

**Recovery plan for the endemic land snails of
Bermuda; *Poecilozonites bermudensis* and
*Poecilozonites circumfirmatus***



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

Recovery plan for the endemic land snails of Bermuda; *Poecilozonites bermudensis* and *Poecilozonites circumfirmatus*

Prepared in Accordance with the Bermuda Protected Species Act 2003

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Cover photo: Greater land snails *Poecilozonites bermudensis* by Mark Outerbridge
Photos throughout this document were taken by M. Outerbridge unless otherwise noted.
Maps were prepared by Mandy Shailer.

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

“To conserve and restore Bermuda’s natural heritage”

CONTENTS

CONTENTS.....	3
LIST OF FIGURES & TABLES.....	4
DISCLAIMER	5
ACKNOWLEDGEMENTS	6
EXECUTIVE SUMMARY	7
PART I: INTRODUCTION	9
A. Brief Overview	9
B. Taxonomy and Description of Species	10
C. Current Status.....	12
Global Distribution	12
Local Distribution	12
Species Protection	14
Habitat Protection	14
D. Ecology.....	14
Habitat Requirements.....	14
General biology	14
Reproduction	15
Life Cycle.....	15
Diet.....	15
E. Current Threats	15
F. Current Conservation Actions.....	18
PART II: RECOVERY	20
A. Recovery Goals.....	20
B. Recovery Objective and Criteria	20
C. Recovery Strategy	20
D. Tools Available for Strategy	21
E. Step-down Narrative of Work Plan.....	21
PART III: IMPLEMENTATION	24
REFERENCES	25

LIST OF FIGURES & TABLES

Figure 1. <i>Poecilozonites bermudensis</i>	10
Figure 2. <i>Poecilozonites circumfirmatus</i> adult (left) and hatchling (right).....	11
Figure 3. Locations of dead and live specimens of <i>P. bermudensis</i> on Bermuda.....	13
Figure 4. Locations of dead and live specimens of <i>P. circumfirmatus</i> on Bermuda.....	13
Figure 5. <i>Euglandina rosea</i> preying upon an adult <i>P. bermudensis</i>	16
Figure 6. <i>Gonaxis quadrilateralis</i> preying upon an adult <i>P. circumfirmatus</i>	17
Figure 7. Predatory behavior of <i>Bipalium vagum</i> on <i>P. circumfirmatus</i>	17
Figure 8. Adult <i>P. bermudensis</i> marked with a fluorescent, numbered microtag.....	19

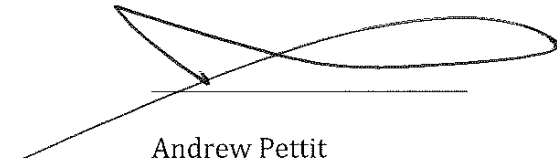
Table 1. Some species of terrestrial snails introduced to Bermuda.....	16
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DISCLAIMER

Recovery plans delineate reasonable actions that are believed to be required to recover and/or protect listed species. We, the Department of Environment and Natural Resources, publish recovery plans, sometimes preparing them with the assistance of field scientists, other government departments, and other affected and interested parties, acting as independent advisors to us. Plans are submitted to additional peer review before they are adopted by us. Objectives of the recovery plan will be attained and necessary funds made available subject to budgetary and other constraints affecting the parties involved. Recovery plans may not represent the views nor the official positions or approval of any individuals or agencies involved in the recovery plan formulation, other than our own. They represent our official position only after they have been signed by the Director of Environment and Natural Resources as approved. Approved recovery plans are subject to modifications as dictated by new findings, changes in species status, and the completion of recovery actions.

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An electronic version of this recovery plan will also be made available at www.environment.bm



Andrew Pettit
Director
Department of Environment and Natural Resources
Bermuda Government

29th May 2018

Date

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We express our profound gratitude to Bruce Lines for rediscovering *Poecilozonites bermudensis* in the city of Hamilton in 2014 and to Miguel Mejias for reporting the presence of *P. bermudensis* on Port's Island to the Department of Environment and Natural Resources in 2017. Wolfgang Sterrer's initiative in the preservation of *Poecilozonites circumfirmatus* at the turn of the millennium likely kept this species from going extinct. The work of Paul Pearce-Kelly, Dave Clarke, Craig Walker, Ben Tapley and the rest of the invertebrate team at the Zoological Society of London for their pioneering efforts in successfully breeding both species in captivity is gratefully acknowledged. Gerardo Garcia, Heather Prince and the invertebrate team at the Chester Zoo have continued these vital works. In Bermuda, Robin Marirea has been responsible for the captive husbandry of *Poecilozonites*. Kristiina Ovaska, with assistance from Alison Copeland and Heather Prince, was responsible for undertaking field research on the population of *P. bermudensis* established on Nonsuch Island and provided many observations pertaining to the ecology of this species. This plan received valuable input from Kristiina Ovaska, Wolfgang Sterrer and Kathryn Coates.

EXECUTIVE SUMMARY

This is an updated recovery plan and supersedes the Recovery Plan for the Bermuda Land Snail *Poecilozonites circumfirmatus* published in 2010.

