdom Overseas Territories; *Coral Reefs of the World* 4. Pp. 271-282.

Carr P, Votier S, Koldeway H, Godley B, Wood H, Nicoll MAC. (in review) Status and phenology of breeding seabirds and a review of Important Bird and Biodiversity Areas in the British Indian Ocean Territory.

Caut S, Angulo E, Courchamp F. (2008) Dietary shift of an invasive predator: rats, seabirds and sea turtles. *Journal of Applied Ecology* 45: 428-437.

Caut S, Angulo E, Pisanu B, Ruffino L, Faulquier L, Lorvelec O, Chapuis JL, Pascal M, Vidal E, Courchamp F. (2012) Seabird modulations of isotopic nitrogen on islands. *PloS One* 7: e39125.

Cole N. (2009) Herpetofaunal observations on Eagle Island, Middle Brother, North Brother and Diego Garcia, with an overview of previous records from the Chagos Archipelago. *Phelsuma* 17: 40-48.

Cook ASCP, Ward RM, Hansen WS, Larsen L (2018). Estimating Seabird Flight Height using LiDAR. *Scottish Marine and Freshwater Science* 9 (14); 1-52.

Cowan P, Warburton B. (2011). Animal welfare and ethical issues in island pest eradication. *In*: Veitch, C. R.; Clout, M. N. and Towns, D. R. (eds.). *Island invasives: eradication and management*. IUCN, Gland, Switzerland.Pp. 418-421.

Croll DA, Newton KM, Matthew McKown M, Holmes N, Williams JC, Young HS, Buckelew S, Wolf CA, Howald G, Bock MF, Curl JA, Tershy BR. (2016) Passive recovery of an island bird community after rodent eradication. *Biological Invasions* 18: 703-715.

Cromarty PL, Broome KG, Cox A, Empson RA, Hutchinson WM, McFadden I. (2002). Eradication planning for invasive alien animal species on islands – the approach developed by the New Zealand Department of Conservation. *In*: Veitch CR & Clout MN (eds.). *Turning the tide: the eradication of invasive species*. IUCN SSC Invasive Species Specialist Group, IUCN, Gland, Switzerland and Cambridge UK.

Doube J. 2019. Is poisoning rodents a health hazard. *In*: Veitch, C. R., Clout, M.N., Martin, A.R., Russell, J.C. and West, C. J. (eds.) *Island Invasives: scaling up to meet the challenge*. Occasional Paper SSC no. 62. Gland, Switzerland: IUCN. Pp. 709.

Dowding JE, Lovegrove TG, Ritchie J, Sharon N, Puckett KM. (2006) Mortality of northern New Zealand dotterels (*Charadrius obscurus aquilonius*) following an aerial poisoning operation. Notornis 53: 235-239.

Ðpakauskas V, Klimienë I, Ruþauskas M, Bandzaitë V. (2005) Toxicity and effectiveness of indirect anticoagulants bromodiolone and brodifacoum. *Biologija* 4:77–81.

Eason CT, Wickstrom M. (2001) Vertebrate pesticide toxicology manual (poisons): information on poisons used in New Zealand as vertebrate pesticides. Department of Conservation Technical Series 23. Department of Conservation, Wellington.

Eason CT, Murphy EC, Wright GRG, Spurr EB. (2002) Assessment of risks of brodifacoum to non-target birds and mammals in New Zealand. *Ecotoxicology* 11: 35-48

Eason CT, Ogilvie S. (2009) A re-evaluation of potential rodenticides for aerial control of rodents. DOC Research & Development Series 312. Department of Conservation, Wellington. 33 p.

Ebbert S, Burek-Huntington K. (2010) Anticoagulant residual concentration and poisoning in birds following a large-scale aerial application of 25 ppm brodifacoum bait for rat eadication on Rat Island, Alaska. *In*: Proceedings of the 24th Vertebrate Pest Conference, 24 (R. M. Timm and K. A. Fagerstone, Eds.) Published at University of Calififornia, Davis. Pp. 153-160.

Fea N, Hartley S. (2018) The balancing act of nest survival: survival of a small endemic bird in the face of ship rat predation and other risk factors. *Avian Conservation and Ecology* 13 (2).

Fisher P. (2011) Non-target risk to Galapagos tortoises from the application of brodifacoum bait for rodent eradication: captive feeding trials. Landcare New Zealand. Unpublished report for Island Conservation, USA. Pp: 33.

