

Management Plan for the Giant Land Crab (*Cardisoma guanhumii*) in Bermuda



Government of Bermuda
Ministry of Home Affairs
Department of Environment and Natural Resources

Management Plan for the Giant Land Crab (*Cardisoma guanhumi*) in Bermuda

Prepared in Accordance with the Bermuda Protected Species Act 2003

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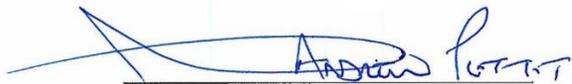
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DISCLAIMER

Management and recovery plans delineate reasonable actions that are believed to be required to manage, recover and/or protect listed species. Recovery is defined under the Protected Species Amendment Act (2003) as any action (be it monitoring, assessment, research, restoration, maintenance or management) that enables the preservation, protection or restoration of a protected species. The Department of Environment and Natural Resources (DENR), publishes management and recovery plans, sometimes preparing them with the assistance of field scientists, other government departments, as well as other affected and interested parties, acting as independent advisors. Plans are submitted to additional peer review before they are adopted by DENR, and formulated with the approval of interested parties mentioned in Parts II and III. Objectives of the management plan will be attained and necessary funds made available subject to budgetary and other constraints affecting the parties involved. Management plans may not represent the views nor the official positions or approval of any individuals or agencies involved in the plan formulation, other than our own. They represent the official position of DENR only after they have been signed by the Director as approved. Approved plans are subject to modifications as dictated by new findings, changes in species status and the completion of management and/or recovery actions.

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Director,
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Date

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EXECUTIVE SUMMARY

This management plan addresses the need for actions to conserve the native giant land crab (*Cardisoma guanhumii*).

Current species status

Legal protection for this species is provided by the Protected Species Act (2003). Following IUCN criteria, the Bermudian population of *Cardisoma guanhumii* is listed as Vulnerable under the Protected Species Amendment Order (2016). This species has not been assessed for the IUCN Red List, nor is it protected by any treaties. A population estimate for Bermuda has never been made, but it is thought to be no more than a few hundred.

Habitat requirements and threats

The giant land crab's complex life cycle requires different habitats, both on land and sea. It primarily inhabits coastal mangroves where it digs burrows in muddy substrate. Upon reaching maturity, female *C. guanhumii* require access to the sea to shed their eggs, which develop as planktonic larvae, before returning to land as juveniles. The most significant threat to giant land crabs in Bermuda is habitat loss and alteration, through foreshore development and destruction of coastal mangroves by human and natural causes. Invasive species, pollution, habitat fragmentation, traffic and lack of public awareness are also threats.

Management objective

The principal aim of this management plan is to protect giant land crabs and their habitats in Bermuda, and contribute to national and regional conservation of these crabs through sharing of knowledge and participation in research and monitoring, and mitigation of threats.

Management criteria

A positive conservation status for giant land crabs in Bermuda will be achieved when there is:

1. Evidence of an increasing or stable population
2. More known about Bermuda's giant land crab population and its ecology
3. Crab habitat is protected, and both quality and quantity are enhanced
4. Threats have been identified and addressed to the extent possible
5. The public are aware of this species and champion its conservation

Actions needed:

- An accurate assessment of the current population and distribution of giant land crabs in Bermuda.
- Monitoring of critical habitat sites to establish a population trend and provide for a rapid response to new threats when they arise.
- Protection of critical habitats supported by public cooperation, legislation and effective enforcement.

- Increased public education regarding the threats to protected crabs and their habitats.
- An improved programme for surrendering and reporting crabs in danger (e.g rehabilitation and relocation).
- Explore the possibility of establishing new colonies through translocation
- Put mitigation measures in place, where possible, against threats to crabs from human and natural sources.

Management costs

The total cost of management actions cannot be defined at this point. Funding needs to be secured through non-governmental organizations (NGO's), overseas agencies, and other interested parties for implementing the necessary research and monitoring, awareness and management activities. Developing budgets and securing funds for each action are the responsibility of the leading party as outlined in the work plan.

PART I: INTRODUCTION

A. Brief Overview

The giant or blue land crab (*Cardisoma guanhumi*) is a species of terrestrial crab native to Bermuda. It is also widely distributed in the Caribbean, Central and South America where it is frequently harvested for food and supports economically and socially valuable fisheries. Although not harvested in Bermuda, giant land crabs have become rare and face threats which required the local population to be legally protected in 2012. At present only three main colonies are known, with scattered individuals reported island-wide over the last 10 years (Table 2, Appendix I).

A population estimate for *Cardisoma guanhumi* has never been calculated for Bermuda but the local population is estimated to be no larger than a few hundred individuals (Thomas, 1986). It is hypothesised that Bermuda's isolation from other land masses with *C. guanhumi* populations, combined with the loss of local planktonic larvae to the open ocean, will continue to keep the local population low (Thomas, 1986). *Cardisoma guanhumi* have not been successfully bred in captivity, which limits the ability to artificially increase abundance. The Bermuda population of *Cardisoma guanhumi* is at the northern limit of its range, making the environmental conditions here less ideal for survival (Thomas, 1986).

This management plan outlines conservation efforts for *Cardisoma guanhumi*, and present knowledge of their local distribution, habitat requirements, biology and the threats they face. The plan also recommends areas for future research and monitoring, focused on both the crabs and their habitats. Known threats to these crabs are discussed, and suggestions made on how the threats can be mitigated through management actions and legislation. Other land crab species, such as the more common red land crab (*Gecarcinus lateralis*), are not covered by this plan.

B. Taxonomy and Description of Species

Kingdom: Animalia
Phylum: Arthropoda
Class: Malacostraca
Order: Decapoda
Family: Gecarcinidae (Land Crabs)
Genus: *Cardisoma*
Species: *guanhumi*

Common names: giant land crab, white land crab, great land crab, blue land crab (not to be confused with the fully marine blue crab *Callinectes sapidus*.)

Taxon author: Latreille, 1828

Cardisoma guanhumii can be distinguished from other terrestrial crab species in Bermuda by its large size, and the significantly different sizes of the two major chelipeds (the large front claws). In males the difference is particularly pronounced (Maynard and Oxenford, 2014). The larger chela may be on either the right or left, with data showing an almost even split in most populations, including Bermuda (Mitchell, 1990; Govender, 2019).



Figure 1: A giant land crab (*Cardisoma guanhumii*) (Photo: JP Rouja/ Nonsuch Expeditions)

Measurements of carapace widths and weights in harvested *C. guanhumii* from Trinidad and Puerto Rico showed that males were significantly larger than females (Maynard and Oxenford, 2014; Govender, 2019). Maximum carapace widths of 150 mm (6 in) and body weights of 400 to 500 grams were reported in various sub-populations from Florida and the Caribbean (Hill, 2001; Wedes, 2004; DaCosta-Cottam et al., 2009; Hostetler et al. 2019). Mitchell (1990) reported that the largest giant land crab caught at Hungry Bay (Bermuda) had a carapace width of 125 mm (4.9 in) and a major chela size of 205 mm (8 in).

Colouration in *Cardisoma guanhumii* depends on the sex of the crab and its stage of development. In juveniles, the dorsal part of the carapace is often yellowish brown with light purple sides, and orange or yellowish-brown legs. Sub-adult and adult crabs vary from intense dark bluish purple, to lavender, to a whitish grey or yellowish grey colour (Silva et al., 2014). Several authors reported that the whitish grey or yellowish grey colouration is most common in adult females (Hill, 2001; Silva et al. 2014; Maynard and Oxenford, 2014).

Aside from colouration and cheliped size, the gender of a giant land crab can be determined from the shape of the ‘apron’ on the underside of the abdomen. In females it is broad and round, to accommodate the clutch of eggs which she carries externally before they are shed whereas the abdomen of male crabs is narrow and pointed (Fig. 2).

