Conservation Approach
for
Goblin fern (Botrychium mormo, W. H. Wagner)

USDA Forest Service, Eastern Region

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This Conservation Approach was prepared using current published and unpublished information to propose measures to conserve the subject taxon. It does not represent a management decision by the U.S. Forest Service. Though the best scientific information available was used and subject experts were consulted in preparation of this document, it is expected that new information will arise. In the spirit of continuous learning and adaptive management, if you have information that will assist in conserving the subject taxon, please contact the Eastern Region of the Forest Service Threatened and Endangered Species Program at 310 Wisconsin Avenue, Suite 580 Milwaukee, Wisconsin 53203.

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1. Executive Summary

Botrychium mormo (Goblin fern) is a small species of moonwort found in rich hardwood forests in the northern portions of Minnesota, Wisconsin, and Michigan, and one site in Quebec. *B. mormo* is state-listed as Endangered in Wisconsin, Threatened in Michigan, Special Concern in Minnesota, and is a Regional Forester Sensitive Species for Region 9 of the Forest Service. *B. mormo* is known to occur on five National Forests: the Chippewa (116 sites), the Superior (2 sites), the Chequamegon-Nicolet (61 sites), the Ottawa (2 sites), and the Hiawatha (1 site).

This document uses the best available information to suggest conservation measures to promote the persistence of this species on National Forest lands. Although there may be sufficient habitat and known populations on the Chippewa and Chequamegon-Nicolet National Forests to maintain a high likelihood of persistence in the short-term, the likelihood of long-term persistence of this species is threatened by habitat loss due to exotic earthworms. Conservation measures seek to reduce effects to *B. mormo* from land management activities, and help prevent the spread of exotic earthworms in *B. mormo* habitat.

Based on information from the Goblin fern Population Habitat Viability Assessment (PHVA) for the Goblin Fern (Berlin et al., 1998) and further contacts with species experts, the following conservation measures summarize the recommendations of the Goblin fern Team. It is expected that forests will use discretion in applying these measures depending on local life history needs, habitat, distribution, and associated threats. By definition, conservation strategies are not complete until implemented through individual Forest Plans. Conservation approaches are typically incorporated as new information at the project level until forest plans are amended or revised.

<u>Conservation measures:</u>

1. Eliminate activities that threaten *Botrychium mormo* populations, and manage the habitat of known *B. mormo* sites to promote a high likelihood of persistence of Goblin fern populations. Activities that can threaten *B. mormo* populations and habitat are discussed in Section 7.

   Recommendations: Activities which could disturb *Botrychium mormo* plants, their habitat, or microhabitat should not occur within 250 feet[1] of *B. mormo* populations. The extent of *B. mormo* populations will be determined by a Botanist, Biologist, Ecologist, or other qualified observers (technicians or contractors) designated by a Botanist, Biologist, or Ecologist.

   In suitable habitat that is immediately adjacent and contiguous to existing populations beyond the 250-foot no-activity zone, site disturbing activities should occur only during frozen ground conditions; or where that is not possible, ten inches or more of protective snow cover should be in place to eliminate site disturbance. In addition, a minimum canopy closure of 70% should be maintained.

   On the Chippewa and Chequamegon-Nicolet National Forests, this measure will not apply in cases where a population has been extirpated due to exotic earthworms. A population will be judged as extirpated when all of the following three conditions are met: (1) The O horizon of the soil profile has been eliminated due to earthworm activity (not including leaf fall within the last year); (2) A thorough survey by a qualified observer during an appropriate time for 5 consecutive years has failed to detect any *B. mormo* plants; or a below ground extraction/examination indicates that there are no gametophytes or underground sporophytes existing or developing; (3) A Biological Evaluation[2] indicates that the population is likely extirpated. There should be no exception for earthworm-impacted *B. mormo* sites on the Hiawatha, Ottawa, and Superior National Forests. *Botrychium mormo* is known from too few sites on these forests to risk impacting any current or historic sites.

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[1] The January 2000 Population Viability Assessment on upland forested ferns, offered 250 feet as a distance of edge effects. See Section 7b, Threats from Forestry Practices.

[2] A Biological Evaluation is "A documented Forest Service review of Forest Service programs or activities in sufficient detail to determine how an action or proposed action may affect any threatened, endangered, proposed, or sensitive species" (Forest Service Manual 2670.5).

2. Make efforts to control or minimize the spread of exotic earthworms.

 Recommendations: *Botrychium mormo* habitat, and apparently non-occupied potential habitat, as described in this document, should be analyzed for worm invasion potential. An area will be considered to have a lower worm invasion potential if it is far from existing worm populations, or is geologically isolated from worms by wetlands or some other condition that is not conducive to worm colonization. In addition, it would typically be void of roads and trails, developments, and lakes and streams that support game fish. Areas identified as having a low potential for earthworm invasion should be managed to minimize the likelihood of invasion. Worm introduction factors to be managed include transport of worms, eggs and cocoons in soils through movement of soils in potted plants, soil packed on heavy equipment or on off-road vehicles or their tires, soil packed on livestock hooves, or transport of worms as fishing bait.

 Each Forest should promote public awareness of the threats exotic earthworms pose to native ecosystems. The Forests should encourage measures such as proper disposal of angler worms and off-road vehicle cleaning which may help to reduce the spread of exotic earthworms.

These conservation measures should not be interpreted as an exemption from any National Forest policies concerning field surveys for listed species prior to management activities.

2. Introduction and Objectives

Goblin fern is a small species of moonwort endemic to the northern portions of Minnesota, Wisconsin, and Michigan, and one site in Quebec[3]. The scientific name is *Botrychium mormo*, and the species was first described by W. H. Wagner in 1981. *Botrychium mormo* is state-listed as Endangered in Wisconsin, Threatened in Michigan, and Special Concern in Minnesota. It is a Regional Forester Sensitive Species for Region 9 of the Forest Service. The species is assigned a G3 Global rank (globally rare or uncommon) and a N3 National Rank (nationally rare or uncommon) by the Association for Biodiversity Information (2001).

Sensitive species are defined by the Forest Service Manual (FSM) section 2670.5 as "Those plant and animal species identified by the Regional Forester for which population viability is a concern, as evidenced by: (a) significant current or predicted downward trends in population numbers or density or (b) significant current or predicted downward trends in habitat capability that would reduce a species' existing distribution." The objectives for managing sensitive species are to ensure their continued viability throughout their range on National Forest lands, and to ensure that they do not become threatened or endangered because of Forest Service activities (FSM 2670.22). The management of sensitive species is rooted in requirements of the National Forest Management Act and Forest Service policy that requires National Forest lands be managed to maintain viable populations of all native plant and animal species (36CFR 219.19).[4] A viable population is one that has the estimated numbers and distribution of reproductive individuals to ensure the continued existence of the species throughout its existing range within the planning area (FSM 2670.5-22).

To preserve the viability of *Botrychium mormo*, the National Forests have so far adopted a method of protection similar to that of other sensitive species: When a project is proposed that may affect suitable habitat, then a survey is conducted. If a population is found, then a buffer of various definitions is placed around the population, and mitigation measures or design criteria are implemented. These measures often exclude activity from the vicinity of the population.

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[3] The Association for Biodiversity Information (2001) reports that *Botrychium mormo* is known from Quebec, Canada. Jacques Labrecque with the Quebec Natural Heritage Data Center reports that the species is known from one collection, made by Herb and Florence Wagner in 1990 (Labrecque, personal communication, 2000). This site was not reported in their treatment of *Botrychium* in the Flora of North America (Wagner and Wagner, 1993).

[4] National Forest Management Act Regulations state, "Fish and wildlife habitat shall be managed to maintain viable populations of existing native and desired non-native vertebrate species in the planning area" (Title 36, part 219.19). USDA Regulations state "Habitats for all existing native and desired non-native plants, fish, and wildlife species will be managed to maintain at least viable populations of such species" (USDA Regulation 9500-004). The Forest Service Manual states, "Maintain viable populations of all native and desired nonnative wildlife, fish, and plant species in habitats distributed throughout their geographic range on National Forest System lands" (FSM 2670.22-2).

The Forest Service is directed to "develop and implement conservation strategies for populations and /or habitat of sensitive species so that species do not trend towards federal or endangered status because of Forest Service activities" (FSM 2670.22). The Forest Service Manual says further, "Develop and implement management objectives for populations and/or habitat of sensitive species" (FSM 2670.22-3). The Forest Service develops these management objectives through the conservation assessments, conservation strategies, and conservation agreement process. Region Nine includes conservation approaches as an interim step until Conservation Stategies are implemented through individual forest plans.

> *A conservation assessment* is defined as "The analysis and documentation of the current status and distribution of a species, species group or ecosystem" (FSM 2672.05, R9 Amendment). The Forest Service Manual states, "The conservation assessment defines what is needed to develop a plan to conserve the species or ecosystem (e.g. a recovery or conservation strategy)" (FSM 2672.11, R9 Amendment).
>
> *Conservation approaches* use the information gathered in conservation assessments to prepare interdisciplinary analysis to document a suggested array of interim conservation measures to be applied on National Forest system lands. Conservation measures serve to correct or mitigate the threats or limiting factors identified in the Conservation Assessment. Each National Forest must determine approaches that are appropriate based on their individual management situation. Conservation approaches are typically incorporated at the project level until Forest Plans are amended or revised, if needed.
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> *A conservation strategy* is defined as "The documentation of the management actions designed to conserve a species, group or ecosystem" (FSM 2672.05, R9 Amendment). The Forest Service Manual elaborates, "The conservation strategy uses the information provided in the conservation assessment to establish conservation objectives and develop management actions designed to accomplish those objectives. A conservation strategy is complete when adopted through appropriate forest planning processes or determined to be consistent with existing plans" (FSM 2672.11-6, R9 Amendment).
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> *A conservation agreement* is defined as, "A formal agreement that is developed with one or more cooperating agencies or groups that identifies how a conservation strategy will be implemented." (FSM 2672.05, R9 Amendment). The Forest Service Manual states, "The conservation agreement clarifies how actions to be taken by the various agencies or groups within the agreement may conserve the species, species group, or ecosystems" (FSM 2670.11-7, R9 Amendment).

The Chippewa National Forest developed a conservation strategy for *Botrychium mormo* in 1994 (Casson et al., 1994). The document recognized a lack of information concerning this plant and recommended a protective strategy for known populations. It also identified information needs and action items considered necessary for conservation of the species. These included continued inventory of potential habitats, identification and description of preferred habitat, a study to determine the species' response to habitat changes related to timber harvest, monitoring of known populations, and a Forest Plan amendment to incorporate protective measures as direction. A plan amendment was initiated in 1994 but was not ultimately completed. In 1995, the Chippewa National Forest received an appeal on a timber sale decision because it used the recommendations in the conservation strategy without formalizing them with an amendment. The appeal-reviewing officer determined that the recommendations in the conservation strategy could be considered and used to protect and manage the species as long as they were not used consistently as to imply Forest direction. The Forest was advised that continued use of the recommendations without a plan amendment would result in the next appealed decision being remanded.

