POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA) FOR THE GOBLIN FERN (*Botrychium mormo*)

FINAL REPORT

Horseshoe Bay Resort
Walker, Minnesota
6-9 October, 1997

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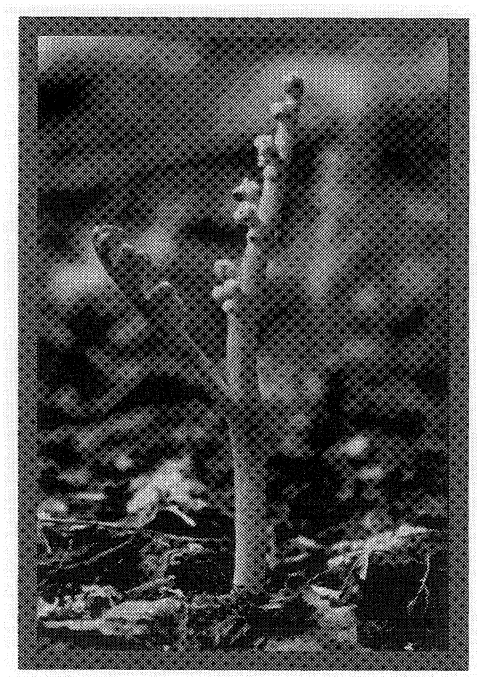

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The Conservation Breeding Specialist Group (SSC/IUCN)

A contribution of the IUCN/SSC Conservation Breeding Specialist Group in collaboration with the United States Forest Service, The Minnesota Department of Natural Resources, and The Institute for Sustainable Natural Resources.

Photos courtesy of Steve Mortensen, S & C Nature Photography

Berlin, N., P. Miller, J. Borovansky, U.S. Seal and O. Byers (eds.). 1998. *Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report*. CBSG, Apple Valley, MN.

Additional copies of *Population and Habitat Viability Assessment Workshop for the Goblin Fern (*Botrychium mormo*): Final Report* can be ordered through the IUCN/SSC Conservation Breeding Specialist Group, 12101 Johnny Cake Ridge Road, Apple Valley, MN 55124.

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POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE GOBLIN FERN
(Botrychium mormo)

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SECTION 1
EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The goblin fern (*Botrychium mormo*) was first described by Wagner and Wagner in 1981. *Botrychium mormo* is on the state endangered species list in Wisconsin, a species of special concern in Minnesota and Michigan, a U.S. Fish and Wildlife Service (USFWS) 'species of concern', and categorized as G3 by The Nature Conservancy (TNC). In addition, *B. mormo* is listed as threatened in the draft Leech Lake Reservation Threatened and Endangered list. Based on its TNC ranking, the U.S. Forest Service (USFS) lists the goblin fern as a Sensitive Species for the Eastern Region.

It is found in only three states, Michigan, Wisconsin and Minnesota. The preferred habitat of this small (2 – 5 cm), plant is shaded forest floor under mature deciduous forest. The unusual biology of the goblin fern makes its status difficult to assess. Plants grow in the dark, moist environment provided by the rich leaf litter of forests with a maple-basswood component. *B. mormo* has a strong fungal (mycorrhizal) association which permits it to survive even though covered by this dense leaf litter. If habitat conditions are poor, the goblin fern can remain underground for years until conditions improve. Although extensive surveys have been conducted in some areas in each of the three states, there has been no range-wide effort made to inventory the species. However, the need for determination of the status of the species and its management needs has been acknowledged by those responsible for maintenance of the species and/or its habitat.

The USFS recognized a need to assess the viability of the species on a range-wide basis and formally invited the Conservation Breeding Specialist Group to conduct a Population and Habitat Viability Assessment (PHVA) workshop.