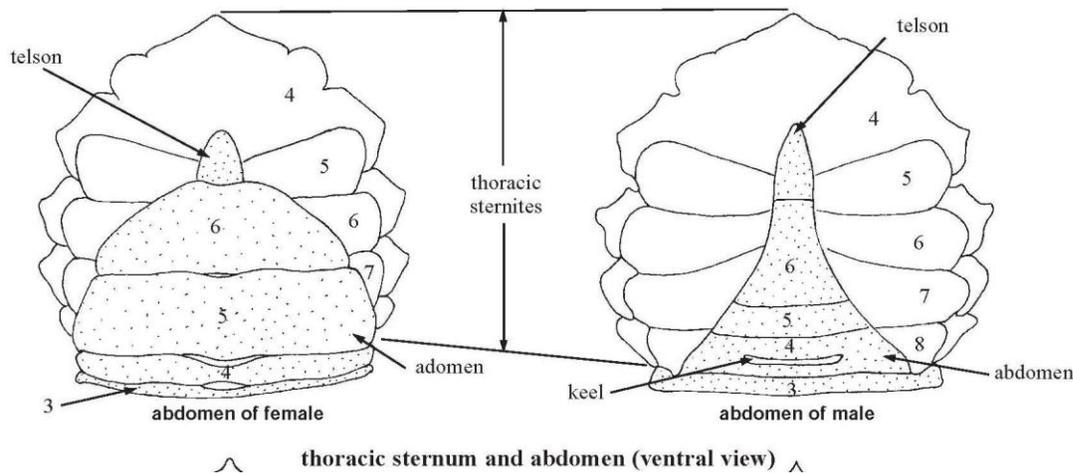


Figure 2: The shape of a female crab abdomen (left) and male crab (right), from Tavares (2002) pg.329. The width of the 5th abdominal segment indicates level of sexual maturity in the female.

C. Ecology

General information on the ecology of the giant land crab has been summarized below from the literature, and data more specific to Bermuda have been incorporated when available.

Habitat requirements

Cardisoma guanhumii is a burrowing species, often creating burrows with multiple entrances. Burrows are usually dug in clay-rich soil, but also in somewhat sandy sediments (Thomas, 1986). When sealed with mud, the burrow provides a safe place to moult, away from predators and adverse environmental conditions. The burrow of an adult can be up to 13 cm (5 in) wide and up to 1.5 m (5 ft) deep (Hostetler et al., 2019). Juvenile crabs which are too small to dig their own burrows may share the burrow of an adult crab (Hill, 2001). The burrow must be deep enough to reach the water table and maintain a pool of water year-round. The pool may be fresh, brackish or salt water and is used to replenish a water reserve held in the branchial chamber of the carapace to keep the gills wet. As Hill (2001) notes, this requirement limits the habitat of *C. guanhumii* to low-lying areas where the water table is within 2 m of the surface.

Over much of its range, *C. guanhumii* is known as a mangrove-associated species (Govender, 2019). Thomas (1986) notes the species was “formerly common in muddy mangroves.” Mangroves provide shade, silty substrate for burrowing, as well as preferred food items (Hill, 2001). The habitat used by *Cardisoma guanhumii* at Hungry Bay is described by Mitchell (1990) as: “burrows are found on the edge of the mangrove stand where the ground is still muddy, and the burrows are shaded by the stand of red mangroves (*Rhizophora mangle*).” He noted that at normal high tide the water level was about 3 metres from the nearest burrows. Elevated entrances protected by mounds of mud were observed at some of the burrows closer to tide level, which may serve as a defence to keep the burrow from flooding on an exceptional tide,

or may prevent debris from entering the burrow (Mitchell, 1990). *Cardisoma guanhumii* displays site fidelity to a territory near its burrow for much of the year, with males moving further afield at the start of the breeding season (Moraes-Costa and Schwamborn, 2018).

Diurnal and seasonal activity

Cardisoma guanhumii is often nocturnal, remaining in its burrow during the day to avoid desiccation and high temperatures. At dusk they leave the burrow to forage nearby. Mitchell (1990) reported crabs emerging about two hours after sunset. Giant land crabs may be active during the day after heavy rain, on cloudy days, and in shaded habitats (Hill, 2001; Naqqi Manco, 2008). During breeding season large numbers can be active during the day (Tedford, 2017).

In the Caribbean, giant land crabs are inactive during the dry season, with migration and breeding initiated by seasonal rains in spring (Naqqi Manco, 2008; Tedford, 2017; Govender, 2019). May to September is reported as the active period in the Turks and Caicos Islands, and crabs have gone into burrows in October (Naqqi Manco, 2008). In Trinidad, crabs seal themselves in their burrows in January to moult, emerging in May and June to mate, then the spawning migration to the sea occurs from July to September (Maynard and Oxenford, 2014). Bermuda has a dry spell from April to June, but it is more likely latitude and temperature that drive seasonal activity here.

Evidence from Bermuda suggests that the common red land crab (*Gecarcinus lateralis*) is less active in the winter when the daytime temperature falls below 70°F, but will emerge for brief periods during winter warm spells (Dunstan, 1959). There is no information on seasonal activity for *Cardisoma guanhumii* in Bermuda, but they likely follow a similar pattern. Thomas (1986) notes that giant land crabs only remain fully active above 20°C (68°F).

Feeding

The giant land crab is an omnivorous scavenger, its diet is composed of plant material and some animal protein. On occasion they will eat beetles or other large insects (Hostetler et al., 2019) and will scavenge dead animals and eat faeces. Cannibalistic behaviour towards smaller crabs has been reported, but primarily they eat plant material including all kinds of flowers, fruits, grasses and leaves (Hill, 2001; Tedford, 2017). Captive individuals have been kept successfully on a diet of raw clams, fish, dog food, egg shells, lettuce and a variety of plant materials (Thomas, 1986). Harvesters in Trinidad reported that *C. guanhumii* can be attracted with coconut and sweet-smelling fruits like pineapple (Maynard and Oxenford, 2014).

Unlike some land crabs which feed gregariously, individual *Cardisoma guanhumii* at Hungry Bay were observed to avoid contact with conspecifics if possible (Mitchell, 1990). Giant land crabs at Hungry Bay were observed eating the fallen leaves of the red mangrove (*Rhizophora mangle*), and green grasses. Mitchell (1990) also observed a crab pulling green leaves from a low-growing buttonwood (*Conocarpus erectus*) and eating them. There is evidence of preferential feeding on mangrove and buttonwood leaves (Hill, 2001). A large male found dead at Hungry Bay in July 2020 had a stomach full of what appeared to be zoysia grass; possibly mowed clippings from the lawn where it was found (Table 2).

Age

Silva et al. (2014) reported that *Cardisoma guanhumi* is a slow growing and long-lived species, and that this profile does not aid the recovery of this species when it has been depleted by over harvesting. *C. guanhumi* can make 60 moults before reaching maximum size, and may reach 13 years of age (Hill, 2001; Henning 1975 in Silva et al. 2014).

Sex ratio

Coleman (2001) reported a sex ratio skewed toward males, with 13 males and 6 females recorded at Hungry Bay (32% female). Similarly, Mitchell (1990) noted that only 20% of the 30 crabs captured from burrows at Hungry Bay were female (i.e. 6 females). Sex ratios for other Bermuda sub-populations are not available. The reasons for the skewed ratio in Bermuda merit investigation, and may be tied to the sampling strategy of the studies. There is evidence that a population free from substantial harvesting and predation (such as Bermuda's) may exhibit a high male to female ratio, but in many studied harvested populations the ratio was closer to balanced (Moraes-Costa and Schwamborn, 2018).

Reproduction

Although it is a terrestrial crab, the giant land crab relies on the sea for reproduction. After mating, the female carries a dark brown egg mass containing up to 700,000 eggs beneath her body for about 2 weeks (Hill, 2001; Hostetler et al., 2019). The egg-bearing females (Fig. 3) must migrate to the sea, where they wash the eggs off their abdomen. The eggs hatch into planktonic, and later free-swimming larvae, which make their way ashore as tiny crabs. There is evidence that water temperatures below 20°C (as occur in Bermuda in the winter) impact the development success of *C. guanhumi* larvae (Hill, 2001).