As a result of these events a meeting on "Population and Habitat Viability Assessment" (PHVA) for the Goblin Fern was held in Walker, Minnesota, on October 6 to 9, 1997. The meeting was sponsored by the USDA Forest Service, the Minnesota Department of Natural Resources, and the Institute for Sustainable Natural Resources, in collaboration with the Conservation Breeding Specialist Group. Twenty eight people attended this meeting representing various organizations, including authorities on goblin fern ecology from thoughout its range. The meeting contained four working groups:

1. Population life history and viability working group
2. Threats and risk working group
3. Management and social issues working group
4. Distribution and status working group.

The Final Report from this meeting was released in January 1998 (Berlin et al., 1998), and this document serves as the Conservation Assessment for *Botrychium mormo*.

Although many of the initial questions concerning *Botrychium mormo* have been addressed, many others remain, particularly concerning threats and risk factors. Management of this species has become a contentious issue due to threats and risk factors, biology of the species, and impacts of its conservation on other management activities. The PHVA was approached as a Regional effort, addressing the species' viability range-wide. With the accumulated information since 1994, the conservation strategy developed by the Chippewa National Forest is considered outdated and obsolete.

The objective of this conservation approach is to recommend measures for the conservation and management of *Botrychium mormo* to promote the persistence of the species on National Forest lands throughout its range. This approach summarizes available knowledge concerning *B. mormo*, discusses threats to its persistence, and provides conservation measures. It is expected that national forests with known populations of this species will incorporate conservation measures into their forest plans to facilitate the conservation of this species. Measures need to be taken to attempt to ensure the future viability of *B. mormo*, but because of the many questions yet unanswered, this conservation approach may be updated and revised as new information becomes available.

This conservation approach follows the suggested outline for conservation strategies in the Region 9 Amendment to the Forest Service Manual (FSM 2672.11-6).

3. Distribution and Status

During August and September 2000, Natural Heritage Programs and National Forests from Minnesota, Wisconsin, and Michigan provided occurrence information for *Botrychium mormo*. Table 1 gives the summary of occurrences by state and ownership.

Table 1. Summary of *Botrychium mormo* occurrence by State or Province and Ownership. Plants have not been located at "historic" sites since the 1950's. The State totals, in bold, do not include historic sites.

Minnesota	**162**
County	5
Indian Reservation	5
National Wildlife Refuge	5
Chippewa National Forest	116
Superior National Forest	2
Private	16
State	11
Unknown	2
Wisconsin	**74**
Chequamegon-Nicolet National Forest	61
County	6
Private	7
Historic	3
Michigan	**3**
Ottawa National Forest	2
Hiawatha National Forest	1
Historic	8
Quebec	**1**
Private	1

Wagner and Wagner (1993) discuss the similartities and differences between *B. mormo* and the western species *B. montanum*. They stated that "*Botrychium montanum* may come to be recognized as a subspecies of the eastern *B. mormo*." Donald Farrar (Farrar, personal communication, 2000) has compared the genetics of these two species using enzyme electrophoresis and found they share a very high genetic similarity. However, Farrar suggests that the two taxa differ sufficiently in range, habitat, habit, and morphology to warrant distinction, at least at the varietal level.

4. Life History

Botrychium is a genus of ferns in the Order Ophioglossales. Ferns in this group are defined by being homosporous (producing a single type of spore), eusporangiate (with a sporangium that develops from multiple initial cells), and siphonostelic (having a particular type of stem venation). These ferns also possess a leaf that is divided into a fertile segment (the sporophore) and a sterile, vegetative segment (the trophophore). A common stalk of various lengths holds the two leaf segments together.

The life cycle of *Botrychium* is generally similar to that of other ferns. The green, above-ground photosynthetic plant represents one leaf of the sporophyte. Sporophytes are diploid (having two sets of chromosomes) and bear sporangia. Each sporangium produces 2,000 or more spores (Whittier, 1972, 1973; Gifford and Foster, 1989). The spores are the result of meiosis and are therefore haploid (with one set of chromosomes). The spores are released from the sporangia and develop into small, subterranean, haploid gametophytes. Spores require darkness to germinate (Whittier, 1972, 1973). Each gametophyte may bear both sperm-producing organs (antheridia) and egg-producing organs (archegonia). The sperm are multiflaggellate and mobile. When a sperm fertilizes an egg, a diploid sporophyte develops from the resulting zygote. *Botrychium mormo* has a sporophyte chromosome number of 2n=90 (Wagner and Wagner, 1981).

There are three subgenera within the genus *Botrychium* (Wagner and Wagner, 1993): subgenus Osmundopteris (the rattlesnake ferns), subgenus Sceptridium (the grapeferns in a strict sense), and subgenus Botrychium (the moonworts). Rattlesnake ferns and grapeferns often produce sterile leaves (a sterile leaf is a leaf with a trophophore present without a sporophore). Moonworts tend to be smaller than rattlesnake ferns and grapeferns, and the leaves always have both a trophophore and sporophore. Moonwort and rattlesnake fern leaves appear in spring or summer, but die back by the winter, while grapefern trophophores persist through the winter.

Botrychium mormo is a moonwort. The sporophyte is shiny yellow-green and relatively succulent. The total above-ground height is usually less than 8 cm tall. The trophophore is little divided compared with other moonworts, with each trophophore having one to three pairs of lobes (pinnae). These lobes have margins ranging from entire (smooth) to coarsely dentate (toothed). The lobes are usually fused together in the upper portion of the trophophore. Venation on these lobes is like a fan, without a midrib. The sporangia appear partially embedded or sunken within the sporophore stalk. Figure 1 shows four habit variations of *Botrychium mormo*.

There is some disagreement about spore dispersal of *Botrychium mormo*. Although there are some reports that the sporangia do not open (Wagner and Wagner, 1993; Association for Biodiversity Information, 2001), most accounts support that the sporangia open slightly, with a narrow aperture of 15 to 30 degrees (Wagner and Wagner, 1981; Tans and Watermolen, 1997). The succulent nature of the plant and the poor spore dispersal led Wagner and Wagner (1993) to hypothesize that herbivory may be a method of spore dispersal in goblin fern. Tans and Watermolen (1997) reported signs of browse on some plants. Mortensen and Mortensen (2000, personal communication) have observed webbing and apparent herbivory by small caterpillars on plants. In the Conservation Assessment, the Population Life History and Viability working group reported that if spores were released by the sporangia, dispersal would be a few centimeters at best (Johnson-Groh et al., 1998). They thought that the sporangia adaptation suggests that dispersal is primarily by animal ingestion. However, other reports support wind dispersal of spores. Tans and Watermolen (1997) noted, "On mature plants…we observed that at least some of the capsules dehisce and release a miniature yellow-brown spore cloud when bumped." Mortensen and Mortensen (2000, personal communication) have also observed spore release when plants are bumped, but only on an estimated 1 out of 15-20 large, mature plants. Johnson-Groh (personal communication, 2000b) has also observed open sporangia with dispersing spores. For spores released from above-ground sporophytes, spore dispersal should be expected to show a leptokurtic distribution, with most spore deposition near the source but some at significantly greater distances away (Wagner and Smith, 1993; Briggs and Walters, 1997).

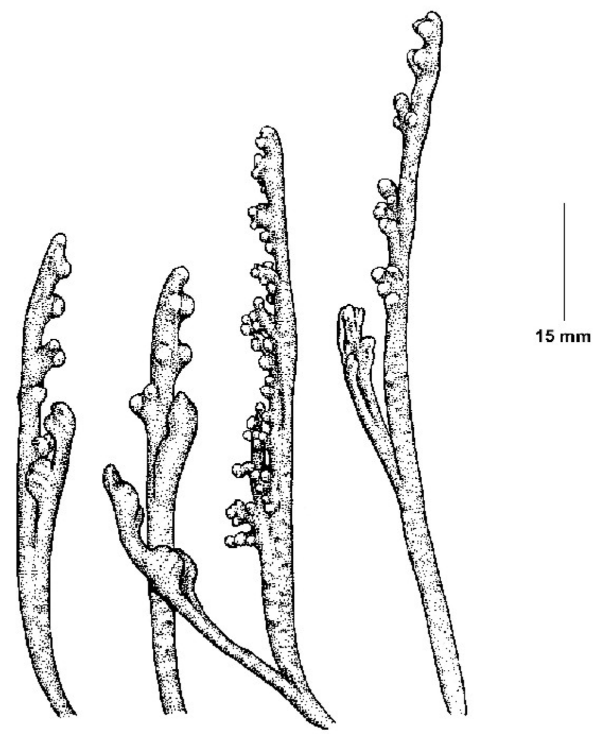

Figure 1. Four forms of *Botrychium mormo.* Original artwork by Paul Nelson, property of Eastern Region, U.S. Forest Service.

After release from the sporangia, spores must percolate into the soil and become infected with mycorrhizae to germinate (Gifford and Foster, 1998; W. H. Wagner, 1998). Whittier (1972, 1973) demonstrated a dark requirement for spore germination in *Botrychium*. After development of the subterranean gametophyte, fertilization may take place. Currently it is believed that most fertilizations take place by inbreeding (Farrar, 1998). This is based on the proximity of antheridia and archegonia on the same gametophyte, and the lack of genetic variation observed by enzyme electrophoresis (Farrar and Wedel, 1996). Farrar (1998) states that the reproductive cycle of *B. mormo* is essentially equivalent to vegetative reproduction. Between-gametophyte fertilizations may occur at a low frequency (Johnson-Groh et al., 1998). The existence of sterile interspecific hybrids for some species of *Botrychium* (W. H. Wagner, 1998) supports that *Botrychium* sperm are capable of swimming from one gametophyte to another and accomplishing fertilization.

The whole sporophyte develops underground from the fertilized egg within the gametophyte. The stem and roots of *Botrychium mormo* (and all species of *Botrychium*) are underground. The stem grows upright and is unbranched. The leaves develop at the top of the stem, still below the surface of the soil, with the oldest leaf embracing the next lower leaf within its basal sheath. The roots are fleshy, sparsely branched, and lack root hairs (W. H. Wagner, 1998). Wagner and Wagner (1993) report that the living gametophytes tend to persist on the below-ground sporophytes. Gemmae production from below-ground sporophytes has been observed in some species of *Botrychium* (Farrar and Johnson-Groh, 1990), but not for *B. mormo*.

Both the roots and the gametophyte have a mycorrhizal association, with the mycorrhizae providing some of the nourishment for the plant (W.H. Wagner, 1998; Johnson-Groh, 1998). The fungal associate has been reported to be a vesicular arbuscular mycorrhiza (U.S. Forest Service, 2000). Vesicular arbuscular mycorrhizae penetrate inside the outer plant cells of the roots and gametophyte, where they form arbuscules, which transfer nutrients and sugars between the fungi and host plant (Brady and Weil, 1999). The species of the fungal associate has not been identified.