A planning meeting was held on 27 May 1997 to identify stakeholders, discuss the agenda and initiate discussions of the issues involved and data needed for the PHVA process. Ten people, representing USFWS, USFW, Minnesota Department of Natural Resources (MNDNR), TNC, the University of Minnesota, the Minnesota Zoo and independent researchers, met at the Minnesota Zoo. This meeting finalized the PHVA invitation list and formulated a set of problem statements from which the following goal developed for the PHVA: **"to achieve a broad acceptance of a range-wide viability assessment for the goblin fern using updated information and involving subject experts and stakeholders."**

The PHVA Process

Effective conservation action is best built upon critical examination and use of available biological information, but also very much depends upon the actions of humans living within the range of the threatened species. Motivation for organising and participating in a PHVA comes from fear of loss as well as a hope for the recovery of a particular species.

At the beginning of each PHVA workshop, there is agreement among the participants that the general desired outcome is to prevent the extinction of the species and to maintain a viable population(s). The workshop process takes an in-depth look at the species' life history, population history, status, and dynamics, and assesses the threats putting the species at risk.

One crucial by-product of a PHVA workshop is that an enormous amount of information can be gathered and considered that, to date, has not been published. This information can be from many sources; the contributions of all people with a stake in the future of the species are considered.

To obtain the entire picture concerning a species, all the information that can be gathered is discussed by the workshop participants with the aim of first reaching agreement on the state of current information. These data then are incorporated into a computer simulation model to determine: (1) risk of extinction under current conditions; (2) those factors that make the species vulnerable to extinction; and (3) which factors, if changed or manipulated, may have the greatest effect on preventing extinction. In essence, these computer-modelling activities provide a neutral way to examine the current situation and what needs to be changed to prevent extinction.

Complimentary to the modelling process is a communication process, or deliberation, that takes place during a PHVA. Workshop participants work together to identify the key issues affecting the conservation of the species. During the PHVA process, participants work in small groups to discuss key identified issues, whether management, disease, translocation, or other emerging topics. Each working group produces a brief report on their topic, which is included in the PHVA document resulting from the meeting. A successful PHVA workshop depends on determining an outcome where all participants, coming to the workshop with different interests and needs, "win" in developing a management strategy for the species in question. Workshop report recommendations are developed by, and are the property of, the local participants.

Goblin Fern PHVA

The PHVA was held at Horseshoe Bay Lodge on Leech Lake, near Walker, Minnesota 6 - 9 October 1997. The workshop was sponsored by the Chippewa National Forest, Minnesota Department of Natural Resources and the University of Minnesota Institute of Sustainable Resource Management Education. Twenty-eight participants (see participant list, Appendix II) were present, representing the entire range of the species including Minnesota, Wisconsin and Michigan. Stakeholders from various organizations were invited but representatives of the timber and mining industries were unable to attend (see invitation list, Appendix III).

Following presentations on *Botrychium* taxonomy, genetics and life history (Appendix I) working groups were formed to address the primary areas of concern for the participants: life history and modeling; distribution; threats and risks; and management and social issues. Each working group produced a detailed written report and recommendations that were individually reviewed in plenary session and discussed. General consensus was reached on each recommendation to be included in the workshop report.

Several issues became clear in the course of the discussions. For example:

a) very little specific life history information is available for the species. The effects of dispersal and disturbance and the importance of mycorrhizal associations and photosynthesis on *B. mormo* were identified as crucial aspects to be investigated;

b) the apparent impact of exotic earthworms on *B. mormo* habitat. This became one of the primary issues of concern for the workshop participants and several working group recommendations reflect this concern; and
c) the fact that conflict or risk comes in mixed stands of maple, basswood, and aspen, where aspen is represented well enough to meet the increasing demand for aspen harvest.

Another area of significant concern was the need for increased stakeholder involvement, particularly by the timber industry. Specific suggestions for inclusion are discussed in this report.

Distribution data were collected during the workshop and 191 populations (quarter quarter section = population) were identified in 1997. A follow-up meeting of the Distribution Working Group was held on 20 November to compile and analyze the available data. The results of this follow-up meeting are included in this report. Using the life history modeling assumption that populations with at least five above ground stems were sustainable; and considering potential threats of documented exotic earthworm infestation and potential harvest of aspen sites, the Distribution Working Group concluded that 51 of the 191 Goblin fern populations are stable. With this knowledge in hand, the need for an overall metapopulation analysis becomes an important component of a broad species management plan. These spatially explicit models should be based at least in part on an assessment of the proportional degree of occupancy of suitable microhabitats (microsites) across the distribution of the species.

