Management Plan for the Bermuda Campylopus Moss *Campylopus bermudianus syn. Campylopus trachyblepharon*

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

Management Plan for the Bermuda Campylopus Moss
Campylopus bermudianus syn. Campylopus trachyblepharon

Prepared in Accordance with the Bermuda Protected Species Act 2003

This management plan was prepared by:
Alison Copeland M.Sc.,
Biodiversity Officer

Department of Environment and Natural Resources
Ecology Section
17 North Shore Road, Hamilton FL04
Bermuda

Contact email: environment@gov.bm

Cover photo: *Campylopus bermudianus*. Academy of Natural Sciences, Philadelphia Herbarium

Published by

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

CONTENTS

LIST OF FIGURES

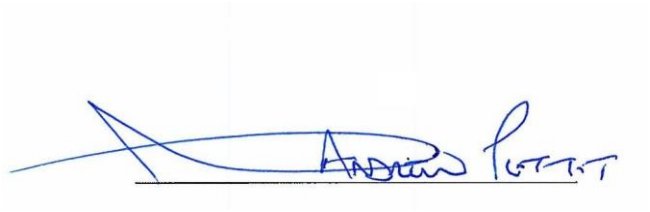
LIST OF TABLES

DISCLAIMER

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

Literature citation of this document should read as follows: Copeland, A.I. 2020. Management Plan for the Bermuda Campylopus Moss *Campylopus bermudianus syn. Campylopus trachyblepharon.* Department of Environment and Natural Resources, Government of Bermuda. pp. 30.

An electronic version of this management plan is also available at www.environment.bm



21st May 2020

Andrew Pettit
Director,
Department of Environment and Natural Resources
Government of Bermuda

Date

ACKNOWLEDGEMENTS

I would like to thank Dr Robbie Smith for searching the Bermuda Natural History Museum collections, and providing me with the observations. Also, Mrs. Alison Green who searched the Bermuda Natural History Museum library, and provided me with references. Dr Mark Outerbridge and Dr Robbie Smith reviewed a draft of this plan and provided helpful edits and suggestions. I would also like to thank the management committee of the Bermuda Audubon Society and staff members at the Bermuda National Trust for supporting the proposed conservation measures in Paget Marsh.

EXECUTIVE SUMMARY

The endemic Bermuda Campylopus Moss *Campylopus bermudianus* was first described in 1913 from a specimen collected in Paget Marsh in 1908 (Britton, 1912; Williams, 1913). Recent taxonomic revision of the genus *Campylopus* has significantly reduced the number of species, including the assimilation of *Campylopus bermudianus* as a range extension of the South American species *Campylopus trachyblepharon* (Frahm, 1991; O'Shea, 2009). The species name *Campylopus bermudianus* is used in this document, as this is how it appears on the Protected Species Amendment Order 2016; however, we accept that this refers to a native population of *Campylopus trachyblepharon*, rather than an endemic species.

Current species status
Legal protection for this species is provided by the Protected Species Act (2003). Following IUCN criteria, Bermuda Campylopus Moss is listed as Critically Endangered under the Protected Species Amendment Order (2016). This species has not been assessed for the IUCN Red List, nor is it protected by any treaties. Campylopus Moss is assumed to be still extant on Bermuda, however an abundance estimate has never been made.

Habitat requirements and threats
Campylopus bermudianus has only ever been reported from Paget Marsh, where it grows on the ground beneath the Bermuda Palmetto forest. As a native species known from only one location, it is at risk of extirpation if the environmental conditions within the marsh become unfavourable. Threats to it include habitat change from rising sea levels and incursion by invasive plants.

Management objectives
The principal aim of this management plan is to determine if this species still exists in Bermuda, and what can be done to protect remaining specimens. It is also necessary to confirm the taxonomy and revise the endemic status of this species. A favourable conservation status will be attained when a self-sustaining population of this moss is achieved, and threats to its survival have been mitigated where possible. The present difficulty with confidently identifying this species in the field will hinder achieving the management objectives.

Management criteria
A positive conservation status for *Campylopus* moss in Bermuda will be achieved when:

1. The taxonomy and native status of this species has been determined
2. There is evidence of an increasing or stable population
3. More is known about the Bermudian population, its distribution and its ecology
4. Threats have been identified and addressed to the extent possible
5. The public are aware of this species and support its conservation

Actions needed:

- Collaboration with a visiting bryologist to train Bermudians in moss identification
- Field surveys to determine that *Campylopus bermudianus* is extant at Paget Marsh, and present in any other wetland environment on Bermuda.
- Population assessment accompanied by ecological observations
- Ongoing monitoring of identified colonies
- Determine native or endemic status through genetic or morphological analysis
- Update Protected Species Order with revised taxonomy and status
- Collect new specimens and photos for the Bermuda Natural History Museum
- Sharing arrangements or repatriation of preserved specimens and historic records from overseas institutions
- Invasive plant control in Paget Marsh
- Explore *ex situ* conservation such as spore banking, on-island translocation and public display at the Botanical Gardens and/or an overseas facility.
- Inclusion of mosses on new signage and education materials for Paget Marsh

Management costs

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

Figure 1: Excerpt from herbarium specimen NY619966, the type specimen of *Campylopus bermudianus* (Photo: the New York Botanical Garden Herbarium)

PART I: INTRODUCTION

A. Brief Overview

As an isolated oceanic island, Bermuda has a relatively poor bryophyte flora (Britton, 1915; O'Shea, 2009) in comparison to countries found on continents. The first systematic study of Bermuda's mosses was begun by Elizabeth Britton in 1905, and she subsequently listed twenty-eight species, from twenty genera (Britton, 1915; Britton, 1918). A more recent list contained forty-four species (O'Shea, 2009).

Campylopus bermudianus was first described as an endemic moss in 1913 from specimens found in Paget Marsh, Bermuda (Britton, 1912; Williams, 1913). Due to its status as an island-endemic species, with a known distribution from only one location, it was listed as Critically Endangered under the Protected Species Act 2003. Recent taxonomic revision of the *Campylopus* moss genus has determined that *Campylopus bermudianus* is a synonym for *Campylopus trachyblepharon*; making it a native species not a Bermuda-endemic (O'Shea, 2009; The Plant List, 2020; Tropicos.org, 2020). This change in status warrants a re-examination of the species conservation needs as laid out in this plan.