Population size is measured by the number of above-ground sporophytes. On the Chippewa National Forest, the number of above-ground sporophytes was recorded for 116 populations. 18% of the populations were a single above-ground sporophyte, 36% were from 2 to 5 above-ground sporophytes, 25% were from 6 to 20 above-ground sporophytes, 18% were from 21 to 100 above-ground sporophytes, and 3% were greater than 100 above-ground sporophytes. This measure does not include underground sporophytes or gametophytes. Dr. Cindy Johnson-Groh has developed a technique for extracting *Botrychium* gametophytes and below-ground sporophytes from soil samples. She has documented up to 7000 gametophytes and 250 non-emergent sporophytes per square meter of soil in *Botrychium* populations (Johnson-Groh, 1998). Although some of these may have belonged to the common species *Botrychium virginianum*, the results show that presence of above-ground sporophytes indicate a larger number of below-ground sporophytes and gametophytes. The large numbers of below-ground sporophytes and gametophytes, along with the life-cycle features discussed above, suggests that a single above-ground sporophyte may be evidence of a self-sustaining population at that site (Johnson-Groh, 1998; Johnson-Groh et al., 1998).

Dr. Johnson-Groh, the Leech Lake Division of Resource Management, the Chippewa National Forest, and other researchers and land managers have conducted annual monitoring of *Botrychium mormo* populations. Monitoring has shown that any given *B. mormo* below-ground sporophyte may or may not produce an above-ground leaf in any given year. When an above ground leaf is produced, one leaf per year per plant is developed, with leaves appearing in summer or fall[5]. Phenological monitoring by Johnson-Groh (1998) showed that population size peaks in mid June, but that the largest plants occur in late September. Most plants do not produce above-ground sporophytes more than two consecutive years (Johnson-Groh, 1998). Gaps in leaf production by individual plants are generally one to three years, with a record of six years (Johnson-Groh, 1998; Tans and Watermolen, 1997). Underground sporophytes often develop small leaves that do not emerge from leaf litter (Wagner and Wagner, 1981; Johnson-Groh, 1998).

Johnson-Groh (1998) has also studied the effects of herbivory, fire, and collection on *Botrychium* populations. One might expect that loss or damage to leaves, and the resulting loss in photosynthetic output, would decrease plant vigor in subsequent years. However, her studies showed that leaf loss had no effect on the subsequent return of the plant. The abundance of non-emergent sporophytes, and the lack of effect from harvesting of emergent plants, suggests that *B. mormo* depends relatively little on photosynthesis. Mycorrhizae alone appear to supply a significant amount of the plant's nutrients and energy (Johnson-Groh, 1998).

The Population and Habitat Viability Assessment (Berlin et al., 1998) included a "Population life history and viability" working group. Participants were Cindy Johnson-Groh, John Casson, June Dobberpuhl, Don Farrar, Ann Hoefferle, Henry Peters, Herb Wagner, Florence Wagner, Candy Westfield, and Paul Miller. The group reviewed the life cycle of *B. mormo*, developed a population model, and made management recommendations.

The population model was developed by Dr. Cindy Johnson-Groh. The purpose of the model was to review the population dynamics of the species and to assess the impact of changes to population variables. For example, the model can be used to predict how a population may respond if spore set is decreased by 80% for three consecutive years. The model depends on certain input variables, including number of spores in the soil spore bank, number of gametophytes in the soil, number of juvenile below-ground sporophytes, number of adult above-ground sporophytes, carrying capacity, and frequency of catastrophes. Values for each of these variables were based upon population studies by Dr. Johnson-Groh and observations by other biologists. The model is a stage-based model developed using a RAMAS/Stage software package.

Results of the population model showed a strong capacity for annual population growth. Spore set, spore germination, and development of gametophytes into juvenile belowground sporophytes had the greatest influence on population growth rate. Johnson-Groh noted that these are the life cycle transitions about which the least is known. Drought models were created to study the long-term effects of a one-year decrease in population stages. If a drought only reduces the number of spores produced per sporophyte, then there is little effect on simulated population viability. Underground stages of the life cycle can buffer the impacts to the population when environmental conditions decrease the number of above-ground sporophytes. If a drought affects other life stages, then there are greater impacts on population growth. For example, if a drought kills 75% of all individuals in all non-spore stages, then a population with carrying capacity of five plants faces a 10% risk of extinction. The model also emphasized that demographic stochasticity could influence long term population growth rate: "A population's average long-term deterministic growth rate may be positive, but it may actually have some risk of extinction if the variation in

[5] Johnson-Groh et al. (1998) reported that *Botrychium mormo*, unlike most *Botrychium* species, has been known to produce more than one sporophyte from the same gametophyte within one growing season.

vital rates is sufficiently large. This is particularly true for smaller populations or in those species with wide fluctuations in vital rates brought on by environmental fluctuation" (Johnson-Groh et al., 1998).

From a metapopulation perspective, it is indeed likely that some *B. mormo* populations become extinct under normal conditions. Johnson-Groh (2000b) considers *Botrychium* populations temporary in nature, with populations continuously colonizing in some locations and dying out in others. Population death may occur as a natural progression of site changes in physical characteristics, pathogens, predators, competition, etc. (Farrar, 2000). Johnson-Groh's data on *B. mormo* suggests that "some populations of *B. mormo* are stable and can be considered source populations. Other populations are small and vulnerable to extinction. Periodic recolonization from the main (source) populations might rescue those populations or they might perish" (Johnson-Groh, 2000b). Farrar (2000) concludes that "it becomes important not only to protect current populations as spore sources, but also to protect unoccupied appropriate habitat for establishment of new populations in sites free of those conditions that caused population death."

5. Habitat

Botrychium mormo is restricted in range to the northern forests of Minnesota, Wisconsin and Michigan, with one site in Quebec. The geographic range includes five national forests: Chippewa, Superior, Chequamegon-Nicolet, Ottawa, and Hiawatha. Within this restricted range, it occurs only within specific habitats defined by forest community and soils.

In general, habitat for *B. mormo* consists of deep leaf mold on shaded forest floors under mid-aged or older deciduous forest, dominated by northern hardwood species and with a relatively closed canopy (Wagner and Wagner, 1993; Tans and Watermolen, 1997; Johnson-Groh et al., 1998). The roots of *B. mormo* have an association with mycorrhizal fungi, which provide some of the nourishment for the plant (see Section 4, Life History). Mycorrhizal fungi are influenced by the soil community in which they occur (Allen, 1991). Therefore, the *B. mormo* mycorrhizae may also depend on the deep organic layer of the forest soil.

The mycorrhizae also allow mature *B. mormo* plants to remain covered by the thick duff layer characteristic of the habitat. *B. mormo* plants can remain underground for several years until conditions are appropriate for leaf emergence and reproduction (Johnson-Groh, 1998). These adaptations make it difficult to comprehensively inventory and assess the status of this plant (see Section 4, Life History). Nevertheless, focusing on key habitat features can help identify the presence of *B. mormo* populations. Survey efforts have resulted in a current total of 240 known populations (see Section 3, Distribution and Status).

Forest communities that provide *B. mormo* habitat are typically dominated by sugar maple (*Acer saccharum*) and basswood (*Tilia americana*). Among the other woody plants are *Ulmus americana*, *Ribes cynosbati*, *Fraxinus nigra*, *Prunus virginiana*, *Dirca palustris*, *Ostrya virginiana*, and *Lonicera canadensis*. Numerous species comprise the herbaceous layer. These include *Asarum canadense*, *Caulophyllum thalictroides*, *Aralia racemosa*, *Actaea rubra*, *Arisaema triphyllum*, *Polygonatum pubescens*, *Osmorrhiza claytonii*, *Uvularia grandiflora*, and *Anemone quinquefolia*. Associated ferns and fern allies include *Athyrium angustum*, *Botrychium lanceolatum*, *B. matricariifolium*, *B. mingananese*, *B. oneidense*, *B. virginianum*, *Matteucia struthiiopteris*, *Equisetum pratense*, and *Gymnocarpium dryopteris*. Invasive plant species are usually absent (Johnson-Groh et al., 1998).

To help define *B. mormo* habitat on the Chippewa National Forest, John Almendinger (2000) examined relevé data from the "Northern Minnesota Drift and Lake Plains" section of Minnesota (Minnesota Department of Natural Resources, 2000). Relevé plots are a type of community sampling, where many different physical and biological measurements are collected from plots located throughout the study area (Barbour, Burk, and Pitts, 1987). Relevé plots are being used by the Minnesota Department of Natural Resources to classify and map forest habitats in Minnesota (Almendinger and Hanson, 1998). Out of 2196 relevé plots within this section, 65 plots contained *B. mormo* (many of these were known *B. mormo* sites beforehand). Sixty-four of these were within the "Mesic Hardwood System" (Almendinger and Hanson, 1998). There are five different plant communities within the Mesic Hardwood System in this section of Minnesota. Table 2 lists how many *B. mormo* occurrences are known within each of these communities.

Table 2. Number of *Botrychium mormo* occurrences within the communities of the Mesic Hardwood Forest System in Minnesota. Forest communities and descriptions are from Almendinger and Hanson (1998).

Forest Community	**Description**	**Number and percent of occurrences of *B. mormo***
Mesic Oak Forest	Fire-tolerant, multiple-aged, brushy, oak/birch/aspen forests of well-drained sandy/gravelly over clayey/loamy soils, undulating to steeply rolling habitats	no known occurrences in 182 relevés
Mesic Boreal Hardwood Forest	Fire-tolerant, multiple-aged, brushy, oak/birch/maple/aspen forests of well-drained sandy loam soils over clayey/loamy soils, undulating to steeply rolling habitats	2 known occurrences in 187 relevés (1%)
Mesic Northern Hardwood Forest	Fire-sensitive, all-aged, open, maple/basswood/ironwood/birch forests of well- to moderately-well drained loamy soils over clayey/loamy soils, undulating to moderately rolling habitats	26 known occurrences in 302 relevés (9%)
Rich Hardwood Forest	Fire-sensitive, all-aged, open, maple/basswood/ironwood/yellow birch forests of well- to moderately-well drained silty/loamy soils over clayey soils, undulating to moderately rolling habitats	30 known occurrences in 135 relevés (22%)
Lowland Hardwood-Conifer Forest	Fire-sensitive, all-aged, brushy, aspen/fir/birch forests of somewhat poorly drained loamy soils over clayey soils, flat to moderately rolling habitats	6 known occurrences in 269 relevés (2%)

John Almendinger concluded the following:

> *Botrychium mormo* habitat is best defined by the Rich Hardwood Forest community. The composition, structure, and soil conditions typical of this community may be used to describe the general habitat of goblin ferns. The occasional occurrence of goblin ferns in the Mesic Northern Hardwood Forest community probably results from the fact that this community grades into Rich Hardwood Forest, and these two communities can occur side-by-side in some landscapes. Alternatively, the richer microhabitats of Northern Hardwood Forest (moist swales) may account for the occurrences within this type. The sporadic occurrence of goblin ferns in Lowland Hardwood-Conifer community is most likely in microhabitats (slight rises) that are inclusions of richer and better-drained forest within a matrix of this class. The two occurrences in the Mesic Boreal Hardwood community are probably best explained as misclassification of these 2 relevés. The occasional surface fire and sandy soil cap characteristics of this community are inconsistent with what we know about goblin fern habitat.