The timing of the female migration is linked to the lunar cycle, with most heading toward the sea within 1-2 days of the full moon (Hill, 2001). Maynard and Oxenford (2014) reported female migrations 3 days after the full and new moons during the summer in Trinidad.

The timing of the reproductive season in *C. guanhumi* is thought to vary with latitude (Hill, 2001). In Florida the spawning season, and associated migration of females to the sea lasts from June to December, but peaks in October and November (Hill, 2001; Hostetler et al., 2019). In Trinidad, crabs breed in June, and migrate to the sea from July to September (Maynard and Oxenford, 2014). In Bermuda the timing of reproductive activity has not been studied, but given the high latitude it may be similar to Florida. At Hungry Bay Coleman (2001) observed 21 crabs nocturnally the night before the first full moon of July. Of these, 6 were female, however no notes on the presence of eggs were reported.



Figure 3: Female giant land crab carrying eggs (Photo: Bryan Naqqi Manco)

D. Current Status

Global distribution

Cardisoma guanhumi is found in the western north Atlantic, from Florida to Southern Brazil. Its native range includes 23 countries and territories throughout the Gulf of Mexico, Central America, South America and the Caribbean (Palomares and Pauly, 2019). Bermuda is the northern limit of its distribution.

Local distribution

Historically, there was a population of *Cardisoma guanhumi* on Cooper's Island at the turn of the 20th century. Verrill (1902) wrote that Cooper's Island was largely cultivated and was "one of the few places where the great land crab (*Cardisoma guanhumi*) can still be found, burrowing its large, deep holes in the sandy soil". A small sub-population of fewer than 5 crabs persisted at Cooper's Island and at Ferry Reach until the 1990's (Madeiros, 2016).

Nonsuch Island formerly supported a sub-population of giant land crabs (Madeiros, 2016). The salt marsh pond habitat, created behind the dunes at the South Beach on Nonsuch Island, supported a sub-population of 8-12 adult crabs in burrows beneath Black and Red Mangroves on the southern and eastern sides of the pond (Jeremy Madeiros, pers. comm.). All of the *Cardisoma guanhumi* in the Nonsuch sub-population had been translocated from Hungry Bay between 1990 and 1995, and a few may have come from the Wreck Hill colony (Jeremy Madeiros, pers. comm.). The Nonsuch Island colony was partly buried by ground swells during

Hurricane Felix (1995) and Hurricane Gert (1999). A few survived until the habitat was washed away down to bedrock by Hurricane Fabian in 2003. The area continues to be scoured by storm events, so there are no plans to rebuild the pond and mangrove habitat, or reintroduce *C. guanhumi* at Nonsuch Island.

The island-wide destruction of coastal habitats, particularly mangroves, in the 20th century reduced the giant land crab's distribution. The construction of the airport and associated US military base between 1941 and 1943 reportedly wiped out approximately 1/3 of Bermuda's total mangrove acreage (Sterrer and Wingate, 1981) as well as a giant land crab colony within Castle Harbour (Thomas, 1986), however crabs have been observed recently around Kindley Field, the Bermuda Institute of Ocean Sciences, at Walsingham Bay and at Stocks Harbour (Table 2).

Verrill (1902) recorded seeing "a number" of giant land crab holes at Hungry Bay, where he says they dug burrows among the roots of cedars. He noted that already in 1902, the giant land crab was declining, reporting "this species was probably much more abundant formerly than at present." In 1986, Martin Thomas reported a small colony of *Cardisoma guanhumi* at Wreck Hill, and a larger colony at Hungry Bay, with an island-wide population of "at most a few hundred specimens" (Thomas, 1986).

Giant land crabs currently have a highly fragmented distribution across Bermuda (Fig.4). The largest known extant sub-population is found in the largest remaining mangrove swamp on the island, in Hungry Bay Nature Reserve. This site is a limited-access Government nature reserve, surrounded by private property. It contains mostly red mangroves, with some black mangroves, buttonwood and a small saltmarsh. Ellison (1991) reported two separate colonies at this location in the early 1990's, on the northern and southwestern margins of the swamp. An early attempt to assess the Hungry Bay sub-population was undertaken by Mitchell (1990) who captured 30 crabs from their burrows and measured, marked and determined sex. The intent of the study was to gain knowledge rather than perform a population census. He counted 95 large burrow entrances, but noted the impossibility of using this as a proxy for population because burrows may have multiple entrances and the mangrove crab (*Goniopsis cruentata*) also created holes in this habitat. Small juvenile *C. guanhumi* share burrows with larger crabs, further complicating the relationship between burrow number and actual population size (Hill, 2001). A repeat count of entrances in 2001 reported 240 burrows within Hungry Bay, of which 186 were deemed to be active by the presence of fresh soil and faecal matter around the entrance (Coleman, 2001).

The second largest extant sub-population of *C. guanhumi* can be found in the fringing mangroves along Wreck Road, in Sandys parish. Coleman (2001) reported 20 active holes in the mangrove community at the Wreck Hill estate. At least 31 active holes were still present at this location in December 2015 (personal observation) and crabs were photographed here in 2016 (Jessica Riederer, pers. comm. 2017). There were at least 9 additional active holes at other residences along Wreck Road in the Pilchards Bay area in 2015 (Table 2).

There is a small sub-population of *C. guanhumi* within the Government-owned nature reserve at Stocks Harbour, St. Georges. An estimate of numbers has not been carried out, but 3 active

burrows were observed there by the author as recently as 2018. There are likely scattered *Cardisoma guanhum* throughout St. David's in fringing mangroves, as occasional observations have been made (see summary in Table 2).

In October 1985 a pair of adult giant land crabs were trapped at Hungry Bay and translocated to a mangrove area on the Vesey property on Harrington Sound, where another giant land crab had previously been released by BAMZ staff (Thomas, 1986). This is the only recorded effort to translocate *Cardisoma guanhum* in Bermuda, and the success or failure of the endeavour has not been reported. The translocated crabs dug burrows, but there is no information on how long they remained at this site, and if they still occur there.

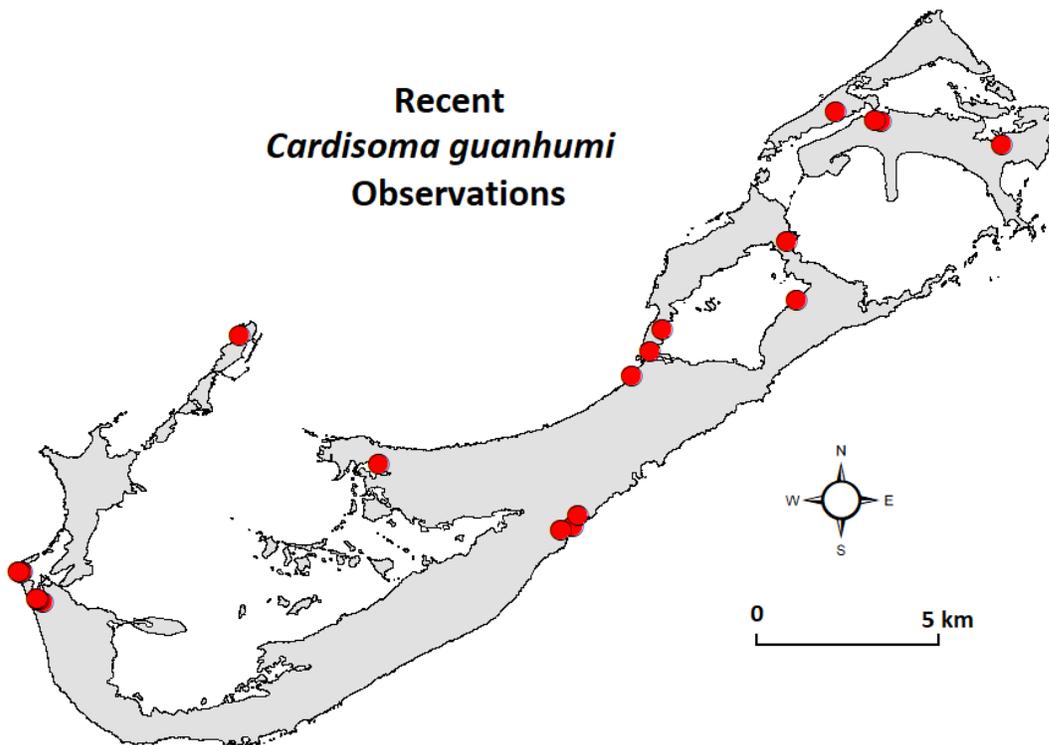


Figure 4: Map of Bermuda showing the known colonies of *Cardisoma guanhum* and confirmed observations made between 2009 and 2020.

