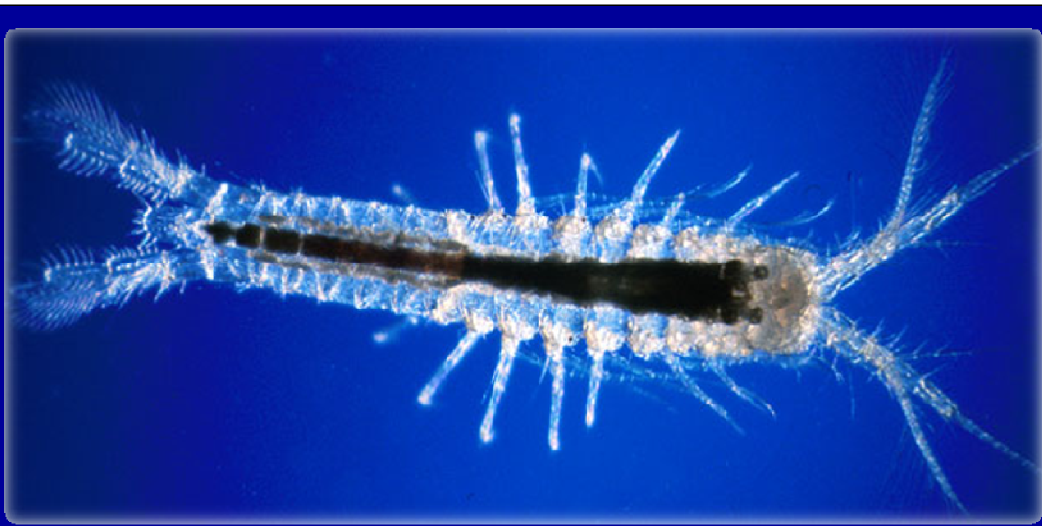
Management Plan for Bermuda's Critically Endangered Cave Fauna



Government of Bermuda
Ministry of Health Seniors and Environment
Department of Conservation Services

Management Plan for Bermuda's Critically Endangered Cave Fauna

Prepared in Accordance with the Bermuda Protected Species Act 2003

Funded in part by:

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"To conserve and restore Bermuda's natural heritage"

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An electronic version of this management plan will also be made available at www.conservation.bm

26th September 2014.

Director
Department of Conservation Services
Government of Bermuda

Date

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EXECUTIVE SUMMARY

Current species status:
This management plan addresses the need for actions to conserve 22 cave adapted species (listed below) from various taxonomic groups which are all endemic to Bermuda, and which are listed as Critically Endangered under the Protected Species Act 2003. Although many of these cave-dwelling species appear to be restricted in their distribution, having only been found in a single cave system or in some instances in just one cave within a system, the level of connectivity known to exist between the submerged underwater passages of the Island's caves suggests that an effective management plan must address the cave system in its entirety and the species collectively. Bermuda's caves are afforded protection from development under Section 28 of the Planning Act 1974 (Fourth Schedule).

Listed cave species:

Copepods
- *Antriscopia prehensilis*
- *Erebonectes nesioticus*
- *Paracyclopia naessi*
- *Speleophira bivexilla*
- *Speleophriopsis scottodicarloi*
- *Nanocopia minuta*
- *Speleoithona bermudensis*

Ostracods
- *Spelaeoecia bermudensis*

Isopods
- *Atlantasellus cavernicolus*
- *Currassanthura bermudensis*
- *Arubolana aruboides*

Amphipods
- *Idunella sketi*
- *Cocoharpinia iliffei*
- *Pseudoniphargus grandimanus*
- *Ingolfiella longipes*
- *Bermudagidiella bermudensis*

Shrimps
- *Typhlatya iliffei*
- *Procaris chacei*

Mysids
- *Platyops sterreri*

Mictaceans
- *Mictocaris halope*

Segmented worms
- *Phallodriloides macmasterae*
- *Leptonerilla prospera*

Habitat requirements and threats:
All of the 22 listed Critically Endangered cave-dwelling species live submerged within Bermuda's extensive cave systems, below sea level. The diversity of species found has resulted in global recognition of the Island's caves as a 'biodiversity hotspot'.

Approximately 200 known cave entrances have been discovered to date. By far the most significant concentration of caves and associated species is found in the narrow strip of land separating Harrington Sound from Castle Harbour where the island's oldest limestone (Walsingham formation) is exposed. Three major systems have been identified in Bermuda: the Walsingham System, the Palm System and the Green Bay System. Tidal exchange of these subterranean waters with the sea takes place in some caves whilst in others the water may be nearly stagnant. As a result, the cave pools have a thin brackish layer at the surface (which may border on fresh in caves most distant from the sea), overlying fully marine waters at depth. However, almost nothing is known about the specific habitat requirements of the listed species.

The primary threats to the cave fauna are: ongoing land development and quarrying activities which can lead to direct habitat destruction; pollution, primarily from seepage of sewage from household cesspits and possibly from deep sealed bore holes; vandalism, and dumping of trash and other waste into sinkholes, all of which can disrupt the normally stable environmental conditions within the cave system. An additional threat may also be posed by unqualified SCUBA divers exploring the caves and disturbing the habitat. Finally, a lack of detailed knowledge about the exact geographical extent of the caves, as well as limited understanding of the biology and ecology of the cave fauna hinders our ability to manage these threats.

Management objective:
The primary goal of this plan is to promote and enhance self-sustainability of Bermuda's unique cave-adapted fauna by ensuring adequate protection of the entire cave habitat.

Management criteria:
Given that this plan focuses on the protection of the entire cave habitat, it is unlikely that caves will ever be completely lifted from protected status. However it is hoped that through successful implementation of this plan, there may eventually be relaxation of certain restricted activities. This will be considered when:

- Due legislative protection is given to the entire cave habitat preventing further physical destruction, pollution, vandalism and dumping of waste in the caves.
- The cave systems have been accurately mapped to ensure a better understanding of the relationship between above ground activities and the underlying caves such that detrimental activities can be adequately managed.
- Hatchery-rearing of selected cave species is accomplished and eco-toxicological experiments have been undertaken on these to establish tolerance levels to local contaminants.

