Restoration of Allen Cay:

A Feasibility Assessment for the Removal of Mice

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EXECUTIVE SUMMARY

Allen Cay, located in the Allen Cay's of the Exuma Island Chain supports a breeding population of Audubon's Shearwaters (*Puffinus lherminieri lherminieri*) and is home to the endangered Allen Cay Rock Iguana (*Cyclura cychlura inornata*). Currently the recovery of both of these species on Allen Cay is limited by the presence of introduced house mice (*Mus musculus*) and the shearwaters are suffering high rates of predation by Barn Owls (*Tyto alba*).

This proposal recommends a strategy for the restoration of Allen Cay. Removing mice and discouraging barn owls from using Allen Cay will permit the recovery of the shearwater population which has decreased dramatically in the last two decades and should benefit other native species present. Subsequent plans to enhance breeding habitat will increase the chance of recruitment and increase of the iguana population.

Eradication of mice from Allen Cay is an achievable goal using current techniques that have been applied successfully around the world. The initial phase, undertaken in 2011, which included securing the necessary funding, undertaking a site visit and completing a field trial, has been completed. Most of the iguanas on Allen Cay have also been captured, radio-tagged and re-located to a nearby cay in anticipation of the mouse eradication. The second phase to be completed during 2012 requires operational planning, removal of the last iguanas, establishment of biosecurity measures and implementation of an eradication campaign involving personnel from Bahamas National Trust, Island Conservation, and scientists with assistance from the RV Coral Reef II of the Shedd Aquarium and Nigel Bowers of Powerboat Adventures. The final phase, planned for 2013, requires confirmation of eradication success, monitoring of the recovery of the ecosystem, return of the iguanas to the cay, and the edition of ideal nesting habitat for iguanas.

If successful, this project would be the first removal of house mice to be undertaken at an island in the Bahamas. Invasive species are one of the key threats to biodiversity in the Bahamas so the effective demonstration of techniques and development of capacity within the region will be a significant achievement for Bahamas National Trust. It is hoped that any positive publicity and media coverage from a successful operation will increase regional awareness of invasive species issues and the conservation benefit that can accrue from their removal. This project will demonstrate how conservation management can be used to protect biodiversity and ensure the protection of wildlife populations for future generations.

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1 INTRODUCTION

The Bahamas is the largest small-island archipelago in the tropical Atlantic, comparable in scale and complexity to the Hawaiian Islands and the Lesser Antilles. The islands and cays within the Bahamas were formed not by volcanism but by the deposition of calcareous sediment, and the archipelago consists of several massive banks divided by deeper waters. During glaciations of recent millennia, sea levels were sometimes almost 100-m lower than at present and many of the separate cays of today were connected into several large islands. In interglacial periods, including the last 10,000 years, only the high places of the banks are above the ocean and the land mass is reduced to a fraction of the potential area. This reduction in area puts strain on populations and makes any rare species more susceptible to extinction.

The many islands and cays of the Bahamas provide critical habitat for diverse plants and animals. Correll and Correll (1982) report that nearly nine percent (121 taxa) of plant species found in the Bahamas are endemic Over 1350 species of flowering plants and ferns have been described, representing approximately 660 genera and 144 families. The Bahamas also provides a stronghold for a number of seabird and reptile species, with endemic species and subspecies of reptiles that once occurred across the larger islands now restricted to a handful of cays, as is the case for the Allen Cays Rock Iguana, a subspecies of the iguana that was native to the great Bahama Bank and is now found only on Andros Island and a handful of cays including the Allen Cays.

When humans arrived in the Bahamas about 2000 years ago, the animals faced a new predator that coincided with large declines in their populations and the loss of many species including tortoises, crocodiles, rails, and others (Steadman et al. 2007). Today, invasive rodents and other introduced species probably pose the greatest threat to the biodiversity that remains. Rodents are one of the most devastating of all of the invasive species introduced to island ecosystems. They impact native plants and animals through direct predation, competition or changes in the food web. Rodents have been introduced to more than 80% of islands worldwide, causing ecosystem-wide perturbations, including profound effects on the distribution and abundance of native flora and fauna (e.g. Atkinson 1985, Jones et al. 2008, Kurle et al. 2008, Towns et al. 2009). As voracious omnivores and consumers of seeds, first principles of ecology predict myriad perturbations to islands by the establishment of mice or rats; more research on the ecosystem-wide effects of these species is ongoing.

It is unknown when house mice (*Mus musculus*) were introduced to Allen Cay but their presence is now recognized as having an impact on Audubon's shearwaters (*Puffinus lherminieri lherminieri)*, but the impact is primarily indirect. The shearwaters at Allen Cay experience higher levels of predation by Barn Owls than other shearwater colonies in the area. The best explanation is that the owls are attracted to Allen Cay in higher numbers than to other cays because there are mice on the island. If we can decrease the owl predation levels, the shearwaters can rebound to the levels seen in 2000 where about twice as many breeding pairs were found.

We do not know to what extent, if any, the mice are affecting the iguana population at Allen Cay. There are healthy populations of iguanas on the cays to the south and east of Allen Cay (Southwest Cay and Leaf Cay, respectively), but only 20 iguanas inhabited Allen Cay at the beginning of this project. The geology at Allen Cay differs from the other islands, and there is very little sandy habitat where iguanas tend to breed. Our project includes creation of ideal nesting sites for iguanas (see below). Mice may be affecting the iguanas in some way, but we do not know of any direct threats and the owls do not appear to be predating iguanas in the way that they have been killing shearwaters.

The two primary goals for the restoration of Allen Cay are to halt the decline of Audubon's shearwaters and to increase the population of the iguanas. This assessment supports these goals by exploring the feasibility of removing introduced mice from the cay. We present background on Allen Cay and its biodiversity and explain the threat that is currently posed by the continued presence of mice. We recommended for a methodology for the removal of mice and assesses whether this approach is feasible. Incorporated into the assessment is an exploration of the projects technical, social and political feasibility as well as an analysis of the ability to sustain the project's anticipated benefits.

The removal of invasive species is a simple and cost-effective means of protecting island species and the suggested approach outlined in this assessment has been used many times before to recover seabird and reptile populations.

2 OBJECTIVES

The objectives of this plan are to:

- Explore the costs and benefits of removing mice from Allen Cay
- Assess the feasibility of removing mice from Allen Cay and preventing their reintroduction
- Advance an eradication strategy for the removal of mice from Allen Cay

3 SITE DESCRIPTION

Allen Cay is located within the Allen Cays in the northern portion of the Exuma Islands in the Commonwealth of the Bahamas (24° 45' N, 76° 50.5' W). The Allen Cays contain four small cays (Allen Cay, 6 ha; SW Allen Cay (= U Cay), 3 ha; Leaf Cay, 4 ha; Flat Rock Reef Cay, 4 ha), all which are of conservation concern. Allen Cay is Crown Land, as is Flat Rock Reef Cay, and hence their biota is protected by Bahamian law; the latter cay was leased at one time, but the lease has lapsed. The other two cays are privately owned. The cays are just 60 km southeast of Nassau and because of this proximity, are regularly visited by recreational boaters. Two companies – Powerboat Adventures and Island World Adventures tour companies' makes daily visits to see the iguanas at Leaf Cay when the weather is calm.

Allen Cay is a small limestone island approximately 1 km in length and 50-100 m wide. Elevation changes minimally across the island, a variation of 4-5 m. The cay encompasses 6 ha of emergent land, consisting of a rocky substrate composed of honeycombed limestone with low (<3m) interior coppice vegetation. Only one small sandy beach exists, evidence of the limited suitable nesting habitat for iguanas.

3.1 Climate

Having a tropical maritime wet and dry type climate with winter incursions of modified polar air, the Bahamas do not experience frost, snow, sleet, hail or extremes of temperatures. Trade winds blow almost continually throughout the islands of the Bahamas and produce a warm climate which varies little throughout the year. Humidity is fairly high, especially in the summer months. Winds are predominantly easterly throughout the year, with a tendency to become northeasterly from October to April and southeasterly from May to September. Wind speeds are, on average below 10 knots; in winter months, periods of north and northeast winds of about 25-30 knots may occur. May and June are typically rainy months with heavy squalls and thunderstorms that arise quickly (Figure 1). Allen Cay is subject to tropical storms and hurricanes from Jun until November. The climate in the winter is mild with lows of 16° C, (60° F).

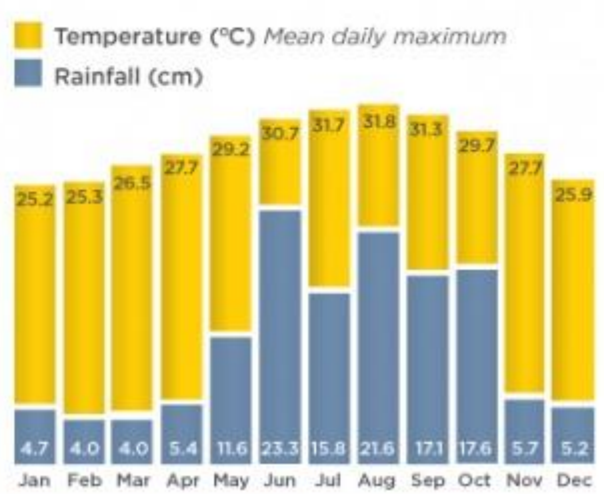

Figure 1. Average monthly rainfall and temperatures for the Bahamas (The Bahamas Meterology Department www.bahamasweather.org).

3.2 Socio-cultural value

Allen Cay is uninhabited and visited occasionally by a small number of individuals for wildlife conservation and research. Tourism and banking are the most important economic activities in the country, and this area has the closest wild iguana population to Nassau. With offshore powerboats offering daily trips to the adjacent Leaf Cay for tourists to see the iguanas and feed them by hand. The harbor formed between the Allen Cays is very important to the boating community, which has a huge impact on the culture and economy of the Bahamas. In addition, several companies offer scuba diving tours to the Exumas from Nassau that use the harbor extensively as a shelter from weather and safe anchorage.