Current Species Status:

Legal protection for both extant species of endemic land snails (*Poecilozonites bermudensis* and *Poecilozonites circumfirmatus*) is provided by the Protected Species Act (2003) which have been classified as Critically Endangered (CR) under the Protected Species Amendment Order (2016).

Habitat Requirements and Threats:

A moist habitat is necessary to snail survival. Snails are generally found on the underside of loose limestone rocks and logs lying in leaf litter under herbaceous cover during the day or when inactive in the wild. Predation from introduced terrestrial snails and flatworms are thought to have significantly contributed to the decline of these species on Bermuda.

Recovery Objective and Recovery Criteria:

The principal aim of this recovery plan is to re-introduce both species to suitable habitats in the wild in order to develop self-sustaining populations. Additional objectives are to protect existing remnant populations in the wild and to conduct surveys to document possible undiscovered populations. Improved conservation status for these snail species will occur when the following has been accomplished:

- Protection of existing remnant populations in the wild has been achieved,
- Surveys to document possible undiscovered populations have been conducted,
- Suitable sites in the natural environment for translocation and/or re-introduction are identified and managed,
- Sources of predation are identified and effective measures for control are implemented,
- Populations of *P. bermudensis* and *P. circumfirmatus* are found to be self-sustainable at a minimum of ten suitable sites island-wide,
- Captive breeding programmes are continued for both species until there are at least ten separate self-sustaining populations established on Bermuda from which to draw upon for future translocations.

Actions Needed:

1. Continued captive breeding.
2. Evaluate and manage optimal habitats.
3. Site selection for re-establishment of captive bred populations in the natural environment.
4. Develop and implement quarantine measures for predator control on selected sites.
5. Reintroduce/translocate individuals to selected sites.
6. Monitor survival and growth of newly established populations.
7. Continued surveys for extant populations in the wild.

Recovery Costs:

The total cost of recovery 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 studies. Developing budgets for each action are the responsibility of the leading party as outlined in the work plan.

PART I: INTRODUCTION

A. Brief Overview

The genus *Poecilozonites* is endemic to Bermuda. It is one of the oldest endemic elements of the land fauna of Bermuda (Gould, 1969) and has survived radical changes in land area and ecology on these remote oceanic islands for more than a million years (Hearty and Olson, 2010). The evolutionary paleontologist Stephen J. Gould described Bermuda's endemic land snails as having undergone an adaptive radiation comparable in scope with that of Darwin's finches on the Galapagos Islands (Gould, 1993). At least 12 different species are known from the fossil record and are believed to represent a single lineage that exhibited pulses in shell size and shape that correlate with fluctuating sea levels throughout the Pleistocene era (Hearty and Olson, 2010). Historical predation is considered the factor most likely to have selected for gigantism in the anagenetic lineage of *Poecilozonites*. During the last 500,000 years, pulses of gigantism in these snails corresponds with periods when the island was colonized by large vertebrate predators (specifically birds and a species of tortoise – now extinct), which created selection pressure favoring large size and rapid growth in the snails (Olson and Hearty, 2010).

Only two species remained living on Bermuda by the middle of the 20th century; *Poecilozonites bermudensis* (Fig. 1) and *P. circumfirmatus* (Fig. 2), but both rapidly declined island-wide after the introduction of several species of predatory snails during the 1950s and 1960s (Gould, 1968). By the early 1990s *P. bermudensis* was believed to be extinct (Gould, 1993), and at the turn of the millennium *P. circumfirmatus* was only confirmed to be surviving in four locations (Lines, 2002).

This recovery plan outlines threats and conservation efforts for Bermuda's endemic land snails, summarizing distribution, habitat requirements, and reproductive cycles. The discovery of live specimens of *P. circumfirmatus* in 2002 (by Alex Lines, a summer intern for the Department of Conservation Services) and the serendipitous re-discovery of live specimens of *P. bermudensis* in 2014 (by Bruce Lines, the father of Alex) led to conservation efforts in assessing and enhancing population status through surveys and translocation of individuals. Observations on the impact of terrestrial flatworms and predatory snails (Sterrer, pers. comm., Outerbridge, pers. obs.) imply the need to identify and control such predatory species for the re-establishment of self-sustaining populations in the natural environment. A collaborative effort with scientists from the Zoological Society of London and the Chester Zoo has successfully demonstrated the feasibility of reproduction by both *P. bermudensis* and *P. circumfirmatus* under controlled conditions, and at least one translocation attempt has been effective.

B. Taxonomy and Description of Species

Poecilozonites is a genus of terrestrial pulmonate snail. While the genus has been historically included in the family Zonitidae, newer classification places it in Gastrodontidae (Bouchet and Rocroi, 2005).