- All point sources of contamination have been identified and managed such that contamination levels do not exceed the tolerance levels of this representative group of cave species.
- There has been demonstrated proof that caves can be successfully restored (through restoration of Sear's and Bitumen Caves).

Actions needed:

1. Protect the cave habitat through legislation and raised public awareness.
2. Undertake a comprehensive mapping initiative of the Islands' cave systems and integrate maps into the GIS framework.
3. Identify point sources of pollution and implement the necessary procedures to manage these so that they do not exceed species tolerance levels. If necessary, explore and implement alternative technologies for sewage disposal where required.
4. Establish long-term monitoring of both the air and water in the cave systems, taking consideration of physical, chemical, geological and biological indicators.
5. Evaluate the potential for ex-situ/hatchery breeding of representative cave species and conduct experiments to determine their tolerance to known contaminants of the cave system.
6. Facilitate ongoing research to gain a better understanding of the population status, distribution, movements, breeding and feeding habits of the cave species and the hydrography of the cave system.
7. Undertake active restoration of suitable, impacted caves.

Management costs: The total cost of management and/or 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 on Bermuda's cave fauna. Developing budgets for each action are the responsibility of the leading party as outlined in the work plan.

Date of management: Meeting the objective for the management of cave fauna in Bermuda depends primarily on preventing further physical damage to the cave habitat and on identifying and managing point sources of pollution. It also relies on engaging the necessary expertise to map the caves and fill in the suite of information gaps concerning the biology and ecology of the species and their habitat requirements. Given the logistical challenges of studying the cave environment, it is anticipated that it would take at least 20 years to undertake this work and reach a point where the cave habitat was sufficiently well managed to allow some elements of protection to be relaxed if it was deemed that to do so would benefit Bermuda without prejudice to the habitat.

PART I: INTRODUCTION

A. Brief overview

Despite Bermuda's relatively small land mass, the Island has one of the highest concentrations of limestone caves in the world. With their strong local cultural significance, and their promotion for over a century as a tourist attraction due to their spectacular cave formations (speleothems), these caves have more recently taken centre stage for the remarkably diverse community of cave-adapted (stygobitic) animals living within their submerged environ. They are globally acknowledged as a global biodiversity hotspot (Iliffe, www.tamug.edu/cavebiology). Seventy-five species which exclusively inhabit the Island's caves have now been identified, of which 22 are currently listed as Critically Endangered according to IUCN criteria (CR, B1 +2c) under the Protected Species Act 2003.

This management plan discusses threats and conservation efforts for Bermuda's cave habitat and critically endangered species within, following a summary of our current knowledge of their status. The primary recommendation of this plan is that given the diversity of species, their erratic distribution patterns, extremely low recorded numbers and the logistical challenges inherent in learning more about their biology and ecology, there is a need for immediate legislative protection for the entire cave habitat. The plan also calls for the prioritized mapping of the various cave systems with integration of the data into the Island's GIS, and it focuses on the actions needed to broaden our understanding of the biology, ecology and general habitat requirements of Bermuda's cave fauna and focuses on the actions needed to broaden our understanding of these. It calls for the active restoration of at least two damaged or polluted caves. If studies indicate that the species are more numerous than data gathered to date indicate, and that environmental conditions within the cave systems are stable and contaminants below species tolerance levels it may be possible to lift some of the restrictions placed on activities but it is not anticipated that the cave habitat itself will be entirely lifted from protection.

B. Current protection status

Most of Bermuda's caves are currently protected from development under Section 28 of the Planning Act 1974 (Fourth Schedule). The Act states that "*The Protection of caves shall take precedence over all other planning considerations and the Board shall refuse any development application or plan of subdivision if, in the opinion of the Board, the proposal will have a detrimental impact on a cave entrance or underlying cave*". Most of the known caves fall within the Cave Protection Area however the above protection applies to all caves whether or not they are in this designated zone. The 22 species listed in this management plan are protected under the Protected Species Act, 2003, where they are classified as Critically Endangered as per IUCN criteria, based on the low recorded numbers of mature animals living in the natural environment, and their limited distribution.

Legal Protection
Legal protection is afforded these 22 listed cave-dwelling fauna under the Protected Species Act.

Habitat Protection
The cave habitat is currently protected as indicated above under the Fourth Schedule of the 1974 Planning Act.

C. Taxonomy and description of species

See Appendix 1 for details

D. Ecology

Habitat Requirements
Little is currently known of the habitat requirements of the listed cave species. All recorded to date have been found in submerged and an often integrated network of passages between 17 and 20 m below sea-level (Iliffe, (www.tamug.edu/cavebiology). Tidal exchange of these subterranean waters with the sea takes place in some caves whilst in others the water may be nearly stagnant. As a result, the cave pools have a thin brackish layer at the surface, which may border on fresh in caves most distant from the sea, overlying fully marine waters at depth. The highly stratified cave water column results from the absence of wind and wave-induced mixing. Similarly, water temperatures, dissolved oxygen levels and pH are vertically stratified with the salinity gradient, before becoming more stable at depth. Specimens of the various species have been collected either free swimming in the water column, or in association with bottom sediments ranging from silt to coarse sand or from exposed rock surfaces.

General Biology
Again, there is little available literature on the general biology of any of the listed cave species, although it may be assumed that they conform in some measure to like species within their respective taxonomic affinities. It is worth noting though that Fosshagen (www.tamug.edu/cavebiology) reports that *Antrisocopia prehensilis* is a “raptoral feeder and a bottom–dweller, unusual for a copepod”.

Feeding
Little is known about the feeding behaviour or nutritional requirements of any of the listed cave fauna, however, it is presumed that they feed on plankton which in most of the caves is primarily believed to be derived from the sea through tidal currents. Attempts to feed specimens of *Mictocaris halope* in an aquarium tank with freeze-dried tube worms

were reportedly unsuccessful, but the presence of dense complex setae on the 2nd maxilla suggest they are filter feeders according to Iliffe (1985).

Reproduction and Life Cycle

Nothing is known about the reproduction and life cycle of any of the listed cave fauna however from specimens collected to date, the populations for most species seem heavily skewed towards females. Indeed, of 15 specimens collected of *Speleophria bivexilla*, all were female.