Detailed recommendations from each working group are presented below.

SUMMARY OF RECOMMENDATIONS

Population Life History and Viability Working Group

1. Maintain sufficient northern hardwood habitat.

2. Preserve significant *B. mormo* sites as Ottertail Peninsula and others as they are located.

3. Monitor the demographics of disturbed populations (e.g., earthworms, timber harvesting) though permanent plots.

4. Search for additional occurrences of *B. mormo* in all habitats including less likely sites.

5. Study and compare the underground biology of *B. mormo* in normal and disturbed communities.

6. Study spore dispersal strategy, including the distance dispersed and agents of dispersal.

7. Conduct *B. mormo* transplant experiments.

8. Study mycorrhizal components of population dynamics such as the presence of absence of mycorrhizae with regard to habitat type and disturbance.

9. Study ecophysiology including contribution of photosynthesis to overall energy budget of *B. mormo*.

10. Examine the potential importance of *B. mormo* to the entire community including other species of *Botrychium.*

Threats and Risk Working Group

1a. In areas affected by exotic earthworms, especially Ottertail Peninsula, Institute a minimum 24-month moratorium from other impacts on *B. mormo* sites in order to adequately assess the earthworm risk; these sites should be protected by ecological Land Type Association phase-level buffer zones.

1b. Study the impact of earthworms on the viability of *B. mormo* and its habitat, survey all sites (and control sites) for worm presence, develop methods to prevent the spread of worms and control them.

2. 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.

3. Conduct research on the life cycle and function of the mycorrhizae associated with *B. mormo*.

4. Survey historic, current, and potential *B. mormo* sites to determine abundance, distribution, demographic and other limiting factors data.

5. Federal/state licensing/permitting agencies should conduct/require pre-project site surveys and include conservation conditions in any permit/license issued.

6. Provide public/landowner information on *B. mormo*; assist landowners in developing voluntary site protection plans; provide information on threats.

Management and Social Issues Working Group

<u>Stakeholder Participation</u>

1. Add stakeholders to PHVA mailing list. (Timber industry, political delegations, Michigan Native Plant Society, Wisconsin Native Plant Society, other herbarium curators, DNR Forestry, County Land Departments, Environmental Groups, Tribal representatives, State DOTS).

2. Establish personal contacts with critical stakeholders who did not attend the PHVA (Timber industry, Superior National Forest, USFS Regional Office, TNC, environmental groups).

3. Host a one-day overview in neutral location aimed at bringing critical participants listed above "to the table."

4. Provide general letter/overview to updated mailing list within two weeks following the workshop.

5. Include goblin fern information on the Chippewa National Forest Homepage (www.fs.fed.us/r9/chippewa); other entities can link to site. Focus to be on rangewide status, general life history and ongoing research and monitoring.

6. Publish popular articles (Minnesota Volunteer, Mpls. Star Tribune-Dean Rebuffoni and Tom Meersman, St. Paul Pioneer Press- Anne Brataas, Dennis Lien) on goblin fern in general and on rouge worms.

7. Provide copies of Goblin Fern PHVA Workshop Report to all participants, critical stakeholders and all other interested parties.

Information and Monitoring

1. Update, integrate and share all information rangewide across all agencies and interested parties annually.

2. Continue project level Forest Service inventories and encourage other landowners (state, county, tribal and private) to do the same.

3. Seek grants and partnerships to support proactive rangewide inventories and associated habitat research.

4. Summarize all existing monitoring studies rangewide including study objectives and progress and subsequently share this information with all agencies and interested parties.