E. Current Threats

Globally

Harvesting

Cardisoma guanhum is a high value food item in Latin America and the Caribbean, where it is harvested in often unregulated commercial and recreational fisheries. Such harvests occur in

the Turks and Caicos Islands (Naqqi Manco, 2008), Trinidad and Tobago (Maynard and Oxenford, 2014), the Bahamas (Bahamas National Trust, 2020) and Venezuela (Carmona-Suárez and Guerra-Castro, 2012). In Florida and Puerto Rico harvesting is regulated, but population declines continue (Govender, 2019; Hostetler et al., 2019). The harvest of *C. guanhumi* in Brazil is controlled by each state with varying regulations (Moraes-Coast and Schwamborn, 2018). Silva et al. (2014) reported it is a favoured ingredient in the cuisine of north-eastern Brazil, resulting in a significant population decline there. Illegal international trade of this species is reported from unregulated fisheries (Carmona-Suárez and Guerra-Castro, 2012).

Habitat loss and change

Habitat change and loss is the second greatest threat to *C. guanhumi* regionally, and will seriously impact their ability to adapt to climate change and other future threats. Loss of mangrove habitats, habitat fragmentation, changing land use and associated change in vegetation cover and hydrology are affecting *C. guanhumi* survival across its range (Govender, 2019). Silva et al. (2014) reported that the expansion of industrial complexes such as ports, shrimp farms and salt production has negatively impacted the mangrove habitat of the giant land crab in coastal Brazil. Protecting habitat is as critical to crab conservation as protecting the crabs themselves (Govender, 2019). In the Bahamas, a protected area was established in 2002 as a tool to maintain stocks of land crabs for continued collection, in response to public fears about overharvesting. The 4,000-acre Crab Replenishment Reserve on Andros Island protects crab habitat and allows crabs access to undeveloped shoreline for breeding (Bahamas National Trust, 2020).

Persecution and poisoning

In much of its range, *C. guanhumi* is treated as a pest, as they are notorious for destroying crops, digging up lawns and damaging gardens, parks and golf courses (Hill, 2001; Naqqi Manco, 2008; DaCosta-Cottam et al., 2009; Hostetler et al., 2019). This leads to targeted killing of crabs and accidental poisoning through exposure to agricultural chemicals.

In Bermuda

Poisoning and predation

Bermuda historically supported a large population of the red land crab (*Gecarcinus lateralis*) which was considered a nuisance and an agricultural pest. Bermudians have always undertaken some kind of crab control, and in the mid-20th century effort intensified to control *Gecarcinus lateralis*, including the introduction of biocontrol agents and extensive use of poison baits. In the 1950s poison bait was available from the Health Department, and the Department of Agriculture “devoted considerable time to devising a cheap and effective method of controlling land crabs. Low cost is essential if crabs are to be eliminated in large tracts of land, such as parklands and on farms” (Dunstan, 1959). This intense persecution of *Gecarcinus lateralis* likely had a considerable negative effect on the *Cardisoma guanhumi* population, given that poison baits would have been consumed by both species.

A breeding population of yellow-crowned night herons (*Nyctanassa violacea*) was established on Bermuda in 1976 from juveniles introduced from Florida. These herons were used as a biocontrol agent to reduce the use of toxic baits across the island (Wingate, 1982). The species was a known crab-eater that visited Bermuda as a seasonal migrant and the introduction was intended to fill the ecological niche left empty by the extinction of an endemic heron thought to be a crab-eating specialist (Wingate, 1982). Yellow-crowned night herons are now abundant and widespread on Bermuda and are certainly capable of preying upon *Cardisoma guanhumii*. Elsewhere, yellow-crowned night herons are reported to be significant predators of juvenile *Cardisoma guanhumii* as they emerge from the sea, and to also predate adults (Naqqi Manco, 2008).

The effect of invasive species on *Cardisoma guanhumii* in Bermuda is not well understood. The great kiskadee (*Pitangus sulphuratus*) is abundant in coastal habitats and predate small *C. guanhumii* (Jessica Riederer, pers. comm. 2017). Other potential predators or competitors are the Argentine ant (*Linepithema humile*), brown rat (*Rattus norvegicus*) and black rat (*Rattus rattus*).

Habitat loss and change

Historic habitat loss was a significant contributor to *Cardisoma guanhumii* decline in Bermuda, and it remains an ongoing and difficult to mitigate threat. Bermuda's largest remaining mangrove swamp at Hungry Bay has experienced significant documented retreat over the last 100 years (Ellison, 1991; Ellison, 1993). A rocky peninsula on the south side of Hungry Bay protects the mangrove from rough open ocean conditions; however, an erosional gap in this protective barrier has been cause for concern for since the 1980's (Ellison, 1991). Subsequent hurricanes have continued to expand the gap, resulting in the loss of a number of mangrove trees along the perimeter of the swamp where *C. guanhumii* were previously recorded (Mitchell, 1990; Ellison, 1991). The continued erosion of the rocky shore will seriously impact the stability of the mangrove habitat at Hungry Bay in the future, and may lead to its eventual loss.

Sediment transport during recent hurricanes led to the deposition of copious sand into the saltmarsh and mangrove community in Hungry Bay, covering areas formerly dominated by mangrove peat and mud. This firm substrate has allowed invasive plants like Brazil Pepper (*Schinus terebinthifolia*) to colonise the area of the crab burrows. The shade provided by these trees should be beneficial in the short term, but they are less adaptable to sea level rise than mangroves, and do not provide the crabs preferred food. The impact of this change in substrate and plant community on the crabs is unknown.

The encroachment of open lawns and roadways up to the edge of the Stocks Harbour Nature Reserve, and the placement of fences between the reserve and the sea are cause for concern. A habitat buffer between the crab burrows and the edge of the reserve is urgently needed.

Climate change

The most significant climate-related challenge *C. guanhumii* face in Bermuda relates to habitat. Mangrove habitats are able to adapt to rising sea levels provided they are given space to retreat landward, and are of sufficient size and productivity to generate peat deposits (Ellison, 1993; Govender, 2019). Most of Bermuda's mangroves have been reduced to thin fringes bordering

land converted to other uses, and as such do not meet these criteria. At Hungry Bay, the front of the mangrove swamp has eroded significantly, and the back of the swamp is hemmed in by roads and residential development. The predicted increase in hurricane frequency and severity will also negatively impact *C. guanhumii* and their habitats. Given the fact that Bermuda is at the northern limit of the range for giant land crabs, any climate change-related increase in air or water temperature may not severely impact them here. However, changing rainfall patterns and ocean acidification could have negative impacts.

Pollution

The location of the Seabright sewage outfall in the vicinity of the largest *Cardisoma guanhumii* population in Bermuda at Hungry Bay is cause for concern. Mitchell (1990) noted that in July 1990 the bacterial levels in Hungry Bay were found to be “unacceptable levels according to Bermuda standards but are within international standards.”