Almendinger (2000) conducted a second analysis to identify potential plant indicators for the presence and absence of *B. mormo*. A database of relevé plots from 107 stands that have been searched for *B. mormo* was created to calculate plant fidelity and presence values in stands classified as having goblin ferns and those without. Table 3 lists the top fifteen potential plant indicators for the presence of *B. mormo*.

Table 3. Top fifteen potential plant indicators for the presence of *Botrychium mormo* within the Northern Drift and Lake Plains Section of Minnesota (Almendinger, 2000).

Species	Common name	Fidelity[6]	Presence[7]
Tilia americana	Basswood seedlings and saplings	64.21	93.85
Acer saccharum	Sugar maple seedlings and saplings	61.39	95.38
Acer saccharum	Sugar maple trees	63.44	90.77
Carex pensylvanica	Pennsylvania sedge	65.52	87.69
Polygonatum pubescens	Solomon's seal	65.52	87.69
Uvularia grandiflora	Large-flowered bellwort	62.11	90.77
Botrychium virginianum	Rattlesnake fern	65.88	86.15
Tilia americana	Basswood trees	68.35	83.08
Osmorhiza claytonii	Clayton's sweet cicely	63.22	84.62
Prunus virginiana	Chokecherry	66.23	78.46
Aralia nudicaulis	Wild sarsaparilla	62.96	78.46
Oryzopsis asperifolia	Mountain rice-grass	62.96	78.46
Athyrium angustum	Lady fern	64.10	76.92
Ostrya virginiana	Ironwood	64.86	73.85
Botrychium mormo	Goblin fern	100.0	36.92

To help further predict the habitat of *B. mormo*, Almendinger (1997) selected EC&I (Ecological Classification and Inventory) relevé plots that contained sugar maple and were located within the Chippewa National Forest. He then used these to create a detrended correspondence analysis ordination. Ordination is a technique used to summarize sampling data in a graphical form. In this case, each point represents a relevé and the distance between the points represents their degree of similarity or difference. Detrended correspondence analysis is a specific method of ordination that seeks to produce the best unbiased separation of points on axes that are independent of each other (Barbour, Burk, and Pitts, 1987).

The DCA ordination is given in Figure 2. The axes (DCA Axis-2 and DCA Axis-3) are computer-generated combinations of all the relevé data, designed to produce the representative spread of the relevé points. All of the plots contained sugar maple. A cross represents plots that did not contain *B. mormo*, and plots with *B. mormo* are represented by a dot. The plots with *B. mormo* tended to be grouped on one end of the ordination. The relevé plots that scored higher than 200 on DCA axis-2 were considered to have a high probability of supporting *B. mormo* colonies.

The "High probability" region of the DCA ordination contained relevé plots that all occurred in habitat described by Almendinger and Hanson (1998) as the Rich Hardwood Forest Community of the Mesic Hardwood System. This community is dominated by a sugar maple and basswood canopy with yellow birch, paper birch, black ash, green ash and sometimes American elm as minor canopy components. Shrubs provide only 7-14% cover and are dominated by beaked hazel, leatherwood and mountain maple. Almendinger and Hanson (1998) state, "A fairly diverse fern flora is typical of the Rich Hardwood Forest, but they provide just 4-8% cover in the average stand. Lady-fern, present in 83% of the sample stands, provides the most cover when present. Rattlesnake fern is equally frequent, but does not occur in great abundance. This community appears to be good habitat for the entire genus *Botrychium*, in that not only is rattlesnake-fern frequent, but the much rarer goblin fern and matricary grape-fern can often be found with diligent searching in these stands." In addition they state, "Rich Hardwood Forest and Mesic Northern Hardwood Forest are the only two native forest communities within the Northern Minnesota Drift and Lake Plain where thick duff layers accumulate without being periodically removed by fire or floodwater, where the duff has comparably high nitrogen and low lignin content, and where the soils are not waterlogged."

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[6] Fidelity is an expression of a plant's affinity for a group of samples. It is expressed here as a percent based upon the proportion of occurrences in a group divided by all occurrences of the plant. For example, a plant that occurs in 13 relevés where goblin ferns are present and in 3 relevés where goblin ferns are absent has a fidelity of 81.25% ((13/16)*100).

[7] Presence (frequency) is an expression of how often a plant occurs in a group of samples. It is expressed here as a percent based upon the proportion of occurrences in a group divided by the number of relevés in the group. For example, a plant that occurs in 13 of the 64 relevés where goblin ferns are present has a presence of 20.31% ((13/64)*100).

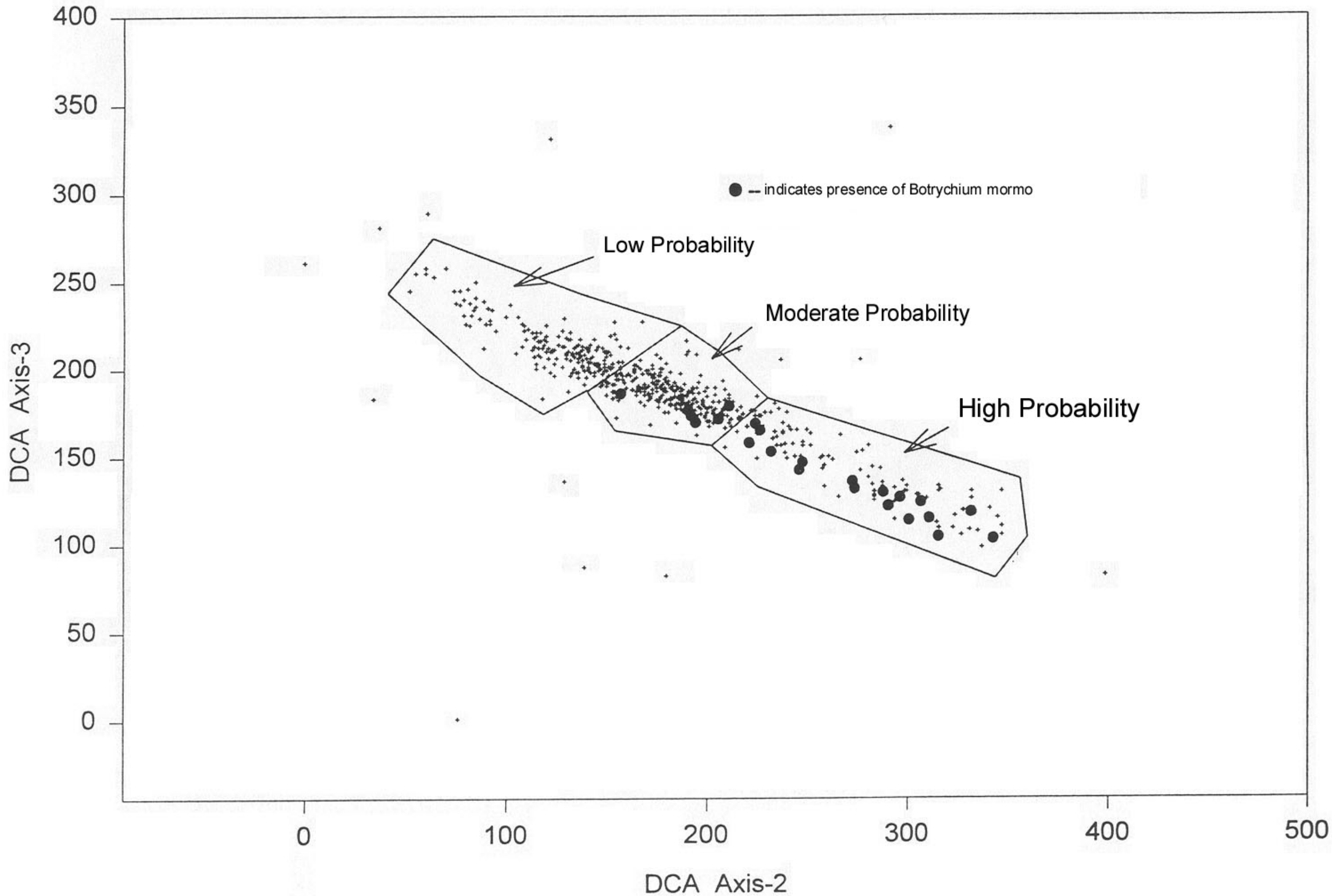

Figure 2. Detrended Correspondence Analysis ordination of 591 relevé plots with sugar maple, within the Chippewa National Forest (Almendinger, 1997). A small cross represents plots that did not contain *B. mormo*, and plots with *B. mormo* are represented by a larger dot. The distance between the points represents the degree of similarity or difference between the biological and physical data collected at that relevé. The axes (DCA Axis-2 and DCA Axis-3) are computer-generated combinations of all the relevé data, designed to produce the representative spread of the relevé points.

Pre-screening sites for rich maple/basswood habitat can increase the likelihood of finding *B. mormo*. Wagner and Wagner (1981) estimated that during their surveys, one in fifty "seemingly suitable sites" yielded specimens. Tans and Watermolen (1997) eliminated all "less than ideal" habitat from their surveys, which resulted in one out of three sites yielding specimens. After the DCA ordination by John Almendinger was created, personnel from the Chippewa National Forest used the ordination as a screen for likely *B. mormo* sites. They re-visited the forty-two relevé plots that were scored as a "high probability" for *B. mormo* (but which were not already known to contain *B. mormo*) and surveyed the associated forest stands. After adjusting the results for stands that had been logged or showed obvious signs of earthworm damage, the survey effort resulted in a 48% success rate for finding *B. mormo*. Considering the cryptic nature and rarity of this species, this ordination appears to be a highly confident predictor of *Botrychium mormo* habitat on the Chippewa National Forest.

Botrychium mormo habitats almost always have a similar soil profile. There is an overlying duff layer (the soil O horizon) composed of old decayed leaves and persistent leaf veins and rachises (Wagner and Wagner, 1981; Johnson-Groh et al., 1998). Below the duff layer is a humus-rich mineral soil of intermediate drainage (Johnson-Groh et al., 1998). Rich Hardwood Forest soils typically have loamy or silty surface textures and a shallow (mean depth 16") horizon of heavy clay or clay loam. This clayey layer restricts the internal, downward drainage of water (Almendinger and Hanson, 1998). Underfoot, the duff layer will make the ground feel moderately spongy.

Several biologists have emphasized that a rich duff layer is a common habitat feature of *B. mormo* populations (Wagner and Wagner, 1981; Tans and Watermolen, 1997; Johnson-Groh et al., 1998; Almendinger and Hanson, 1998). John Almendinger (1995) compared the soil profiles of sugar maple habitat with and without *B. mormo*. He examined 248 relevé plots from the Chippewa National Forest that contained sugar maple. Seven of these plots also contained *B. mormo*. The O horizon in the plots containing *B. mormo* were all greater than 3 inches thick, compared to the remainder of the plots where only 12% had O-horizons greater than 3 inches. The presence of a thick duff layer of hardwood leaves appears to be an important factor of *B. mormo* habitat.