E. Current threats

A number of environmental threats to Bermuda's caves have been identified and it should be noted that Church Cave and Bitumen Cave were twice named by the Karst Waters Institute in their list of the Top Ten Most Endangered Karst Ecosystems on Earth (IUCN, 1996). Ongoing land development pressures pose the most significant threats to Bermuda's caves and cave fauna, largely through direct habitat destruction. In the absence of maps of the subterranean caves, developers may 'break through' into a cave unknowingly during construction activities, causing the collapse of large sections of cave and obstructing subterranean flow channels. Additional physical destruction has also resulted from ongoing quarrying activities.

Pollution is another major threat to the cave system. Household sewage has traditionally been handled through individual cesspits, which may seep their contents through into the underlying caves. Since many of Bermuda's caves are important tidal conduits to the island's inshore waters, nutrients leaking from cesspits into caves can readily be transported to open waters. 'Deep-sealed' boreholes have been encouraged for larger developments (e.g. hotels and condominium complexes) as a way to dispose of sewage and wastewater, however many may be of a depth that results in their effluent being released at or near the limestone/basalt interface where the caves form. Of considerable concern is the pool of Bassett's Cave, which was referred to in 1837 as the longest and geologically most instructive cave in Bermuda, and which was subsequently used by the U.S. Navy for the disposal of raw sewage and waste fuel oil.

Further threats arise from the fact that many of Bermuda caves have been used as dumping sites. For example, the bulldozing of large piles of partially burned rubbish into the pool of Government Quarry Cave resulted in depletion of dissolved oxygen and anaerobic production of poisonous hydrogen sulfide, which was then transmitted through groundwater circulation to several other caves (Iliffe *et al.*, 1984). Many of Bermuda's larger caves also show evidence of vandals breaking and removing fragile stalactites and stalagmites or defacing cave walls with graffiti.

One final potential threat to the caves has emerged in recent years from unqualified SCUBA divers venturing into the submerged passages. Aside from the obvious personal danger such activity presents, an untrained diver also has the potential to cause significant damage to cave features as well as disruption to the generally undisturbed cave environment.

Threats/Gaps in local knowledge

Whilst observation and explorations of Bermuda's caves date from the earliest days of human settlement (Iliffe, 1993), the fact that most of the caves form part of an extensive network of submerged passages connecting otherwise isolated, anchialine pools has limited access to a select group of skilled cave experts. For this reason our knowledge is extremely sparse. Whilst the following questions need answering, the logistical challenges and costs must be considered in order to prioritise those needed for the management plan to be successful.

I Accurate prioritised (based on threats) 3-dimensional maps are needed of the whole cave system. Some maps do exist for certain cave networks, but there is an absence of metadata with these so the level of accuracy is not known. There is a critical need to employ standard tools and technologies including the need for accuracy on boundaries and establishing the entrance location as a locator for both the survey work and the creation of the maps. These maps then need to be integrated into the island GIS.

II Identification and subsequent monitoring of point sources of contamination (nutrients, herbicides, pesticides, heavy metals, etc.) is needed in both the long and short term. Groundwater monitoring of water quality, tides, water and air temperature is also needed as is the identification of potential indicator species of water quality (e.g. algae at cave mouths, bacterial counts). Instigation of a time series of bacterial counts would be helpful, as would monitoring of algal species and blooms and levels of faecal coliforms. Surface sites suitable for drilling for monitoring purposes should be identified and studies of historically polluted caves should be undertaken to assess changes. Suitable speleothems should be identified for monitoring purposes. In caves close to quarries or heavy construction sites, subtle shifting of breakdown blocks can be assessed by gluing glass microscope slides between boulders or inside cracks. Any earth movement or vibration will break the glass.

III An evaluation of the feasibility of ex-situ breeding of a representative group of cave species with regard to undertaking eco-toxicological studies on them and assessing their tolerance limits should be undertaken.

IV Basic biological questions that need answering include information on; the distribution and abundance of the cave fauna (including seasonal patterns), their feeding and reproductive behaviour and an explanation of why the sex ratios appear to be so highly skewed, trophic pathways, how these marine species survived the Ice Ages and whether they are living in other habitats or in caves which perhaps extend into the basalt. Additionally, information is needed concerning how much gene flow exists and the effective population size of each species.

V. More detailed hydrographic information is needed for the whole cave system to determine whether individual caves have signature characteristics, the extent of water connectivity and residence times and, how habitats might be delineated.

In addressing these information gaps it is recognised that there is a need to develop a set of standards and code of ethics for researchers and for a wider set of public observations, as well as to increase Government policy and regulation regarding research in the caves.

F. Current status

Global Distribution

An extraordinarily rich and diverse stygobiotic fauna inhabits Bermuda's caves, with 75 stygobitic species so far identified propelling the Island's caves into the global arena as a biodiversity hotspot (Iliffe, 1993). With 67 of these classified as endemics, the cave fauna comprises a significant proportion (nearly 25%) of Bermuda's total endemic species composition (Sterrer *et al*., 2004). But just how these species first reached Bermuda remains unanswered as Iliffe (www.tamug.edu/cavebiology) reports that some species are related to similar forms from caves on opposite sides of the Atlantic, whilst others have close affinities to cave species from the Pacific Ocean or even from the deep sea. He suggests that "some of Bermuda's marine cave invertebrates may have reached the island via the Gulf Stream from the Caribbean, while others may have survived on submerged and emergent seamounts along the Mid Atlantic Ridge for 100 million years. Still other species may represent relict deep sea fauna or even descendents of animals which once inhabited the Tethys Sea - the name for the world ocean that existed at the time all the Earth's land masses were combined into one supercontinent".

Local Distribution

Bermuda's limestone caves began forming approximately 1-2 mya during glacial periods when sea level was as much as 125 m lower than present (Palmer *et al*., 1977) and the land mass was about 1000 km^2. At this time, there would have been a sizeable fresh groundwater body, which resulted in the formation of the caves. Post glacial sea-level rise subsequently led to large portions of these caves becoming drowned with seawater which displaced the freshwater. This is evident by the presence of submerged stalactites and stalagmites, features which only form by freshwater dripping in air-filled caves. Unevenly distributed across Bermuda, most of the caves are located in the narrow strip of land separating Harrington Sound from Castle Harbour where the island's oldest limestone (Walsingham formation) is exposed. Of considerable concern is that many of Bermuda's cave-dwelling animals appear to be restricted in their distribution having been found only in a single cave or cave system (Iliffe, (www.tamug.edu/cavebiology)), although this may allude to insufficient sampling effort.