Traffic

Traffic on coastal roads poses a significant threat to giant land crabs during their breeding migrations (Naqqi Manco, 2008; DaCosta-Cottam et al., 2009). Anecdotal evidence from Bermuda suggests that roadkill occurs infrequently along South Shore in Paget and Devonshire. Roadside burrowing in St. David’s has also been observed in recent years (Fig. 5). A number of crabs brought to the Bermuda Aquarium Museum and Zoo have been found by members of the public on the road. The well-intentioned movement of crabs from roadsides to another location by members of the public can disrupt spawning migrations and lead to territorial fighting with other crabs, resulting in injury or death.



Figure 5: Large *Cardisoma guanhumii* burrow excavated under a fence next to a major road (Photo: Alison Copeland).

It is possible that illegal collection of giant land crabs for food or bait still occurs in Bermuda, but it is unlikely to be substantial given low crab numbers and ready availability of alternatives.

Additional possible threats to *Cardisoma guanhumii* in Bermuda include ground water pollution, artificial lighting in coastal areas, vibrations from traffic and other sources, and marine plastic pollution in mangrove habitats.

The large mounds of soil excavated from *C. guanhumii* burrows can make them unpopular with gardeners and the crabs may also interfere with shallowly buried utilities. The targeted killing of giant land crabs on Bermuda is prohibited, however the above issues can be dealt with through education, compromise and the mitigation measures permitted by the Protected Species Act 2003.

F. Current Protection Status

International protection

None. The IUCN Red List of Threatened Species contains assessments of the extinction risk faced by a species across its global range. *Cardisoma guanhumii* has not been assessed at the global level, so it does not appear on the Red List. The Convention on International Trade in Endangered Species of Wild Flora and Fauna (CITES) protects species from over-exploitation through international trade. No crabs are currently protected by CITES.

National protection

Current legal protection for the giant land crab is provided by the Protected Species Act (2003). Under this legislation the wilful destruction, damage, removal or obstruction of crab habitats and burrows is an offence. Further, it is an offence to wilfully damage, destroy, injure, disturb or kill a protected species. The Protected Species Act (2003) also prohibits the taking, importing, exporting, selling, purchasing, transporting or having in one's possession a protected species or its parts. The giant land crab is listed as a Level 1 protected species, the highest level of protection under the Act, therefore anyone who commits an offense involving this species is liable to a fine of \$25,000, or 2 years imprisonment. Following IUCN Red List criteria, the giant land crab is listed as 'Vulnerable' [VU] under the Protected Species Amendment Order (2016).

Habitat protection

The migratory nature of this species makes habitat protection a challenge. Mangroves are listed on the Protected Species Amendment Order 2016, so their removal without authorization is illegal. Further, most remaining sizable mangrove stands in Bermuda have been zoned as Nature Reserve under the Draft Bermuda Plan 2018 (Department of Planning, 2018). This zoning restricts development within the nature reserve zoned lot and requires a setback for adjacent developments.

The Bermuda National Parks Act 1986 protects the giant land crabs found in the nature reserves of the National Parks System at Hungry Bay and Stocks Harbour. Therefore, two of the three currently known sub-populations are found within protected areas.

G. Current Conservation Action

Little formal conservation action has been undertaken, aside from listing on the Protected Species Order in 2012.

The Bermuda Aquarium, Museum and Zoo (BAMZ) and Department of Environment and Natural Resources (DENR) both receive crabs from members of the public when they are found in the road, in buildings or other places where they are not wanted or may be in danger. Received crabs are released as soon as possible in suitable mangrove habitats.

PART II: MANAGEMENT

A. Management Goals

The principal aim of this management plan is to protect giant land crabs and their habitats in Bermuda, and contribute to national and regional conservation of these crabs through sharing of knowledge, participation in research and monitoring, and mitigation of threats.

At present little is known of the ecology of Bermuda's giant land crabs. It is unclear if the population is stable, but small, following historic loss of habitat; or if it is continuing to decline and therefore at high risk of extirpation. In the short term, assessing the population to determine how many crabs remain and where they reside is a management priority. In the longer term, researching giant land crab ecology so that informed management decisions can be made is critical.

The short-term goals (5 years) are to undertake a comprehensive population assessment, minimize identified threats where possible, and to identify and protect critical habitats.

The long-term goals (15 years) are to monitor trends in abundance of land crabs across the island, improve knowledge of land crab ecology through research, respond to emerging threats, establish and enforce habitat protection, obtain comprehensive data on critical habitat use, where possible establish new sub-populations in appropriate protected habitat, and participate in any regional conservation action for this species.

B. Management Objective and Criteria

A favourable conservation status for giant land crabs in Bermuda will be achieved when there is:

1. Evidence of an increasing or stable population
2. More known about Bermuda's giant land crab population and its ecology
3. Crab habitat is protected, and both quality and quantity are enhanced
4. Threats have been identified and addressed to the extent possible
5. The public are aware of this species and champion its conservation

These overall objectives translate into specific actions outlined below:

Actions needed:

- An accurate assessment of the current population and distribution of giant land crabs in Bermuda.
- Monitoring of critical habitat sites to establish a population trend and provide for a rapid response to new threats when they arise.

- Protection of critical habitats supported by public cooperation, legislation and effective enforcement.
- Increased public education regarding the threats to protected crabs and their habitats.
- An improved programme for surrendering and reporting crabs in danger (e.g rehab and relocation).
- Explore the possibility of establishing new colonies through translocation
- Put mitigation measures in place, where possible, against threats to crabs from human and natural sources.

C. Management Strategy

Once sub-populations of giant land crabs have been mapped and assessed, it will likely become clear that the threats faced by each are different, with a few common elements. Similarly, the conservation opportunities at each sub-population will differ, based on factors like land ownership, sub-population size and habitat quality. Therefore, management of Bermuda's giant land crabs will require a multi-scale strategy that includes actions for the island-wide population as a whole, and targeted actions necessary to safeguard each sub-population.

The strategy will also need to be flexible. As the tools outlined in part D are applied to the actions proposed in part E, priorities will change; both as knowledge is gained, and in response to emerging threats, such as major coastal developments and hurricanes or emerging opportunities like new collaborations and policies. This management plan should be re-visited and updated regularly.

D. Tools Available for Strategy

A repeatable method of population assessment should be prepared using published techniques and repeated every five years to see a population trend over a 15-20-year time-frame.

Sample and Albrecht (2016) demonstrated that an inexpensive fibre optic camera can be used as a minimally invasive method of investigating *Cardisoma guanhumii* burrows. This type of 'burrow scope' offers a tool to investigate holes found on development sites or reported by the public to see if they house *C. guanhumii*, other crab species, or rats. It can also be used to map areas of active crab habitat, and to monitor the number of burrows that remain active over time. Also, the burrow scope camera can be used as a quick assessment method for planning further work. The ability to identify the occupant of a burrow with the camera should be tested before it is used for population assessment, and ideally, would be combined with other techniques such as capture-mark-recapture.

It is difficult to permanently mark a species that moults up to 60 times in its life; however, temporary marking has been achieved for a period of time long enough to allow population assessment through capture-mark-recapture studies using various external marks paired with implanted Passive Integrated Transponder (PIT) tags. During an investigation of PIT tag tolerance, Forsee and Albrecht (2012) found no mortality or tag loss over seven months, however they noted that their study subjects did not moult while in captivity. One study in

Puerto Rico involving 397 crabs over a one-year period reported using PIT tagging as an appropriate method of marking *C. guanhumi* for population assessment (Forsee and Albrecht, 2012). Similarly, Moraes-Costa and Schwamborn (2018) PIT tagged and externally marked the carapaces of 291 crabs, from which they calculated a tag loss rate of 18% over approximately one year.