Fisher P, Griffiths R, Speedy C, Broome K. (2011) Environmental monitoring for brodifacoum residues after aerial application of baits for rodent eradication. *In*: Veitch, C. R.; Clout, M. N. and Towns, D. R. (eds.). 2011. *Island invasives: eradication and management*. IUCN, Gland, Switzerland. Pp. 300-304.

Fisher P, Campbell K. (2012) Non-target risk assessment for rodenticide application on Pinzón and Plaza Sur, Galápagos Islands. Landcare New Zealand. Unpublished report for Island Conservation, USA. Pp: 21.

Fisher P, Funnell E, Fairweather A, Brown L, Campion M. (2012) Accidental discharge of brodifacoum baits into a freshwater Lake: A case study. *Bulletin of Environmental Contamination and Toxicology* 88:226–228.

Gerlach J, Florens V. (2000) Considering molluscs in rodent eradication projects. *Tentacle - The Newsletter of the IUCN/SSC Mollusc Specialist Group* 9: 7-8.

Graham NAJ, Wilson SK, Carr P, Hoey AS, Jennings S, MacNeil MA. (2018) Seabirds enhance coral reef productivity and functioning in the absence of invasive rats. *Nature* 559: 250-253.

Gronwald M, Genet Q, Touron M. (2019) Predation on green sea turtle, *Chelonia mydas*, hatchlings by invasive rats. *Pacific Conservation Biology*. https://doi.org/10.1071/PC18087

Harper GA, Bunbury N. (2015) Invasive rats on tropical islands: their population biology and impacts on native species. *Global Ecology and Conservation* 3: 607-627.

Harper GA. 2017. Northern Chagos Islands Biosecurity Plan, Chagos Conservation Trust, UK. Pp. 42.

Harper G.A., Carr P., Pitman H. (2019). Eradicating black rats from the Chagos – working towards the whole archipelago. *In*: Veitch, C. R., Clout, M.N., Martin, A.R., Russell, J.C. and West, C. J. (eds.) *Island Invasives: scaling up to meet the challenge*. Occasional Paper SSC no. 62. Gland, Switzerland: IUCN. Pp. 26-30.

Harper, G.A. (2020 [a]). The feasibility of eradicating black rats *Rattus rattus* from the outer Chagos Archipelago. Report prepared for the Chagos Conservation Trust, UK. Pp 53.

Harper, G.A. (2020. [b]). Operational Plan for eradication of black rats on the outer Chagos Islands. Pp 71.

Herrera-Giraldo JL, Figuerola-Hernández CE, Holmes ND, Swinnerton K, Bermúdez-Carambot EN, González-Maya JF, Gómez-Hoyos DA. (2019) Survival analysis of two endemic lizard species before, during and after a rat eradication attempt on Desecheo Island, Puerto Rico. *In*: Veitch, C. R., Clout, M.N., Martin, A.R., Russell, J.C. and West, C. J. (eds.) *Island Invasives: scaling up to meet the challenge*. Occasional Paper SSC no. 62. Gland, Switzerland: IUCN. Pp.191-195.

Hoang T. (2013) A literature review of the effects of aircraft disturbances on seabirds, shorebirds and marine mammals. https://pdfs.semanticscholar.org/72bb/55fb6d046d1bf06de929a870a8e2d69001f9

Hoare JM, Hare KM. (2006) The impact of brodifacoum on non-target wildlife: gaps in knowledge. *New Zealand Journal of Ecology* 30: 157-167.

Holmes ND, Griffiths R, Pott M, Alifano A, Will D, Wegmann AS, Russell JC. 2015. Factors associated with rodent eradication failure. *Biological Conservation* 185:8-16.

Howald G, Donlan C, Galván JP, Russell JC, Parkes J, Samaniego A, Wang Y, Veitch CR, Genovesi P, Pascal M, Sanders A, Tershy B. (2007) Invasive rodent eradication on islands. *Conservation Biology* 21: 1258–1268.

Innes J, Warburton B, Williams D, Speed H, Bradfield P (1995) Large-scale poisoning of ship rats (*Rattus rattus*) in indigenous forests of the North Island, New Zealand. *New Zealand Journal of Ecology* 19:5-17.

Jongbloed, R.H. (2016) Flight height of seabirds. A literature study IMARES. Report C024/16.

Keitt B, Griffiths R, Boudjelas S, Broome K, Cranwell S, Millett J, Pitt W, Samaniego-Herrera A. (2015) Best practice guidelines for rat eradication on tropical islands. *Biological Conservation* 185:17-26.

Kym E. Wilkins KE, Thomas AA, Prowse PC, Thomas PQ, Ross JV. (2018) Pest demography critically determines the viability of synthetic gene drives for population control. *Mathematical Biosciences* 305:160-169.