B. Taxonomy

Kingdom: Plantae
Phylum: Bryophyta – mosses, non-vascular land plants
Class: Bryopsida
Order: Dicranales
Family: Dicranaceae
Subfamily: Campylopodioideae
Genus: *Campylopus*
Species: *bermudianus*
Common names: Bermuda Campylopus Moss

Synonyms: The name *Campylopus bermudianus* is considered a synonym of *Campylopus trachyblepharon* (Müll. Hal.) Mitt. (O'Shea, 2009; The Plant List, 2020).

The genus *Campylopus* contains around 180 species, making it one of the largest moss genera (Frahm, 1990; Frahm, 1991). The genus name is derived from the Greek campylos = curved and pous = foot, referring to the curved setae (Frahm, 1991).
The genus *Campylopus* has undergone substantial taxonomic revisions, which has significantly reduced the number of species in this genus (Frahm, 1991; Frahm et al., 2003). The species name *Campylopus bermudianus* is no longer an accepted species name (O'Shea, 2009; The Plant List, 2020; Tropicos.org, 2020). The herbarium specimens of *C. bermudianus* held in Berlin, Philadelphia, Missouri and Wisconsin have been recently determined as *Campylopus trachyblepharon* (Table 1; GBIF.org, 2020; Tropicos.org, 2020).

Some sources place the genus *Campylopus* in the White Moss Family Leucobryaceae (Hodgetts et al., 2019), while most place it within Dicranaceae (Britton, 1918; Frahm, 1991; The Plant List, 2020; GBIF.org, 2020).

C. Description of the Species

The type specimen from which *Campylopus bermudianus* was first described was collected by Stewardson Brown in 1908, and is housed at the New York Botanical Garden herbarium (Table 1; Fig.1). The new Bermudian moss was described by the New York Botanical Gardens bryologist Robert Stratham Williams as follows: "Plants in rather dull-green, not very compact tufts, tomentose within; stems about 4cm. high, branching often with flagella, more or less interruptedly foliate; leaves often comose at the apex, mostly laxly spreading-flexuous all around, the upper about 6mm long, lanceolate, grooved above, not subtubulose, sharply serrate at the apex and more or less serrulate on the margin one half down or more; costa percurrent of slightly excurrent, about 225 μ wide below and one third the width of the lower part of the leaf, with prominent serrate lamellae 2 or 3 cells high on the back above, in cross-section near the middle showing a median row of 7 or 8 large cells with stereid-bands above and below, the lower band with a row of differentiated outer cells; alar cells reddish, inflated, the cells just above mostly rectangular, pale, broad toward the costa, narrow toward the margin, with scarcely thickened or pitted walls, in the leaf above soon becoming smaller, with slightly thickened walls rarely pitted near the costa; median and upper cells of the blade mostly 6-8μ wide and 8-20μ long, with uniformly slightly thickened walls; flowers and fruit unknown. Type locality: Paget Marsh, Bermuda. Distribution: Known only from the type locality" (Williams, 1913; pg. 148).

Campylopus bermudianus is also described by Elizabeth Britton in her chapter on mosses in the *Flora of Bermuda* published in 1918: "Plants in dark green, loose tufts, stems about 2 ½ inches high, branching, often with flagellae; leaves often crowded at the apex, mostly spreading all around, lanceolate, grooved above, sharply serrate at the apex and more or less serrulate on the margin; vein broad, percurrent or slightly excurrent, with prominent serrate lamellae 2 or 3 cells high on the back above; alar cells inflated, the cells just above mostly rectangular, pale, broad toward the vein, narrow toward the margin, smaller above, with slightly thickened walls rarely pitted near the vein. Paget Marsh, under palmetto. Endemic." (Britton, 1918, page 433)

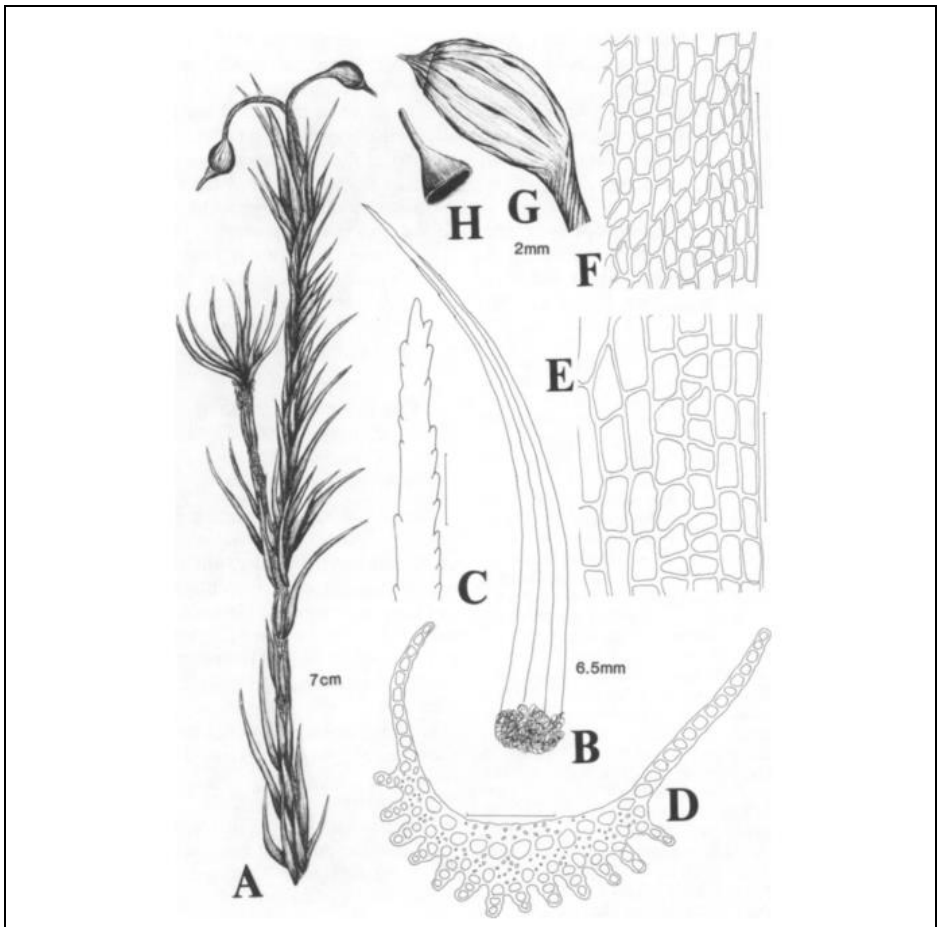


FIG. 130. *Campylopus trachyblepharon* (*Campylopodes Brasiliae Exsiccatae 16*). **A.** Plant. **B.** Leaf. **C.** Leaf-tip. **D.** Transverse section of leaf. **E.** Basal laminal cells. **F.** Upper laminal cells. **G.** Capsule. **H.** Operculum. Unlabeled scale bar for microscopic details = 50 μm.