Kingdom: Animalia

Phylum: Mollusca

Class: Gastropoda

Order: Pulmonata

Family: Gastrodontidae

Genus: *Poecilozonites*

Species: *P. bermudensis* (Pfeiffer, 1845)

Common name: Greater Bermuda land snail

Pilsbury (in Heilprin, 1889) described *P. bermudensis* as follows:

“Shell solid, coarsely irregularly striate and acutely carinate at the periphery; a broad chestnut band usually encircles the shell above the periphery, and another below it, but these are sometimes absent; the inner whorls of the spire usually retain traces of the original color-pattern of radiating flames, and the base in young examples is radiately streaked. The base is convex, and not indented around the narrow and deep umbilicus, but is angulated at its margin; the parietal wall is generally covered by a shining white layer, with which the interior of the shell is lined.”

Adult shell can reach 22.5 mm in diameter (apical view) and 12.1 mm in height (umbilicus to protoconch) (Outerbridge, unpub. data), although Gould (1971) reported a shell diameter up to 28 mm.

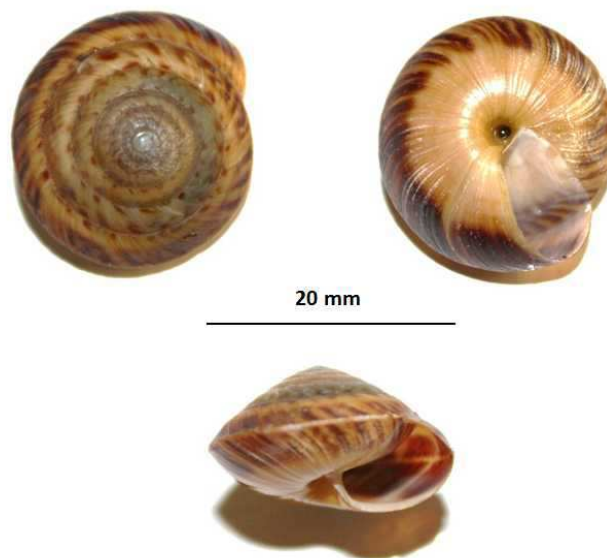


Figure 1. *Poecilozonites bermudensis*.

Kingdom: Animalia
Phylum: Mollusca
Class: Gastropoda
Order: Pulmonata
Family: Gastrodontiidae
Genus: *Poecilozonites*
Species: *P. circumfirmatus* (Redfield, 1853)
Common name: Lesser Bermuda land snail

Redfield (1853) described *P. circumfirmatus* as follows:

“Shell umbilicated, depressed-conoidal, with faint oblique incremental striae, brownish horn-colored, obscurely rayed with yellowish brown spots above and lines beneath; spire obtuse; whorls 7.5; very slightly convex, last one obtusely carinated, not deflected, convex beneath; umbilicus moderate; aperture lunar, strengthened within by a sharp but strong white lamella which revolves beneath the periphery, and is plainly visible through the substance of the shell, throughout the last whorl; columella very oblique, thickened into a callus which extends inwardly around the umbilical portion of the shell; lip simple, acute.”

Pilsbury (in Heilprin, 1889) described the colouration of the shell as *“a delicate, subtranslucent, yellowish-brown, marked with brown streaks, spots and flammules.”*

Adults can reach 9.0 mm in diameter (apical view) and 5.1 mm in height (umbilicus to protoconch) (Outerbridge, unpub. data).



Figure 2. *Poecilozonites circumfirmatus* adult (left) and hatchling (right).

C. Current Status

Global Distribution

The genus *Poecilozonites* is not found to naturally occur anywhere else on the planet.

Local Distribution

Historical Distribution

Fossils, empty shells, and living specimens have been recorded across Bermuda (Bieler and Slapcinsky, 2000) (Figs. 3 and 4). Historical records suggest that both species were once common and widespread (especially *P. bermudensis*) and occurred over much of Bermuda's forest habitat. In fact, *P. bermudensis* appeared to have been so common during the late 19th/early 20th century that residents collected the snails in barrels and burned them (Gould, 1969). By the 1960s extant populations of *P. bermudensis* were only known from two locations in St. George's Parish and two locations in Hamilton Parish (Gould, 1969), during the 1980s no living snails were found and only recently-dead specimens (i.e. empty shells with intact periostracum) were discovered at one location in Southampton Parish (Bieler and Slapcinsky, 2000), and by the early 1990s this species was considered to be extinct (Gould, 1991; 1993). By the 1980s *P. circumfirmatus* was believed to be restricted to two locations; one in Hamilton Parish and the other in Smith's Parish (Bieler and Slapcinsky, 2000).