There have been at least two *Botrychium mormo* collections from somewhat unusual habitat. One site, from Pictured Rocks National Lakeshore in Michigan, has plants growing in a loamy sand soil of a mesic deciduous forest. Another site from the Chippewa National Forest in Minnesota has plants growing under white cedar litter in a stand with maple, basswood, and upland white cedar.

6. Relationship to Land Management and Human Activity

The goblin fern has been described as a distinct species for only 20 years. Previously, plants that are now known as *Botrychium mormo* were included in either *Botrychium lunaria* (L.) Swartz or *B. simplex* E. Hitchcock. There is one report of a traditional use for *Botrychium lunaria*. Meeker, Elias, and Heim (1993) report that the bruised roots were applied to cuts. The foremost relationship between the goblin fern and human activities has involved species conservation and land management.

7. Threats

The Threats and Risk Working Group of the Population and Habitat Viability Assessment (PHVA) identified and ranked potential threats to *Botrychium mormo* plants and habitat (Sather et al., 1998). Participants of this group were: Nancy Sather, Chuck Kjos, Carol Mortensen, Jim Gallagher, Steve Mortensen, Carol Leibl, Bob Wolff, Chuck Stone, Sue Trull, and Onnie Byers. With assistance from the Life History Group, the following items were determined to be detrimental to *B. mormo* or its habitat, regardless of the activity causing them, via direct or indirect effects:

1. Soil compaction
2. Loss of soil nutrients
3. Loss of duff layer (O horizons)
4. Loss of darkness provided by the duff layer or forest canopy
5. Changes to moisture regime (drying, such as by canopy removal, or flooding)
6. Changes in soil characteristics (pH, aeration, structure)
7. Inhibition of spore dispersal.

The above items may result from various natural and human activities. These activities may be grouped as follows:

1. Direct threats
2. Habitat changes
3. Direct human activity
4. Other.

Direct threats include activities that would both remove *B. mormo* habitat and likely destroy exiting *B. mormo* above-ground and below-ground sporophytes within activity areas. Such threats could be from construction of roads, trails, right-of-ways, mines, and housing developments. These developments are often permanent fixtures on the landscape once they are built.

Threats from habitat change include those activities that may not directly destroy *B. mormo* plants, but could change habitat from a suitable to unsuitable condition. Habitat change threats include timber harvest and earthworms, both of which are discussed in greater detail below (sections 7a and 7b).

Threats from human activity include off-road vehicle use, dispersed recreation, plant surveys, forest resource gathering, or any activity where a human may pass through a *B. mormo* population. These activities can impact plants and soil, but may leave the habitat otherwise intact. When visiting known or potential *B. mormo* habitat, care is recommended to avoid disturbing the leaf litter or duff (Sather et al., 1998).

Other types of threats may include natural and unnatural changes or disturbances to *B. mormo* and its habitat. Natural threats include events such as drought, floods, wildfire, herbivory, or windstorms. Droughts may become more common due to climate change, floods may become more common due to increased beaver numbers, and herbivory may increase from high deer numbers. However, many of these threats were considered minor by the Threats and Risk Working Group of the PHVA. Some other unnatural threats include competition from non-native plant species such as garlic mustard. Johnson-Groh et al. (1998) noted that invasive plant species are usually absent from *B. mormo* sites. However, the spread of existing non-native invasive plant species, and the potential for new non-native introductions, is a serious threat to many plant habitats and species (Olson, 1999; Westbrooks, 1998).

7a. Threats from Exotic Earthworms

<u>Effects of exotic earthworms on forest soils in the Great Lakes area</u>

During the last ice age, some 18,000 years ago, earthworms were eliminated from the northern portions of the United States and all of Canada. Colonization by native earthworms that survived south of the glaciated zone has been very slow, less than 100 miles in thousands of years (James, 1998; Berlinger, 2000). As a result, the northern portions of the United States and Canada, roughly above 40 degrees latitude, still have no native earthworm populations (Scheu and Parkinson, 1994; Conover, 2000). This zone of North America with no native earthworm populations includes the entire range of *Botrychium mormo*. These northern forest ecosystems have evolved in the absence of earthworms (James, 1990).

With European settlement, European earthworms were introduced to North America. They likely arrived in soil associated with potted plants and sailing ship ballast (Mortensen and Mortensen, 1998). Their movement and colonization of northern forested habitats has been greatly accelerated by humans through horticulture and landscaping practices, use as fishing bait, transport of eggs and cocoons on motorized equipment tires, and deliberate introductions for gardening and fishing bait purposes (Kalisz and Wood, 1995; Berlinger, 2000). Today, European earthworms are widely distributed and so common, that most people have no idea that they are exotics and no concept of their invasiveness. The invasion continues however, as more remote forests that have yet to be infested with earthworms become colonized by spreading infestations.

The occurrence of exotic earthworms and their effects on soil properties has been recognized and studied. Most studies have emphasized the earthworm's role in improving agricultural soils and improvement in growth and production of cultivated plants and trees (Vimmerstedt and Finney, 1973; Stockdill, 1982; T.L. Wagner et al., 1977). Other studies have focused on the earthworm's role in decomposition of organic litter and development of the A horizon in soils from natural ecosystems (Swift et al., 1979; Satchell, 1983; Lee, 1985; Langmaid, 1964; Alban and Berry, 1994).

Earthworms can severely impact the duff and litter layers of forest soil (Hale et al., 1999). The duff layer of the forest floor plays a fundamental role in forest ecosystem function. It is important in forest trophic structure, is the center of nutrient cycling, provides habitat for decomposers, fungi, arthropods and small vertebrates, and provides a seedbed for all forest vascular plants. Mortensen and Mortensen (1998) estimate that it takes leaf litter 3-5 years to break down in a natural forest system. This causes a thick continuum of litter to build up, from whole leaves on the upper surface, to small fragments, to organic humus at the lower levels of the accumulation. With the presence of worms, leaf litter can be broken down in 4 weeks, allowing no build-up (Knollenberg et al., 1985). Vimmerstedt and Finney (1973) introduced *Lumbricus terrestris* (night crawlers) to mine spoil banks and found that they explode in numbers and fully consume the litter layer in less than 5 years.

Langmaid (1964), in one of the first studies of non-native earthworms in forested habitats, compared four sites before and after earthworm invasion. He documented the total transformation of the forest soils over a three-year period due to earthworm colonization. In all four sites, the organic horizons completely disappeared except for freshly fallen litter. The top mineral layer (the A horizon) increased in depth and changed in character due to the addition of earthworms' casts and mixing with adjacent soil layers. The soil B horizon (mineral soil with an illuvial accumulation of organic material) decreased in depth due to mixing with the above A horizon.

The first documentation of an earthworm invasion into a forest ecosystem in Minnesota was by Alban and Berry (1994) while studying the effects of aspen harvest on soil properties at the Cloquet Experimental Forest. Some of their control study plots were invaded during the study resulting in a significant reduction in the litter and duff layers and an increase in A horizon soils. Their study area was near a stream frequented by fishermen and they speculated that escaped bait was the source of the infestation. However, their work focused on changes in soil properties.

Groffman et al. (2000) conducted research on the impacts of earthworms on north temperate forests in New York State. They conducted controlled introductions of earthworms in forest plots and compared forest sites with worms to sites without worms. They concluded that worms "eliminated the forest floor," decreased the carbon to nitrogen ratios (which causes a decline in the ability of forests to retain atmospheric nitrogen), decreased phosphorus in the soil, and decreased fine root biomass.

Table 4 lists earthworm species currently known from hardwood forests in Minnesota. Different worm species have different "ecological strategies" within the soil (Tomlin et al., 1997; Doube and Brown, 1998). Epigeic species live and feed in the duff and litter layers. Endogeic worms burrow laterally and occur below the duff layer and the upper portions of the mineral soil. Anecic species construct vertical burrows, thereby mixing different soil layers and affecting gaseous and water regimes. Hale (1999) has observed a succession of worm invasions. Epigeic worms, such as *Dendrobaena octaedra* and *Lumbricus rubellus* appear to pioneer in forest systems, setting the stage for colonization by other species of endogeic and anecic worms. Habitat preferences suggest that initial degradation of the forest floor by epigeic species may facilitate subsequent invasion by endogeic and anecic species. Which species cause the most damage to forest soils is uncertain. Mortensen and Mortensen (1998) report that in north-central Minnesota, "The large, deep-burrowing night crawler, *Lumbricus terrestris*, seems to be responsible for most of the changes we are now seeing in some forests." Observations by Hale (2000, personal communication) have pointed to *Lumbricus rubellus* as the worm with the greatest impacts to forest soils.

Table 4. Non-native earthworms reported within hardwood forest habitat in Minnesota, Wisconsin, and Michigan. Presence information was provided by Cindy Hale (2000, personal comunication) and Ed Berry (1996, personal communication). Information on ecological strategies is from Tomlin et al. (1995), Doube and Brown (1998), Parkinson and McLean (1998), and Hale (2000, personal communication). Other non-native earthworms within this range, but not necessarily in hardwood habitats, include *Aporrectodea trapezoides, Aporrectodea turgida, and Dendrodrilus rubidus* (Reynolds, 1995).

Scientific name	Ecological strategy	References
Aporrectodea caliginosa	endogeic	Hale (2000)
Aporrectodea rosea	endogeic	Berry (1996), Hale (2000)
Aporrectodea tuberculata	endogeic	Berry (1996), Hale (2000)
Dendrobaenia octaedra	epigeic	Scheu and Parkinson (1994), Reynolds (1995), Hale (2000)

Lumbricus castaneus	epigeic	Berry (1996)
Lumbricus rubellus	epigeic	Alban and Berry (1994), Berry (1996), Reynolds (1995), Hale (2000)
Lumbricus terrestris (night crawler)	anecic	Reynolds (1995), Mortenson & Mortenson (1998), Hale (2000)
Octolasium tyrteum	endogeic	Reynolds (1995), Hale (2000)

Earthworm invasions can also affect numbers of other soil invertebrates. Wolff et al. (1997) sampled sowbugs (*Isopoda*) along a worm infestation front and found a continuum of increasing numbers with increased worm impacts to the soil. They speculate that soil changes created by earthworms facilitate colonization of sites with exotic sowbugs. Sowbugs eat fungi and could also contribute to the loss of mycorrhizal fungi at worm-impacted sites.

Hale et al. (1999) hypothesizes that invading earthworm biomass is highest, and impacts on the plant communities are greatest, in forests with thick forest floors. Invading earthworms appear to be limited by food supply (forest floor) with higher populations where the forest floor is thickest (Satchell, 1983). Earthworm numbers decline as the previously accumulated litter is consumed. Subsequent population levels are litter-regulated and maintain themselves at levels that prevent litter build-up and forest floor reestablishment (Alban and Berry, 1994; Mortensen and Mortensen, 1998). Hale et al. (1999) suggest that European earthworms are incompatible with the survival of many North American hardwood understory species.