Figure 2: Diagram of *Campylopus trachyblepharon* showing reproductive structures, from Frahm, 1991.

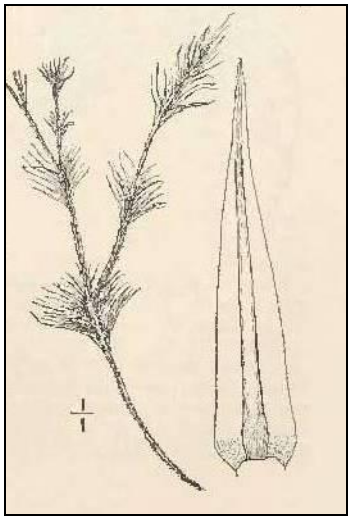


Figure 3: Sketch of *Campylopus bermudianus* from Britton (1918). The original sketch appears with the herbarium specimen NY619966.

D. Ecology

General information on the ecology of *Campylopus* mosses has been summarized below from the literature, and data more specific to *Campylopus trachyblepharon* and the Bermuda population have been incorporated when available.

Habitat requirements

Campylopus species only grow on acidic substrates such as humic soils, peat, decomposing plants and rotting wood (Frahm, 1990; Frahm, 1991). The 20th century observations of *Campylopus bermudianus* all note that the moss is on the ground below trees (Williams, 1913; Britton, 1915; Britton, 1918), and Frahm (1990) notes that *Campylopus sp.* are rarely epiphytic. Elizabeth Britton described the habitat as "On damp ground in shade of palmetto" (Britton, 1915). Retired Government Conservation Officer, Dr. David Wingate describes the growth habit as "just around the base of palmetto trunks where the ground rises slightly" (D.B. Wingate, pers. comm. 2020).

Frahm (1991) described *Campylopus trachyblepharon* as growing "on bare open wet sand on coastal areas near sea level, very frequent in restingas of SE Brazil." Frahm (1991) states that *Campylopus* species in general prefer open habitats and are usually not shade tolerant, which contradicts the description of *C. bermudianus* habitat use in Paget Marsh (Britton, 1915) (Fig.4). Frahm does list *C. trachyblepharon* as a tropical forest species.

Figure 4: Bermuda Palmetto-dominated peat hammock forest in the interior of Paget Marsh (Photo: Alison Copeland).

Type Location: Paget Marsh

Paget Marsh is a 12ha freshwater treed-swamp in Paget Parish, Bermuda. In 1900 Bermuda had 116.5ha of vegetated peat marsh, 68ha (58%) of which had been modified or destroyed by the 1980's through garbage dumping, filling for agriculture and digging drainage canals to reduce mosquito-borne illness (Wingate, 1986; Thomas, 2004). Except the latter, Paget Marsh escaped these disturbances and was made a nature reserve in the 1950s, owned by the Bermuda National Trust and Bermuda Audubon Society.

The peat hammock forest of Paget Marsh is particularly valuable as it hosts a community of plants unique in the world; including the Bermuda Palmetto (*Sabal bermudana*), Bermuda Cedar (*Juniperus bermudiana*), Bermuda Sedge (*Carex bermudiana*), and the Bermuda Spike Rush (*Eleocharis bermudiana*) (Fig. 4). Public access is limited to the northeast of the reserve, where a boardwalk was constructed in 1997 (Fig. 5). Here the juxtaposition of peat forest with sawgrass savannah, red mangrove swamp and brackish pond make Paget Marsh extremely popular for school fieldtrips, bird watching, nature photography and peaceful recreation.