Contemporary Distribution

Lines (2002) reported four locations in the central parishes along the southern coastline of Bermuda containing live specimens of *P. circumfirmatus*; Spittal Pond, Happy Talk Lane, Devonshire Bay and the Alfred Blackburn Smith Nature Reserve. Numbers of live snails found at those four sites ranged from 2 - 36 individuals per site (Lines, 2002; Sterrer et al. 2004). Repeated surveys in 2010 and 2015 failed to find any living specimens of *P. circumfirmatus* at the above locations (or anywhere else), although recently dead snails (i.e. empty shells with intact periostraca) were encountered (Ovaska, unpub. data; Smith, pers. comm.). The finding of recently dead but no living specimens suggests that declines have continued; however, the persistence of live individuals at very low densities at a small number of sites cannot be ruled out. Bieler and Slapcinsky's report of several freshly dead specimens of *P. bermudensis* suggested that there may have been an extant relict population in at least one location during recent times, but conclusive evidence did not come until September 2014 when Bruce Lines reported finding a living snail within the city of Hamilton (Outerbridge, 2015). A second extant population of *P. bermudensis* was encountered on Port's Island in August 2017. Additionally, since 2016, two translocated populations of *P. bermudensis* have been surviving on Nonsuch Island - a nature reserve owned and maintained by the Bermuda Government. This island serves as a 'living museum' of pre-colonial Bermuda and functions as a wildlife sanctuary for species that are native and endemic to the Island. Access by the public is restricted and quarantine protocols are in place to prevent the unwanted introduction of alien species.

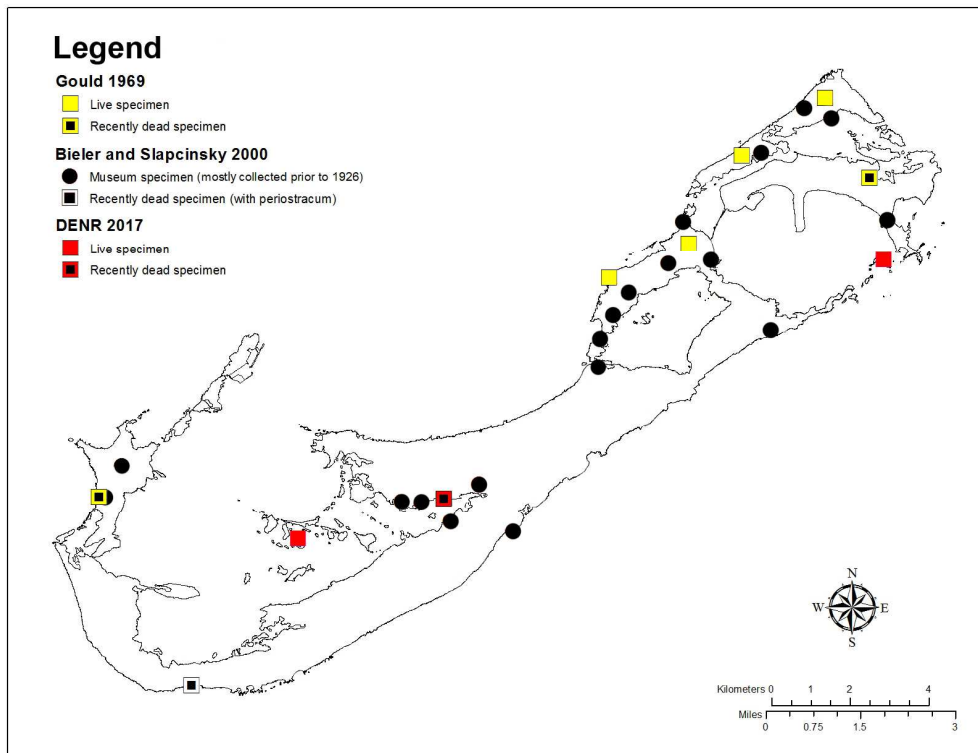


Figure 3. Locations of dead and live specimens of *P. bermudensis* on Bermuda.

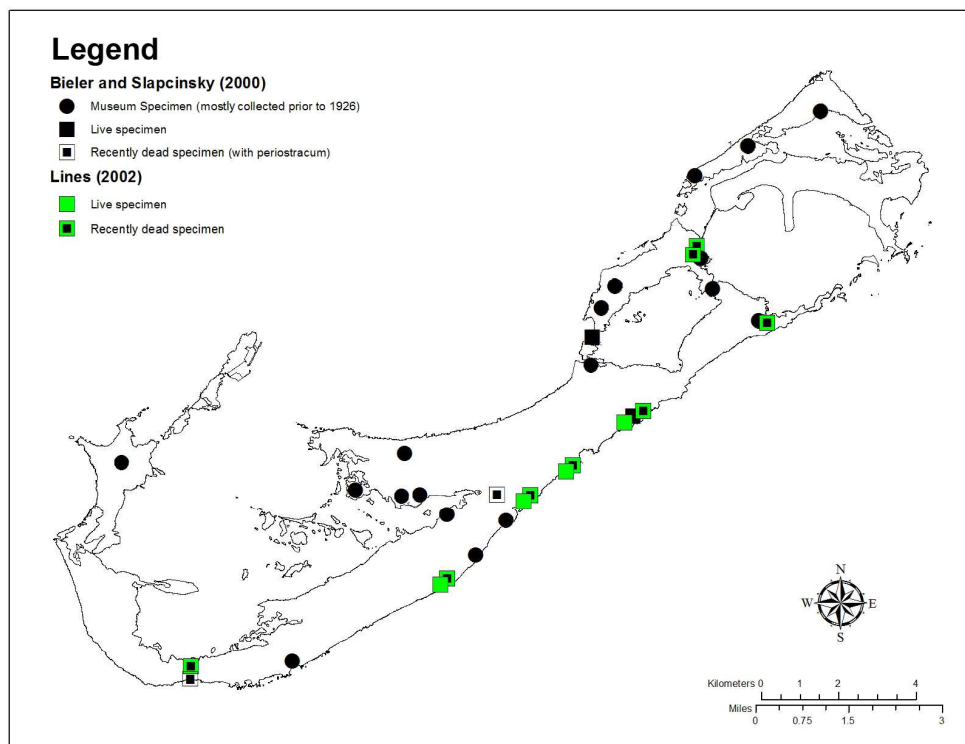


Figure 4. Locations of dead and live specimens of *P. circumfirmatus* on Bermuda.