Allen Cay itself is the least visited of the 4 cays in the group. Nearly all of Allen Cay consists of karst limestone. The sharp, rocky terrain is appears to minimize activity on the island, but the number of visitors to Allen Cay or their on-island activities are currently unknown. A makeshift amphitheater was created on the ridge of the island around 2005 and indicates that some groups have used the island as a place to take a break from their boats while in the harbor and likely to enjoy the spectacle of the shearwater chorus that occurs on dark nights during the breeding season. With shearwaters present on the cay for 8 or 9 months of the year, this cay represents the most accessible, visited, and well-known shearwater colony in the Caribbean region. The approximately 300 breeding pairs at Allen Cay are significant in terms of the regional population (~3000 pairs in 2009 with several thousand more expected at colonies in the Cay Sal Bank), but they have additional significance in that the island is so well-known, is visited by tourists, and is close to Nassau. Thus, this project represents an opportunity to protect an important population and promote the value and beauty of Audubon's Shearwater to the Bahamas at a time when ecotourism and the desire to experience natural beauty represent a growing part of the tourism market.

3.3 Biodiversity values of Allen Cay

Three species of ground iguana are found in the Bahamas: *Cyclura cychlura*, *C. carinata* and *C. rileyi*. Each of these species has one or more sub-species, which are found only on certain islands or cays. The Allen Cay iguana (*Cyclura cychlura inornata*) occurs naturally only in the Allen Cays of the northern Exuma Islands (Schwartz and Carey 1977). A small population (*c*. 20 individuals) inhabits Allen Cay. This subspecies is strictly protected by law under the Wild Animals Protection Act 1968 and is formally listed as Endangered on the 2011 IUCN Red List and CITES Appendix I. While the decline in numbers of all these species and sub-species is partly due to development, it is also due to poaching of live iguana for sale as pets and for food. The bulk of the population lives on Southwest Allen Cay and Leaf Cay, both of which have good sandy habitat with plenty of space for nesting. Allen Cay is separated from those cays by 100 to 200 m of water in the natural harbor that occurs there. Allen Cay is much rockier than Southwest Allen Cay and Leaf Cay. It is long and thin in shape and has fewer trees and no sandy areas above the high tide line where a female iguana could nest.

Allen Cay also supports other reptile species. Brown anoles (*Anolis sagrei*) and one species of dwarf gecko (*Sphaerodactylus nigropuntatus*) are mainly insectivorous. Brown racers (*Cubophis vudii*) mostly prey on insects and lizards, but it is unknown if they consume mice as well. The only amphibians suspected to occur in the cays are the Cuban treefrog (*Osteopilus septentrionalis*) and the greenhouse frog (*Eleutherodactylus planirostris*), which are mostly insectivorous. The curly tail lizard (*Leiocephalus carinatus*) was reported to occur on the cay, but it has not been detected in repeated visits since 2000 and we expect that this report is erroneous.

Audubon's Shearwater is another species of conservation concern. This shearwater is a tropical pelagic species represented in the western Atlantic by an endemic subspecies consisting of a total population of around 5,000 pairs. Most of the population breeds in the Bahamas. This bird nests on three local cays, Allen Cay, Barn Owl Cay (1 km North), and Pimlico Cay (2 Km North). These populations have not been censused thoroughly, but estimates from 2007 indicate approximately 300 breeding pairs at Allen Cay. We plan to census the populations at Barn Owl

Cay (9 ha) and Pimlico Cay (12.5 ha) for the first time in 2012. These large islands could hold significant numbers but are somewhat difficult to access and were only recently found to have shearwaters.

Laughing Gulls (*Larus atricilla*) are known to breed on Allen Cay with a significant colony of several hundred pairs at Flat Rock Reef Cay in summer months. This species is common and increasing in the Atlantic and Caribbean, as it benefits from human development. A complete list of birds recorded at Allen Cay in December of 2011 can be found in Appendix II.

Allen Cay has many species of plants with a standard complement insects and invertebrates. There is a long list of breeding, migrating, and wintering land and shorebirds including some species of concern such as the American Oystercatcher (*Haemotopus palliatus*). Endangered Piping Plovers (*Charadrius melodus*) and Kirtland's Warblers (*Dendroica kirtlandii*) winter on nearby cays but are not likely to occur on Allen Cay itself and have not been seen there.

3.4 Invasive species on Allen Cay

Only one invasive mammal has been reported from Allen Cay, the house mouse (*Mus musculus)*. It is unknown when or how mice were introduced to the cay. The first confirmed sighting of mouse on the cay was recorded in 2003 by Dr. Will Mackin. The mice attract barn owls which, in addition to hunting mice, prey on Audubon's shearwaters. The only invasive plant species documented is a handful of now-killed *Casuarina equisetifolia* trees.

4 BENEFITS OF REMOVING MICE FROM ALLEN CAY

Removing mice from Allen Cay will not only provide for the recovery of the cay's Audubon's shearwater population and allow enhanced habitat restoration for the Allen Cay iguana but it will also develop capacity for invasive species management in the Bahamas.

Audubon's Shearwaters were once very common around the West Indies and Caribbean, but have lost most of their former breeding habitat. A marked decline in the population of Audubon's shearwaters on Allen Cay has been witnessed since the late 1980s. Each year, hundreds of adult shearwaters are found dead at Allen Cay, and almost all are killed by barn owls and left to be eaten by hermit crabs. The death rate at this colony is twice the rate at nearby colonies that do not have mice (Mackin 2007). The explanation for these observed impacts is known as 'hyperpredation'. This phenomenon occurs because mice provide a food source that allows barn owls to persist on Allen Cay throughout the year. Shearwaters that are only present for a part of the year are exploited by barn owls seasonally. In the Bahamas, large numbers of shearwaters on several cays are killed by barn owls including Channel Cay, Rocky Dundas, Long Cay and sites on the Little Bahama Bank (Jim Kushlan, pers. comm.). However, shearwater mortality is higher at Allen Cay because barn owls are supported at elevated numbers by the mice.

Mice have been established on Allen Cay for an unknown period. The time of origin of Barn Owls in the Bahamas is unclear, but their arrival in the fossil record coincides with the arrival of humans (Storrs Olson, pers. comm..). Furthermore, recent development activities on the larger islands of the Exumas may have caused an increase in the rat and mouse populations in the chain of islands. Eradicating mice and disrupting the favored nest and roost sites for owls on the Allen Cays should lead to an increase in adult survival and fledgling success of shearwaters each year and allow the population to increase from around 300 pairs to between 600 and 1200 pairs (Mackin 2007). This project proposes to restore the biodiversity value of Allen Cay through removal of invasive mice and deterring barn owls from roosting and nesting on the cay.

One additional objective of the project is to understand more about the movements of owls to these offshore cays. If the owls are fairly sedentary and do not often cross open water to get to nesting islands, then we may be able to drastically increase the survival of shearwaters by controlling owl populations at this breeding colony and potentially others. If the owls regularly move among sites and colonize small islets, then control efforts at the breeding colonies would be less cost-effective and other techniques to decrease owl predation (i.e. regional initiatives to eliminate mice and rats from whole island groups) would be required to improve conditions for shearwaters regionally.

The Iguana Specialist Group of IUCN has been working to create more breeding populations of *Cyclura cychlura inornata*. It is estimated that modifying the environment to create reproductive habitat could double the breeding population on Allen Cay. Allen Cay is currently home to approximately 20 endemic Allen Cay's iguanas that cannot breed due to lack of suitable habitat. This project will create nesting sites for the iguanas and aims to double the breeding population.

5 PROPOSED APPROACH TO REMOVING MICE AND DISCOURAGING BARN OWLS FROM USING ALLEN CAY

5.1 Alternatives

Three alternative management strategies can be considered for Allen Cay:

No action: A 'no action' alternative for Allen Cay is not considered the best strategy to protect the island's biodiversity. If invasive mice are not removed, the impacts described will persist. Over time, this will result in the continued decline of the seabird colony. Because there are several nearby colonies without mice, Allen Cay could act as a long-term sink for the area where vocal activity at the island and the availability of nest sites attracts young birds to attempt to nest on Allen Cay. These colonists would suffer unsustainable mortality and represent a continual drain on the shearwater population in the Northern Exuma Cays.

Control: Invasive species control is a management strategy to reduce the abundance of the target species to a level sufficient to protect the seabirds, reptiles, and vegetation. A control approach is typically used when reinvasion or immigration of the pest species is frequent or continuous and complete eradication cannot be achieved. Invasive species control is typically used in a mainland situation where the pest population is reduced but not completely eradicated, for example culling deer populations to protect sensitive habitat (Tanentzap et al. 2009).

On Allen Cay, a control operation for mice would be inefficient, costly, and of only short-term benefit. Control operations would require several visits to the island each year to maintain traps and bait stations, and field personnel would need infrastructure and trails for fieldwork. In addition, long-term use of trails would result in habitat impacts and regular visits would likely increase biosecurity risk. The overall biodiversity benefits from control operations would be much less and the long-term costs higher than for an eradication.

Eradication: Eradication is the complete and permanent removal of the pest species, and is the most effective option to address the goal and desired outcomes of biodiversity protection; eradication can provide permanent biodiversity protection from invasive species impacts. Eradication operations can be implemented within a relatively short time-frame and only require follow-up field visits to confirm absence of the target species; thus eradication is more cost-effective and time-efficient than control operations. For an eradication approach to be sustainable in the long-term, implementation of biosecurity measures are needed to prevent reintroductions of non-native and invasive species.