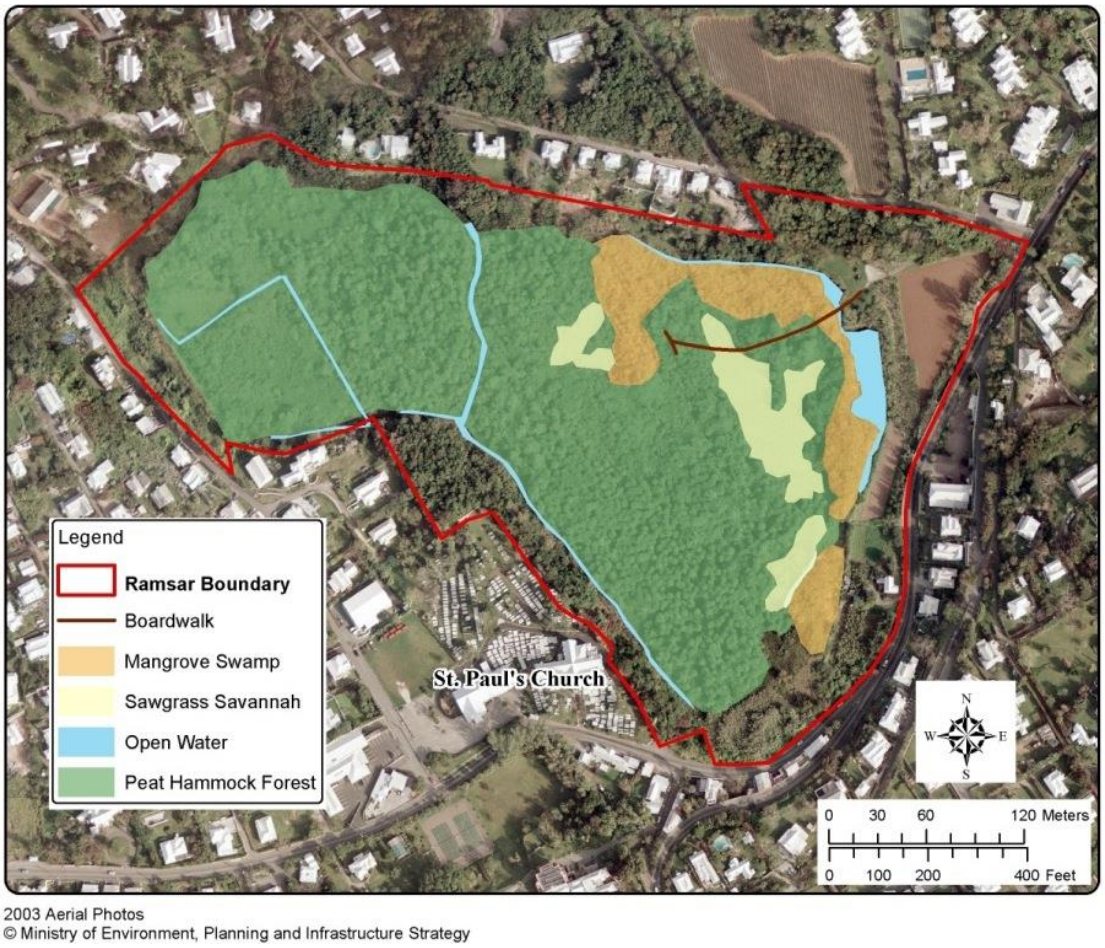


Figure 5: Map of Paget Marsh showing management boundary and vegetation types. (Created by M.L Shailer at the Dept. of Environment and Natural Resources, and reconfigured by the author).

Mosses as Indicator Species
The presence of mosses is a valuable indicator of the age of primary growth forests (Frahm et al., 2003), such as the old growth palmetto forest in Paget Marsh where the Bermuda Campylopus is found. Mosses are sensitive to human disturbance (Frahm et al., 2003; Hodgetts et al., 2019). Mosses are also sensitive to changes in light and water conditions, and certain species act as ground-level indicators of changes in forest environmental conditions (Frahm et al., 2003; O'Shea, 2003).

Reproduction
The method of reproduction in Bermuda Campylopus Moss is not known. *Campylopus* mosses can reproduce asexually through several methods of vegetative propagation or sexually through the production of spores. Frahm (1990) suggests that vegetative propagation is relatively important in *Campylopus sp*. compared with other moss genera.

Campylopus sp. are dioicous (Frahm, 1990). Moss spores are held in capsules (sporangia) on slender stems above the diploid sporophyte. The capsules open and release the spores, which develop into haploid gametophytes. Fertilisation of the gametophytes is facilitated by water drops. The presence of capsules is not described in the literature for Bermuda Campylopus, nor are any seen in preserved specimens. The capsule shape of *C. trachyblepharon* is shown in Figure 2.

E. Current Threats

Globally
There is no specific information on threats to *Campylopus trachyblepharon* at the global level, and it does not appear on any international Red Lists.

In Bermuda
Alteration to habitat due to climate change and invasive species are likely the greatest threats to Bermuda Campylopus Moss. As a species that relies on moist microhabitat, the historic draining of Bermuda's wetlands for mosquito control may very well have reduced the abundance and distribution of this and other mosses. In 1915 Elizabeth Britton suggested that Bermuda's rarer mosses, including *Campylopus*, are "likely to become extinct with the clearing, burning and cultivation of the marshes" (Britton, 1915). Agriculture has been restricted to the perimeter of Paget Marsh, and fortunately the interior was never cleared and has so far escaped the fires that have repeatedly affected Bermuda's other wetlands. Devonshire Marsh, for example, is now almost completely devoid of tree canopy following a series of fires over the last 100 years, most recently in 2018 when 30 acres of the east basin burned (Shailer, 2018).

If annual rainfall becomes patchy and dry spells lengthen in the future due to climate change, all wetland-dependant species could be negatively affected. Additionally, as global sea levels rise, the water table in Paget Marsh will be raised. Paget Marsh is 0.5m above sea level (Wingate, 1986) and standing water occurs in parts of the forest.

During a period of raised sea level in 2002, caused by a warm water eddy from the Gulf Stream, many of the Bermuda Cedar trees in Paget Marsh died (David Wingate, pers. comm.; UKOTCF, 2004). Similar warm-eddy induced high water events occurred in 2011 and 2017, with the 2017 event lasting four months (Copeland, 2019). We can only assume these events will continue to affect both the canopy and understory vegetation of the marsh by saturating the substrate and raising the salinity. A projected two metre rise in sea level would negatively impact 182 nature reserves (95.6 ha) on Bermuda and cause salt water inundation affecting 92% of the current area of low-lying marshes (Glasspool, 2008).

Paget Marsh is one of the few remaining habitats in Bermuda that is not dominated by invasive flora, but that is rapidly changing. Paget Marsh was subject to intensive management of invasive plants from the early 1970's until the early 2000's. Due to a reduction in management in the last 20 years the abundance of invasive plants has increased. In particular, *Ardisia polycephala*, *Ficus microcarpa*, *Schinus terebinthifolius* and *Schefflera actinophylla* are now noticeable in the forest. The Marlberry *Ardisia polycephala* in particular is a threat to understory native plants due to the sheer volume of seedlings now crowding this habitat. Frahm (1991) states that *Campylopus* species in general prefer open habitats and are usually not shade tolerant, so the increasing density of the shrub layer within Paget Marsh from invasive plants could negatively affect the *Campylopus* growing below it.

The observation of *Campylopus bermudianus* by LaGreca near the boardwalk (Table 1) suggests the possibility of impacts from visitors on some specimens of this moss. Similarly, photo records from the Bermuda Natural History Museum show mosses very close to the boardwalk. Trampling from visitors straying from the boardwalk, or accidental damage during maintenance of the boardwalk, are potential threats that can be easily avoided.

F. Current Protection Status

International protection
None. The IUCN Red List of Threatened Species contains assessments of the extinction risk faced by a species across its global range. Neither *Campylopus bermudianus* or its synonym *Campylopus trachyblepharon* have been assessed at the global level, and do not appear on the Red List.

National protection
Current legal protection for *Campylopus bermudianus* is provided by the Protected Species Act (2003). Under this legislation the wilful destruction, damage, removal or obstruction of moss habitats is an offence. Further, it is an offence to wilfully damage, destroy, injure, disturb or kill a protected species. The Protected Species Act (2003) also prohibits the taking, importing, exporting, selling, purchasing, transporting or having in one's possession a protected species or its parts. *Campylopus bermudianus* is listed as a

Level 1 protected species, the highest level of protection under the Act, therefore anyone who commits an offense involving this species is liable to a fine of $25,000, or 2 years imprisonment. Following IUCN Red List criteria, *C. bermudianus* is listed as 'Critically Endangered' [CR] under the Protected Species Amendment Order (2016).