Species Protection

Following IUCN criteria, the Greater Bermuda land snail *P. bermudensis* is listed as 'Critically Endangered' (CR, A2) and the Lesser Bermuda land snail *P. circumfirmatus* is listed as 'Critically Endangered' (CR, A2, B2a) under the Protected Species Amendment Order (2016). Current legal protection for both is provided by the Protected Species Act (2003) and the Protected Species Amendment Act (2014). These acts consider the willful destruction, damage, removal or obstruction of habitats, and the taking, importing, exporting, selling, purchasing, or transporting either of these species an offence. Offenders are liable to a fine of up to \$25,000 or two years imprisonment.

Habitat Protection

Some of the localities where the endemic land snails have been encountered are within park lands and nature reserves and are therefore protected under the National Parks Act (1986) and the National Parks Regulations (1988), both of which provide protection by prohibiting the destruction and collection of any plants and animals found within protected areas.

D. Ecology

Very little is known on the requirements for growth and reproduction of Bermuda's endemic land snails in its natural environment. Some information has been obtained through captive breeding efforts, while observations of habitat use and dietary preferences have been made possible through studying a population of snails recently established on Nonsuch Island.

Habitat Requirements

Historically reported upon weathered rocks in private gardens (Gould, 1969), but more recent surveys have often found them in association with Bay Grape *Coccoloba uvifera* and the endemic Bermuda palmetto *Sabal bermudana* leaf litter (Lines, 2002; Ovaska, pers. comm.) Additional observations of *P. bermudensis* on Port's Island have shown that moist microhabitats under rocks and decaying logs are also important. The small colony of snails discovered within the city of Hamilton was found to be living under refuse and in the cracks of old cement (Outerbridge, 2015). The occurrence of *P. bermudensis* in a narrow, damp, concrete service alley within the central business district of Hamilton, an island (Port's) comprised almost entirely of non-native vegetation (Outerbridge, pers. obs.), and an island that is the only remaining example of an exclusively native woodland (Nonsuch) serves as a testament to this species ability to survive in a diversity of environments, provided its needs for moist retreats and food are met.

General biology

Temperatures of 20-25 °C and a soil acidity of pH 6.5 appear suitable for growth and survival; mortalities were recorded when air temperatures reached 36 °C (Pearce-Kelly and Walker, 2006). Faecal samples obtained from a limited number of wild *P. circumfirmatus* were examined and tested positive for 'scanty adult helminthes' and flagellates, and in some cases helminthes ova were recorded; however, the helminth species were not identified (Pearce-Kelly and Walker, 2006). A study of endo-parasites in *P. bermudensis* is presently underway at the Chester Zoo.

Observations made *in vitro* have shown that *P. bermudensis* and *P. circumfirmatus* are predominantly active during periods of darkness or subdued lighting (Pearce-Kelly and Walker, 2006; Outerbridge, pers. obs.), suggesting that both species are nocturnal but may be also active during periods of rainfall. More recent observations in the field indicate that nocturnal activity is the norm for *P. bermudensis* (Ovaska, 2017).

Reproduction

The reproductive behaviour and life history of *P. circumfirmatus* are known only from captive populations (Walker and Pearce-Kelly, 2006) and anatomical studies (Pilsbry, 1889). Pilsbry (1889) noted that the duct of the spermatheca was connected with the penis for *P. bermudensis*. Both species are capable of sexual and asexual reproduction (see Gould, 1969). Observations made under controlled conditions indicate that eggs are laid in a chamber that has been excavated in the soil after the adult has burrowed into it. The majority of the eggs were observed to form a cluster at the bottom of the excavated chamber (Pearce-Kelly and Walker, 2006). Eggs are white and almost spherical in shape; approximately 1.5 mm for *P. circumfirmatus* (Pearce-Kelly and Walker, 2006) and approximately 2.2 mm for *P. bermudensis* (M.O., pers. obs.).

Life Cycle

In captivity, ca. 15 days after copulation, *P. circumfirmatus* were reported to lay small clutches of eggs that hatched in 33 - 44 days (Walker and Pearce-Kelly, 2006). Lines (2002) reported hatchling size for *P. circumfirmatus* as 2 mm (shell diameter) and 5 mm after one month in captivity. Sexual maturity is reached in 5 - 6 months, and the lifespan in captivity is approximately 18 months (Pearce-Kelly and Walker, 2006).