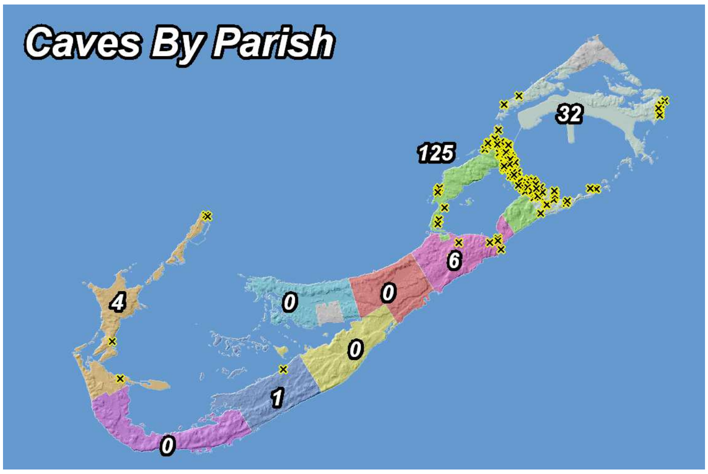

Figure 1. Distribution map of known cave entrances in Bermuda (B. Szukalski, 2002)

SPECIES	**Caves**	**Specimens**
Phylum Annelida (segmented worms)		
Leptonerilla prospera (Sterrer & Iliffe, 1982)	6	27
Phallodriloides macmasterae (Erséus, 1986)	1	2
Subclass Copepoda (copepods)		
Erebonectes nesioticus Fosshagen, 1985	5	7
Paracyclopia naessi Fosshagen, 1985	6	70
Antrisocopia prehensilis Fosshagen, 1985	1	7
Nanocopia minuta Fosshagen, 1988	1	3
Speleoithona bermudensis Rocha & Iliffe, 1993	2	32
Speleophria bivexilla Boxshall & Iliffe, 1986	1	15
Speleophriopsis scottodicarloi (Boxshall & Iliffe, 1990)	1	1
Subclass Ostracoda (ostracods)		
Spelaeoecia bermudensis Angel & Iliffe, 1987		
Infraorder Caridea (shrimp)		
Typhlatya iliffei Hart & Manning, 1981	2	3
Procaris chacei Hart & Manning, 1986	2	2
Order Isopoda (isopods, pill bugs)		
Atlantasellus cavernicolus Sket, 1979	1	6
Arubolana aruboides (Bowman & Iliffe, 1983)	2	11
Curassanthura bermudensis Wägele & Brandt, 1985	1	1
Order Amphipoda (amphipods)		
Bermudagidiella bermudensis (Stock, Sket & Iliffe, 1987)	2	5
Ingolfiella longipes Stock, Sket & Iliffe, 1987	1	1
Idunella sketi Karaman, 1980	1	2
Cocoharpinia iliffei Karaman, 1980	1	10
Pseudoniphargus grandimanus Stock, Holsinger, Sket & Iliffe, 1986	4	195
Order Mictacea (mictaceans)		
Mictocaris halope Bowman & Iliffe, 1985	4	56
Order Mysidacea (mysids)		
Platyops sterreri Băcescu & Iliffe, 1986	2	5

Table 1. A list of the number of specimens and caves in which they are known from for the listed cave species (Courtesy of T. Iliffe, 2004)

G. Current conservation action

Dr. Tom Iliffe from Texas A&M University has pioneered much of the cave biology research in Bermuda. The Bermuda Cave Diving Association and more recently the Bermuda Cavers Group have provided valuable dive support for much of this work, and have also taken on responsibility for maintaining the safety lines in the caves. In 2002, the multidisciplinary Bermuda Cave and Karst Information System (BeCKIS) project was established with the primary goals of promoting the scientific study of the Island's caves in order to assist local resource managers in making informed decisions, as well as increasing public awareness of Bermuda's caves and cave life (Szukalski, pers. com. 2007). The project has leveraged the efforts of professionals and volunteers alike, and represents a multi-national effort with partner organisations on both sides of the Atlantic as well as from Bermuda. It is coordinated through the Natural History Museum at BAMZ and has recently focused on assessments of water quality, some small-scale mapping and taxonomic studies. Additionally, a partnership with the US Cambrian Foundation has resulted in some innovative education transmissions live from within the cave system to local school children. Several local T.V. shows have also focused on the caves, their significance and the threats. Local NGO's (Bermuda Underwater Exploration Institute, Waterstart and Bermuda Zoological Society) all provide educational materials and learning experiences incorporating Bermuda's caves.

The Crystal Caves, Bermuda's only public show caves and a member of the International Show Caves of the World, undertakes active monitoring of air and water quality within Crystal Cave and Fantasy Cave, and helps raise public awareness both locally and globally about the unique nature of Bermuda's caves.

PART II: MANAGEMENT

A. Management goal

The primary aims of this management plan are to provide protection for the critical cave habitat which supports 22 listed, critically endangered endemic cave fauna. This protection addresses threats from development, pollution, dumping of trash, quarrying, vandalism and unauthorized access so restoring the delicate natural equilibrium of the cave environment and supporting the unique species inhabiting it.

The short-term goal (3 years) is to ensure that there is no further willful destruction of the cave habitat, that identification of point sources of pollution has begun and that no new cesspits are located over mapped caves.

The long-term goal (20 years) is to ensure that as well as no further willful damage, pollution levels in the caves have been reduced to acceptable levels based on species tolerance, that the restoration potential of selected caves has been realised, and that local resource managers are in possession of the necessary information and/or technology to prevent new cesspits beings located over the Island's caves. It is further intended that the reproductive and feeding behaviour of a representative group of critically endangered cave fauna is understood, that a system for ongoing monitoring of air and water quality and of the cave fauna is established, and that the percentage of residents aware of the significance of Bermuda's caves is at least 75%.

B. Management objective and criteria

Favourable conservation status will be achieved when:

- Due legislative protection is given to the entire cave habitat preventing further physical destruction, pollution, vandalism and dumping of waste in the caves.