Habitat protection

Paget Marsh, the only reported location for *Campylopus bermudianus*, falls entirely within a protected area. The Paget Marsh Nature Reserve is comprised of parcels of land owned by the Bermuda Audubon Society and Bermuda National Trust. Additionally, Paget Marsh as a whole was designated as a Ramsar Site, or Wetland of International Importance in 1999 (Fig. 5).

G. Current Conservation Action

Campylopus bermudianus has been listed under the Protected Species Act 2003 since the first Protected Species Order was written in 2007. Aside from this, no active conservation measures are underway for this species.

PART II: MANAGEMENT

A. Management Goals

The principal aim of this management plan is to guide efforts to determine if this species still exists in Bermuda, and what can be done to protect remaining specimens. If found to be extant, it will also be necessary to confirm the taxonomy and revise the endemic status of this species. A favourable conservation status will be attained when a self-sustaining population of this moss is achieved, and threats to its survival have been mitigated where possible. The present difficulty in confidently identifying this species in the field will hinder achieving these management objectives.

At present little is known of the ecology of Bermuda Campylopus Moss. It is unclear if the population is stable or if it is declining and therefore at high risk of extirpation. In the short term, assessing the population to determine how many moss colonies remain and where they occur is a management priority. In the longer term, researching moss ecology so that informed management decisions can be made is necessary.

The short-term goals (5 years) are to train Bermudians in moss identification to enable confirmation that the species is extant, followed by a comprehensive population assessment.

The long-term goals (15 years) are to monitor any moss colonies found during assessment, record ecological observations, mitigate threats if possible, including habitat management at Paget Marsh, and to update policy, and if necessary, establish *ex situ* collections.

B. Management Objectives and Criteria

A positive conservation status for Campylopus moss in Bermuda will be achieved when:

1. The taxonomy and native status of this species has been determined
2. There is evidence of an increasing or stable population
3. More is known about the Bermudian population, its distribution and its ecology
4. Threats have been identified and addressed to the extent possible
5. The public are aware of this species and support its conservation

These overall objectives translate into specific actions outlined below:

Actions needed:

- Collaboration with a visiting bryologist to train Bermudians in moss identification

- Field surveys to determine that *Campylopus bermudianus* is extant at Paget Marsh, and present in any other wetland environment on Bermuda.
- Population assessment accompanied by ecological observations
- Ongoing monitoring of identified colonies
- Determine native or endemic status through genetic or morphological analysis
- Update Protected Species Order with revised taxonomy and status
- Collect new specimens and photos for the Bermuda Natural History Museum
- Sharing arrangements or repatriation of preserved specimens and historic records from overseas institutions
- Invasive plant control in Paget Marsh
- Explore *ex situ* conservation such as spore banking, on-island translocation and public display at the Botanical Gardens and/or an overseas facility.
- Inclusion of mosses on new signage and education materials for Paget Marsh

C. Management Strategy

The management strategy for *Campylopus* moss in Bermuda should focus initially on determining whether or not *Campylopus* moss is still present in Paget Marsh, and then determining the identity of the species using genetics or other techniques. If the species is not a Bermuda endemic, its conservation status will immediately improve. If no specimens can be found, the local population can be considered extirpated, and no further conservation action will be necessary. If the species has been extirpated, de-listing from the Protected Species Order should be considered. Periodic searches at various times of the year should be done for *Campylopus* at Paget Marsh if none are initially found, in case the early life stages are cryptic. This management plan should be revised once initial surveys have been conducted to reflect necessary actions based on findings. If *Campylopus bermudianus* is found in Paget Marsh, recommended conservation actions will be undertaken.

D. Tools Available for Strategy

A repeatable method of population assessment should be prepared using published techniques and repeated every five years to determine abundance and distribution trends over a 15-20-year time-frame. There is a body of literature available on population assessment techniques for threatened bryophytes (Hallingbäck and Hodgetts, 2000; Frahm et al., 2003; O'Shea, 2003; Hodgetts et al., 2019). The ecological character assessment tools available from the Ramsar Secretariat might also be helpful for habitat assessment because an ecological character assessment of the Paget Marsh Ramsar Site has not yet been completed, and the existing information sheet is over 15 years old (UKOTCF, 2004).

A brief description of methods for collecting, drying and storing bryophyte specimens for herbaria and DNA extraction can be found in the Manual of Tropical Bryology (Frahm et

al., 2003). A guide for collecting bryophytes in the tropics is also included (O'Shea, 2003).

The Department of Environment and Natural Resources (DENR) should build relationships with academic institutions and researchers studying the ecology of *Campylopus sp.* and other mosses. Collaborations should be explored, including the use of students and volunteers in the implementation of this plan. Sources of funding and expertise should be identified and sought.

The International Union for the Conservation of Nature (IUCN) supports the Species Survival Commission (SSC) with 140 specialist subgroups of global experts in specific taxa. Contacting the IUCN SSC Bryophyte Specialist Group for expert assistance in identifying and assessing the extinction risk faced by *Campylopus* in Bermuda would be beneficial.

The area of habitat occupied by *Campylopus* moss in Bermuda can be increased by liaising with local NGOs undertaking wetland restoration projects to experimentally translocate colonies of moss to new suitable areas. The Bermuda Palmetto forests on Trunk Island (owned by the Bermuda Zoological Society) and at the Butterfield Nature Reserve (owned by the Bermuda National Trust) might make good test areas, however they are drier than the Palmetto forest of Paget Marsh. The interior woodland of Nonsuch Island would also be a potential trial introduction area. Due to their preference for open habitat, *Campylopus* species make suitable pioneer species in open habitats (Frahm, 1991), which may make it a good candidate for introduction to the recently burned wetland at Devonshire Marsh.

There is literature on translocation and artificial propagation of bryophytes for conservation purposes, should these actions become necessary. *Ex situ* conservation of mosses in botanic gardens, and spore and gene banks has been undertaken successfully in Europe (Hallingbäck and Hodgetts, 2000; Hodgetts et al., 2019). The keeping of an *ex situ* collection of *Campylopus bermudianus* at either the Bermuda Botanical Gardens, BAMZ or DENR could be a beneficial way to study its ecology, while at the same time raising public awareness.