Larkin, Ronald P., Larry L. Pater, and David J. Tazik. 1996. Effects of Military Noise on Wildlife. A Literature Review. No. USACERL-TR-96/21. Construction Engineering Research Lab (army) Champaign, Illinois, USA.

Le Corre M, Danckwerts DK, Ringler D, Bastien M, Orlowski S, Rubio CM, Pinaud D, Micol T. (2015) Seabird recovery and vegetation dynamics after Norway rat eradication at Tromelin Island, western Indian Ocean. *Biological Conservation* 185: 85-94.

Littin KE, O’Connor CE, Eason CT 2000. comparative effects of brodifacoum on rats and possums. *New Zealand Plant Protection* 53: 310-315.

Lusk MR, Bruner P, Kessler C. (2000) The avifauna of Farallon de Medinilla, Mariana Islands. *Journal of Field Ornithology* 71: 22-34.

Manser A, Cornell SJ, Sutter A, Blondel DV, Serr M, Godwin J, Price TAR. (2019) Controlling invasive rodents via synthetic gene drive and the role of polyandry. *Proceedings of the Royal Society* B 286: 20190852.

McCauley DJ, DeSalles PA, Young HS, Dunbar RB, Dirzo R, Mills MW, Micheli F. (2012) From wing to wing: the persistence of long ecological interaction chains in less-disturbed ecosystems. *Scientific Reports* **2**: 409.

Mason G, Littin KE (2003) The humaneness of rodent pest control. *Animal Welfare* 12: 1-37.

Masuda BM, Fisher P, Beaven B. (2015) Residue profiles of brodifacoum in coastal marine species following an island rodent eradication. *Ecotoxicology and Environmental Safety*113: 1–8.

Merton, D.V. 1987. Eradication of rabbits from Round Island, Mauritius: a conservation success story. *The Dodo* 24: 19-24.

Morgan DR, Wright GR, Ogilvie SC, Pierce R, Thomson P. (1996) Assessment of the environmental impact of brodifacoum during rodent eradication operations in New Zealand" (1996). *In*: Proceedings of the 17th Vertebrate Pest Conference: 38.

Morgan D, Waas JR, Innes J. (2006) The relative importance of Australian magpies (*Gymnorhina tibicen*) as nest predators of rural birds in New Zealand. *New Zealand Journal of Zoology* 33: 17-29.

Morriss GA, O'Connor CE, Airey AT, Fisher P. (2008) Factors influencing palatability and efficacy of toxic baits in ship rats, Norway rats and house mice. Science for Conservation 282. Department of Conservation, Wellington. 26 p.

Murray M. (2018) Ante-mortem and post-mortem signs of anticoagulant rodenticide toxicosis in birds of prey. *In*: N.W. van den Brink et al. (eds.), Anticoagulant Rodenticides and Wildlife; *Emerging Topics in Ecotoxicology* 5;109-134

Newton KM, McKown M, Wolf C, Gellerman H, Coonan T, Richards D, Harvey AL, Holmes N, Howald G, Faulkner K, Tershy BR, Croll DA (2016) Response of native species 10 years after rat eradication on Anacapa Island. *California Journal of Fish and Wildlife Management* 7: 72-85.

Ogilvie SC, Pierce RJ, Wright GRG, Booth LH, Eason CT. (1997) Brodifacoum residue analysis in water, soil, invertebrates, and birds after rat eradication on lady alice island. *New Zealand Journal of Ecology* 21: 195-197.

Pain DJ, Brooke M de L, Finnie JK, Jackson A. (2000) Effects of brodifacoum on the land crab of Ascension Island. *The Journal of Wildlife Management* 64: 380-387.

Pascal M, Olivier Lorvelec O, Bretagnolle V, Culioli J-M (2008). Improving the breeding success of a colonial seabird: a cost-benefit comparison of the eradication and control of its rat predator. *Endangered Species Research* 4: 267–276.

Peake JF. (1971) Non-marine Mollusca of Diego Garcia. *Atoll Research Bulletin* 149: 173-174.

Pitt WC, Berentsen AR, Shiels AB, Volker SF, Eisemann JD, Wegmann AS, Howald GR. (2015) Non-target species mortality and the measurement of brodifacoum rodenticide residues after a rat (*Rattus rattus*) eradication on Palmyra Atoll, tropical Pacific. *Biological Conservation* 185: 36–46.