- The cave systems have been accurately mapped to ensure a better understanding of the relationship between above ground activities and the underlying caves such that detrimental activities can be adequately managed.

- Ex-situ breeding of a representative group of listed cave species is accomplished and eco-toxicological experiments have been undertaken to establish tolerance levels to local contaminants.

- All point sources of contamination have been identified and managed such that contamination levels do not exceed the tolerance levels of this representative group of cave species.

- There has been demonstrated proof that caves can be successfully restored (through restoration of Sear's and Bitumen caves).

These overall objectives translate into specific targets outlined below:

Short-term target (3 years):

- Declaration of the entire cave system as "critical habitat" under the Protected Species Act 2003, so providing legal protection with associated restriction and/or permitting of human activities;
- development of a set of standards for research, mapping, development of inventories and environmental impact assessments;
- establishment of an information sharing network between resource managers, landowners, scientists and permitted cave divers;
- establishment of permanent locator and access points for monitoring and mapping; clarification of land ownership for all caves;
- initiation (or continuation of existing, in the case of Crystal Cave and Fantasy Cave) monitoring of air and water quality in caves believed to be affected by contaminants;
- mapping of the Green Bay System;
- support for educational activities; identification and engagement of scientific researchers to expand our biological and ecological knowledge of the cave fauna and their environmental requirements; and
- procurement of funding to support all of these activities.

Long-term target (20 years):

- Mapping of all the known cave systems;
- continued expansion of the monitoring network to ensure all point sources of contamination are identified;
- implementation of measures to ensure contamination levels do not exceed acceptable tolerance limits of representative species;
- ex-situ breeding of representative group of cave fauna species and eco-toxicological studies to assess their tolerance limits to local contaminants;
- ongoing support for educational activities and for the engagement of scientific researchers to expand our biological and ecological knowledge of the cave fauna and their environmental requirements;
- implementation of a rigorous system for detecting and monitoring change in the cave fauna; and
- procurement of sufficient funding to support all of these activities.

C. Management strategy

The underlying element to the management strategy for the 22 listed endemic cave fauna will be to protect their habitat in its entirety. Although many of these cave-dwelling species appear to be restricted in their distribution having only been found in a single cave system, or in some instances in just one cave within a system, the level of connectivity known to exist between the submerged underwater passages of the Island's caves suggests that an effective management plan must address the cave system in its entirety and the species collectively. The approach taken will be to compliment proposed legislative protection of the caves which will restrict deleterious human activities, with ongoing monitoring of the cave environment to identify and mitigate further contaminant input, quarrying, dumping and vandalism. At the same time, ongoing support will be given to mapping and research initiatives which further our understanding of the geography, hydrography, biology and ecology of the cave environment and critically endangered cave fauna.

D. Tools available for strategy

Many of the tools needed to support implementation of the management plan already exist. With approximately 200 known cave locations, declaration of the caves as "critical habitat" can be supported immediately, with the recognition that over time, more locations will be added as they are discovered. Moreover, with the major threats to the caves identified, establishing the activities that will need to be restricted as well as those that should be permitted will be fairly straightforward. The majority of the cave landowners are also known and with liaison with the Departments of Works and Engineering and Planning, property boundaries may also be clarified.

Through the expertise of those already involved in the BeCKIS programme, as well as with the support of the local cave divers and the US Cambrian Foundation, mapping of the various cave systems can be undertaken, despite the obvious logistical challenges of such a venture. These experts will also provide invaluable input into the development of the necessary standards for research, mapping, development of inventories and environmental impact assessments. Local GIS expertise at the Department of Conservation Services will insure integration of the data into the local GIS framework, and armed with this information and the legislative back of the Planning Act 1974, planners at the Department of Planning will be able to ensure that developers avoid locating cesspits above the caves.

Building on the ongoing monitoring of air and water quality in Crystal and Fantasea caves which can serve as a template, the establishment of more extensive monitoring programmes throughout the cave system will be based upon the identification of the point sources of contamination and these may be determined in large part through dye tracing. Again, local and overseas cave expertise is available for ensuring that monitoring programmes extract as much information as possible in order to accurately assess contaminant levels.

The expertise amongst the Crystal Caves team, the BeCKIS team, the Bermuda Cavers Group and the Cambrian Foundation will enable the information gaps regarding the baseline database of information on the biology, ecology, and hydrography within the cave system to be addressed and local scientists and resource managers to be equipped with the necessary tools for identifying the cave fauna. It will also enable a rigorous system for detecting and monitoring change in the cave fauna to be established, and will enable staff and volunteers to be trained in the necessary techniques for successfully restoring suitable caves.

Hatchery-breeding of representative cave fauna species (the most numerous) will present perhaps the most significant challenge to this management plan. Producing hatchery-reared individuals is believed necessary in order to assess their tolerance levels to local contaminants without risking further depleting the wild populations. The hatchery at Coney Island will provide the venue for this breeding programme.

The tools for education and public awareness are already in place through the public show caves at Crystal Caves, as well as through the various NGO educational teams and T.V. and media networks.

E. Step-down narrative of work plan

The required management actions are as follows:

1. Protect the cave habitat by declaring the caves as "critical habitat" under the Protected Species Act 2003.

Actions Proposed:

- Determination of actions to be restricted.
- Meet with private cave landowners to get their input.
- Drafting of restricted activities and those requiring permitting.
- Gazetting of notice of intent to declare the caves as "critical habitat".

Work Team: DCS, Attorney General's Chambers.
Team Leader: Cave fauna management plan coordinator.
Assistance: DCS, BeCKIS.
Outputs: Legal protection afforded to the entire cave habitat to prevent further willful damage.
List of Equipment: None

2. Undertake a comprehensive mapping initiative of the Islands' cave system and integrate into the GIS framework.

Actions Proposed:

- Secure permission of cave owners for access.
- Define level of accuracy required and establish survey protocols.

- Develop criteria for deciding upon priorities for selecting systems to be mapped.
- Ensure dive guidelines are properly laid and maintained in cave systems to be mapped.

Work Team: BeCKIS, Cambrian Foundation, Bermuda Cave Divers.
Team Leader: Cave fauna management plan coordinator.
Assistance: DCS, GIS coordinator.
Outputs: Accurate, 3 dimensional, GIS integrated maps of the Islands' cave systems for guiding decision-making.
List of Equipment: Cave diving equipment, guidelines, SCUBA tanks, GIS software, computer, funding for overseas mapping assistance.