E. Step-down narrative of work plan

Abbreviations:
DENR – Department of Environment and Natural Resources
BAMZ – Bermuda Aquarium, Museum and Zoo
BZS – Bermuda Zoological Society
BNT – Bermuda National Trust
BAS – Bermuda Audubon Society
DoP – Department of Parks
BBG – Bermuda Botanical Gardens

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

1. Abundance and distribution mapping

Actions proposed:
- Collaboration with a visiting bryologist to train Bermudians in moss identification
- Confirmation that *Campylopus* moss is extant in Paget Marsh
- Current population estimated through surveys
- Distribution of current population mapped
- Abundance estimate and distribution map revisited every 5 years to establish temporal trends

Work Team: DENR, academic institutions, visiting bryologist

Team Leader: DENR

Assistance: BNT staff, volunteers, students

Outputs: extant status known, current abundance estimated, distribution map, population trend once repeated

Needed Resources: population survey equipment, mapping software, hand-held GPS, field survey team, travel funds and stipend for visiting bryologist

2. Taxonomy and Status Confirmation

Actions proposed:
- Determine native or endemic status through genetic or morphological analysis
- Update Protected Species Order with revised taxonomy and status
- Collect new specimens and photos for Bermuda Natural History Museum
- Establish sharing arrangements or repatriation of preserved specimens and historic records from overseas institutions

Work Team: BAMZ, DENR, academic institutions, museums and herbaria

Team Leader: BAMZ

Assistance: volunteers, graduate students, academic institution with genetic analysis capability, overseas colleagues to process genetic samples, Attorney General's chambers

Outputs: confirmation of local status, policy and legislation updated with new status and taxonomy, BAMZ collection improved, biodiversity database updated

Needed Resources: Funding for collection, shipment and analysis of genetic samples, shipping funds for repatriating museum specimens, herbarium sheet preparation materials, digital camera, specimen databases

3. Ecology and Habitat Assessments

Actions proposed:

- Ongoing monitoring of identified colonies
- Record ecological observations, such as timing of sporangia and recruitment success
- Occupied habitat at Paget Marsh described and mapped
- Include translocated mosses in NGO-led habitat restoration projects and consider introduction to Nonsuch Island

Work Team: DENR, BNT, BAS, BZS, other landowners

Team Leader: DENR

Assistance: students, volunteers

Outputs: persistence of known colonies recorded, phenology and reproduction method recorded, moss habitat described, area of occupied habitat increased

Needed Resources: ecological monitoring team, field survey team for habitat mapping, field team for habitat restoration, land for restoration

4. Threat Mitigation and Awareness

Actions proposed:

- Undertake invasive plant control in Paget Marsh
- Ensure visitors do not touch or trample moss colonies through improved signage
- Safeguard mosses during boardwalk maintenance
- Explore *ex situ* conservation such as spore banking, on-island translocation and public display at the Botanical Gardens and/or an overseas facility
- Relocate moss colonies at risk from water level rise
- Monitor the effects of sea level rise on vegetation in Paget Marsh
- Include mosses in educational materials on wetlands, especially Paget Marsh field trip materials

Work Team: DENR, BNT, BAS

Team Leader: DENR and BNT

Assistance: Dept of Parks (Botanical Gardens), BAMZ, overseas spore banks, volunteers, educators, general public

Outputs: invasive species impacts understood and mitigated, invasive plants removed near moss colonies, invasive plants in Paget Marsh culled regularly, BNT boardwalk maintained, *ex situ* collections established, visitors to Paget Marsh aware of *Campylopus* and its rarity, visitors have no impact on mosses or marsh habitat

Needed Resources: funds to establish and maintain *ex situ* collections, invasive plant culling equipment, volunteer plant cullers, funds to create and distribute awareness materials, funds to create and install signs

F. Estimated Date of Down-listing

Down-listing will be considered when the conservation status of *Campylopus bermudianus* has improved above a baseline established when the implementation of this plan begins. Down-listing can only be considered if the long-term sustainability of the population is achieved. At least 15 years would be needed for population trend monitoring, and to achieve long-term goals. If no specimens of *Campylopus* are found following a comprehensive survey of Paget Marsh, or any other suitable habitat, with guidance from an expert bryologist, then down-listing or de-listing can be considered immediately.

PART III: IMPLEMENTATION

Priority 1: An action that must be taken to prevent extinction or to prevent the species from declining irreversibly.
Priority 2: An action that must be taken to prevent a significant decline in the species population/habitat quality, or some other significant negative impact short of extinction.
Priority 3: All other actions necessary to provide for full management of the species.

Priority #	Task #	Task description	Task Duration	Responsible Party
		Abundance & Distribution		
1	1	Bermudians trained in moss identification	1 month	DENR, visiting bryologist
1	2	Confirmation *Campylopus* is extant	1 year	DENR
2	3	Current abundance estimated through surveys	3 months	DENR
2	4	Distribution mapped	3 months	DENR,
2	5	Abundance and distribution map revisited to establish temporal trends	every 5 years	DENR
		Taxonomy & Status		
1	6	Determine native or endemic status through genetic or other analysis	2 years	DENR, overseas institution
2	7	Update Protected Species Order with revised taxonomy and status	1 year	DENR
3	8	Collect new specimens and photos for Bermuda Natural History Museum	1 year	BAMZ
3	9	Establish sharing arrangements or repatriation of preserved specimens and historic records from overseas institutions	2 years	BAMZ, overseas institutions
		Ecology & Habitat		
1	10	Ongoing monitoring of identified colonies	1 year	DENR, BNT, BAS
2	11	Phenology and other ecological observations	ongoing	DENR, BNT, BAS
3	12	Occupied habitat described and mapped	1 year	DENR
3	13	Translocate mosses to restored habitats and Nonsuch Island	ongoing	DENR, BNT, BZS, BAS
		Threat Mitigation & Awareness		
1	14	Invasive plant control in Paget Marsh	ongoing	DENR, BNT,

				BAS
2	15	Signage to prevent disturbance	1 year	BNT, BAS
1	16	Safeguard mosses during boardwalk maintenance	ongoing	BNT, BAS
3	17	*Ex situ* conservation at spore banks and public display.	ongoing	DENR, DoP, overseas facilities
1	18	Relocate mosses at risk from water level rise	ongoing	DENR, BNT, BAS
3	19	Monitor the effects of sea level rise on vegetation in Paget Marsh	ongoing	DENR, BNT, BAS
3	20	Ensure educational resources on wetlands, and Paget Marsh field trips include mosses	1 year	BNT, BAS, BZS

References

Britton, N.L. 1912. Botanical Exploration in Bermuda. Journal of the New York Botanical Garden. Vol. 13 #156. December, 1912.

Britton, E. G. Mosses. *In*: Britton, N. L. *Flora of Bermuda (Illustrated).* 1918. Charles Scribner's Sons, New York, USA.