5. Seek grants and partnerships to support studies to evaluate the effects of clear-cutting and intermediate harvesting.

6. Conduct studies to thoroughly research site and plant characteristics in specified locations.

7. Conduct studies on *B. mormo* life history.

8. Monitor and control earthworms.

Management (Note: the assumption was made that an undetermined, but small number of populations outside the main concentrations of *B. mormo* occurrence might be expendable. If it is determined that no populations are expendable, then protection will need to be afforded populations both within and outside areas of major concentration.)

Rangewide Management

1. Plot geo-morphic region equivalents (e.g. Land Type Associations - LTA) across the entire range of *B. mormo*.

2. Designate those LTA's that hold the largest number of known *B. mormo* occurrences and/or have the greatest potential for *B. mormo* occurrence or habitat for *B. mormo* management.

3. 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 throughout its range.

4. Develop a rangewide communication network to track status, distribution, new technology, biology, research findings, data collection and monitoring results.

Landscape Level Management

1. Within the selected LTAs, further identify and designate the landscapes which are, or recently were dominated by forests with a maple-basswood-beech component as *B. mormo* habitat management areas (BMHMAs).

2. Implement landscape level forest management strategies on these BMHMAs designed to maintain or promote the composition, structure and historic disturbance regime associated with these forest habitats, including an uneven-aged silvicultural system and rarely prescribed fire on some landscapes.

3. Encourage multi-agency management compatible with habitat objectives within the designated BMHMAs.

4. In areas of *B. mormo* concentrations within the BMHMAs (10,000+ acres), designate large areas (300-3000 acres) for a high level of protection for *B. mormo* and associated species.

Site/Stand Level Mangement

1. Within the BMHMAs, for stands without *B. mormo* occurrences, two recommended management options are:
   - defer harvest; or
   - implement uneven-aged silvicultural practices (single-tree or group selection).

2. Within the BMHMAs, for stands with *B. mormo* occurrences, recommended management options are:
   - defer harvest in the stand; or
   - permit single tree or group selection beyond 300 feet of known occurrence in the remainder of the stand.

3. For known *B. mormo* occurrences outside the BMHMAs and within the selected LTAs, the recommended management options are:
   - defer from harvest landtype phase or stand; or
   - allow any harvest greater than 300 feet* from an occurrence.

4. For known *B. mormo* occurrences outside the selected LTAs, the recommended management options are:
   - defer the stand from harvest; or
   - allow harvest beyond 300 feet of known occurrence.

*This buffer distance is subject to change as new information is gained.

Distribution and Status Working Group

Using the criteria for risk and security outlined in this working group report, 51 of the 191 element occurrences documented throughout the species range are considered secure. It may, therefore, seem appropriate for The Nature Conservancy global rank of the species to be changed to G4. However, more conservative and widely accepted guidelines for viability in plant populations generally assume a MVP of 100 plants. According to this more conservative guideline for viability, only two of five populations known to be as large or larger than 100 above-ground plants are free of threat.

Recommendation: The G rank for *B. mormo* should not be modified until there is better documentation of the actual size of unthreatened populations, the geographic extent and intensity of earthworm threat has been evaluated and managing agencies have developed guidelines that assure avoidance of impacts to large known populations as a result of timber harvest.

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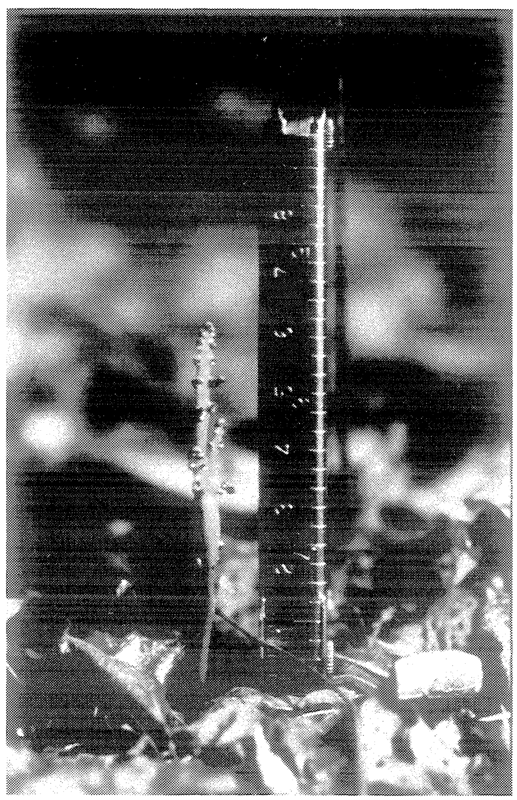