John Almendinger (1998) compared six relevé plots with earthworms with six nearby relevé plots without earthworms, all within similar habitat on Ottertail Peninsula on the Chippewa National Forest. The comparison identified several plant species that were present in the worm-free sites and absent from worm-affected sites. He noted 25 species as "apparently killed by worms," 50% of all the species recorded in the relevé plots. *Botrychium mormo* was among the list of plants apparently killed by the worm invasion.

Some plant species have been observed to increase in number after worm invasion. Almendinger (1998) observed blue cohosh (*Caulophyllum thalictroides*), bloodroot (*Sanguinaria canadensis*), yellow birch (*Betula alleghaniensis*), rough-leaved mountain ricegrass (*Oryzopsis asperifolia*), and green ash (*Fraxinus pennsylvanica*) more often in relevé plots with earthworms than in similar nearby plots without earthworms. Cindy Hale has observed that Pennsylvania sedge (*Carex pensylvanica*) and jack-in-the-pulpit (*Arisaema triphyllum*) appear more common in earthworm-infested sites (Hale, personal communication, 2000; Berlinger, 2000). Although some species appear to become more common in earthworm-infested sites, species diversity appears to be greatly reduced. Heavily wormed sites also may contain fewer sugar maple seedlings than non-wormed sites, which may present problems for the long-term forest maintenance of rich hardwood sites (Hale, 2000, personal communication; Berlinger, 2000).

A Forest-wide worm evaluation was conducted on the Chippewa National Forest in 1999. Established ecological classification and inventory plots, which included soil measurements, were revisited and soil measurements were retaken. A sample of 49 plots dominated by deciduous trees was evaluated. All of the plots had been established prior to 1995. Soil measurements from pre-1995 and 1999 were compared to estimate the extent of worm occupation on the Forest and to get an estimate of the rate of invasion (Table 5). The results show approximately 45% of the sampled plots had worms in 1999, a 12% increase in a 5-7 year period. A linear projection estimates that complete occupation of all deciduous forest would occur within approximately 30 years. However, Lee (1985) presents an exponential growth curve in relation to the colonization and spread of introduced earthworms and discusses physiological and behavioral characteristics responsible.

Table 5. Results of soil measurements at 49 EC&I plots, Chippewa National Forest, 1999.

Date	Worm Status	Number	Percent of sites with earthworms
Pre-1995	Plots with worms	16	33%
Pre-1995	Plots with no worms	33	67%
1999	Plots with worms	22	45%
1999	Plots with no worms	27	55%

Effects of exotic earthworms on *Botrychium mormo*

The importance to *Botrychium mormo* of a thick forest floor with intact fungal communities is well established (see Section 5, Habitat). In addition, the effects of exotic earthworms on virgin soils of northern hardwood communities are well documented. This leads to the hypothesis that exotic earthworms are causing a loss of viability to populations of *B. mormo*, and that this loss of viability is spreading along with worm infestations. Available field monitoring and observations support this hypothesis.

Dr. Cindy Johnson-Groh from Gustavus Adolphus College has established permanent study plots for *B. mormo* located on Ottertail Peninsula on the Chippewa National Forest. Earthworm invasion and coincident *B. mormo* population decline were observed on one plot established in 1994 (Johnson-Groh, personal communication, 2000a). In 1996, the plot contained 72 *B. mormo* above-ground sporophytes. In 1997 the O layer was "partially destroyed" and only 11 above-ground sporophytes were observed. In 1998 the O layer was "totally destroyed" and no above-ground sporophytes were observed. No above-ground sporophytes were observed in 1999 or 2000. Dr. Johnson-Groh's data support the loss of *B. mormo* above-ground sporophytes, but there is currently no data on the status of below-ground plant parts.

Carol Mortensen and Steve Mortensen, Biologists with the Leech Lake Band of Ojibwe Division of Resource Management, have also observed a decline in *B. mormo* numbers coincident with duff depletion due to exotic earthworms (Mortensen and Mortensen, 1997; C. Mortensen, unpublished data, 2000). In 1995 a large population of *B. mormo* was discovered on Ottertail Peninsula of the Chippewa National Forest. In 1996 three monitoring plots were installed. A total of 136 above-ground sporophytes were observed in the three plots, with no unusual duff conditions. In 1997 there were 81 above-ground sporophytes, and some worm damage to the duff layer was observed in one plot. In 1998 there was a total of 6 above-ground sporophytes, with duff intact but apparently reduced in depth at all three plots. In 1999 there was a total of 16 above-ground sporophytes, with worm damage observed in all three plots. In 2000 there was a total of 5 above-ground sporophytes, with all three plots showing worm activity and significant reduction of the duff layer. General observations of *B. mormo* and earthworms throughout the site reflected the specific observations made within the three monitoring plots.

In 1998 and 1999, the Chippewa National Forest revisited 57 *B. mormo* sites to assess soil profiles with regard to exotic worms. Evaluation of the data suggests that in nine of the sites visited (16%), *B. mormo* is likely extirpated (no duff layer present and no *B. mormo* observed), and an additional twelve sites (21%) appear to be threatened with *B. mormo* extirpation (worms are present, and duff layer appears to be declining). The remaining sites had an intact duff layer and there was no evidence of earthworms.

Gundale (2000) visited 28 *B. mormo* sites on the Chippewa National Forest during 2000 and evaluated *B. mormo* sporophytes, soil properties and worm populations. He found three species of worms present at *B. mormo* sites: *Lumbriscus rubellus, Dendrobaena octaedra,* and unidentifiable immature unpigmented worms. Gundale found that *Lumbriscus rubellus* was strongly associated with a reduction in the O horizon, and an increase in the A horizon thickness. *Lumbriscus rubellus* also had a statistically significant association with the absence of *B. mormo* sporophytes. Nine of the 28 sites visited had no O horizon, and *B. mormo* is likely extirpated.

Known sites of *B. mormo* on other National Forests were checked for earthworms in 1999 and 2000. Both of the Ottawa National Forest sites appear to have worms and may be threatened. The single Hiawatha National Forest site has earthworms as well. Thirty-one *B. mormo* sites on the Chequamegon-Nicolet National Forest were revisited during the 2000 field season. An estimated 28 of these sites were found to contain earthworms (some of these sites were checked for worms in the vicinity, but not actually at the specific *B. mormo* population). Nightcrawlers (*Lumbricus terrestris)* were not documented and none of the Chequamegon-Nicolet sites showed a complete loss of the duff layer.

Although the precise mechanism of harm to *B. mormo* from exotic earthworms is uncertain, the importance to *B. mormo* of a thick forest floor with intact fungal communities is well established (see Section 5, Habitat). The changes in soil characteristics from exotic earthworms could directly make the site less suitable for *B. mormo* growth and reproduction. Another possible explanation is that earthworms cause the loss of the mycorrhizal fungi upon which *B. mormo* depends. Earthworms could cause mycorrhizal loss through changes in the soil habitat (Allen, 1991; Nixon, 1995), by direct consumption (Doube and Brown, 1998), or both. Earthworms could also create habitat conditions for other species, such as sowbugs, which are known to eat fungi and could be responsible for the loss of mycorrhizal fungi (Wolff et al., 1997).

More research and information on this subject is needed. What are the effects of earthworm invasions in less productive forests with shallower duff layers (marginal habitat) where *B. mormo* occurs? What are the mechanisms of *B. mormo* loss?

Can viable populations of *B. mormo* be sustained if only marginal habitat remains after earthworms colonize its entire range? Can *B. mormo* be successfully transplanted, and can earthworms be excluded from sites or otherwise be controlled?

Even without answers to these questions, the threat posed to *B. mormo* by invading exotic earthworms is serious and puts the future survival of this species into question. All of the data and evidence further show that earthworm colonization of forest soils is on going and permanent, and that soil characteristics are permanently changed from earthworm activity. There is no evidence to suggest an alternative conclusion, and there is currently no viable mechanism for long-term earthworm control. The extent of the threat to *B. mormo,* and the future expansion of earthworm invasions to yet unaffected sites need further study, but the seriousness of this phenomenon to the security of *B. mormo* is clear.

7b. Threats from Forestry Practices

Habitat and life history observations indicate that certain forestry practices may be a potential threat to *Botrychium mormo*. Almost all *B. mormo* populations occur in mature hardwoods with an intact tree canopy (see the discussion of habitat in Section 5). Changes in habitat may have a detrimental impact on *B. mormo* populations. Wagner and Wagner (1981) noted that *B. mormo* plants often fail to emerge during drought years. Activities that open up the tree canopy can cause desiccation of leaf litter and plants, thereby potentially harming *B. mormo* populations (Association for Biodiversity Information, 2001; Tans and Watermolen, 1997).

Sather et al. (1998) discussed how timber harvests might impact different aspects of *B. mormo* habitat and populations (Table 6). They identified four categories of threats related to forestry practices: harvest practices, roads/landings/skid trails/accesses, logging policy, and restoration activities.

Table 6. Harvest practices threat matrix, from the Threats and Risk Working Group Report of the Population and Habitat Viability Assessment (Sather et al., 1998).

	SOIL COMPACTION	LOSS OF SOIL NUTRIENTS	CHANGES IN MOISTURE REGIME	INHIBITION OF SPORE DISPERSAL	LOSS OF DARKNESS	LOSS OF DUFF LAYER (O-horizon)
clearcutting	X	X	X	?	X	X
intermediate harvest (thinning)	X	X	X	?	?	?
single tree selection	X	X	X	?	?	?
group selection	X	X	X	?	?	?
salvage sales	X	X	X	?	X	X

Harvest practices include clearcutting, intermediate harvests (thinning), single tree selection (also an intermediate harvest), group selection, and salvage harvests to recover dead or down trees. Clearcutting (defined as the complete removal of tree cover except for reserve trees or islands) was ranked as the greatest threat to *B. mormo* due to soil compaction, loss of soil nutrients, changes in moisture regime, loss of darkness, loss of duff layer, and conversion of suitable maple-basswood habitats to unsuitable aspen habitats. Intermediate harvests, single tree selection, and group harvests may simulate natural gap-forming processes, but may still impact *B. mormo* from soil compaction, loss of soil nutrients, and changes in moisture regimes.

The following summary of silvicultural treatments and the effects on *B. mormo* is taken from Sather et al. (1998):

> Clearcutting is the complete removal of tree cover, except for reserve trees or islands. It is an even-aged system intended to regenerate a site to trees all the same age. It is commonly used to manage for aspen forest or in final harvests in other hardwood communities. Clearcut harvest at a site may occur every 40 years to 60 years. Permanent road systems within a stand are not required, though both temporary and permanent roads are commonly used to access stands. Temporary roads are intended to be obliterated after the harvest but may persist for many years after their intended purpose is accomplished. Pure aspen stands are generally not recognized as *B. mormo* habitat. The conflict or risk comes in mixed stands of maple, basswood, and aspen, where aspen is represented well enough to successfully reforest a stand after harvest. At these types of sites *B. mormo* has been frequently found and harvest would greatly alter the habitat conditions for this species.