The basic principles to achieving successful eradication of an invasive mammal are:

- All individuals of the target species must be put at risk by the methods used.
- Target species must be removed at a rate faster than they can reproduce.
- Risk of reinvasion must be zero or able to be managed effectively.
- Environmental benefits outweigh the impacts of eradication methods
- Project is socially acceptable to stakeholders

In addition, the methods used should comply with the relevant local regulations. Additional or revised techniques are often needed to remove the last few animals and to confirm that eradication is complete.

5.2 Recommended approach

It is recommended that mice are permanently removed from Allen Cay as this would provide the greatest lasting benefit to the endangered species present. Allen Cay is an ideal site for an eradication because it is small (6 ha) and sufficiently distant from any other mouse populations that could re-infest the cay.

At the same time as mice are removed it is proposed that barn owls be discouraged from roosting and nesting on Allen Cay and nearby islands. Barn owls are dependent upon having good roost sites and nesting sites to successfully inhabit an area. In the Bahamas, they nest and roost in sinkholes. These are limited in number on Allen Cay.

5.2.1 Mice

The fundamental methodology used in rodent eradications is the delivery of rodent bait containing a toxicant. Bait is distributed consistently across the island and during a time of year when mice are relatively food deprived. In dry tropical environments this period is closely aligned with a characteristic dry season. Depending on island topography and size, climate, native species assemblages, operational logistics and other factors, successful eradication operations have applied bait using either bait stations or a broadcast method, or both.

Because of the flat terrain on Allen Cay, the cay's size, and the accessibility of the entire cay (no cliff faces etc.), the recommended strategy for mice eradication is to apply bait by hand broadcast. In order to achieve success, bait must be placed in every mouse territory on the cay and it must remain accessible to the mice for several days to ensure that all individuals consume a lethal dose.

The project must achieve eradication of all mice from the cay and have minimal impacts to non-target wildlife and the cay's ecosystem. Further assessment and consultation will be required by all partners for the continued development of this approach. Issues that need to be considered include:

- Probability of successfully eradicating mice from the cay.
- Potential impacts to non-target vertebrates such as reptiles and birds, especially endemic and locally threatened species.
- Potential distribution of seeds onto the cay via personnel.
- Potential impacts to the marine environment.
- Prevention of the introductions of other invasive species or the re-introduction of rodents.

For the successful eradication of invasive mice from Allen Cay, the fundamental requirement is that every last rodent is removed or killed. The use of bait containing a rodenticide is the only known technique capable of achieving successful eradication of mice. The choice of rodent bait is important in achieving eradication success, but its use must be also evaluated against potential negative consequences, such as harm to non-target species

From an eradication perspective, the choice of bait used must:

- contain an active ingredient that is known to be highly toxic to mice
- be palatable and demonstrate low or no bait shyness by mice
- be delivered into the territory of each mouse on the cay
- be available long enough for each rodent to consume a lethal dose.
- be consumed in sufficient amounts by every single mouse to receive a lethal dose

From an efficacy standpoint, the bait must contain a rodenticide that has the ability to kill mice and prevent the possibility of incurring bait avoidance before all individuals consume a lethal dose. In addition, the bait product must be legally available for use in the Bahamas. About 58% of successful rodent eradications from islands have used a second-generation anticoagulant (e.g. brodifacoum, bromadiolone) (Howald et al. 2007, Island Conservation unpubl. data).

For successful rodent eradication from Allen Cay, brodifacoum is the toxicant mostly likely to achieve success. Brodifacoum is a coumarin-based second-generation anticoagulant. It is a vertebrate toxicant that acts by interfering with the blood's ability to form clots, causing sites of even minor tissue damage to bleed continuously. Before the toxicant can have any measurable physiological effects, brodifacoum levels in the liver must reach a toxic threshold (which can vary widely between species). The relative threshold level for mice to experience negative effects from brodifacoum exposure is very low, but can be higher in other vertebrate species. Brodifacoum is the primary rodenticide used in rodent eradications on islands (Howald et al. 2007). Detailed descriptions of brodifacoum and its effects on other native species or "non-targets" can be found in: Kaukeinen 1993; Eason and Spurr 1995; Eason et al. 2002; Erickson and Urban 2004; and Hoare and Hare 2006.

Available bait products containing brodifacoum are typically formulated as a bait block or pellet with the rodenticide locked within a grain-based matrix; the grain matrix is typically very attractive to rodents. The formulation is designed to persist for a time period that both maximizes the probability of exposure for the target rodents, and minimizes the risk of exposure to non-target species. To reduce the impact of brodifacoum to non-target species, the bait product can be formulated to be less attractive; typically bait blocks or bait pellets are dyed green or blue – colors which birds and reptiles tend to avoid (Tershy et al. 1992; Buckle 1994, H. Gellermen, unpubl. data).

Hand broadcasting bait results in an even ground distribution of bait. Typically bait is spread from regularly-spaced points along transects defined with a hand-held GPS to ensure even coverage across the island. Hand broadcasting is limited by the rate at which bait can be spread (number of personnel and physical demands of the terrain) and accessibility to all parts of an island. Ideally hand broadcast across the entire island should be complete within one day so that mice do not move from unbaited areas into baited areas where some or all of the bait has already been eaten. Because Allen Cay is relatively small and flat, and access to all areas is possible, hand broadcast is recommended as a cost-effective eradication technique.

5.2.2 Barn owls

Owls may be dissuaded from inhabiting Allen Cay if roost sites are unsuitable. This can be accomplished by filling them with rocks from the surrounding area. If there are no roosting locations, owls will hopefully not remain in the area. Three actions are proposed to complete the deterrent of barn owls. First, owls caught at Allen Cay will be euthanized to stop the predation immediately. It is believed that only a handful of owls inhabit Allen Cay and the adjacent cays and we are requesting permission to collect study specimens of as many as 10 owls at Allen Cay. The specimens will be tissue-sampled, exported, curated, and saved for study at the Smithsonian Museum of Natural History in Washington, DC.

In December 2011, we began working to control and capture owls at Allen Cay. Only one owl was seen in a week of work. The cavity where the bird was roosting was filled with rocks to make it unsuitable. We set up one or two mist nights every night for 4 nights and played back vocalizations of Barn Owls and mammals in distress each night. After 4 nights we did not detect a single owl. After talking to the manager and staff of Highbourne Cay, we learned that they frequently see owls including Barn Owls, Burrowing Owls, and Short-eared Owls. We spent the last two night of the trip at Highbourne Cay. We attracted an owl but it did not enter our net on the first night. We also captured 4 norway rats at the trash dump on the north end of the island and used them to bait our bal-chatri traps on the second night. We saw four Barn Owls on that second night including 3 near the dump site on two different occasions. Just before Dawn on December 11, 2011, two Barn Owls were attracted to our playback and made repeated dives on the Bal-chatri traps within the dump site.

From this work and discussion with people who live in the Bahamas and encounter Barn Owls, it appears that they are spending more time at the inhabited islands that have large rodent populations, at least during December. It is still our expectation that removing the mice from Allen Cay will cut predation rates there down to the lower levels seen at other shearwater colonies in the Exumas. During the May 2012 removal process, we will record all dead shearwaters found in the colony and attempt to collect any owls that are actively hunting there. A licensed Bahamian hunter (and BNT Warden) will take part in the restoration effort and carry a shotgun to collect Barn Owls found at Allen Cay. Any nests discovered at Allen Cay or Barn Owl Cay will also be collected. After the removal of mice, we will continue to study the killing of shearwaters by owls and look for cost-effective ways to reduce predation to minimal levels.

6 PROJECT FEASIBILITY

6.1 Technical feasibility

To date, successful rodent eradications have been achieved on at least 304 islands in 20 different countries (Howald et al. 2007). The first successful rodent eradication was in 1951 on Rouzic Island in France (Lorvelec and Pascal 2005). Subsequently, through the 1970s and 1980s, New Zealand biologists developed the methodology for systematic rodent eradication techniques and successfully eradicated rats from several small islands (Moors 1985, Thomas and Taylor 2002). With the application of new strategies and research to monitor the campaigns, rats were eradicated from increasingly larger islands (e.g. Taylor and Thomas 1989, Taylor and Thomas 1993, Cromarty et al. 2002, Morris 2002, Clout and Russell 2006) and culminating on Campbell Island in 2002 (11,300 ha), the largest island to date from which rats have been completely eradicated.

The feasibility of eradicating mice from Allen Cay by hand broadcasting brodifacoum based bait pellets across the cay’s land area is high. All requirements to successfully eradicate mice can be met with few personnel and minimal equipment. There are two major challenges to the eradication, both of which are surmountable. First, there is moderate to high risk of primary and secondary poisoning to non-target bird and reptile species which need to be considered when developing the operation. Second, there are considerable logistics and planning that will be required to transport and deploy field teams and equipment to the cay.

A bait-availability study in December 2011 indicated that an application rate of 20 kg/ha or greater is sufficient for bait availability and exposure for mice (Appendix III). Special attention will need to be paid to ensuring a uniform bait application across the cay and rocky shoreline, in sinkholes, and areas of thick vegetation as well as offshore islets.

For personnel safety and project efficiency, the ideal operational window would likely be during the dry season when weather conditions are less severe. May is at the end of the dry season at Allen Cay, where intermittent squalls can blow up rapidly bringing rainfall and strong winds. Measures must be taken to protect bait, operational equipment, and camp equipment from exposure to the elements during such occurrences. Regardless of the time of year, there is always a threat of rain within the first 4 days of the baiting. Along with the chance that a few territories of mice are accidentally not baited or missed during the application process, the standard operating procedure for eradications is to include a second baiting application approximately 10 days after the first that should remove any mice that were missed. In addition, we will monitor the site for a year to ensure that no mice remain on the island before reintroducing the iguanas. The primary method of travel to the islands is by boat; therefore sea conditions may at times preclude safe travel. Careful planning will be required to identify critical needs and prepare for potential challenges. Failing to do so may threaten success of the eradication effort.