Britton, E. G. 1915. Mosses of Bermuda. Bulletin of the Torrey Botanical Club, Vol. 42, No. 2 (Feb., 1915), pp. 71-76.

Copeland, A.I. 2019. Walsingham Trust Nature Reserve: Special features and potential projects. Unpublished report prepared for the Walsingham Trust. Department of Environment and Natural Resources, Government of Bermuda. pp. 16.

Frahm, J-P. 1990. The origin and distribution of Neotropical species of Campylopus. Tropical Bryology 3: 1-18.

Frahm, J-P. 1991. Dicranaceae: Campylopodioideae, Paraleucobryoideae. Flora Neotropica Monograph 54. The New York Botanical Garden, 21 February 1991. Pp.1-237. https://www.jstor.org/stable/4393822?read-now=1&seq=5#page_scan_tab_contents

Frahm, J-P. (ed)., O'Shea, B., Pocs, T., Koponen, T., Piippo, S., Enroth, J., Rao, P., and Fang, Y-M. 2003. Manual of Tropical Bryology. Tropical Bryology No.23.

GBIF.org. 2020. *Campylopus bermudianus* R.S. Williams GBIF Occurrence Download https://doi.org/10.15468/dl.ae5qfd. Downloaded 12 May 2020.

GBIF Secretariat. 2019. *Campylopus trachyblepharon* Mitten, 1869 in GBIF Secretariat (2019). GBIF Backbone Taxonomy. Checklist dataset https://doi.org/10.15468/39omei accessed via GBIF.org 14 May 2020.

Glasspool, A. F., 2008. The Impact of Climate Change on Bermuda. Report Prepared for the Bermuda National Trust. 190 pp.

Hallingbäck, T. and Hodgetts, N. 2000. Mosses, liverworts and hornworts: status survey and conservation action plan for bryophytes. IUCN/SSC Action Plans for the Conservation of Biological Diversity Monographic Series. IUCN, Gland, Switzerland.

Hodgetts, N., Cálix, M., Englefield, E., Fettes, N., García Criado, M., Patin, L., Nieto, A., Bergamini, A., Bisang, I., Baisheva, E., Campisi, P., Cogoni, A., Hallingbäck, T.,Konstantinova, N., Lockhart, N., Sabovljevic, M., Schnyder, N., Schröck, C., Sérgio, C., Sim Sim, M., Vrba, J., Ferreira, C.C., Afonina, O., Blockeel, T., Blom, H., Caspari, S., Gabriel, R., Garcia, C., Garilleti, R., González Mancebo, J., Goldberg, I., Hedenäs, L., Holyoak, D., Hugonnot, V., Huttunen, S., Ignatov, M., Ignatova, E., Infante, M., Juutinen, R.,

Kiebacher, T., Köckinger, H., Kučera, J., Lönnell, N., Lüth, M., Martins, A., Maslovsky, O., Papp, B., Porley, R., Rothero, G., Söderström, L., Ştefănuţ, S., Syrjänen, K., Untereiner, A., Váňa, J. Ł, Vanderpoorten, A., Vellak, K., Aleffi, M., Bates, J., Bell, N., Brugués, M., Cronberg, N., Denyer, J., Duckett, J., During, H.J., Enroth, J., Fedosov, V., Flatberg, K.-I., Ganeva, A., Gorski, P., Gunnarsson, U., Hassel, K., Hespanhol, H., Hill, M., Hodd, R., Hylander, K., Ingerpuu, N., Laaka-Lindberg, S., Lara, F., Mazimpaka, V., Mežaka, A., Müller, F., Orgaz, J.D., Patiño, J., Pilkington, S., Puche, F., Ros, R.M., Rumsey, F., Segarra-Moragues, J.G., Seneca, A., Stebel, A., Virtanen, R., Weibull, H., Wilbraham, J. and Żarnowiec, J. (2019). A miniature world in decline: European Red List of Mosses, Liverworts and Hornworts. Brussels, Belgium: IUCN

O'Shea, B.J. 2003. A Guide to collecting bryophytes in the tropics. *In*: Frahm, J-P. (ed)., O'Shea, B., Pocs, T., Koponen, T., Piippo, S., Enroth, J., Rao, P., and Fang, Y-M. 2003. Manual of Tropical Bryology. Tropical Bryology No.23.

O'Shea, B. J. 2009. A new view of Bermuda's mosses. Archive for Bryology, 57 (2009). pp.3.

Shailer, M. 2018. Beyond the Fire: Aerial Surveys of Devonshire Marsh. Envirotalk Newsletter Summer 2018. Vol. 82#2. Department of Environment and Natural Resources, Bermuda.

The Plant List. 2020. *Campylopus bermudianus* R. S. Williams. The Plant List: A working list of all plant species, Version 1.1. Downloaded May 12th 2020. http://www.theplantlist.org/tpl1.1/record/tro-35154565

Thomas, M.L. 2004.The Natural History of Bermuda (1st edition). Bermuda Aquarium Museum and Zoo and the Bermuda Zoological Society publication. BBP contribution #69. Brimstone Media. pp255.

Tropicos.org. 2020. Missouri Botanical Garden. 14 May 2020. http://www.tropicos.org/Specimen/90198649

UKOTCF. 2004. Ramsar Information Sheet UK41004: Paget Marsh. Prepared by the UK Overseas Territories Conservation Forum and the Bermuda Dept. of Conservation Services for the JNCC. Available at: https://environment.bm/ramsar-sites

Williams, R. S. 1913. (Bryales) Dicranaceae, Leucobryaceae. In: North American Flora, Vol. 15, Part 2. The New York Botanical Garden. August 8th 1913.

Wingate, D. B. 1986. Taking Stock of Bermuda's Wetland Heritage. In: D. A Scott and M. Carbonell (eds). Directory of Neotropical Wetlands. IUCN Conservation Monitoring Centre, Cambridge UK.