SECTION 2
POPULATION LIFE HISTORY AND VIABILITY WORKING GROUP REPORT

POPULATION LIFE HISTORY AND VIABILITY WORKING GROUP REPORT

Introduction

Working Group Goals and Problems

The collective group formulated a list of goals and problems. The working group then separated these goals and problems into three categories according to the issues they addressed. These groups were categorized as life cycle, environment, and geography / species distribution.

Life Cycle
Conservation goals pertinent to the species' life cycle included:
- Maintain a healthy, viable population into the future;
- Determine the criteria for a viable, self-maintaining population;
- Establish temporal and spatial effects of factors which limit population growth;
- Include uncertainty in viability projections.

To achieve these goals, a series of pertinent problems/issues/questions were formulated:
- Address the lack of knowledge concerning underground components of the species' life history;
- Compile a life-history table;
- Establish priorities for underground status studies;
- How do we define a population of *B. mormo*?
- What do we know of the detailed breeding system for this species, and how do we study it?
- Does the life history of other plant species apply to this species?
- What research priorities are needed?

Environment
Conservation goals pertinent to the species' environmental context included:
- Determine the type of suitable habitat and how much is needed for species viability;
- Predict impacts of multiple factors on population viability;
- Address the potential for *B. mormo* to serve as a "flagship" or "indicator" species.

To achieve these goals, a series of pertinent problems/issues/questions were formulated:
- What is the role of disturbance on plant succession in *B. mormo* habitat?
- What is the role of non-hardwood forest habitat on *Botrychium*?
- Identification of stand history of presently occupied stands. (What is the history of the stands where *B. mormo* occurs?)
- Do the removal and the compaction of leaf litter impact the species?
- Can *B. mormo* and logging coexist?
- How much buffer is needed to minimize the impact to existing population of *B. mormo*.

Geography and distribution
Conservation goals pertinent to the species' geography and distribution included:
- To predict the occurrence of *B. mormo* on the landscape.

To achieve these goals, a series of pertinent problems/issues/questions were formulated:

- How is *B. mormo* distributed throughout its range?
- How do you assess the status of a species that is rare and patchy in its distribution?

The working group's activities were geared towards addressing as many of these goals and issues as practicable within the time constraints of the workshop.

The Uniqueness of *Botrychium mormo*

The plant in question is remarkable among moonworts as well as all other ferns. Annually, the appearance of the new frond is exceptional in that the new frond may appear anytime during late spring to fall. The sexual plant or gametophyte, instead of dying after producing a sporophyte, can retain its connection to the sporophyte for several years. Also the gametophyte can produce more than one sporophyte. The gametophyte is non-photosynthetic and develops under ground. The sporangia or spore-producing capsules never open completely as do other botrychiums; the line of dehiscence is much shorter and may open up only 20 to 30 degrees. The species has a narrow and very distinctive range in the northern parts of Minnesota, Wisconsin and Michigan. The morphology is peculiar with respect to the extreme succulence of the leaves, the poorly developed trophophore or blade, and the relatively small sporangia. These unique features present in the goblin fern justifies the special attention it receives from naturalists, ecologists, and botanists.