6.2 Project sustainability

Allen Cay is beyond the swimming distance for rodents (~3 km from an island with rodents) and its barren, rocky coastline prohibits easy access. There remains a significant risk that mice or other pests could be introduced from boats in the harbor or by visitors exploring the island. During the December trial, a dead Cuban tree frog inadvertently arrived on the cay inside a cooler full of ice. This frog is native to the Bahamas and had died in the cooler, but this means of transport may be the mechanism by which mice were inadvertently introduced to Allen Cay. . Consequently, a critical component of sustaining the project will be the development of a plan to prevent the re-introduction of mice, and new introductions of other non-native species. The effort and conservation gains made could be rapidly undone by future invasive species introductions. Invasive species, including vertebrates, invertebrates, weeds and pathogens, can be transported to the island inadvertently.

A National Biosecurity Strategy for the Bahamas exists (http://www.best.bs/Documents/Bahamas_Biosecurity_Strategy.pdf) and serves as a broad-scale national approach (legislation, programs, agriculture, invasive species etc.). Specific priorities for keeping individual islands secure could be added once strategies, action measures, and enforcement resources have been identified. Successful biosecurity for Allen Cay will rely upon the programs and practices put in place across The Bahamas.

An invasive species re-introduction prevention program should be part of a larger management plan for Allen Cay that ensures long-term protection through proactive management of the island's ecosystem and island use by visitors and local communities. The successful implementation of this plan will be dependent on a strong policy and compliance by all island users including government staff, researchers, fishermen, and tourists.

Preventing non-native species from reaching Allen Cay requires that the potential introduction pathways be closed, or the risk via those pathways be reduced to a level deemed acceptable by the project partners. An effective plan should include guidelines for:

- Prevention of species introductions to Allen Cay
- Monitoring for early detection, response, and eradication where feasible
- Continuous monitoring of invasive species on Allen Cay
- Education for all stakeholders including local island residents and boaters
- Developing guidelines for island users/visitors
- Prohibiting certain activities and materials on the island

The full benefit to the island from invasive species removal will not be realized if rodents reinvade the island and the costs of the eradication program will have been wasted.

Biosecurity of equipment and people during the operation is important to minimize the chances of transporting seeds, invertebrates, rodents and other potentially invasive species to the islands. For the purposes of biosecurity management all equipment, clothing, storage containers, tents etc., will be prepared and packed in Miami or in Nassau, and will be visually inspected and cleaned. Prior to island transfer, equipment will be stored or packaged in sealed containers.

A biosecurity plan focused on preventing the re-introduction of the mice and the arrival of other invasive species is being prepared. In addition to setting the standards necessary to prevent reinvasion the biosecurity plan will also set out measures for monitoring the pest free status of the island and responding to incursions if detected. Remote surveillance systems may be a possibility to reduce the need for frequent site visits.

A sign will be installed at Allen Cay that concisely describes this project and asks visitors not to bring non-native species including rats, mice, cats, dogs, raccoons, livestock, reptiles, amphibians, or plants on to Allen Cay or any other island in the Bahamas.

6.3 SOCIAL ACCEPTABILITY

Restoration projects are perceived by communities in very different ways depending on the project’s relevance to their own interests and livelihood. This project will depend on public outreach to improve prevention of the arrival of invasive alien species through better knowledge, improved legislation and greater management capacity.

The Bahamas Environment, Science, and Technology (BEST) Commission of The Ministry of the Environment granted a permit to conduct scientific research in the Bahamas that allowed the December field trial to occur. These include permits to export specimens (Ministry of Agriculture) and a CITES permit to export owl specimens, if collected. Both Island Conservation and Bahamas National Trust are committed to obedience of local laws and guidelines and will regulate all aspects of the project accordingly.

The project provides the opportunity for staff from the Bahamas National Trust to be recruited for the operation, providing valuable training investment. Field staff will be needed to implement the operation and conduct monitoring activities during and after the project. Recruitment of field assistants from local volunteers, non-governmental conservation organizations, or from academic institutions is a possibility. Collaboration through community outreach and consultation may be conducted by organizations who already work in the area (BNT, Shedd Aquarium, Powerboat Adventures, etc.), and government agencies. This project will be the first eradication of mice from a cay in the Caribbean region, and the knowledge gained from this project would be useful globally in mouse eradication work.

7 ENVIRONMENTAL RISK ASSESSMENT AND RECOMMENDED MITIGATION ACTIONS

People and wildlife on Allen Cay during the hand broadcast operation will potentially be exposed to bait. People involved in the operation will wear personal protective equipment (PPE) and will take care not to consume the bait. Direct (primary) poisoning of wildlife can occur if non-target species consume the bait directly. Shearwaters do not eat foods from the ground of the colony and are very unlikely to ingest the bait. Other birds (e.g. Laughing Gulls, Clapper Rails, or Bahama Mockingbirds) would be more likely to consume bait and effort will be made to harass these species and keep them away from the bait. Indirect (secondary) poisoning can occur if individuals scavenge poisoned dead or moribund animals, or consume contaminated prey (such as mice or invertebrates). Risk of direct exposure will be limited to the period when bait is available in the environment, typically no more than 10 days after each broadcast, but risk of secondary exposure will be longer until the mouse carcasses or other sources (e.g. land crabs, hermit crabs) of the toxin are no longer available for consumption by predators.

While accidental mortality of individual animals during invasive species eradication operations has been documented, island populations of native and endemic wildlife have not been seriously impacted because breeding rates are higher in the absence of predators (mice, barn owls) than before the invasive species were present. Typically, species have shown rapid population growth or increased breeding success after invasive species have been removed, for example in seabirds (e.g. Howald et al. 2005, Whitworth et al. 2005, Smith et al. 2006, Regehr et al. 2007, Amarel et al. 2010), reptiles (e.g. Newman 1994, Daltry 2006, Towns et al. 2001, 2007), invertebrates (e.g. Sinclair et al. 2005, Towns et al. 2009, St Clair et al. 2010) and plants (e.g. Allen et al. 1994). Non-target risk assessment is informed through a food-web model (Appendix III) to determine which species might be at risk.

Bird species may be at risk of exposure from feeding directly on bait (primary), or by feeding on contaminated prey (secondary). Species at risk of primary exposure include generalists, omnivores, and ground foraging seed eaters such as the Zenaida Doves, Bahama Mockingbirds, and Clapper Rails. Resident species are at greater risk whereas migrant species will only be at risk if they are present on the island during and shortly after bait application.

The effect of anticoagulants on reptiles is poorly known. However, most rodent eradication campaigns have reported significant increases in reptile populations after rodent eradication (Towns 1991, 1994, Cree et al. 1995, Newman 1994, Towns et al. 2001, Parrish 2005, Daltry 2006) and to our knowledge no rodent eradication campaign has extirpated a local population of an endemic or native reptile.

The reptile fauna on Allen Cay is considered to be at low risk of primary and/or secondary exposure to bait, although secondary exposure (by eating contaminated invertebrates) is possible. No reptiles were observed with evidence of biomarker exposure during the December trial. As a precautionary measure every effort is being made to remove all iguanas from the cay prior to the bait application. Capturing iguanas is difficult work that requires a team of experienced personnel. Most individuals were moved in May and August 2011, and a third trip has been organized to get the last few holdouts that were missed in August because of Hurricane Irene cutting the trip short. These individuals are being released on Flat Rock Reef Cay and will be returned to Allen Cay following confirmation that mice have been successfully removed. Large sinkholes or artificial boxes will then be filled with sand to create habitat in which iguanas prefer to lay eggs.

The invertebrates present on Allen Cay are not susceptible to the effects of anticoagulant toxicants (Hoare and Hare 2006). However, both marine and terrestrial invertebrates can consume bait pellets and may function as intermediate toxicant pathways (Eason and Spurr 1995). Ants (Figure 9), termites, and cockroaches were observed feeding on placebo bait pellets during the trial in December 2011. Land crabs and other invertebrates are not known to be harvested for human consumption from Allen Cay, and should not pose secondary exposure risk to humans. During the eradication it would be important that the field crew not harvest crabs or other animals from Allen Cay for use as fishing bait.

Eradication operations for removal of rodents could negatively impact native and endemic species through physical disturbance from on-island activities, such as disturbance to nesting birds, trampling nests and rare plants, soil impaction and erosion from increased foot-traffic.

Ironwood, aka Lignum vitae (tree of life) (*Guaiacum sanctum*) is the national tree of the Bahamas and is prevalent on Allen Cay. It is slow growing and can live as long as 1,000 years. This tree should be identified by all personnel and avoided when cutting transects
Specific measures to minimize the risk of physical disturbance to the wildlife on the cay will be taken, and include:

- Minimizing damage to vegetation and especially to any rare or threatened plants that are found (e.g. orchids, bromeliads, Lignum Vitae) Use GPS locations to mark areas with sensitive wildlife and plants
- Educate field staff on techniques to reduce disturbance and identification of key wildlife and plants to avoid.
- Where possible, establish main routes from base camp to access different sections of the island, to limit impacts to vegetation and soils from increased foot traffic.

The removal of rodents from Allen Cay will result in the loss of a significant food source for barn owls, forcing them to choose alternative prey such as reptiles and birds. To avoid significant impact to native species, barn owl removal and deterrent will coincide with rodent eradication activities.

Further short-term unpredictable effects could include short-term fluctuations in abundance of resident species, for example high productivity of invertebrates leading to defoliation of native plants. An increase in plant pests that may have been suppressed by mice consuming seeds could also occur.