Appendix 1

Table 1: Summary of herbarium and museum specimens of *Campylopus bermudianus*

Record Type	Herbarium	Institutional ID	Collection Date	Collector	Collection Location	Note	Citation
Preserved specimen	New York Botanical Garden	NY Barcode 619966	February 1908	S. Brown	Paget Marsh	Type specimen	Ramirez J, Tulig M, Watson K, Thiers B (2020). The New York Botanical Garden Herbarium (NY). Version 1.21. The New York Botanical Garden. Occurrence dataset https://doi.org/10.15468/6e8nje accessed via GBIF.org on 2020-05-13.
Preserved specimen	New York Botanical Garden	NY Barcode 619965	22 September 1913	E.G. Britton	Paget Marsh	Mounted with 619964 and 66	Ramirez J, Tulig M, Watson K, Thiers B (2020). The New York Botanical Garden Herbarium (NY). Version 1.21. The New York Botanical Garden. Occurrence dataset https://doi.org/10.15468/6e8nje accessed via GBIF.org on 2020-05-13.
Preserved specimen	New York Botanical Garden	NY Barcode 619964	December 1912	S. Brown	Paget Marsh	Mounted with 619965 and 66	Ramirez J, Tulig M, Watson K, Thiers B (2020). The New York Botanical Garden Herbarium (NY). Version 1.21. The New York Botanical Garden. Occurrence dataset https://doi.org/10.15468/6e8nje accessed via GBIF.org on 2020-05-13.
Preserved specimen	University of Michigan (MICH)	558976	22 September 1913	E.G. Britton	Paget Marsh		
Preserved specimen	University of Michigan (MICH)	558977	22 September 1913	E.G. Britton	Paget Marsh		

Preserved specimen	University of Michigan (MICH)	558979	22 September 1913	E.G. Britton	Paget Marsh		
Preserved specimen	University of Michigan (MICH)	558978	22 September 1913	E. G. Britton	Paget Marsh		
Preserved specimen	University of Michigan (MICH)	525309	10 February 1908	S. Brown	On ground, Paget Marsh	Type specimen duplicate sent from NYBG.	University of Michigan Herbarium (2020). University of Michigan Herbarium. Version 1.12. Occurrence dataset https://doi.org/10.15468/nl8bvi accessed via GBIF.org on 2020-05-13
Preserved specimen	Muséum National d'Histoire Naturelle (MNHN-Paris).	PC0148771	February 1908	S. Brown	Paget Marsh	Type specimen duplicate sent from NYBG.	Citation: Muséum national d'Histoire naturelle, Paris (France) Collection: Cryptogams (PC) Specimen MNHN-PC-PC0148771
Preserved specimen	Canadian Museum of Nature (CMN)	CANM197412	March 1908	S. Brown	On ground, Paget Marsh	Type specimen duplicate sent from NYBG.	Doubt J, Shorthouse D (2020). Canadian Museum of Nature Herbarium. Version 1.133. Canadian Museum of Nature. Occurrence dataset https://doi.org/10.15468/kowta4 accessed via GBIF.org on 2020-05-13.
Preserved specimen	Herbarium Berolinense, Berlin (B)	B 30 0040613	February 1908	S. Brown	On ground, Paget Marsh	Type specimen duplicate sent from NYBG.	Image should be cited as: Curators Herbarium B (2000+). Digital specimen images at the Herbarium Berolinense. [Dataset]. Version: 13 May 2020. Data Publisher: Botanic Garden and Botanical Museum Berlin. http://ww2.bgbm.org/herbarium/ [https://herbarium.bgbm.org/object/B300040613, image ID: 409620.
Preserved specimen	Herbarium Berolinense, Berlin (B)	B 30 0213307	22 September 1913	E. G. Britton	Paget Marsh	Isotype. Determined *C. trachyblepharon*	Image should be cited as: Curators Herbarium B (2000+). Digital specimen images at the Herbarium Berolinense. [Dataset]. Version: 13

							May 2020. Data Publisher: Botanic Garden and Botanical Museum Berlin. http://ww2.bgbm.org/herbarium/ [https://herbarium.bgbm.org/object/B300213307, image ID: 410152.]
Preserved specimen	Academy of Natural Sciences Philadelphia (PH)	PH00003260	Nov. Dec. 1912	S. Brown with N.L Britton and F. j Seaver	Paget Marsh	Type? Stored *C. bermudianus.* Verified J.C. Lendemer 2007/01 *C. trachyblepharon* (Mull.Hal)Mitt. Verified M.S. Ussher 2011/08/22	
Preserved specimen	University of Cincinnati (CINC)	Cinc-b-0013844	6 March 1908	S. Brown	On ground, Paget Marsh	Type specimen duplicate sent from NYBG.	
Preserved specimen	University of Cincinnati (CINC)	Cinc-b-0013842	22 September 1913	E. G. Britton	Paget Marsh	Duplicate sent from NYBG	
Preserved specimen	University of Cincinnati (CINC)	Cinc-b-0013843	22 September 1913	E. G. Britton	Paget Marsh	Duplicate sent from NYBG	
Preserved specimen	Miami University (MU)	000217101	Nov. Dec. 1912	S. Brown with N.L Britton and F. J Seaver		Duplicate sent from NYBG	
Preserved specimen	University of Wisconsin	WIS-B-0042767	Nov. Dec. 1912	S. Brown with N.L Britton	Paget Marsh	Duplicate sent from NYBG. Filed as	

	Madison (WIS)			and F. J Seaver		*Campylopus trachyblepharon*	
Preserved specimen	Michigan Technological University Cryptogamic Herbarium (MCTC)	Mctc-b-0005775 Mctc-b-0005776	22 September 1913	E. G. Britton	Paget Marsh	Duplicate sent from NYBG	
Preserved specimen	Missouri Botanical Garden (MO)	90198649	22 September 1913			*Campylopus trachyblepharon*	Magill B, Solomon J, Stimmel H (2020). Tropicos Specimen Data. Missouri Botanical Garden. Occurrence dataset https://doi.org/10.15468/hja69f accessed via GBIF.org on 2020-05-13.
Preserved specimen	Missouri Botanical Garden (MO)	90198648	29 Nov 1912				Magill B, Solomon J, Stimmel H (2020). Tropicos Specimen Data. Missouri Botanical Garden. Occurrence dataset https://doi.org/10.15468/hja69f accessed via GBIF.org on 2020-05-13.
Notation	Duke University Herbarium Bryophyte Collection (DUKE)	273969	11 August 2006	Scott A. LaGreca	Paget Marsh east, 100m from boardwalk	Describes collected *Riccardia sp*. As: "At base of fern, under palmetto. Overgrowing *Campylopus bermudianus*"	Consortium of North American Lichen Herbaria (CNALH). 2020. http//:bryophyteportal.org/index.php. Accessed on May 14, 2020.
Photographs	Bermuda Natural History Museum (BAMZ)	270103078, 270103080, 270103086	2003		Paget Marsh		