The time to maturity and lifespan of *P. bermudensis* are unknown, but both are probably considerably longer (based on larger size) than those of the smaller *P. circumfirmatus*. The generation time for *P. bermudensis* is estimated to be at least 2 years (Ovaska, pers. comm.)

Diet

Recent observations of foraging behavior and food preferences for *P. bermudensis* released on Nonsuch Island have shown that this species is omnivorous, consuming plant material, fungi/microbes growing upon vegetation surfaces, and even scavenging opportunistically upon dead animal remains (Ovaska, 2017). Captive individuals (both *P. bermudensis* and *P. circumfirmatus*) readily eat fresh vegetables including sweet potatoes, carrots, bok choy, and lettuce leaf (Pearce-Kelly and Walker, 2006); calcium appears to be mined from fresh, damp pieces of limestone rock placed within the breeding tanks (Marirea, pers. comm.). Interestingly, the snails in the city of Hamilton were observed to feed upon the algal biofilm coating moist cement surfaces (Outerbridge, 2015).

E. Current Threats

The introduction of other snail species to Bermuda, as a food product or a biological control, proved troublesome to the native populations (Gould, 1969). Several of these

introductions are summarized in Table 1. The decollate snail *Rumina decollata* is a known predator of other snails, and in Bermuda it is also regarded as a significant agricultural pest. The predatory rosy wolf snail *Euglandina rosea* was intentionally introduced to control *Rumina*, as well as *Otala lactea* (another garden pest). *Euglandina rosea* has been implicated in the extinction and endangerment of many land snails endemic to the Pacific Islands and became so widespread and abundant on Bermuda that more than 1000 individuals were exported to numerous countries ranging from the Bahamas to India after only a few years of its introduction to Bermuda (see Bieler and Slapcinsky, 2000). Two other species of predatory snails, *Gonaxis kibweziensis* and *Gonaxis quadrilateralis*, were also intentionally introduced as a biological control attempt during the 1960s. All three deliberate introductions ultimately failed to control either *Otala* or *Rumina*; however, both *E. rosea* and *G. quadrilateralis* have been observed preying upon *P. bermudensis* and *P. circumfirmatus* in captivity (Figs. 5 and 6).

Table 1. Some species of terrestrial snails introduced to Bermuda.

Species	Date of introduction
<i>Polygyra plana</i> (Dunker, 1843)	Before 1853; accidental
<i>Rumina decollata</i> (Linné, 1758)	Late 1870s; accidental
<i>Bradybaena similaris</i> (Rang, 1831)	Before 1889; accidental
<i>Otala lactea</i> (Müller, 1774)	1928; intentional as food source
<i>Euglandina rosea</i> (Férussac, 1821)	1958–1960; intentional as biocontrol
<i>Gonaxis kibweziensis</i> (Smith, 1894)	1960; intentional as biocontrol
<i>Gonaxis quadrilateralis</i> (Preston, 1910)	1968 & 1972; intentional as biocontrol



Figure 5. *Euglandina rosea* preying upon an adult *Poecilozonites bermudensis*.



Figure 6. *Gonaxis quadrilateralis* preying upon an adult *Poecilozonites circumfirmatus*.

Terrestrial flatworms and ribbon worms may represent a more recent threat to Bermuda's endemic land snails. Jones and Sterrer (2005) recorded seven species of terrestrial planarians and nemertine worms on Bermuda, of which three (*Bipalium vagum*, *Gigantea gouvernoni* and *Geonemertes pelaensis*) are known to eat snails (Fig. 7).



Wolfgang Sterrer

Figure 7. Predatory behavior of *Bipalium vagum* on *Poecilozonites circumfirmatus*.

Poecilozonites snails have not been observed sealing the opening of their shells with a membrane of dried mucous, as does the introduced milk snail *Otala lactea*, and may therefore be much more prone to desiccation during dry environmental conditions. The landscape of Bermuda has been extensively modified since the human settlement in the 1600s, and presently natural habitats are confined to a few, isolated patches mainly within parks and nature reserves. These remnant habitat patches continue to be degraded by introduced invasive plants and animals, and it is reasonable to assume that the composition of the litter layer and associated fungi on the forest floor has changed. Feral chickens are ubiquitous on the larger islands and, despite control efforts, continue to modify the forest floor through their scratching, including conservation areas and sites where live specimens of the snails were found most recently, such as the Spittal Pond Nature Reserve (Ovaska, pers. comm.).

Finally, predation from rats (*Rattus spp.*) and the introduced Argentine ant *Linepithema humile* may also be a contributory factor in the decline of Bermuda's endemic land snails (see Gould, 1969; Pearce-Kelly and Walker, 2006). It is suspected that possible remnant populations on the main islands of Bermuda will continue to decline based on threats mainly from introduced predators.

F. Current Conservation Actions

Designation of international conservation status

Both *P. bermudensis* and *P. circumfirmatus* have recently undergone IUCN red-listing evaluations using RAMAS Red List version 3.0.4.0. Both evaluations are being reviewed at the time of writing.