8 WHAT WILL IT TAKE?

9.1 Island access and personnel safety

Field teams will be supported by daily visits by project-partner Powerboat Adventures for re-supplying, staff rotation, and emergency transport. Allen Cay can be accessed by zodiac or small boat. A 28-ft dive boat owned by the Bahamas National Trust's Exuma Cays Land and Sea Park was hired by the park during the field trial and was moored in the inlet by anchoring the bow in deep water and securing the stern to with a separate line. The beach near the south end of the cay is the only safe mooring site, however it is fairly easy to step off a boat anywhere onto the cay, as the rocky shelf extends out over the water. Having a boat available to transport staff and bait during the eradication is important for transporting teams around the cay and increasing the efficiency of the work. Larger boats can provide off island support and anchor in the channel safely. Due the remoteness of the island, an evacuation plan is needed regardless of the method used to access the island. Powerboat Adventures provided emergency support in the December trial and has offered to do so again for the May operations to remove mice.

For broadcast bait operations, careful handling, storage, and application of bait should occur under careful supervision to minimize the risk of accidental poisoning. All personnel that handle bait or monitor bait application in the field should meet or exceed all requirements for personal protective equipment (PPE) described on the bait's pesticide label for broadcast operations. This formulation requires gloves (leather, cloth, or rubber), sturdy closed-toed shoes, long sleeved pants and shirts.

9.2 Base camp for operations

A base camp will be needed on a live aboard vessel, on Allen Cay or on a nearby cay to support field teams during the implementation and confirmation phases of the operation. The camp would need to function as an efficient base from which to conduct operations (sleeping, cooking, data management, equipment storage) and serve as a radio communications center. Tents should be small and low to the ground, built to withstand strong winds and be watertight in inclement weather. All personnel will need adequate personal gear like sleeping bags, hiking boots, field clothes, headlamps, etc.. Community equipment to support the entire staff may require the additional purchase or shipment of radio and cellular or satellite phone. Communications must be established in advance.

A logistics base might be needed in Nassau. This base would function to receive and store supplies and equipment, and house field personnel prior to departure to Allen Cay and during field staff change-over if necessary.

In December 2011, the team camped directly on Allen Cay and used gear for camping owned by the education department of the Bahamas National Trust in addition to gear owned by island conservation and the independent scientists on the trip. We purchased camping gear including a stove, cooking pots, plastic bins, tables, and chairs. This setup worked but we need to ensure that workers have adequate boots and that the tents are built to withstand high winds. We will purchase several new tents for the second part of the trip. The Exuma Park allowed us to use an excellent skiff that we hope we can use again during the eradication. Cell phones on the Batelco network had reception at the island, and our solar array purchased for the project worked very well to allow our computers and cell phones to be charged at any time.

9.3 Personnel

To aid with bait spreading, personnel will need to cut transects through areas of thick vegetation in advance of the project. Personnel trained in the use of chainsaws would expedite the process and possibly reduce the risk of musculoskeletal injuries and heat-related illnesses. A crew of 5 people cut transects on 2 ha of the island at 10 meter spacing in one day, using machetes and hand saws. If chainsaws are unavailable, ensuring all staff have high quality cutting tools, specifically machetes, can greatly increase efficiency.

Completing bait coverage in a single day poses least risk of failure due to rodents moving from unbaited areas into areas where bait has degraded or disappeared. A hand broadcast approach increases the number of people involved, thereby increasing the chance that mistakes will be made (Department of Conservation 2011). More people allow the project to be completed quicker but this also means that more complex logistics for transportation to and living on the island will be needed.

In ground-based rodent eradications, every team member must be fully committed to the operation – a mistake, careless action or failure to carry out work in accordance to operational requirements by any one person could easily result in failure of the entire project. A carefully selected team should have at least 50% of all field staff with prior eradication experience (Department of Conservation 2011).

A crew of four people successfully baited 2 hectares in a day on Allen Cay. To complete a hand broadcast of the 6 ha island in one day, a crew of 6-8 may be needed. A high level of fitness in team members will reduce the likelihood of mistakes being made from fatigue. Heat and humidity may limit the amount of heavy work that the team can complete in a day. The work schedule will be set according to the abilities of the slowest team member.

Between bait applications, crew members can be used to survey shearwater monitoring plots at the three islands that need to be surveyed (Pimlico Cay, Barn Owl Cay, and Allen Cay), disrupt barn owl roost sites, and conduct monitoring of the loss of bait from plots. We will also pick up all dead shearwaters from each island to compare the numbers killed at Allen Cay and the two colonies that do not have mice.

9.4 Operational Timing

In seasonal environments, it's ideal to time the eradication when a target population is most likely to consume lethal doses of bait. The two major factors that enable this qualification are limited natural food resources and high population density. Targeting the population during the beginning of the dry period when the mouse density is still "high" and food resources are low is the standard recommendation. In this case, May is the end of the dry season at Allen Cay, but the seasonality is minor with no freezing winter temperatures and no known periods of extreme stress for mouse populations. Mice obtain water from their food and the tropical vegetation on the island matures throughout the year. The main season to avoid is Hurricane Season, which occurs from June until November. The dry season in the Bahamas occurs in the winter. This time would be ideal except for the fact that strong winter gales frequently happen from December through March. Such an event would disrupt the eradication in a similar way to a hurricane. Thus, the ideal window at Allen Cay is the mid-spring, before the onset of the hurricane season but after the season of strong winter storms. The first window of opportunity is mid-May, 2012 when the removal of the last few iguanas inhabiting Allen Cay will be completed. For these reasons, we propose to conduct the operation in May 2012 beginning around May 13.

9.5 Rodent DNA collection

If mice are detected after the eradication, DNA from pre- and post-eradication can be compared to determine if the presence of the rodents is a result of a failed eradication (matching DNA signatures) or a reinvasion or reintroduction (different DNA signatures). Genetic tissue samples were collected from trapped mice, and will be stored for future analysis.

9.6 Baseline monitoring of rodents

Baseline monitoring provides an index of activity that can be used as a predictor of activity during post-eradication monitoring. The pre-eradication monitoring of mice populations were tested using three techniques: live traps, chewblocks, and tracking tunnels (Figure 2).

Figure 2. Mouse detection devices on Allen Cay (left) Tracking Tunnel (right) chewblock.

Live traps were the only method that was successful, potentially because of low mouse density, abundance of other food sources, neophobia, or light from the full moon that prevented foraging. We were unable to detect the presence of mice using chewblocks and tracking tunnels. More research is required to determine suitable detection devices for mice on Allen Cay. All these techniques will be established in May 2012 and monitored on quarterly visits in Summer, Fall, Winter, and Spring 2012-2013.

9.7 Operational Monitoring

- **Non-target species -** surveys of resident land birds, seabirds, and reptiles could be implemented to detect non-target mortality of individuals; any carcasses found should be assayed in a laboratory to determine mortality from bait exposure or from other causes. Finally, all shearwaters carcasses found on Allen Cay will be collected and removed during the eradication period and on subsequent visits. Future regular censuses for carcasses will be conducted and used as a gauge of owl predation, and therefore a measure of the effects of eradicating mice.
- **Bait availability rates** – bait availability (i.e. minimum, mean quantity (kg/ha) of bait that is available to mice at any given time) will be monitored over time from the date of the application. These rates are calculated by closely monitoring 10-m segments of transects and counting every pellet within the transect each day. This monitoring allows for adaptive management during the second application if needed (e.g. adjustment of application rate and schedule to ensure 4 days of pellet availability within all plots) and provides information on bait availability to and uptake by mice and non-target species.
- **Bait degradation** – bait degradation is monitored to determine ambient environmental factors influencing bait availability and persistence over time. Bait pellets placed in a small enclosure that excludes rodents and monitored daily.

9.8 Eradication Confirmation

Field surveys to detect mice presence will be undertaken after two mouse breeding seasons (~ 1 year) have elapsed since the last bait application. If no mice are detected, a successful eradication can be declared. A range of tools will be used to detect mice during field surveys including: traps, tracking tunnels, chew sticks, chew blocks, hair traps and remote camera traps. Traps can include live traps and snap-traps that kill mice; however kill traps are only recommended if they can be modified to prevent risk to native and endemic reptiles and birds. In addition, rodent sign should be searched for including den sites, food storage sites, fecal deposits and footprints. In the event the eradication fails, mice will be tested genetically and compared to our samples to determine whether the population regenerated or was reintroduced from another island.

9 STRATEGY FOR CREATING IGUANA NESTING HABITAT ON ALLEN CAY

Restoration of Allen Cay includes the creation of nesting habitat for the endangered Allen Cay Rock Iguanas (*Cyclura cychlura inornata*). Iguanas that currently reside and thrive on the cay cannot breed due to lack of quality nesting sites. The iguana nesting sequence includes digging, laying, covering, and defense (Wiewandt 1982), and most species nest from early June to mid-July (including *C. c. inornata*) with an incubation period of 80-85 days (Iverson et. al 2004). Females migrate to nest sites 3-7 weeks after mating, excavate a new burrow for oviposition, refill that burrow after egg-laying, and then defend the nest site (Iverson, 1979, and Wiewandt, 1982).

The rocky nature of Allen Cay currently prevents iguanas from locating suitable sandy habitat in which to dig nests and lay eggs. Sinkholes or artificial nest boxes will be filled with sand, providing nesting chambers with sufficient depth, and may increase the annual rate of population growth. This part of the project will be conducted after the eradication has been completed and when iguanas are returned to the cay.

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Powerboat Adventures supported the field staff while running daily trips from Nassau to the Cay, maintaining the safety and well-being of our team from their base on Ship-channel Cay. Re-supply of water, food, and other essentials were available, as well as help if there were an emergency. The R/V Coral Reef II of the Shedd Aquarium runs regular trips to Allen's Cay and provided free transportation from Miami for equipment and personnel. Earlham College Biology Department provided funding for boat transportation and telemetry equipment.

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11 REFERENCES

Allen, R. B., W. G. Lee, and B. D. Rance. 1994. Regeneration in indigenous forest after eradication of Norway rats, Breaksea Island, New-Zealand. *New Zealand Journal of Botany* **32**: 429-439.