There is available literature on methods for baited trapping, hand netting and other techniques for capturing *C. guanhumi* for ecological studies (Forsee and Albrecht, 2012; Maynard and Oxenford, 2014; Silva et al., 2014; Moraes-Costa and Schwamborn, 2018). Hand capture of crabs outside of burrows at night yields higher catches than trapping (Forsee and Albrecht, 2012). The recommendations in Mitchell (1990) regarding use of heavy nets should be followed.

The DENR should build relationships with academic institutions and researchers studying the ecology of *Cardisoma guanhumi*. Collaborations should be explored, including the use of students and volunteers in the implementation of this plan. Sources of funding and expertise should be identified and sought.

The existing consultation arrangement between the Department of Planning and the Ecology Section of the Department of Environment and Natural Resources can be used to implement actions in this plan; particularly for reporting crab burrows at development sites and including land crab considerations in conservation management plans (CMPs) for coastal developments. Landowners willing to host translocation trials on their property will also be valuable assets which can be identified through this process.

The scattered distribution of *Cardisoma guanhumi* around the island will make identification of undiscovered sub-populations difficult, particularly on private property. An online reporting form, email address and phone number will be valuable tools for soliciting public reporting of crabs and their burrows. New public awareness materials combined with existing events should be used to raise the profile of this species and its needs. An excellent model of a giant land crab and its burrow exists on display in the Natural History Museum at BAMZ and should be used for educational purposes.

The Government of Bermuda commissioned updated air photo mosaics of the islands in late 2019, which will provide a valuable tool for crab habitat mapping, along with existing contours and maps of known mangroves. The GIS capabilities of the DENR are available for implementation of this plan, including previously mapped *C. guanhumi* observations. The delineation of crab habitats can be paired with ongoing shoreline classification for oil spill emergency response planning to make it cost effective.

Section 6 of the Protected Species Act 2003 provides tools for legal protection of crab habitat. Opportunities should be sought to zone crab habitat on private property as nature reserve, to transfer land into the national park system or other innovative public/private management arrangements. The quantity of crab habitat can be increase by liaising with NGOs undertaking wetland or coastal restoration projects to encourage the planting of mangroves and creation of stable muddy banks in low-lying areas. Replanting the damaged mangrove at Hungry Bay

should be a priority. Techniques for planting mangroves have been successfully tested at this site previously, and should be employed again. A summary of habitat challenges at Hungry Bay and management responses can be found in Ellison (1991), and implementation of these should be considered.

Targeted awareness programmes in neighbourhoods where crabs live would be a valuable tool for mitigating a number of threats, particularly related to traffic, coastal lighting and chemical use. The DENR has an active pest bird control programme, and the resources of this programme could be used to mitigate the threat of avian predators in key habitats.

There is a body of knowledge, mostly available from harvesters and via unpublished sources, on the keeping of *Cardisoma guanhumii* in captivity. This could perhaps be leveraged for a head starting programme for juveniles or another short-term *ex situ* programme. Aquaculture of *C. guanhumii* does not appear to have been explored to date. The hatchery facility at Coney Island may present an opportunity for this, if a protocol can be developed. If genetic analysis indicates Bermuda's *C. guanhumii* are identical to other populations, augmentation through the importation of additional animals would be possible.

E. Step-down narrative of work plan

Abbreviations:

DENR – Department of Environment and Natural Resources

BAMZ – Bermuda Aquarium, Museum and Zoo

BZS – Bermuda Zoological Society

NHM – Natural History Museum

UKOT – United Kingdom Overseas Territories

The actions needed to achieve species recovery to an improved conservation status are as follows:

1. Population assessment and distribution mapping

Actions proposed:

- Current population estimated through surveys
- Distribution of current population surveyed and mapped (in tandem with habitat identification in action 3).
- Both population estimate and distribution map revisited every 5 years to establish trends
- Voluntary expansion of species distribution onto private property
- Genetic analysis to: a) confirm if the Bermuda population is genetically different from Caribbean and Floridian populations, to inform possible population augmentation from overseas b) investigate if the local population is self-sustaining

Work Team: DENR, coastal landowners, academic institutions

Team Leader: DENR

Assistance: volunteers, graduate students, academic institution with genetic analysis capability, overseas colleagues to collect genetic samples

Outputs: current population estimate, distribution map, increased area of occupancy, confirmation of population genetic status, population trend once repeated

Needed Resources: Funds for collection, shipment and analysis of genetic samples (possible project cross-territory UKOT grant), population survey equipment (PIT tags, fibre optic camera etc.), mapping software, hand-held GPS, field survey team, student stipend, access to private property

2. Ecology

Actions proposed:

- Establish timing of breeding activity and seasonal inactive period
- Investigate migration routes and need for corridors between burrows, foraging habitat, breeding habitat and the sea
- Investigate diet preferences including use of introduced plants and native plants, which could be planted at restoration sites
- Investigate impacts of invasive species, including competition with ants and other introduced species, use of invasive plants, and predation by birds
- Investigate the possibility of captive breeding or head-starting

Work Team: DENR, academic collaborators

Team Leader: DENR

Assistance: public reporting, coastal landowners, graduate students, volunteers

Outputs: breeding season defined, inactive period identified, migration routes identified, migration corridors established, diet known, invasive species impacts understood and mitigated, *ex situ* conservation started if possible

Needed Resources: field survey team, student stipend, access to private property, *ex situ* holding and breeding facility, aquaculture facility, resources to mitigate threats, policy to establish migration corridors

3. Habitat

Actions proposed:

- Classify habitat types occupied by giant land crabs (in tandem with mapping in action 1).

- Ensure no net loss of mangrove habitat, possibly including erosion protection at Hungry Bay.
- Habitat quality enhancement – including mangrove planting, invasive plant removal, installation of culvert pipes and crab stairs to maintain habitat connectivity.
- Shoreline hardening and steepening prevented on shorelines near known crab sub-populations, and discouraged elsewhere.
- Create policy to include land crabs as part of the Environmental Impact Assessment process and create a national standard quick survey method for land crabs at developments.
- Include habitat for crabs in ongoing restoration projects (e.g NGO-led projects) and consider reintroduction to Nonsuch Island
- Identify areas where crabs could be introduced and make necessary modifications in habitats to support land crabs.

Work Team: DENR, Department of Planning, landowners, NGOs

Team Leader: DENR

Assistance: volunteers, landscape architects, environmental consultants, policy analyst

Outputs: habitats used by crabs classified, loss of mangrove habitat halted, Hungry Bay habitat stabilised, breeding crabs safely able to reach the sea and return to burrows, crabs introduced to restored habitats, national standard survey for land crabs created, policy to prevent shoreline hardening and steepening, policy requiring land crab survey at coastal developments

Needed Resources: field survey team for habitat mapping, field team for habitat restoration, field team to carry out standardised quick survey at development sites, access to private property, mangrove propagules for planting, land for restoration

4. Threats

Actions proposed:

- Ensure crabs are not used for food or bait through awareness and prosecution
- Explore voluntary reduction in garden and roadside spraying of chemicals
- Work to prevent roadkill of crabs
- Investigate the impact of yellow-crowned night herons and kiskadees on giant land crabs, and reduce predation through culling if necessary.

Work Team: DENR, judiciary, Works and Engineering roadside herbicide team, residents near crab habitat, pest control shooters

Team Leader: DENR

Assistance: general public, BAMZ, students

Outputs: public awareness materials, roadside spraying reduced, understanding of avian predation, birds culled if required

Needed Resources: funds for production of awareness materials, contacts for neighbours near crab hotspots, student stipend, salary and resources for pest control shooter

5. Awareness

Actions proposed:

- Ensure the public know how to safely bring at-risk crabs to BAMZ or to call DENR for assistance. Further, ensure staff are ready to deal with incoming crabs. Emphasize 'leave them be'.
- Promote community appreciation for crabs and their habitats
- Encourage reporting of sightings to DENR and the Natural History Museum (NHM)
- Publicise the protected status of giant land crabs and penalties for offences against the Protected Species Act
- Connect with regional crab conservation initiatives, academic collaborators, fisheries organisations and partners including Caribbean UKOTs which share this species
- Develop educational resources for children and adults on protected crabs
- Do targeted awareness activities in neighbourhoods near important crab sub-populations e.g. Happy Talk Drive, Happy Talk Lane, Wreck Road, Hungry Bay and St. David's.