The Habitat

The primary habitat for *B. mormo* is rich, mature northern hardwood forest with a well-developed layer of duff in various stages of decay lying over the mineral soil. The most prominent trees are 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 thalictroodes*, *Aralia racemosa*, *Actaea rubra*, *Arisaema triphyllum*, *Polygonatum pubescens*, *Osmorrhiza claytoniana*, *Uvularia grandifolia* and *Anemone quinquefolia*. Associated ferns and fern allies include *Athyrium angustum*, *Botrychium lanceolatum*, *Botryum matricariifolum, Botrychium minganense*, *Botrychium oneidense, Botrychium virginianum*, *Matteuccia struthiopteris*, *Equisetum pratense*, and *Gymnocarpium dryopteris*. Invasive plant species are usually absent.

The soil is a humus-rich mineral soil of intermediate drainage. The overlying duff is composed primarily of old decayed tree leaves and persistent leaf veins and rachises. The blades are fragmented and the veinlets are mostly skeletonized. Underfoot the duff is moderately spongy. Most occurrences of the goblin fern are on flat terrain, but occasionally they will be found on a moderate slope. Except for patchy sun spots, all of the occurrences are in deep shade.

The age of a typical *B. mormo* forest averages between 40 and 100 years. However, there are usually various saplings, and in many of the localities the forest floor is dotted more or less completely by small, young maples, often only one to three feet tall.

Where there has been heavy invasion by exotic earthworms, the duff layer is eliminated, the exposed soil surface becomes hard, and there is increased cover of the sedge *Carex pensylvanica.*

Species Definitions

Prior to identifying the life cycle stages and processes of *B. mormo*, definitions of an individual and a population need to be addressed. There was considerable discussion on the definition of a population. Much of this discussion involved life cycle processes and how they relate to identifying population parameters.

Individual

Unlike most Botrychiums, *B. mormo* has been known to send up multiple sporophytes from one gametophyte. However, the group agreed that in general and for bookkeeping purposes that one gametophyte produces one sporophyte. Thus, an individual is defined as one sporophyte above or below ground.

Population

In the past a population has been defined in the context of what is being considered, the scale of consideration, and objectives. Because of the reproductive strategy used by *B. mormo*, which rarely involves genetic transfer by cross-fertilization, defining a population on the basis of genetic transfer is difficult. In addition, dispersal of genetic material is relatively passive, either over very short distances (in centimeters) or infrequently by animal ingestion and subsequent deposition in feces. Probable dispersal by small mammals and insect larvae can be useful in determining the distance to consider in identifying populations. The sporangia of *B. mormo* do not open as completely as do sporangia of other *Botrychium* species. There is some question of whether the spores are actually released by the sporangia or not. If they are, dispersal by wind can not be far, a few centimeters at best. The sporangia adaptation suggests that dispersal occurs primarily by animal ingestion.

Most agencies have used the quarter/quarter section (40 acres) to define populations or distinct sites of *B. mormo*. Microhabitat availability and distributions may also be a factor in population definition. There was some discussion that a distinct population could be separated from other *B. mormo* concentrations by at least 100 meters, or be separated by being in different management units.

The group made the decision to define a *B. mormo* population as at least one aboveground sporophyte within a quarter/quarter section (40 acres square). Implicit in this definition is the consideration that a single above ground individual is likely representative of a larger underground population as well as additional undetected above ground plants.

The Value of Constructing Goblin Fern Population Models

The models presented and discussed in this section were developed to chart the stage-based life cycle of the goblin fern *Botrychium mormo.* Insight gained through this iterative modeling process is vital to a better understanding of the population dynamics of the species. Constructing a model involves both a process and a product. Both can be of significant value, and in some cases, the process may actually be of greater utility than the product. The process of constructing these models required the working group participants to think carefully about the biology of *Botrychium mormo* and evaluate the data available in order to determine quantitative characteristics of the species' life history. It also reveals those portions of the life cycle that we know little or nothing about and which warrant further investigation.