Amaral, J., S. Almeida, M. Sequeria, and V. Neves. 2010. Black rat *Rattus rattus* eradication by trapping allows recovery of breeding Roseate Tern *Sterna dougallii* and Common Tern *S. hirundo* populations on Feno Islet, the Azores, Portugal. *Conservation Evidence* **7**:16-20.

Atkinson, I. A. E. 1985. The spread of commensal species of *Rattus* to oceanic islands and their effects on islands avifaunas.*in* P. J. Moors, editor. Conservation of Island Birds. International Council of Bird Preservation Tech Pub. 3.

Bodey, W. T., Bearhop, S., McDonald, R.A. 2011. The diet of an invasive nonnative predator,the feral ferret *Mustela furo*, and implications for the conservation of ground-nesting birds. European Journal of Wildlife Research, Volume: 57 Issue: 1 Pages: 107-117

Bradley, P.E. and R.L. Norton. 2009. An Inventory of Breeding Seabirds of the Caribbean.University of Florida Press, FL. 353p.

Buckle, A. P. 1994. Control Methods, Chemical. Page 405 *in* A. P. Buckle and R. H. Smith, editors. *Rodent Pests and their Control*. Cab International.

Clout, M. N. and J. C. Russell. 2006. The eradication of mammals from New Zealand islands. Pages 127-141 *in* F. Koike, M. N. Clout, M. Kawamichi, M. De Poorter, and K. Iwatsuki, editors. Assessment and control of biological invasion risks. Shoukadoh Book Sellers and the World Conservation Union (IUCN), Kyoto, Japan and Gland, Switzerland.

Correll, D.S., and H.B. Correll, 1982. The Flora of the Bahamas Archipelago. New York: Lubrecht and Cramer.

Cree, A., C. H. Daugherty, and J. M. Hay. 1995. Reproduction of a rare New Zealand reptile, the tuatara *Spenodon punctatus* on rat-free and rat-inhabited islands. *Conservation Biology* **9**: 373-383.

Cromarty, P. L., K. G. Broome, A. Cox, R. A. Empson, W. M. Hutchinson, and I. McFadden. 2002. Eradication planning for invasive alien animal species on islands - the approach developed by the New Zealand Department of Conservation. Pages 85-91 *in* C. R. Veitch and M. N. Clout, editors. *Turning the Tide: The Eradication of Invasive Species*. IUCN Invasive Species Specialist Group, Gland, Switzerland and Cambridge, UK.

Daltry, J. C. 2006. Control of the black rat *Rattus rattus* for the conservation of the Antiguan racer *Alsophis antiguae* on Great Bird Island, Antigua. *Conservation Evidence* **3**: 28-29.

Department of Conservation, New Zeland. 2011. Current agreed best practice for rodent eradication- hand broadcasting bait. DOCDM-83099. Ver. 1.3, 29p.

Eason, C. T. and E. B. Spurr. 1995. Review of the toxicity and impacts of brodifacoum on non-target wildlife in New Zealand. *New Zealand Journal of Zoology* **22**: 371-379.

Eason, C. T., E. C. Murphy, G. R. G. Wright, and E. B. Spurr. 2002. Assesment of risks of brodifacoum to non-target birds and mammals in New Zealand. *Ecotoxicology* **11**: 35-48

Erickson, W. and D. Urban. 2004. Potential risks of nine rodenticides to birds an non target mammals: a comparative approach. U.S. Environmental Protection Agency, Office of Prevention, Pesticides and Toxic Substances, Washington, DC.

Hoare, J. M., and W. C. D. Hare. 2006. The impact of brodifacoum on non-target wildlife: gaps in knowledge. *New Zealand Journal of Ecology* **30**: 157-167.

Howald, G., K. Faulkner, B. Tershy, B. Keitt, H. Gellerman, E. Creel, M. Grinnell, S. Ortega, and D. Croll. 2005. Eradication of black rats from Anacapa Island: Biological and social considerations *in Proceedings of the Sixth California Islands Symposium*. Institute for Wildlife Studies, Ventura, CA.

Island Conservation, 2010. Planning trip to Desecheo Island, Puerto Rico, to evaluate feasibility of rodent eradication, and further establish baseline biodiversity surveys: February 26-March 11, 2010. *Report to U.S. Fish and Wildlife Service.* Prepared by: M. Pott, K. Swinnerton, M. McKown, and J. L. H. Giraldo. Island Conservation, Santa Cruz, CA.

IUCN (2011) IUCN Red List of Threatened Species. Version 2011.1 http://www.iucnredlist.org.

Iverson, J. B. 1979. Behavior and ecology of the rock iguana Cyclura carinata. Bulletin of the Florida State Museum, Biological Sciences 24:175–358.

Iverson, J.B. 2007. Juvenile Survival in the Allen Cays Rock Iguana (Cyclura Cychlura Inornata) *Copeia* (3), 740-744

Jones, H. P., B. R. Tershy, E. S. Zavaleta, D. A. Croll, B. S. Keitt, M. E. Finkelstein, and G. R. Howald. 2008. Severity of the effects of invasive rats on seabirds: a global review. *Conservation Biology* **22**: 16-26.

Kaukeinen, D. E. 1993. Nontarget organism evaluations for rodenticides *in* K. D. Racke and A. R. Leslie, editors. Pesticides in urban environments: fate and significance. *American Chemical Society*, Washington.

Kurle, C. M., D. A. Croll, and B. R. Tershy. 2008. Introduced rats indirectly change marine rocky intertidal communities from algae- to invertebrate-dominated. *Proc. Natl. Acad. Sci.* **105**: 3800-3804.

Lee, D.S. 2000. Status and Conservation Priorities for Audubon's Shearwaters in the West Indies. Pages 25-30 *in* (Schreiber and Lee, eds.) Status and Conservation of West Indian Seabirds. Ruston: Society of Caribbean Ornithology, Special Publication Number 1. Pages i-v, 1-225.

Lorvelec, O. and M. Pascal. 2005. French attempts to eradicate non-indigenous mammals and their consequences for native biota. *Biological Invasions* **7**: 135-140.

Mackin, W.A. 2007. Conservation of Audubon's Shearwater in The Bahamas: Status, Threats, and Practical Solutions. Proceedings of the 11th Symposium on the Natural History of the Bahamas. San Salvador, Bahamas.

Moors, P. J. 1985. Conservation of island birds: case studies for the management of threatened island birds. International Council for Bird Preservation, Cambridge.

Morris, K. D. 2002. The eradication of the black rat (*Rattus rattus)* on Barrow and adjacent islands off the north-west coast of Western Austrailia. Pages 219 - 225 *in* C. R. Veitch and M. N. Clout, editors. *Turning the tide: the eradication of invasive species*. IUCN Invasive Species Specialist Group, Gland, Swtizerland and Cambridge, UK.

Newman, D. G. 1994. Effects of a mouse *Mus musculus* eradication programme and habitat change on lizard populations of Mana Island, New Island, with special reference to McGregor's skink, Cyclodina macgregori. *New Zealand Journal of Ecology* **21**: 443-456.

Parrish, R. 2005. Pacific rat *Rattus exulans* eradication by poison-baiting from the Chicken Islands, New Zealand. *Conservation Evidence* **2**: 74-75.

Regehr, H. M., M. S. Rodway, M. J. F. Lemon, and J. M. Hipfner. 2007. Recovery of the ancient murrelet *Synthliboramphus antiquus* colony on Langara Island, British Columbia, following eradication of invasive rats. *Marine Ornithology* **35**: 137-144.

Schreiber, E. A. and D. S. Lee. 2000. Status and conservation of West Indian Seabirds. Society of Caribbean Ornithology Special Publication 1, Ruston, Louisiana, USA

Schwartz , A. and W. M. Carey. 1977. Systematic and evolution in the West Indian iguanid genus *Cyclura*. Stud. Fauna Curacao and other Caribbean Islands. 53:1-97

Sinclair, L., J. McCartney, J. Godfrey, S. Pledger, M. Wakelin, and G. Sherley. 2005. How did invertebrates respond to eradication of rats from Kapiti Island, New Zealand? *New Zealand Journal of Zoology* **32**: 293-315.

Smith, D. G., E. K. Shiinoki, and E. A. VanderWerf. 2006. Recovery of native species following rat eradication on Mokoli`i Island, Oahu, Hawaii. *Pacific Science* **60**: 299-303.

St. Clair, J., S. Poncet, D. Sheehan, T. Szekely, and G. Hilton. 2011. Responses of an island endemic invertebrate to rodent invasion and eradication. *Animal Conservation* **14**: 66-73.

Tanentzap, A.J., L.E. Burrows, W.G. Lee, G. Nugent, J.M. Maxwell, and D.A. Coomes. 2009. Landscape-level vegetation recovery from herbivory: progress after four decades of invasive red deer control. *Journal of Applied Ecology* **46**: 1064-1072.

Taylor, R. H. and B. W. Thomas. 1989. Eradication of Norway rats *Rattus norvegicus* from Hawea Island, Fjordland, using brodifacoum. New Zealand Journal of Ecology **12**: 23-32.

Taylor, R. H. and B. W. Thomas. 1993. Rats eradicated from rugged breaksea island (170 ha), Fiordland, New Zealand. Biological Conservation **65**: 191-198.

Tershy, B. R., A. Beese, A. Angeles, M. Cervantes, M. Mandujano, E. Hernandez, and A. Cordoba. 1992. Natural history and management of Isla San Pedro Martir, Gulf of California, Mexico. Report to Conservation International.

Thomas, B. W. and R. H. Taylor. 2002. A history of ground-based rodent eradication techniques developed in New Zealand, 1959-1993. Pages 301-310 *in* M. Clout and C. R. Veitch, editors. *Turning the tide: the eradication of invasive species*. IUCN Invasive Species Specialist Group, Gland, Switzerland and Cambridge, UK.