Work Team: DENR, BAMZ, NGOs

Team Leader: DENR

Assistance: general public, overseas collaborators, educators

Outputs: Land crab sightings recorded in database, BAMZ staff and volunteers briefed on what to do with land crabs, educational resources created, awareness events held in target neighbourhoods

Needed Resources: funds to create and distribute awareness materials, sightings database

F. Estimated Date of Down-listing

Down-listing will be considered when the conservation status of the giant land crab on Bermuda has improved above a baseline established when the implementation of this plan begins. Down-listing can only be considered if the long-term sustainability of the giant land crab population is achieved. At least 15 years would be needed for population trend monitoring, and to achieve long-term goals. Giant land crab generations are about this long

also, therefore down-listing should not be considered for at least two generations, or 30 years from the date of implementation – 2050 at the earliest.

PART III: IMPLEMENTATION

Priority 1: An action that must be taken to prevent extinction or to prevent the species from declining irreversibly.

Priority 2: An action that must be taken to prevent a significant decline in the species population/habitat quality, or some other significant negative impact short of extinction.

Priority 3: All other actions necessary to provide for full management of the species.

Priority #	Task #	Task description	Task Duration	Responsible Party
		Population & distribution		
1	1	Current population estimated through surveys	1 year	DENR
1	2	Distribution of current population mapped	1 year	DENR
2	3	Both population estimate and distribution map revisited to establish trends	every 5 years	DENR
2	4	Expansion of distribution	3 years	DENR, landowners
3	5	Genetic analysis	6 months	Overseas collaborator, DENR
		Ecology		
2	6	Establish timing of breeding activity and seasonal inactive period.	1 year	DENR
1	7	Investigate migration routes and need for corridors	1 year	DENR
1	8	Investigate diet	6 months	DENR
2	9	Investigate interactions with introduced species	1 year	DENR
3	10	Investigate possibility of captive breeding	ongoing	DENR
		Habitat		
2	11	Classify occupied habitats (with mapping)	1 year	DENR
1	12	Ensure no net loss of mangrove habitat including Hungry Bay	ongoing	DENR, Planning
2	13	Enhancement of habitat quality and connectivity	ongoing	DENR, landowners
2	14	Shoreline hardening and steepening prevented	ongoing	DENR, Planning

1	15	Create policy to include crab habitat in EIA process (with national standard survey)	6 months	DENR, Planning
3	16	Include land crab habitat in ongoing restoration projects	ongoing	DENR, NGOs, landowners
2	17	Identify suitable habitat for introduction	1 year	DENR, NGOs, landowners
		Threats		
1	18	Ensure crabs are not used for food or bait through awareness and prosecution	ongoing	DENR, public
2	19	Explore voluntary reduction in garden and roadside chemicals	2 years	DENR, W&E, landowners
1	20	Work to prevent roadkill	ongoing	DENR, public
1	21	Investigate the impact of yellow-crowned night herons and kiskadees and cull if necessary	1 year, then ongoing	DENR
		Awareness		
2	22	Public know to contact BAMZ/DENR about crabs, and staff are prepared to handle them	ongoing	BAMZ, DENR, public
1	23	Promote appreciation of crabs and their habitats	ongoing	DENR, NGOs
2	24	Sightings reported to the NHM and DENR	ongoing	DENR
2	25	Develop educational resources on crabs	2 months	DENR, NGOs
1	26	Do targeted awareness activities in neighbourhoods near crab sub-populations	1 year	DENR, NGOs, public
2	27	Publicise protected status, offences and penalties	1 month	DENR
3	28	Connect with regional crab conservation initiatives and partners	ongoing	DENR

References

Bahamas National Trust. 2020. Crab replenishment reserve. Website of the Bahamas National Trust, accessed April 8th 2020.

<https://bnt.bs/explore/andros/crab-replenishment-reserve/>

Carmona-Suárez, C. A. and E. Guerra-Castro. 2012. Comparison of three quick methods to estimate crab size in the land crabs *Cardisoma guanhumi* Latereille, 1825 and *Ucides cordatus* (Crustacea: Brachyura: Gecarcinidae and Ucididae). *Revista de Biología Tropical*, 60 (Suppl.1) 139-149, March 2012.

Chace, F. A, Jr., J.J. McDermott, P.A. McLaughlin and R.B. Manning. Order Decapoda (Shrimps, lobsters and crabs). In: Sterrer, W.(ed). 1986. *Marine Fauna and Flora of Bermuda: A systematic guide to the identification of marine organisms*. A Wiley Interscience publication, John Wiley & Sons Inc. pg334.

Coleman, G.T.L. 2001. Population study of the great land crab *Cardisoma guanhumi* at Hungry Bay and Ely's Harbour. Bermuda Biodiversity Project Student project. pp15. BAMZ#1103.

DaCosta-Cottam, M., Olynik, J., Blumenthal, J., Godbeer, K.D., Gibb, J., Bothwell, J., Burton, F.J., Bradley, P.E., Band, A., Austin, T., Bush, P., Johnson, B.J., Hurlston, L., Bishop, L., McCoy, C., Parsons, G., Kirkconnell, J., Halford, S. and Ebanks-Petrie, G. 2009. Cayman Islands National Biodiversity Action Plan 2009. Department of Environment, Cayman Islands Government. pg 230-233.

Department of Planning. 2018. Draft Bermuda Plan 2018. Department of Planning, Government of Bermuda. Accessed April 6th 2020 at: <https://planning.gov.bm/wp-content/uploads/2018/11/The-Draft-Bermuda-Plan-2018.pdf>

Dunstan, A. G. January 1959. Land crabs and their control. Bulletin Bermuda Department of Agriculture. BAMZ # 128.

Ellison, J.C. 1991. Hungry Bay Mangrove Swamp, Bermuda present condition and future management. Bermuda Biological Station for Research, St. Georges, Bermuda. pp.35.

Ellison, J. C. 1993. Mangrove retreat with rising sea-level, Bermuda. *Estuarine, Coastal and Shelf Science*. July 1993, 37 (1) 75-87.

Forsee, R. A. and Albrecht, M. 2012. Population estimation and site fidelity of the land crab *Cardisoma guanhumi* (Decapoda: Brachyura: Gecarcinidae) on Vieques island, Puerto Rico. *Journal of Crustacean Biology*, 32 (2), 435-442.

Govender, Y. 2019. Long-term monitoring of crab *Cardisoma guanhumi* (Decapoda: Gecarcinidae) captures in Jobos Bay Estuary, Puerto Rico. *Revista de Biología Tropical*, 67 (4), 879-887, Sept. 2019.

Hill, K. 2001. *Cardisoma guanhumi*. In: Indian River Lagoon Species Inventory. Smithsonian Marine Station at Fort Pierce, Florida, USA.
https://naturalhistory2.si.edu/smsfp/irlspec/Cardis_guanhu.htm

Hostetler, M. E., F.J Mazzotti and A. K. Taylor. 2019. Blue Land Crab (*Cardisoma guanhumi*). WEC30, Dept. of Wildlife Ecology and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, FL USA.

Madeiras, J. 2016. Giant Land Crab *Cardisoma guanhumi*. In: *Flora and Fauna of the Bermuda Protected Species Act (2003)*. The Department of Environment and Natural Resources, Government of Bermuda. pp143.

Maynard, M., and H.A. Oxenford 2014. Characterisation of the Commercial Mangrove Land Crab Fishery in Trinidad. Centre for Resource Management and Environmental Studies, The University of the West Indies, Cave Hill Campus, Barbados. CERMES Technical Report No 76. 87 pp.