3. **Evaluate the potential for ex-situ/hatchery breeding of representative cave species and conduct experiments to determine their tolerance to known contaminants of the cave system.**

Actions Proposed:
- Secure permission of cave owners for access.
- Identification of suitably abundant species for collection of breeding stock.
- Development of optimal techniques for larval, post-larval and juvenile rearing.
- Exposure experiments to known local contaminants.

Work Team: Identified cave fauna biologist, DCS hatchery.
Team Leader: Hatchery manager.
Assistance: Local and overseas cave divers, DCS.
Outputs: Determination of feeding and reproductive biology of selected cave fauna and of culture techniques for rearing, and of their tolerance of known cave contaminants.
List of Equipment: Nets, cave diving equipment, SCUBA tanks, hatchery equipment specific to rearing cave fauna, funding for hatchery staff and for overseas researchers (for collection of specimens).

4. Identify point sources of pollution and implement the necessary procedures to manage these so that they do not exceed species tolerance levels. If necessary, explore and implement alternative technologies for sewage disposal.

Actions Proposed:
- Secure permission of cave owners for access.
- Conduct dye tracer experiments to track sources.
- Install water quality monitoring equipment.

- Map and monitor the spatial distribution of contaminants and liaise with "polluters" to identify alternative solutions to waste disposal, or reduction in contamination.
- Undertake background research to determine what alternative sewage disposal mechanisms exist and if suitable, undertake pilot project.

Work Team: DCS, Local/overseas caves divers, Crystal Caves.
Team Leader: Cave fauna management plan coordinator.
Assistance: Local cave divers, local and overseas researchers, BeCKIS team, Government hydrologist, Department of Health.
Outputs: Point sources of contamination identified and eliminated or contained to within tolerance limits of cave species.
List of Equipment: Dye tracer, cave diving equipment, water quality monitoring equipment, funding for overseas researchers and for chemical analysis of water samples, GIS software.

5. Establish baseline levels of air and water in the cave systems and implement long-term monitoring of these.

Actions Proposed:
- Secure permission of cave owners for access.
- Establish GIS-based system of water and air quality sampling to determine baseline levels and establish appropriately located permanent monitoring stations.
- Explore possibility of drilling surface monitoring stations for easier access.
- Identify possible indicator species for assessing air and water quality.

Work Team: Government Hydrologist, DCS.
Team Leader: Cave fauna management plan coordinator.
Assistance: Crystal Caves, local and overseas researchers and cave mappers, DCS, GIS coordinator.
Outputs: Long-term monitoring of cave air and water quality established to ensure that environmental quality within the cave system is maintained at levels necessary to support the cave fauna.
List of Equipment: Monitoring equipment, cave diving equipment, GIS software, funding for air and water analyses and for researchers and mappers.

6. Facilitate ongoing research to gain a better understanding of the baseline population status and distribution of the cave species ad the hydrography of the cave system and establish a monitoring system.

Actions Proposed:
- Prioritise research activities.

- Identify suitable specialists and extend invitation to study in Bermuda.
- Produce an identification guide for cave species.
- Establish a reference collection of cave species.
- Undertake training in species identification for locals.
- Provide logistical support where appropriate.

Work Team: BeCKIS, Texas A&M University.
Team Leader: Cave fauna management plan coordinator.
Assistance: Local and overseas cave divers, DCS, GIS coordinator.
Outputs: Scientific experts engaged, GIS-integrated faunal inventory and population estimates established, identification guide produced, collection of specimens deposited at Bermuda Natural History Museum, training manual developed and local scientists and resources managers trained, cave fauna monitored.
List of Equipment: Cave diving equipment, collecting equipment, microscope and camera, GIS software, funding for printing of materials and support of scientists.

7. Undertake active restoration of suitable caves.

Actions proposed:
- Secure permission from cave owners of identified caves.
- Engage group of local volunteers.
- Secure necessary equipment for access and removal of trash.
- Organise targeted clean-up of Sear's and Bitumen caves.

Work Team: BeCKIS, DCS.
Team Leader: Cave fauna management plan coordinator.
Assistance: DCS, local volunteers/NGO's.
Outputs: Two caves (Sear's and Bitumen) restored, team of local cave volunteers established.
List of Equipment: Clean-up equipment.

8. Expand current education and public awareness programmes.

Actions proposed:
- Ensure study of Bermuda's caves integrated into local schools curriculum.
- Provide up to date information for educators.
- Develop novel educational programmes.
- Make materials available on the Government website.

Work Team: Local educators (Crystal Caves, BZS, BUEI, Waterstart), Cambrian Foundation.
Team Leader: Local educators.
Assistance: DCS, Ministry of Education (science curriculum officer).

Outputs: 75% of local population aware of significance of Bermuda's caves and cave fauna.
List of Equipment: Resource materials, broadcasting technology, website.

9. Improve Information sharing between key stakeholders.

Actions proposed:

- Identify key stakeholders and create database.
- Ensure that all identified stakeholders are part of electronic information sharing network.

Work Team: DCS.
Team Leader: Cave fauna management plan coordinator.
*Assistanc*e: ITO Department.
Outputs: Improved communication and information sharing between key stakeholders ensuring that information is kept up to date and issues are identified and shared immediately.
List of Equipment: Website/listserve.

F. Estimated Date of Down Listing

Meeting the management objective for the cave fauna in Bermuda depends primarily on preventing further physical damage to the cave habitat and on identifying and managing point sources of pollution. It also relies on engaging the necessary scientific expertise to map the caves and fill in the suite of information gaps concerning the biology and ecology of the species and their habitat requirements. Given the logistical challenges of studying the cave environment, it is anticipated that it would take at least 20 years to undertake this work and reach a point in 2034 where the cave habitat was sufficiently well managed to allow some elements of protection to be relaxed if it was deemed that to do so would benefit Bermuda without prejudice to the habitat.

PART III: IMPLEMENTATION

<u>Priority 1</u>: An action that must be taken to prevent extinction or to prevent the species from declining irreversibly.
<u>Priority 2</u>: 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.
<u>Priority 3</u>: All other action necessary to provide for full recovery of the species.