Towns, D. R. 1991. Response of lizard assemblages in the Mercury Islands, New Zealand, to removal of an introduced rodent: the kiore *Rattus exulans. Journal of the Royal Society of New Zealand* **21**: 119-136.

Towns, D. 1994. The role of ecological restoration in the conservation of Whitaker's skink (*Cyclodina whitakeri*), a rare New Zealand lizard (Lacertillia: Scincidae). *New Zealand Journal of Zoology* **21**: 457-471.
Towns, D. R., C. H. Daugherty, and A. Cree. 2001. Raising the prospects for a forgotten fauna: a review of 10 years of conservation effort for New Zealand reptiles. *Biological Conservation* **99**: 3-16.

Towns, D. R., D. A. Wardle, H. Mulder, G. W. Yeates, B. M. Fitzgerald, G. R. Parrish, P. J. Bellingham, and K. I. Bonner. 2009. Predation of seabirds by invasives rats: multiple indirect consequences for invertebrate communities. *Oikos* **118**: 420-430.

Whitworth, D. L., H. R. Carter, R. J. Young, J. S. Koepke, F. Gress, and S. Fangman. 2005. Initial recovery of Xantus's murrelets following rat eradication on Anacapa Island, California. *Marine Ornithology* **33**: 131-137.

Wiewandt, T. A. 1982. Evolution of nesting patterns in iguanine lizards. Pp. 119–141. In: Burghardt, G. M. AND A. S. Rand (eds.), Iguanas of the World. Noyes Publ., Park Ridge, NJ.

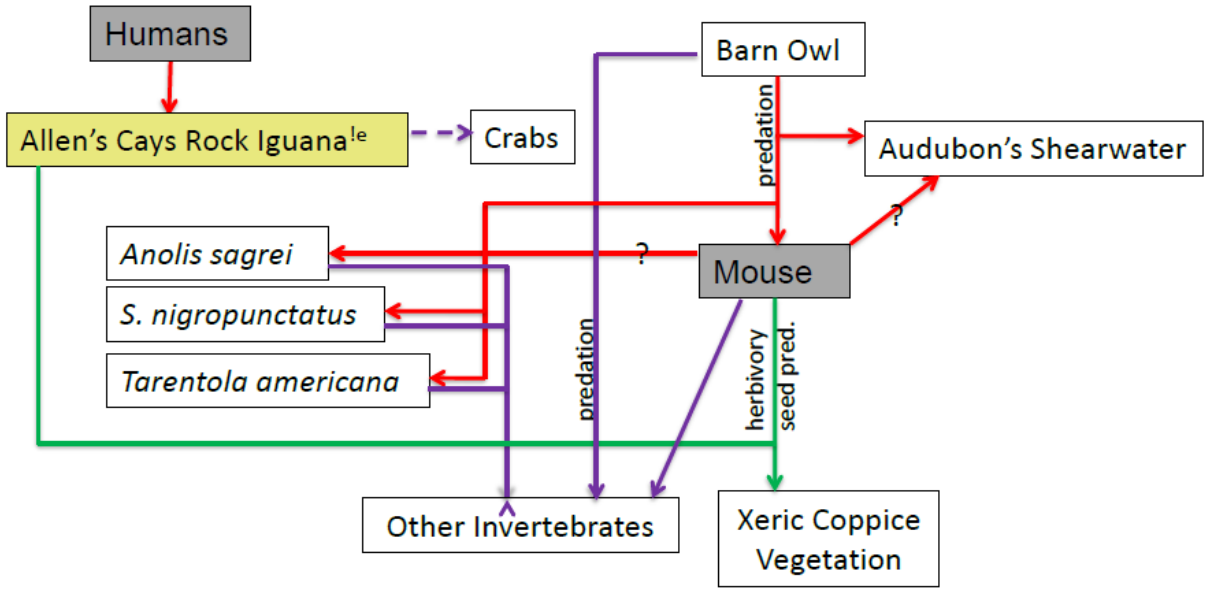
APPENDIX I: Species recorded from Allen Cay

	Common Name	Species Name
Birds	Audubon Shearwater	*Puffinus lherminieri*
	Bahamas Mockingbird	*Mimus gundlachii*
	Bahamas Woodstar	*Calliphlox evelynae*
	Bahamas Yellowthroat	*Geothlypis rostrata*
	Bannaquit	*Coereba flabeola bahamensis*
	Belted Kingfisher	*Ceryle alcyon*
	Black and White Warbler	*Mniotilta varia*
	Brown Pelican	*Pelecamus occidentalis*
	Catbird	*Dumatella carolinensis*
	Clapper Rail	*Rallus longirostris coryi*
	Great Blue Heron	*Ardea herodias*
	Green Heron	*Butorides virvscens bahamensis*
	Merlin	*Falco columbarius*
	Osprey	*Pandion haliaetus*
	Oystercatcher	*Haematopus palliatus*
	Palm Warbler	*Dendroica palmarum*
	Ruddy Turnstone	*Arenaria interpes*
	Thick Billed Vireo	*Vireo crassirostris*
	White Crowned Pigeon	*Patagioenas luecocephala*
	Yellow Crowned Night Heron	*Nyctanassa violacea*
	Zenaida Dove	*Zenaida aurita*
Crabs	Black Land Crab (Gaulin Crab)	*Gecarcinus lateralis*
	Soldier Hermit Crab	*Coenobita clypeatus*
	White Crab	*Cardisoma guanhumi*
Reptiles	Brown Anole	*Anolis sagrei*
	Brown Racer Snake	*Cubophis vudii*
	Curly Tailed Lizard	*Leiocephalus carinatus*
	Dwarf gecko	*Sphaerodactylus nigropuntatus*
	Rock Iguana	*Cyclura cychlura inornata*
Amphibians	Cuban Treefrog	*Osteopilus septentrionalis*
	Greenhouse Frog	*Eleutherodactylus planirostris*
Plants	Alvaradoa	*Alvaradoa amorphoides*
	Bahamas Nightshade, Canker Berry	*Solanum bahamensc*
	Bahamas Strong Back	*Bourreria ovata*
	Bay Cedar	*Suriama maritima*
	Bay Marigold, Sea Ox Eye	*Borrichia arborescens*
	Black Mangrove	*Avicennia germinans*

Bromiliad; air plants	*Sp.*
Bucaneer Palm (Hog Cabbage Palm)	*Pseudophoenix sargentii*
Buttonwood (green)	*Comocarpus erectus*
Buttonwood (silver)	*Comocarpus sericea*
Coastal Sedge	*Cyperus planifolius*
Common Purslane	*Portulaca oleracea*
Darling Plum	*Reynosia septentrionalis*
Dildo Catcus	*Pilosocareus royenii*
Indigo Berry	*Randia aculeata*
Joewood	*Jacquinia cayensis*
Lignum	*Guaiacum sanctum; G. officinale*
Longleaf Bolly	*Guapira discolor*
Moon Vine	*Ipomoea alba*
Morning glory	*Ipomoea indica; I. hederacea*
Mosquito Bush	*Strumpfia maritima*
Native Orchid	*Undetermined species*
Passion Flower Vine	*Passiflora bahmensis ; P. cupraea*
Pearl Necklace/ Necklace Pod	*Sophora tomentosa*
Pigeon Plum	*Coccoloba diversifolia*
Prickly Pear Cactus	*Opuntia dillenii; Opuntia stricta*
Ramshorn	*Pithecellobium keyense*
Red Mangrove	*Rhizophora mangle*
Saltmarsh Cord grass	*Spartina patens*
Samphire/Salt Weed	*Blutaparon vermiculare*
Sea Purslane	*Sesuvium portulacastrum*
Searocket	*Cakile lanceolata*
Seashore Rush Grass	*Sporobolus virginicus*
Semaphore Cactus	*Opuntia spinosissima*
Seven Year Apple	*Casasia clusiifolia*
Shortleaf Fig	*Ficus citrifolia*
Silvertop Palm	*Coccothrimax argentata*
Tamarind	*Tamarindus indica*
Thatch Palm	*Thrinax radiata*
Wild Alamanda	*Urechites lutea*
Wild Bamboo Grass	*Lasiacis divaricata*
Wild Dilly	*Manilkara bahamensis*

APPENDIX II: Food Web Model

The purpose of the food web model is to demonstrate benefits to native biodiversity as a result of removing mice from Allen Cay; native and endemic species that are directly impacted are key species for recovery monitoring (pre- and post-eradication).



APPENDIX III: December 2011 Field Studies

The following studies will inform the operational plan for the eradication.

- **Bait Availability Trial**

  For an effective eradication, bait must be available to mice for as long as possible, and at least 3-5 nights. An effective bait application rate in kg/ha is determined to ensure that sufficient bait is available to mice for the duration of this period, but also to ensure that surplus bait does not remain on the ground which would increase the exposure risk to non-target species.

  In December 2011 two application rates were tested, each rate was spread by hand over 1 hectare of land that included open rocky terrain and thick vegetation. Transects spaced 10 m apart were cut with machetes and pruning saws within a pre-established 1 ha grid. Seven personnel cut 2 hectares of transects in one day. The North end of the cay is narrower and thus had slightly more rocky terrain (less interior for vegetation), this was baited with an application rate of 40 kg/ha (Figure 3).