Mitchell, W. July 1990. *Cardisoma guanhumi*: An overview of the population in Hungry Bay, Paget.

Moraes-Costa, D. and R. Schwamborn. 2018. Site fidelity and population structure of blue land crabs (*Cardisoma guanhumi* Latreille, 1825) in a restricted-access mangrove area, analyzed using PIT tags. *Helgoland Marine Research* 72 (1). <https://doi.org/10.1186/s10152-017-0504-0>

Naqqi Manco, B. 2008. The Crustacean Invasion. The Green Pages, newsletter of the Department of Environment and Maritime Affairs. In: *Times of the Islands*, Summer 2008. Turks and Caicos Islands. <https://www.timespub.tc/2008/06/the-crustacean-invasion/>

Palomares, M.L.D. and D. Pauly. Editors. 2019. SeaLifeBase. World Wide Web electronic publication. www.sealifebase.org, version (12/2019).
<https://www.sealifebase.se/Country/CountryList.php?ID=27250&GenusName=Cardisoma&SpeciesName=guanhumi>

Sample, S. and M. Albrecht. 2016. Determination of the burrow shapes of *Cardisoma guanhumi* on Vieques, Puerto Rico. *Journal of Coastal Life Medicine*, 4 (2): 94-97.

Silva, C.C., R. Schwamborn and J.E. Oliveira. 2014. Population biology and color patterns of the blue land crab, *Cardisoma guanhumi* (Latreille 1828) (Crustacea: Gecarcinidae) in Northeastern Brazil. *Brazilian Journal of Biology* Vol. 74 No. 4, 949-958.

Sterrer, W.E and D. Wingate. 1981. Wetlands and marine environments. In: Bermuda's delicate balance – people and the environment. Bermuda National Trust: 402 pp.

Tavares, M. 2002. "True Crabs." In Carpenter, K.E. (ed.) "The living marine resources of the Western Central Atlantic. Volume1: Introduction, molluscs, crustaceans, hagfishes, sharks, batoid fishes, and chimaeras." *FAO Species Identification Guide for Fishery Purposes and American Society of Ichthyologists and Herpetologists Special Publication No. 5*. 327-352. Rome, Italy. FAO.

Tedford, K. 2017. White land crab (*Cardisoma guanhum*). In: Flicker Bulletin #31 July/August 2017. Bimonthly Bulletin of the Cayman Islands Department of Environments Terrestrial Resources Unit.

Thomas, M.L.H. 1986. Habitat and nutritional requirements of the Giant Land Crab *Cardisoma guanhum*. Report, University of New Brunswick, Saint John, NB. Canada. BAMZ#1069.

Verrill, A. E. 1902. The Bermuda Islands: An account of their scenery, climate, productions, physiography, natural history and geology, with sketches of their discovery and early history, and the changes in the flora and fauna due to man. Transactions of the Connecticut Academy of Arts and Sciences 11: 413-956.

Wedes, S. 2004. "Cardisoma guanhum" (On-line), Animal Diversity Web. Accessed April 07, 2020 at https://animaldiversity.org/accounts/Cardisoma_guanhum/

Wingate, D. 1982. Successful Reintroduction of the yellow-crowned night heron as a nesting resident on Bermuda. Colonial Waterbirds Vol. 5(1982) pp. 104-1115.

Appendix

Appendix I: Recent and historic *Cardisoma guanhum* observations

Table 1: *Cardisoma guanhum* sub-populations reported in the literature

Location	Date	Note	Source
Walsingham Bay	1990	(Billy Mitchell pers. Comm 2020) [REDACTED]	Mitchell, 1990; H. de Silva in Coleman 2001
Nonsuch Island	1990-2016	Recorded destroyed (Madeiros, 2016). 8-12 translocated crabs had inhabited the salt pond until hurricanes destroyed the habitat	Mitchell, 1990; Coleman, 2001
Hungry Bay Nature Reserve	1902-present		Verrill, 1902; Thomas, 1986; Mitchell, 1990; Ellison, 1991; Coleman, 2001
Vesey property, Tuckers Bay, Harrington Sound (introduced by Bermuda Aquarium Museum and Zoo)	1985		Thomas, 1986; Mitchell, 1990; Coleman, 2001
No location	c.1986	“In deep burrows in low-lying muddy regions above high-water mark; wander out at night. Rare.”	Chace et al., 1986 pg. 354.
Wreck Hill mangroves, Ely’s Harbour	1986-present		Thomas, 1986; Mitchell, 1990; Coleman, 2001
Cooper’s Island	Until 1990’s		Verrill, 1902; Madeiros, 2016
Ferry Reach	Until 1990’s		Madeiros, 2016
Stokes Point	c.2000		H. de Silva in Coleman, 2001.

Table 2: Recent *Cardisoma guanhum* observations

Location	Date	Note	Source
[REDACTED]	6 th August 2009	1 found with <i>Coenobita clypeatus</i> at [REDACTED] during census for <i>C. clypeatus</i>	Heather DeSilva
[REDACTED]	21 st October 2009	Female. Beaten up by cat. Missing a leg and lethargic, brought to BAMZ. Released same day at [REDACTED]	BAMZ Wildlife Rehab WR3065
[REDACTED]	1 st August 2010	Found female on the road; released in Hungry Bay mangrove swamp	Mark Outerbridge
[REDACTED]	2 nd August 2010	Released same day at [REDACTED]. Sex unrecorded	BAMZ Wildlife Rehab WR3107

Location	Date	Note	Source
[REDACTED]			
[REDACTED]	27 th August 2010	Released same day to Hungry Bay mangroves. Finder and sex not recorded	BAMZ Wildlife Rehab WR3260
[REDACTED]	22 nd September 2011	Female crab brought to Shorelands from roadside. Released at [REDACTED]	Mandy Shailer, Alison Copeland, Peter Drew
[REDACTED]	22 nd September 2011	WRC record indicates release with no details to confirm date or location, but was only held to permit photographic record so assumed to be within a week of admission	BAMZ Wildlife Rehab WR3535
[REDACTED]	July 2012	One individual GPS ([REDACTED])	Kaitlin Noyes
[REDACTED]	21 st August 2012	[REDACTED]. Finder: Barb Outerbridge. Sex unknown	BAMZ Wildlife Rehab WR3421
[REDACTED]	27 th September 2015	Found (and photographed) male on the road 'stopping traffic near the airport'; left alone	Aalai Wolffe
[REDACTED]	2 nd November 2015	Large soil mound on roadside under BLDC fence from active burrowing. GPS and photos taken.	Alison Copeland
[REDACTED]	3 rd December 2015	At least 31 active burrows under mangroves and on adjacent lawn	Jessica Reiderer with Alison Copeland
[REDACTED]	3 rd December 2015	Active burrow in lawn, edge of mangroves along [REDACTED] Bay	Jessica Reiderer with Alison Copeland
[REDACTED]	3 rd December 2015	At least 8 active burrows in bank between mangroves and [REDACTED]	Jessica Reiderer with Alison Copeland
[REDACTED]	2016	Observations and photos collected in various weather and time of day	Jessica Reiderer
[REDACTED]	20 th June 2017	Excavating a new burrow in garden planter. Photos indicate crab is a young male. Trapping unsuccessful.	Vera Ellison, Mark Outerbridge
[REDACTED]	24 th August 2018	At least 3 active burrows and crabs seen under mangroves.	Alison Copeland, with Mark Outerbridge and Geoff Smith
[REDACTED]	Summer 2018	One individual seen at least twice GPS (32° [REDACTED] N 64° [REDACTED] W)	Tim Noyes
[REDACTED]	8 th July 2020	Male with carapace width 13.4cm found dead on lawn, with large claw missing. Left-handed and uniform beige colour.	Martin Williamson