Captive breeding

A colony of *P. circumfirmatus* was established from 56 individuals (12 adults and 44 juveniles) in February 2004 at the Zoological Society of London (UK) and has been maintained there since then. Within two years the colony had grown to 227 snails (Pearce-Kelly, pers. comm.). An auxiliary colony was subsequently established at the Chester Zoo (UK) in November 2017 using 60 descendants of these snails.

Following the re-discovery of *P. bermudensis* in September 2014 within the city of Hamilton, 166 individuals of mixed ages were sent to the Zoological Society of London. An auxiliary colony was established at the Chester Zoo in June 2016 using 60 descendants from the original shipment. Fourteen months later, the Chester Zoo reported that the captive colony had reached 2621 individuals (Garcia, pers. comm.).

At the time of writing, a small captive colony of *P. bermudensis* is being managed at the Department of Environment and Natural Resources and plans are underway for it to expand and include *P. circumfirmatus*.

Translocations and reintroductions

In 2002, 16 individuals of *P. circumfirmatus* were translocated to Nonsuch Island in an effort to establish a new population. A rapid survey conducted in 2004 indicated the presence of 15 living specimens at the translocation site; however, surveys since 2004

have failed to find live snails anywhere on Nonsuch Island (possibly because the initial propagule size was very small).

Translocation of *P. bermudensis* to Nonsuch Island was first performed in October 1972 using approximately 100 individuals; however, the snail apparently failed to thrive (Wingate, pers. comm.). Efforts were reattempted in March 2016 using 204 snails taken from the remnant population in the city of Hamilton. The latter was prompted by impending development of the site by the property owners. The second translocation attempt proved successful; range expansion and recruitment were observed during the two years that followed (Ovaska, 2017; 2018).

Site selection for future reintroductions

It is unlikely that there are many locations on the main islands of Bermuda which are free of major terrestrial snail predators (the carnivorous snails and snail-eating planarians); however, a few nearshore islands appear to be uninhabited by these organisms (e.g. Nonsuch and Port's islands). Therefore, the islands within St. George's Harbour, Harrington Sound, the Great Sound, and Ely's Harbour should be assessed for establishing additional *Poecilonites* populations.

Field research

Beginning in February 2017, research has been undertaken involving direct observation and mark-recapture (Fig. 8) to determine habitat use, dispersal patterns, diet, survivorship, recruitment, growth rates, and estimates of abundance for snails released on Nonsuch Island (see Ovaska, 2017; 2018). Additional research is presently underway on the population of *P. bermudensis* inhabiting Port's Island. Work is being conducted at six month intervals in order to minimize disturbance to the snails and their habitat.



Figure 8. Adult *Poecilonites bermudensis* marked with a fluorescent, numbered microtag.

PART II: RECOVERY

A. Recovery Goals

The principal aim of this recovery plan is to re-introduce *P. bermudensis* and *P. circumfirmatus* to suitable habitats in the wild in order to develop self-sustaining populations. The short-term goals (3-5 years) are to continue the captive breeding efforts in order to provide sufficient numbers of snails for re-introduction, identify habitats that are free from predatory snails, snail eating flatworms, and ribbon worms, and evaluate the potential for *Poecilozonites* survival in these environments. The longer-term goals include establishing self-sustaining populations for both species of *Poecilozonites* on at least ten suitable sites island-wide, which should include islands within the various bays, sounds, and harbours. The self-sustainability of new populations will be assessed through monitoring reproduction and survival.

B. Recovery Objective and Criteria

Favourable conservation status will be achieved when:

- Protection of existing remnant populations in the wild has been achieved,
- Surveys to document possible undiscovered populations have been conducted,
- Suitable sites in the natural environment for translocation and/or re-introduction are identified and managed,
- Sources of predation are identified and effective measures for control are implemented,
- Populations of *P. bermudensis* and *P. circumfirmatus* are found to be self-sustainable at a minimum of ten suitable sites island-wide,
- Captive breeding programmes are continued for both species until there are at least ten separate self-sustaining populations established on Bermuda from which to draw upon for future translocation.

C. Recovery Strategy

The two species addressed in this recovery plan are greatly restricted geographically; however, the diversity of habitats that *P. bermudensis* is capable of surviving in has demonstrated that, at least for this species, future reintroductions need not be limited to native woodlands. Given the documented declines of *P. bermudensis* and *P. circumfirmatus* after the advent of carnivorous snails and snail-eating flat worms, it is imperative that these predators are absent from sites selected for future reintroductions/translocations. Both *P. bermudensis* and *P. circumfirmatus* have responded well to captive breeding; therefore individuals from any wild populations discovered in the future should be incorporated into these breeding programmes to maximize genetic diversity. The recommended actions outlined in Part III further identify the practical steps that need to be taken to achieve the action plan targets.

D. Tools Available for Strategy

Methodology for survey techniques has been developed in Bermuda and can be used for further updating population information. Methodologies have been developed for other species of terrestrial snails overseas and can serve as resources for future development of local research and management techniques (i.e. Oahu rare snail working group reintroduction guidelines). Continued close collaboration with partner organizations overseas and the transfer of captive breeding techniques to Bermuda-based staff within the Department of Environment and Natural Resources are warranted. The availability of facilities and staff trained in animal husbandry at the Bermuda Aquarium Museum and Zoo should enable the local establishment of a captive breeding area and the subsequent transfer of snails to the natural environment.