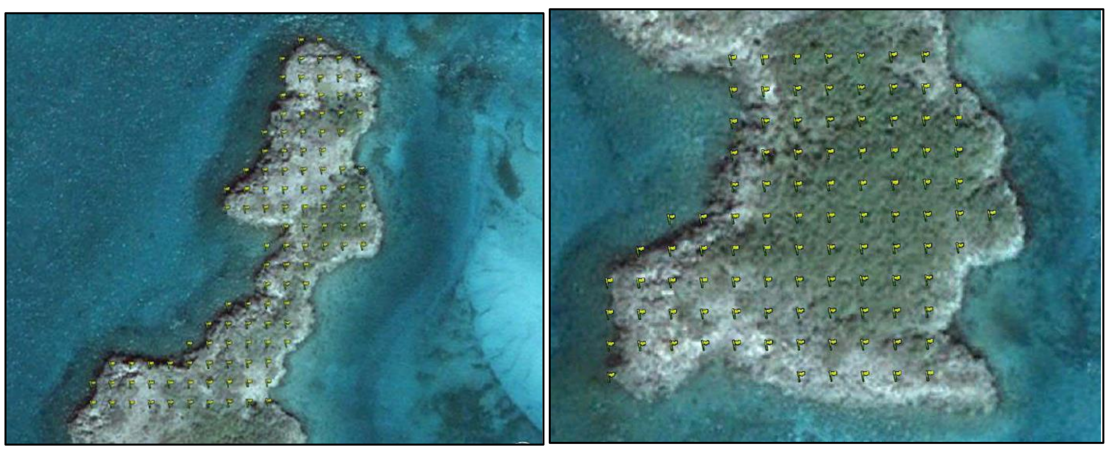


Figure 3: (Left) North Allen Cay grid (40 kg/ha), (Right) South Allen Cay grid (20 kg/ha)

The South end of the island had more vegetation and potential mouse habitat, therefore we tested the smaller application rate (20 kg/ha) there (Figure 3). The lower rate was tested where mice densities were expected to be higher in order to ensure the minimum rate was sufficient where consumption would be highest.

Bait availability on the North end decreased significantly (16 kg/ha) during the first night but this may be an artifact of the rocky terrain (Table 1). Heavy winds (up to 30 kts) swept over open areas, and exposed pellets probably rolled down the rocks and ended up in the sinkholes.

Table 1: Mean rate (kg/ha) of pellets remaining in each grid over a five day period.

Date	Day	South Plot (kg/ha)	North Plot (kg/ha)
12/7/2011	1	20	40
12/8/2011	2	15	24
12/9/2011	3	13	20
12/11/2011	4	9	15
12/12/2011	5	7	13

After that event, bait disappeared at a fairly consistent rate (2-5 kg/ha per day) in both grid locations (Figure 4). This suggests that there is no significant difference in bait uptake in various habitat types, and no areas requiring a higher application rate were identified.

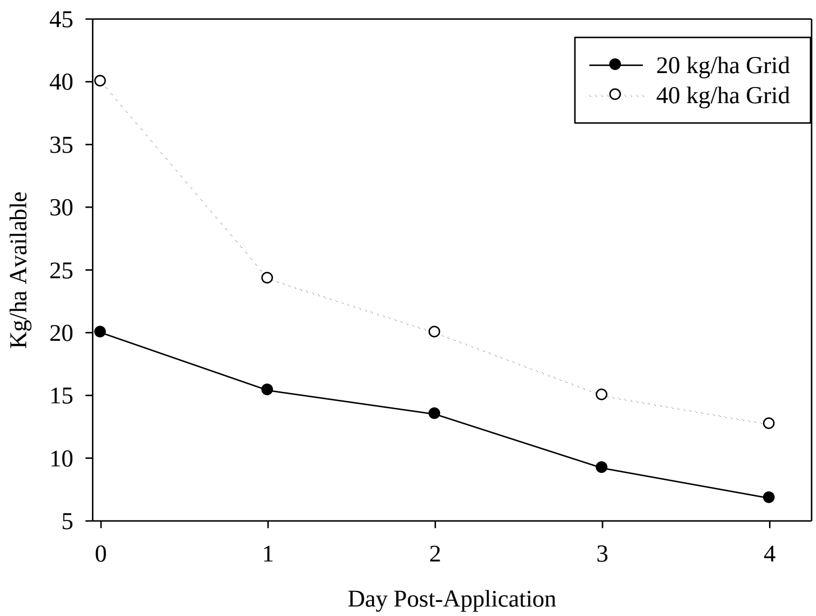


Figure 4. Mean kg/ha remaining in each 1 hectare grid after applying bait at 40 kg/ha on the North end of the cay, and at 20 kg/ha on the South end of the cay.

The entire cay consists of honeycomb limestone. The interior of the cay has a three dimensional structure created by tubes, tunnels, and sinkholes, evidence of several periods of submersion as sea level rose and fell. It’s likely that a most of the wildlife (mice, anoles, racers, geckos, crabs) reside underground. Wind consistently blows leaf litter, fruit and berries, etc. into these depressions, concentrating food resources in a microhabitat that otherwise may not support much life. It is unknown what the densities of the wildlife populations are, how much they depend/subsist off underground resources, or how often they forage on the surface of the cay. The potential for mice to survive underground without surfacing must be considered when selecting a bait application rate and the time interval between applications, and while selecting mouse detection methodologies.

- **Bait uptake in rodents and non-targets**

The placebo bait used in the trial was impregnated with a biomarker that fluoresces under ultraviolet light. We intended to screen mice captured during the trial for the biomarker to monitor bait uptake. Unfortunately, no mice were trapped in the grid despite 150 trap nights. 30 traps were set within the grids, tested to hair trigger, and rebaited daily. Several types of bait were used, including dry oats, peanut butter on cracker bits, and raisins with peanut butter. Traps were found open with bait untouched 67% of the time. Four black land crabs (*Gecarcinus lateralis*) were found in mouse traps throughout the trial. No other non-targets were found in the traps. Seven mice were trapped successfully in camp, but no evidence of pyranine consumption was observed with these mice. The mean body mass of the camp mice was 10.5 g and one male mouse may have been of reproductive age. The mice appeared healthy, with no mites, scabby skin or other wounds.

Potential Reasons for Low Trap Success:

- Mice density is extremely low on the cay
- Bait in traps doesn't appeal to the mice
- Bait in the traps is not as attractive as the placebo bait pellets
- Mice are only attracted to the camp area (smell lots of food)
- Abundance of natural food available (fruit, berries, leaves, insects, intertidal detritus).
- Neophobia to traps (in areas other than beach landing)
- Full moon during trial made predation risk too high to forage above ground
- Mice reside in the honeycomb island interior and rarely forage above ground

Figure 5. Natural food sources on Allen Cay (left) Berries from Strong back tree (*Bourreria ovate*) (Right) Fruit of seven year apple tree (*Casasia clusiifolia*).

Non-Target Species Interactions with Bait

Native and endemic species, such as reptiles, birds, and invertebrates, were captured and screened for the biomarker to determine bait consumption and potential non-target impact in these species (Figure 6). The following list describes observations of non-target species interacting with bait (either by primary or secondary pathways).

- Bahamas Mockingbird observed picking up a bait pellet. It tracked the motion of the pellet as it was flung during hand broadcast and immediately picked it up where it landed. The mockingbird spat out the pellet and ate a berry from the Strong Back tree instead.
- Ants eating bait pellets.
- Black Land Crab caught in trap 93 (south end). Crab weighed 20 grams and had evidence of pyranine on mouth and can see internal glow through the white parts of the carapace.
- Black Land Crab caught in trap 95 (south end). Crab weighed 24 grams and had evidence of pyranine on mouth parts, and later produced excrement that fluoresced under UV light.
- Found a regurgitated pellet (bird?) splattered on the ground during nighttime UV walk.
- Evidence of urine/excrement trails over leaves and on twigs that fluoresce under UV light along the trail. Possible crab or mice.
- Four scorpions found fluorescing under UV light along the trail- this is likely natural fluorescence due to fluorescent chemicals in the cuticle.
- Black Land Crab took mouse carcass placed in front of motion sensing camera.

Figure 6. Examples of pyranine fluorescence in a Black Land Crab (left), and in a fecal sample observed in the South Grid.

No Evidence of Bait Exposure in Non-Targets:

- No Iguanas were found on the cay- it is unknown if iguanas would consume mouse carcasses.
- White-Crowned Pigeon caught in mist net two days after bait application. No sign of pyranine on cloaca or beak.

- Large cockroach species caught in camp, negative for pyranine.
- Several observations of fresh bird excrement, negative for pyranine.
- Six spiders in webs, negative for pyranine.
- Black land crab caught in camp (30 m from bait plot) at night, negative for pyranine.
- Brown anole caught in noose within baited area, negative for pyranine.
- Tiny soldier crab observed on transect, negative for pyranine.
- Greenhouse frog found in camp, negative for pyranine.

- **Reconyx® Camera Traps**

A total of 18 camera "trap nights" captured evidence of non-target species interacting with mice carcasses and with piles of bait placed in the field of view. Cameras focused on fresh mice carcasses for a total of 7 nights. One carcass sat untouched for 3 days (visited by hermit crabs and ants), and was eventually disposed of. One carcass was taken by a black land crab, and two other carcasses disappeared by unknown means, likely a crab.

No evidence of bait consumption by reptiles, amphibians, and several bird species (including Clapper Rails) were recorded on the cameras. Crabs and the Bahamas Mockingbird were the exception; both were captured interacting with bait as seen below in Figure 7. Other interactions captured by the cameras are listed below (Table 2).

Figure 7. Reconyx® photograph of White Land Crab (left), and Bahamas Mockingbird (right) interacting with pile of bait pellets (directly beneath each animal). In both instances bait pellets were disturbed and some potentially consumed.

Table 2. Reconyx® recorded interactions of non-target species with mouse carcasses and piles of bait pellets.

Species in Photo	Interacted with mouse	Interacted with

	carcass?	bait?
Bahamas Mockingbird	No	Yes
Clapper Rail	No	No
Oven Bird	No	No
Zeneida Dove	No	No
Black Land Crab	Yes	Yes
Hermit Crab	Yes	Yes
White Crab	No	Yes
Geckos and Anoles	No	No
House Mouse	No	No

Figure 8. Ants feeding on a placebo bait pellet in December 2011 on Allen Cay.