Intermediate harvest or thinning can be accomplished in an even-aged or uneven aged (all aged) fashion. The even-aged system maintains one age or size class of tree in the stand by removing smaller, larger, or cull trees. Uneven-aged management maintains all ages or size classes of trees (including those at various canopy heights) while removing culls or crop trees. Both systems require multiple harvest entries into the stand over time. Both systems thin forest stands to increase vigor to remaining trees. Both systems may require permanent roads or persistent trails within the stand to access crop trees at an interval of 10 to 20 years. Single tree selection is an intermediate harvest method where individual trees are marked for removal based on tree condition, spacing, or species.

Group selection harvests are similar to clearcuts but at a smaller scale. Patches of trees from 0.1 to 0.5 acre are removed at intervals throughout a forest stand. Multiple entries are made into a forest stand over time. The remaining forest cover is retained until the next entry. While each forest patch in a stand is even-aged, there are multiple age classes throughout the stand.

Both single tree selection and group selection may simulate natural gap-forming processes but the ground impacts would not mimic natural disturbances.

Salvage harvests are conducted after a mortality event (storm damage, disease, etc.) in a forest to capture the commercial value of the trees before rot or insects make them unusable for lumber or fiber. On hardwood forest (including aspen) sites that may contain *B. mormo*, wind events may create single tree gaps or, more severely, may blow down large areas of forest. On federal land, management safeguards usually employed for other harvests may be suspended to conduct salvage operations. In most salvage harvests, in order to regenerate a forest stand, healthy green trees are harvested along with the dead and down trees. The remaining area may or may not have reserve trees or islands. Salvage harvests generally follow unplanned stochastic events.

Roads, landings, and skid trails are another aspect of forestry practices that may impact *B. mormo* populations and habitat (Sather et al., 1998). Many timber harvests require permanent road construction for access. Landings and skid trails are somewhat temporary in nature and may be used only once per rotation age of the forest cover (40 to 60 years) in even-aged aspen or every 10 to 20 years for intermediate harvests in hardwoods. However, temporary roads and landings cause soil compaction and disturbance, and may persist on the land for many years following construction (Brady and Weil, 1999).

Forest management direction and natural resource policies (logging policies) on public land in the Lake States often have worked against maintenance or development of forest habitat suitable for *B. mormo*. To enhance timber production, many public land management agencies have emphasized even-aged aspen on a large portion of their land bases, even though other options frequently exist (Johnson, 1995). With this single species emphasis comes a short rotation age (as young as 40 years) and the conversion of mixed hardwood-stands to even-aged aspen, particularly in Minnesota due to the low quality of sugar maple sawlogs.

With the recent emphasis on ecosystem management on public lands, more attention has been given to tree species that were formerly more common than they currently are. Restoration activities may impact *B. mormo* habitat (Sather et al., 1998). Species being restored include white pine, eastern hemlock, paper birch, and yellow birch. Each of these tree species may be found as a component of forest suitable for *B. mormo*. On many sites, these species may need a soil disturbance to successfully establish seedlings. This is often done artificially by scarification with heavy equipment, during which the organic layer and soil are severely disrupted. This may result in disturbance to *B. mormo* habitat.

Determinations of the effects of timber harvest on *B. mormo* have largely been based on observations of known habitats, knowledge about the physical consequences of timber harvest, and conjecture about how these consequences might apply to *B. mormo* populations. There have been, however, some direct observations of timber harvest in *B. mormo* habitat. Discussions with land managers and a review of the literature found six informal reports from eight sites where timber harvesting occurred within a known *B. mormo* population.

1. Ottertail Peninsula, Minnesota: On August 1, 1994, Karen Myhre observed 100 plants on private land in a site that had been clearcut approximately 17 years earlier (Chippewa NF Record #2014). This site was near the edge of the clearcut, and the population extended into an unharvested area nearby. Earthworms have since reduced the soil organic layer at this site, and no *B. mormo* plants have been observed since 1997. The lack of *B.* mormo plant observations since 1997 is likely a result of the earthworms, and not necessarily due to logging. In August 1997, John Casson and Candy Westfield found one plant within aspen regeneration within a nearby, also-harvested area (Chippewa NF Record #2028).

2. Langlade County, Wisconsin: A population of about 15 plants was found in 1995 on Langlade County land in Wisconsin. The site was thinned during the winter of 1996-1997. The site was revisited in 1997 and 2000 and no *B. mormo* plants were found. A basswood top may have been dropped on a least part of the population.
3. Minisogama Lake, Minnesota: On September 7, 1994, Myrlis Henrickson discovered 10 plants at a site in the vicinity of Minisogama Lake on the Blackduck Ranger District of the Chippewa National Forest. A protection buffer was flagged around the site, but the site was unintentionally clearcut along with the rest of the stand during the winter of 1994/95. Three return visits have been made between 1995 and 2000, and no *B. mormo* plants have been found.
4. Bello Lake, Minnesota: On August 31, 1992, Tom Suddendorf found three *B. mormo* plants in the vicinity of Bello Lake on the Marcell Ranger District of the Chippewa National Forest. In 1995, a clearcut timber harvest intended for nearby land inadvertently included the *B. mormo* site. The site has been revisited each year since and no *B. mormo* plants have been found.
5. William E. Tans and Dreux X. Watermolen are conducting monitoring on a number of *B. mormo* sites in Wisconsin, including three sites in Langlade County and Forest County that have been selectively cut. They observed that the *B. mormo* plants appear unaffected by the logging, as long as the plants are not directly harmed by the activity (Tans and Watermolen, 1997, and personal communication, 2000).
6. Forest County, Wisconsin: Steve Janke found a population of 34 plants at a site in Forest County, Wisconsin, on 14 August 1995. The site was thinned in the spring of 1998. The site was revisited during the 2000 field season and approximately 12 plants were found.

These casual observations appear to support the findings of Sather et al. (1998) that timber harvest may present some threat to *B. mormo*. Populations in the observations appear less tolerant of clearcutting than they are of intermediate harvests. Future, more formal studies will help better document the effects of timber harvest on *B. mormo* populations.

One ongoing study is the Chippewa National Forest's "Goblin Fern Administrative Study." The study site is on the Cass Lake Ranger District of the Chippewa National Forest. *B. mormo* plants occur on both sides of a forest road in maple-basswood habitat. The east side is scheduled to receive an intermediate harvest in 2001 or 2002. In 1995, square meter plots were placed on each side of the road, in areas of *B. mormo* concentrations. The number of above-ground sporophytes within each plot has been recorded every July thereafter (Table 7). Following treatment, both sites will be monitored for another five years. This study is still underway.

Table 7. Number of recorded *Botrychium mormo* plants per plot per year, Goblin Fern Administrative Study, Chippewa National Forest.

TREATMENT SITE

Year	Plot Number										
	1	2	3	4	5	6	7	8	9	10		Total
1995	16	6	7	9	11	17	11	4	10	7		98
1996	32	7	20	13	48	28	28	11	17	16		220
1997	15	3	12	7	15	14	11	4	10	10		101
1998	2	0	4	4	8	14	5	1	5	11		54
1999	4	0	2	5	12	10	9	3	6	7		58
2000	1	0	4	0	3	10	10	0	4	4		36

CONTROL SITE

Year	Plot Number											
	1	2	3	4	5	6	7	8	9	10	11	Total
1995	8	5	13	3	1	14	2	4	29	1	7	87
1996	25	5	26	24	18	44	9	8	76	2	37	274
1997	8	3	7	19	14	29	7	3	20	2	5	117
1998	3	1	3	8	4	12	2	2	20	0	0	55
1999	0	0	2	4	1	13	1	1	5	0	9	36
2000	1	0	1	5	1	7	0	0	6	0	6	27

Timber harvest activities also result in edge effects to adjacent habitats. Site-altering activities in one area may create conditions that change light, temperature, humidity, and understory herbaceous vegetation within an edge zone of adjacent forested sites (Hunter, 1990; Matlack and Litvaitis, 1999). The width of the edge zone depends on the physical variable being measured, the aspect of the edge, and the difference between the interior and exterior conditions (Matlack, 1993). Different species will have different sensitivities to edge effects (Matlack and Litvaitis, 1999). Laurance and Yensen (1991) gave a range of 15 meters (Ranney et al., 1981) to 5 kilometers (Janzen, 1986) for the penetration of edge effects into forest interiors. The "three tree height rule" (or 60 meters) is often cited as the distance at which the effects of wind from adjacent clearcuts are ameliorated (Harris, 1984). Edge effects in temperature, litter moisture, humidity, and shrub cover have been detected 50 meters into a forest interior in eastern deciduous forests (Matlack, 1993). Chen (1991) detected edge effects up to 400 meters into the interior of old growth Douglas fir forests in the Pacific Northwest. Matlack and Litvaitis (1999) recommend that land managers use a conservative maximum width based on many measurements in their local ecosystem. There are no specific data on the requirements of interior conditions for the goblin fern. A population viability assessment for the Goblin fern conducted in January 2000 offered 250 feet (76.2 meters) as the distance of edge effects in *B. mormo* habitat (U.S. Forest Service, 2000) (see Section 8, Population Viability Goals).

8. Population Viability Goals

Forest Service guidelines direct the Forest Service to "Maintain viable populations of all native and desired nonnative wildlife, fish, and plant species in habitats distributed throughout their geographic range on National Forest System lands" (FSM 2670.22-2). This leads to the question, "How many viable populations are needed to maintain the geographic range of Botrychium *mormo*?" As stated in Section 4 (Life History), although small populations are at a higher risk of extinction, a single above-ground sporophyte can be taken as evidence of a self-sustaining population. Furthermore, the lack of genetic differentiation between populations (Farrar, 1998) suggests that no inter-population dynamics are required for species viability (Johnson-Groh et al., 1998).

Two Working Groups of the PHVA addressed population viability goals. Concerning range-wide viability, the Population Life History and Viability Working Group (Johnson-Groh et al., 1998) recommended, "Maintain sufficient northern hardwood habitat," and "preserve significant *B. mormo* sites such as Ottertail Peninsula and others as they are located." The Management and Social Issues Working Group (Berlin, Boe et al., 1998) recommended that, "Based upon known occurrences and habitat conditions, determine the number of populations needed to provide and maintain the long-term viability of *B. mormo* within designated LTAs (Land Type Associations) throughout its range."

In January 2000 a three-day meeting was held in Duluth, Minnesota. The meeting was intended to collect expert information and conduct a "Population Viability Assessment" (PVA) of over 75 rare or focal species of plants to help with Forest Plan revisions in Minnesota and Wisconsin. The meeting included a panel on upland forested ferns, including *Botrychium mormo*. Participants included Don Farrar, Gary Fewless, Candy Fitzloff-Westfield, Colleen Matula, Paula Armstrong, Carol Mortensen, and Gary Walton. Concerning range-wide viability, the group was unable to estimate the number of populations needed to maintain minimum viability of *B. mormo* across the planning area (U.S. Forest Service, 2000).