Primus T, Wright G, P. Fisher P. (2005) Accidental discharge of brodifacoum in a tidal marine environment: A case study. *Bulletin of Environmental Contamination &. Toxicology* 74:913–919.

Sánchez-Barbudo IS, Camarero PR, Mateo R. (2012) Primary and secondary poisoning by anticoagulant rodenticides of non-target animals in Spain. *Science of the Total Environment* 420: 280–288.

Rueda D, Campbell KJ, Fisher P, Cunninghame F, Ponder JB. (2016) Biologically significant residual persistence of brodifacoum in reptiles following invasive rodent eradication, Galapagos Islands, Ecuador. *Conservation Evidence* 13: 38.

Shiels AB, Ramírez de Arellano GE. (2019) Habitat use and seed removal by invasive rats (*Rattus rattus*) in disturbed and undisturbed rain forest, Puerto Rico. *Biotropica* 51:378–386.

Siers SR, Shiels AB, Goldade DA, Volker SF, McAuliffe TW, Coad HL, Pitt WC. (2016) Wake Atoll fish tissue sampling and analysis three years after an island wide rodenticide application. Unpublished Report QA 2241. USDA, APHIS, WS, National Wildlife Research Center. Hilo, HI. 49 pp.

Spalding M. 2015 Report of Official Visit to BIOT (May 2015), Chief Science Advisor. Unpublished report, BIOT Government.

Stoddart DR. (1971a) Rainfall on Indian Ocean coral islands. *Atoll Research Bulletin* 147: 1-21.

Stoddart DR. (1971b) Terrestrial fauna of Diego Garcia and other Chagos atolls. *Atoll Research Bulletin* 149: 163-170.

Stoddart DR. (1971c) Land vegetation of Diego Garcia. *Atoll Research Bulletin 149:* 127-142.

Stoddart DR. (1971d) Terrestrial fauna of Diego Garcia and other Chagos atolls. *Atoll Research Bulletin* 149: 163-170.

Symens, P., 1999. Breeding seabirds of the Chagos Archipelago. *In*: Sheppard, C. R. C., & Seaward, M. R., (eds.). *Ecology of the Chagos Archipelago*. Linnean Society Occasional Publications 2, Westbury Publishing.

Sztukowski LA, Kesler DC. (2013) Bait consumption by Sooty Terns: implications for island eradication programmes. *Bird Conservation International* 23:36-44.

Thorsen M, Shorten R, Lucking R, Lucking V. (2000) Norway rats (*Rattus norvegicus*) on Frégate Island, Seychelles: the invasion, subsequent eradication attempts, and implications for the island's fauna. *Biological Conservation* 96: 133-138.

Vyas NB. (2013) Rodenticide incidents of exposure and adverse effects on non-raptor birds. *Science of the Total Environment* 609: 68-76.

Samaniego A, Boudjelas S, Harper GA, Russell JC. (2019) The critical role of land crabs in tropical island invasive rodent eradications and ecological restoration. *In:* Veitch, C. R., Clout, M.N., Martin, A.R., Russell, J.C. and West, C. J. (eds.) *Island Invasives: scaling up to meet the challenge.* Occasional Paper SSC no. 62. Gland, Switzerland: IUCN. Pp. 209-222.

Weir SM, Yu S, Knox A, Talent LG, Monks JM, Salice CJ. (2016) Acute toxicity and risk to lizards of rodenticides and herbicides commonly used in New Zealand. *New Zealand Journal of Ecology* 40: 342-350

Wegmann A, Flint E, White S, Fox M. Howald G, McClelland P, Alifano A, Griffiths R. (2012) Pushing the envelope in paradise: A novel approach to rat eradication at Palmyra Atoll. *In*: Proceedings of the 25th Vertebrate Pest Conference. (R. M. Timm, Ed.). University of California, Davis. Pp. 48-53.

Wegmann A, Howald G, Kropidlowski S, Holmes N, Shiels AB. (2019) No detection of brodifacoum residues in the marine and terrestrial food web three years after rat eradication at Palmyra Atoll, Central Pacific. *In*: C.R. Veitch, M.N. Clout, A.R. Martin, J.C. Russell and C.J. West (eds.). *Island invasives: scaling up to meet the challenge*. pp. 600–603. Occasional Paper SSC no. 62. Gland, Switzerland: IUCN.

Wolf CA, Young HS, Zilliacus KM, WegmannAS, McKown M, Holmes ND. (2018) Invasive rat eradication strongly impacts plant recruitment on a tropical atoll. *PLoS ONE* 13: e0200743.https://doi.org/10.1371/journal. pone.0200743