Priority #	Task #	Task Description	Task Duration	Responsible Party
1	**1.**	***Protect the cave habitat by declaring the caves as "critical habitat" under the Protected Species Act 2003.***	**4 months**	DCS, AG's Chambers
	1.1	Determination of actions needing to be restricted	1 month	
	1.2	Drafting of restricted activities and those requiring permitting	2 months	
	1.3	Meet with private cave landowners to get input	1 month	
	1.4	Gazetting of notice of intent to declare the caves as "critical habitat".	1 month	
2	**2.**	***Undertake a comprehensive mapping initiative of the Islands' cave system and integrate into the GIS framework.***	**10 years**	DCS
	2.1	Secure permission of cave owners for access	1 month	
	2.2	Define level of accuracy required and establish survey protocols	2 months	
	2.3	Develop criteria for deciding upon priorities for selecting systems to be mapped mapping,	1 month	
	2.4	Ensure dive guidelines are properly laid and maintained in systems to be mapped.	Ongoing 10 years	
2	**3.**	***Evaluate the potential for ex-situ/hatchery breeding of representative cave species and conduct experiments to determine their tolerance to***	**10 years**	DCS/hatchery

		known contaminants of the cave system.		
	3.1	Secure permission of cave owners for access	1 month	
	3.2	Identification of suitably abundant species for collection of breeding stock	4 years	
	3.3	Development of optimal techniques for larval, post-larval and juvenile rearing	4 years	
	3.4	Exposure experiments to known local contaminants	2 years	
1	**4.**	***Identify point sources of pollution and implement the necessary procedures to manage these so that they do not exceed species tolerance levels. If necessary, explore and implement alternative technologies for sewage disposal.***	**10 years**	**DCS**
	4.1	Secure permission of cave owners for access	1 month	
	4.2	Conduct dye tracer experiments to track sources	3 years	
	4.3	Install water quality monitoring equipment	2 years	
	4.4	Map and monitor contaminant levels and liaise with "polluters" to identify alternative solutions to waste disposal, or reduction in contamination	5 years	
	4.5	Undertake background research to determine what alternative sewage disposal mechanism exist and if suitable, undertake pilot project	5 years	
2	**5.**	***Establish baseline levels of air and water in the cave systems and implement long-term monitoring of these.***	**10 years**	Dept. of Environmental Protection, DCS
	5.1	Secure permission of cave owners for access	1 month	
	5.2	Establish GIS-based system of water and air quality sampling to determine baseline levels and	5 years	

		establish appropriately located permanent monitoring stations		
	5.3	Explore possibility of drilling monitoring stations for easier access	2 years	
	5.4	Identify possible indicator species for assessing air and water quality	5 years	
3	**6.**	***Facilitate ongoing research to gain a better understanding of the baseline population status and distribution of the cave species ad the hydrography of the cave system and establish a monitoring system.***	**20 years**	DCS
	6.1	Prioritise research activities	3 months	
	6.2	Identify suitable specialists and extend invitation to study in Bermuda	2 months	
	6.3	Produce an identification guide for cave species	2 years	
	6.4	Establish a reference collection of cave species	5 years	
	6.5	Undertake training in species identification for locals	2 months	
	6.6	Provide logistical support where appropriate	20 years ongoing	
3	**7.**	***Undertake active restoration of suitable caves.***	**5 years**	DCS
	7.1	Secure permission from cave owners of identified caves	1 month	
	7.2	Engage group of local volunteers	3 months	
	7.3	Secure necessary equipment for access and removal of trash	2 months	
	7.4	Organise targeted clean up of Sear's and Bitumen caves	1 year	
3	**8.**	***Expand current education and public awareness programmes***	**20 years**	DCS, Ministry of Education
	8.1	Ensure study of Bermuda's caves on local schools curriculum	1 year	
	8.2	Provide up to date information for educators	20 years ongoing	
	8.3	Develop novel educational programmes	20 years ongoing	
	8.4	Make materials available on the website	20 years ongoing	

3	**9.**	***Improve information sharing between key stakeholders***	6 months	DCS, IT
	9.1	Identify key stakeholders	1 month	
	9.2	Ensure that all identified stakeholders are part of electronic information sharing network.	6 months	

APPENDIX

List of Bermuda's anchialine species (Iliffe, www.tamug.edu/cavebiology):

Phylum Cilophora (ciliates)
Order Euplotida (euplotids)
Family Euplotidae
- *Euplotes iliffei* Hill & Small, 1986

Order Scuticociliatida (scuticociliates)
Family Parauronematidae
- *Glauconema bermudense* Small, 1986

Phylum Annelida (segmented worms)
Class Polychaeta (polychaetes)
Family Nerillidae
- *Leptonerilla prospera* (Sterrer & Iliffe, 1982)
- *Longipalpa saltatrix* Worsaae, Sterrer & Iliffe, 2004

Class Oligochaeta (oligochaetes)
Family Tubificidae
- *Phallodriloides macmasterae* (Erséus, 1986)

Phylum Mollusca (molluscs)
Class Gastropoda (gastropods)
Family Caecidae
- *Caecum caverna* Moolenbeek & Faber, 1987
- *Caecum troglodyta* Moolenbeek & Faber, 1987

Phylum Arthropoda (arthropods)
Subphylum Chelicerata (chelicerates)
Class Arachnida (arachnids)
Subclass Acarina (mites)
Family Halacaridae
- *Agauopsis bermudensis* Bartsch & Iliffe, 1985
- *Agauopsis littoralis* Bartsch & Iliffe, 1985
- *Copidognathus bermudensis* Bartsch & Iliffe, 1985
- *Copidognathus subterraneus* Bartsch & Iliffe, 1985
- *Copidognathus longispinus* Bartsch & Iliffe, 1985

Subphylum Crustacea (crustaceans)
Subclass Copepoda (copepods)
Order Calanoida (calanoids)
Family Arietellidae
- *Metacalanus* sp.
- *Paramisophria* sp.