The authors of this conservation approach have also not attempted to estimate numbers of populations that will provide viability of *Botrychium mormo*. Without estimates from the species' experts, any numbers we provide would be poorly founded conjecture. We do suggest that to maintain populations of *B. mormo* across National Forest System lands, enough populations would be needed to withstand not only stochastic events, but also potential rangewide habitat devastation. Specifically, we believe that exotic earthworms present a potential for future rangewide destruction of *B. mormo* habitat. This is based upon the dependence of *B. mormo* on soil with a thick organic layer (see Section 5, Habitat), the observed effects of exotic earthworms on forest soils, the fact that exotic earthworms are spreading, and the observed extirpation of known *B. mormo* sites on the Chippewa National Forest coincident with earthworm invasion (see Section 7, Threats).

Although the Chippewa and Chequamegon-Nicolet National Forests may have sufficient numbers of populations to ensure short-term persistence of the species on these National Forests (see Section 3, Distribution and Status), the long-term persistence of these populations is in question. Until more is known of the threats from earthworms, we are uncertain if any *B. mormo* population will persist in the long-term. The Superior, Hiawatha, and Ottawa National Forests each have less than 3 known populations, an insufficient number to insure future viability, independent of threats from earthworms.

While this Conservation Approach cannot in itself ensure the long-term viability of Goblin fern populations, hopefully the conservation measures proposed will best address the persistence (Holthausen, 2001) of the species on National Forest lands in light of threats posed by exotic earthworms.

9. Management Recommendations/Conservation Measures

Section 5 reviewed the dependence of *Botrychium mormo* on a well-developed soil organic layer. Section 7a reviewed the impacts of exotic earthworms on the organic layer of forest soils, and the apparent extirpation of *B. mormo* sites following earthworm invasion. Given the widespread distribution of earthworms, it is possible that no *B. mormo* sites are secure. Therefore, it seems prudent to reduce any additional threats to *B. mormo* populations and habitat. This may be the only protective measure within our control. Currently, there are no known methods of controlling earthworms. However, we can manage sites to be less vulnerable to earthworm introductions. The following conservation measures seek to reduce threats to *B. mormo* populations and habitat from forest management activities, as reviewed in Section 7b, and from other activities, as discussed in Section 7.

With the grim prognosis of maintaining *B. mormo* as an extant species, it may be tempting to "write off" this species. This is not an option; a myriad of laws and regulations prohibit giving up on the viability of extant species (National Forest Management Act, Endangered Species Act, Forest Service Manual).

Based on information from the Goblin fern Population Habitat Viability Assessment (PHVA) for the Goblin Fern (Berlin et al., 1998) and further contacts with species experts, the following conservation measures summarize the recommendations of the Goblin fern Team. It is expected that forests will use discretion in applying these measures depending on local life history needs, habitat, distribution and associated threats. By definition, conservation strategies are not complete until implemented through individual Forest Plans. Conservation approaches are typically incorporated as new information at the project level until forest plans are amended or revised.

<u>Conservation measures:</u>

1. **Objective:** Eliminate activities that threaten *Botrychium mormo* populations, and manage the habitat of known *B. mormo* sites to promote a high likelihood of persistence of Goblin fern populations. Activities that can threaten *B. mormo* populations and habitat are discussed in Section 7.

   Recommendations: Activities which could disturb *Botrychium mormo* plants, their habitat, or microhabitat should not occur within 250 feet[8] of *B. mormo* populations. The extent of *B. mormo* populations will be determined by a Botanist, Biologist, Ecologist, or other qualified observers (technicians or contractors) designated by a Botanist, Biologist, or Ecologist.

   In suitable habitat that is immediately adjacent and contiguous to existing populations beyond the 250-foot no-activity zone, site disturbing activities should occur only during frozen ground conditions; or where that is not possible, ten inches or more of protective snow cover should be in place to eliminate site disturbance. In addition, a minimum canopy closure of 70% should be maintained.

   On the Chippewa and Chequamegon-Nicolet National Forests, this measure will not apply in cases where a population has been extirpated due to exotic earthworms. A population will be judged as extirpated when all of the following three conditions are met: (1) The O horizon of the soil profile has been eliminated due to earthworm activity (not including leaf fall within the last year). (2) A thorough survey by a qualified observer during an appropriate time for 5 consecutive years has failed to detect any *B. mormo* plants; or a below ground extraction/examination indicates that

[8] The January 2000 Population Viability Assessment on upland forested ferns, offered 250 feet as a distance of edge effects. See Section 7b, Threats from Forestry Practices.

there are no gametophytes or underground sporophytes existing or developing. (3) A Biological Evaluation[9] indicates that the population is likely extirpated. There should be no exception for earthworm-impacted *B. mormo* sites on the Hiawatha, Ottawa, and Superior National Forests. *Botrychium mormo* is known from too few sites on these forests to risk impacting any current or historic sites.

2. **Objective:** Make efforts to control or minimize the spread of exotic earthworms.

   Recommendations: *Botrychium mormo* habitat, and apparently non-occupied potential habitat, as described in this document, should be analyzed for worm invasion potential. An area will be considered to have a lower worm invasion potential if it is far from existing worm populations, or is geologically isolated from worms by wetlands or some other condition that is not conducive to worm colonization. In addition, it would typically be void of roads and trails, developments, and lakes and streams that support game fish. Areas identified as having a low potential for earthworm invasion should be managed to minimize the likelihood of invasion. Worm introduction factors to be managed include transport of worms, eggs and cocoons in soils through movement of soils in potted plants, soil packed on heavy equipment or on off-road vehicles or their tires, soil packed on livestock hooves, or transport of worms as fishing bait.

   Each Forest should promote public awareness of the threats exotic earthworms pose to native ecosystems. The Forests should encourage measures such as proper disposal of angler worms and off-road vehicle cleaning which may help to reduce the spread of exotic earthworms.

These conservation measures should not be interpreted as an exemption from any National Forest policies concerning field surveys for listed species prior to management activities.

10. Collaborative Potential

As mentioned in Section 8, a lack of genetic differentiation among *Botrychium mormo* populations has been observed (Farrar, 1998), which suggests that no inter-population dynamics are required for species viability (Johnson-Groh et al., 1998). Therefore, collaboration with other landowners is not necessary to promote the persistence of *B. mormo* on National Forest land. However, if *B. mormo* populations continue to be impacted by exotic earthworms, protection of other *B. mormo* sites, especially worm-free sites, outside of National Forests lands may help preclude Federal listing of the species.

Section 11 lists several research and monitoring needs for which the Forest Service should encourage collaboration with other parties. Earthworm research, including development of prevention methods and public awareness efforts should be especially encouraged. This should include direction on proper disposal of angler worms. Study and research on the effects of timber management on *B. mormo*, such as the Chippewa's administrative study, should also be encouraged.

11. Research and Monitoring Needs

The Population and Habitat Viability Assessment for the Goblin Fern (Berlin et al., 1998) included many recommendations concerning research and monitoring needs. Four items strongly recommended by the authors of this Approach are listed below:

- Study and compare the underground biology of *B. mormo* in normal and disturbed communities. The abundance of underground gametophytes and sporophytes in *B. mormo* populations has been documented by Johnson-Groh (1998). It is not known if these life stages persist in sites disturbed by forestry practices or earthworms.
- Study the impact of earthworms on the viability of *B. mormo* and its habitat, and develop methods to prevent the spread of worms and control existing infestations. Survey all known *B. mormo* sites (as well as control sites) for worm presence, including sites off National Forests. What are the effects of earthworm invasions in less productive forests with shallower duff layers where perhaps *B. mormo* occurs? Can *B. mormo* sustain itself as a viable species if only

[9] A Biological Evaluation is "A documented Forest Service review of Forest Service programs or activities in sufficient detail to determine how an action or proposed action may affect any threatened, endangered, proposed, or sensitive species" (Forest Service Manual 2670.5).

marginal habitat remains after earthworms colonize its entire range? What are the mechanisms of *B. mormo* loss after earthworm invasion? What species of earthworms cause the most change to forest soils?
- Monitor the effects of timber harvests on *B. mormo* populations though the use of permanent plots, as with the Chippewa National Forest "*Botrychium mormo* administrative study". Seek grants and partnerships to support studies to evaluate the effects of clearcutting and intermediate harvesting on *B. mormo*.
- Study mycorrhizal components of population dynamics such as the presence or absence of mycorrhizae with regard to habitat type and disturbance.

Additional important research and monitoring needs are listed below:

- Search for additional occurrences of *B. mormo* in all habitats including less likely sites. Survey historic, current, and potential *B. mormo* sites to determine abundance, distribution, demographic, and other limiting factors data.
- Study spore dispersal strategy, including the distance spores are dispersed and agents of dispersal.
- Conduct *Botrychium mormo* transplant experiments. Can *B. mormo* be successfully transplanted?
- Study ecophysiology including contribution of photosynthesis to the overall energy budget of *B. mormo*.
- Examine the potential importance of *B. mormo* to the forest communities they occur in, including other species of *Botrychium*.
- Investigate feasibility of timber harvest methods that do not impact factors critical to *B. mormo* viability such as light, moisture, soil characteristics, duff layer, and mycorrhizal association.
- Summarize all existing monitoring studies rangewide including study objectives and progress and subsequently share this information with all agencies and interested parties, perhaps with a regional conference.
- Do earthworms threaten other species of *Botrychium* that occur in forested communities such as *B. oneidense* or *B. lanceolatum*?
- How do different forest habitats differ in their susceptibility to soil change from exotic earthworms?

12. Action Plan

The following items should be included in each Forests Forest Plan Annual Monitoring and Evaluation Report:

1. The Forest Service Manual (2672.11-6, R9 Amendment) states, "A conservation strategy is complete when adopted through appropriate forest planning processes or determined to be consistent with existing plans." Accordingly, this conservation approach will be considered for incorporation into the ongoing Forest Plan revision or amendment processes for the Chippewa, Superior, Chequamegon-Nicolet, Ottawa and Hiawatha National Forests. Prior to adoption in revised Forest plans or amendments, it is recommended that the above-mentioned National Forests should follow the conservation measures presented in Section 9 on an interim basis.

2. The Forest Service should encourage the research and monitoring items listed in Section 11.

3. This conservation approach should be circulated among other land managers, other interested parties, and all the stakeholders identified in the Population and Habitat Viability Assessment (Berlin et al., 1998).

4. The Forest Service should explore and pursue opportunities for the development of a Conservation Agreement for *Botrychium mormo*.

5. The threats from exotic earthworms are still just beginning to be studied and widely known. Future research on this issue may necessitate changes to this conservation approach. National Forest biologists, natural resource professionals and land managers, and authorities in exotic earthworm research should stay in communication. This conservation approach may be revised as more knowledge is gained on threats to the viability of *Botrychium mormo* and its habitat.

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