E. Step-down Narrative of Work Plan

Abbreviations used in Section E and Part III:

DENR – Department of Environment and Natural Resources

CZ – Chester Zoo (UK)

ZSL – Zoological Society of London (UK)

BAMZ – Bermuda Aquarium Museum and Zoo

Student – MSc or PhD candidate supervised by DENR staff

Volunteers – DENR volunteer interns, keen field ecologists and members of the general public

The actions needed to achieve recovery are as follows:

1. Continued captive breeding.

Actions proposed:

- Continue ex-situ breeding efforts in partner organizations overseas,
- Develop a breeding programme for *P. circumfirmatus* at BAMZ,
- Assess genetic variation between extant *Poecilozonites* populations, including *P. bermudensis* from Nonsuch Island (originating from the Hamilton population) and Port's Island,
- Send a sample of *P. bermudensis* from Port's Island to CZ and ZSL to augment current brood stock.

Work Team: CZ, ZSL, DENR, BAMZ

Outputs: Continued production of juveniles in captivity, safeguard of breeding stock for re-establishment of populations, maximum genetic diversity in brood stocks.

2. Evaluate and manage optimal habitats.

Actions proposed:

- Undertake surveys of habitat use on Nonsuch and Port's islands,
- Produce habitat management guidelines.

Work Team: DENR, student, volunteers

Outputs: Report on habitat use and feeding ecology, habitat management guidelines for land owners.

3. Site selection for re-establishment of captive-bred populations in the natural environment.

Actions proposed:

- Identify islands within the various bays and harbours of Bermuda, beginning with lands designated as Nature Reserves, Woodland Reserves and Parks,
- Contact the land owners and seek permission to perform habitat surveys and to release *Poecilozonites* species to island(s) where habitats are deemed suitable,
- Undertake surveys for land snails and their predators prior to release to assess the suitability of islands and to assess habitat suitability,
- Rank potential release sites in order of priority.

Work Team: DENR, volunteers, student

Outputs: List of suitable sites for future releases of *P. bermudensis* and *P. circumfirmatus*.

4. Develop and implement measures for predator control on selected sites.

Actions proposed:

- Identify invertebrate and vertebrate predators of *Poecilozonites*,
- Develop and publicize quarantine measures to prevent the introduction of terrestrial predators,
- Implement in-situ predator control measures on a routine basis (i.e. use of rodenticides to control rats),
- Perform regular surveys for predators to ensure control measures are effective.

Work Team: DENR

Outputs: Protocols of quarantine measures and methods of predator control developed and implemented.

5. Reintroduce/translocate individuals to selected sites.

Actions proposed:

- Transfer appropriate number of individuals to new locations,
- Monitor survival and growth of newly established populations via mark-recapture studies or other suitable methods; the latter may include tracking changes area of occupancy and size class distribution (as an index of recruitment) over time.

Work Team: DENR, volunteers, CZ, student

Outputs: Reports on the outcome of the reintroductions/translocations.

6. Continued surveys for extant populations in the wild.

Actions proposed:

- Undertake 'presence/absence' (i.e. detected/not detected) surveys,
- Create a PR campaign educating the public about Bermuda's endemic land snails and encourage the reporting of snail sightings.

Work Team: DENR, volunteers, student.

Outputs: Improved understanding of distribution and abundance of *Poecilozonites* on Bermuda; newly discovered populations will provide brood stock to maximize genetic diversity in the breeding programmes.

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 action necessary to provide for full recovery of the species.

Priority #	Task #	Task description	Task Duration	Responsible Party
1		Captive breeding		
	1	Continue ex-situ breeding overseas	Ongoing	CZ, ZSL
	2	Develop programme at BAMZ	5 years	BAMZ
	3	Assess genetic variation	1 year	DENR/student
	4	Augment brood stock	As needed	DENR
2		Evaluation of optimal habitats		
	5	Undertake habitat use surveys	1 month	DENR
	6	Develop habitat management guidelines	1 month	DENR
2		Site selection for future reintroductions/translocations		
	7	Identify islands	1 month	DENR
	8	Contact land owners	1 week	DENR
	9	Undertake surveys & habitat assessments	6 months	DENR
	10	Rank sites	1 week	DENR
2		Develop and implement quarantine measures		
	11	Identify predators	6 months	DENR
	12	Develop and publicize quarantine measures	6 months	DENR
	13	Implement in-situ predator control	Ongoing	DENR
	14	Perform regular predator surveys	Ongoing	DENR
2		Reintroduce/translocate snails to selected sites		
	15	Transfer individuals	As needed	DENR
	16	Monitor survival, growth, and area of occupancy	2 weeks per site	DENR/volunteer
3		Surveys for possible undiscovered extant populations		
	17	Undertake presence/'absence' surveys	Ongoing	DENR
	18	Create PR campaign	1 month	DENR

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