Family Epacteriscidae
- *Enantiosis bermudensis* Fosshagen, Boxshall & Iliffe, 2001
- *Epacteriscus rapax* Fosshagen, 1973

- *Erebonectes nesioticus* Fosshagen, 1985

Family Pseudocyclopiidae

- *Paracyclopia naessi* Fosshagen, 1985

Family Ridgewayiidae

- *Exumella polyarthra* Fosshagen, 1970
- *Ridgewayia marki* Esterly, 1911

Family Stephidae

- *Miostephos leamingtonensis* Yeatman, 1980

Order Platycopioida (platycopioids)

Family Platycopiidae

- *Antrisocopia prehensilis* Fosshagen, 1985
- *Nanocopia minuta* Fosshagen, 1988

Order Cyclopoida (cyclopoids)

Family Halicyclopinae

- *Halicyclops bowmani* Rocha & Iliffe, 1993
- *Halicyclops herbsti* Rocha & Iliffe, 1993
- *Halicyclops ytororoma* Lotufo & Rocha, 1993
- *Neocyclops (Protoneocyclops) stocki* Pesce, 1985

Family Speleoithonidae

- *Speleoithona bermudensis* Rocha & Iliffe, 1993

Order Harpacticoida (harpacticoids)

Family Superornatiremidae

- *Neoechinophora fosshageni* Huys, 1996
- *Neoechinophora daltonae* Huys, 1996
- *Neoechinophora jaumei* Huys, 1996
- *Superornatiremis mysticus* Huys, 1996
- *Intercrusia problematica* Huys, 1996

Order Misophrioida (misophrioids)

Family Misophriidae

- *Speleophria bivexilla* Boxshall & Iliffe, 1986
- *Speleophriopsis scottodicarloi* (Boxshall & Iliffe, 1990)

Subclass Ostracoda (ostracods)

Order Halocyprida (halocyprids)

Family Halocyprididae

- *Spelaeoecia bermudensis* Angel & Iliffe, 1987

Family Polycopidae

- *Metapolycope duplex* Kornicker & Iliffe, 1989
- *Micropolycope eurax* Kornicker & Iliffe, 1989
- *Micropolycope styx* Kornicker & Iliffe, 1989
- *Polycopissa anax* Kornicker & Iliffe, 1989

Order Myodocopida (myodocopids)

Family Philomedidae

- *Pseudophilomedes kylix* Kornicker & Iliffe, 1989

Family Sarsiellidae

- *Eusarsiella styx* Kornicker & Iliffe, 1989

Order Podocopida (podocopids)

Family Bairdiidae

- *Aponesidea iliffei* Maddocks, 1986
- *Havanardia keiji* Maddocks, 1986
- *Neonesidea omnivaga* Maddocks, 1986
- *Paranesidea sterreri* Maddocks, 1986

Family Cytherellidae

- *Cytherella bermudensis* Maddocks, 1986
- *Cytherella kornickeri* Maddocks, 1986

Family Paracyprididae

- *Dolerocypria bifurca* Maddocks, 1986
- *Paracypris crispa* Maddocks, 1986

Family Pontocyprididae

- *Iliffeoecia iliffei* Maddocks, 1991
- *Propontocypris (Propontocypris) minacis* Maddocks, 1986
- *Thomontocypris lurida* (Maddocks, 1986)

Class Malacostraca (malacostracans)
Subclass Phyllocarida (phyllocarids)
Order Nebaliacea (nebaliaceans)

Family Nebaliidae

- *Paranebalia* sp.

Subclass Eumalacostraca (eumalacostracans)
Superorder Eucarida (eucarids)
Order Decapoda (decapods)
Infraorder Caridea (caridean and procaridean shrimp)

Family Alpheidae

- *Bermudacaris harti* Anker & Iliffe, 2000

Family Atyidae

- *Typhlatya iliffei* Hart & Manning, 1981

Family Hippolytidae

- *Barbouria cubensis* (Von Martens, 1872)
- *Janicea antiguensis* (Chace, 1972)
- *Parhippolyte sterreri* (Hart & Manning, 1981)

Family Procarididae

- *Procaris chacei* Hart & Manning, 1986

Superorder Peracarida (peracarids)
Order Isopoda (isopods, pill bugs)

Family Atlantasellidae

- *Atlantasellus cavernicolus* Sket, 1979

Family Cirolanidae

- *Arubolana aruboides* (Bowman & Iliffe, 1983)

Family Gnathostenetroididae

- *Stenobermuda iliffei* Kensley, 1994

Family Paramunnidae

- *Munnogonium somersensis* Kensley, 1994

Family Paranthuridae

- *Curassanthura bermudensis* Wägele & Brandt, 1985

Order Amphipoda (amphipods)

Family Amphilochidae

- *Gitanopsis petulans* Karaman, 1980

Family Bogidiellidae

- *Bermudagidiella bermudensis* (Stock, Sket & Iliffe, 1987)

Family Dulichiidae

- *Podobothrus bermudensis* Barnard & Clark, 1985

Family Ingolfiellidae

- *Ingolfiella longipes* Stock, Sket & Iliffe, 1987

Family Liljeborgiidae

- *Idunella sketi* Karaman, 1980

Family Phoxocephalidae

- *Cocoharpinia iliffei* Karaman, 1980

Family Pseudoniphargidae

- *Pseudoniphargus carpalis* Stock, Holsinger, Sket & Iliffe, 1986
- *Pseudoniphargus grandimanus* Stock, Holsinger, Sket & Iliffe, 1986

Order Tanaidacea (tanaidaceans)

Family Apseudidae

- *Apseudes bermudeus* Băcescu, 1980
- *Apseudes orghidani* Gutu & Iliffe, 1989

Order Mictacea (mictaceans)

Family Mictocarididae

- *Mictocaris halope* Bowman & Iliffe, 1985

Order Cumacea (cumaceans)

Family Nannastacidae

- *Cubanocuma* cf. *gutzui* Băcescu & Muradian, 1977
- *Cumella iliffei* Băcescu, 1992
- *Cumella ocellata* Băcescu, 1992
- *Cumella spinosa* Băcescu & Iliffe, 1991
- *Schizotrema agglutinanta* (Băcescu, 1971)
- *Schizotrema wittmanni* Petrescu & Sterrer, 2001

Order Mysidacea (mysids, opossum shrimp)

Family Mysidae

- *Bermudamysis speluncola* Băcescu & Iliffe, 1986
- *Platyops sterreri* Băcescu & Iliffe, 1986

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