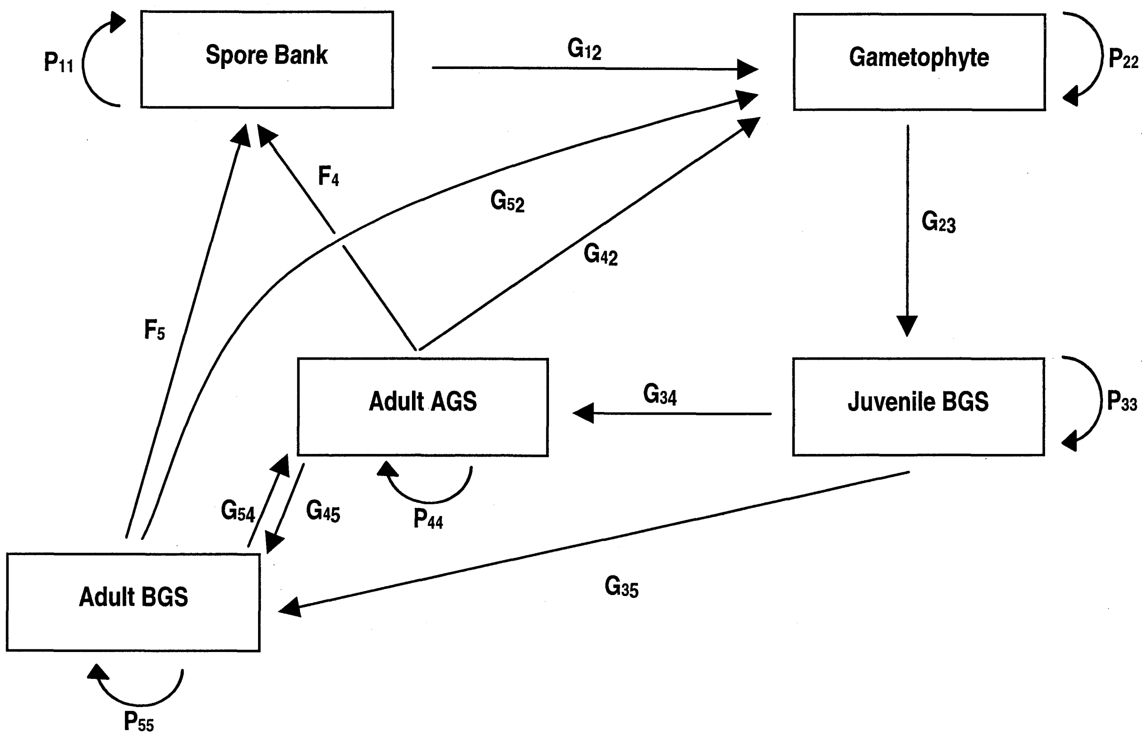
A basic stage-based stochastic model for population dynamics of the goblin fern was developed using the RAMAS/Stage software package (Ferson, 1994). Stage-based models have been shown to be extremely useful in the analysis of species for which the primary unit of population organization is the developmental stage of the individual and not necessarily its age (Ferson, 1994; Lefkovitch, 1965). This characteristic is very common among plants, where individuals may be of the same chronological age but may occupy radically different developmental stages of the species' life history, i.e., gametophyte, juvenile sporophyte, or fertile adult sporophyte. The model's fundamental algorithm describing the growth of the population is composed of a series of equations (called replacement functions) relating the abundances within individual stages at time $t+1$ to the abundances of those stages at time t. These functions include transition probabilities, or estimates of the probability of individuals in stage i in year t either remaining in that stage or developing into stage j at time $t+1$.

Life Stage Definitions

Figure 1 displays the fundamental life cycle of *B. mormo.* There are four basic life stages which this species passes through during its life cycle.

Spore Bank - The spore bank includes all ungerminated spores within the litter, duff, and soil, including those still within sporangia.

Spores are transported by animals through ingestion or external attachment or are dispersed from the sporophye by wind. They are eventually deposited on the ground where they slowly percolate through the duff layer. Spores have relatively thick outer coats, which serve as a preadaptation for animal dispersal. This thick coat may also serve as protection to the spore for a prolonged period prior to germination. It is estimated that spores may take up to five years to percolate through the duff layer. Germination occurs when the spore has percolated sufficiently to reach mineral soil where it receives appropriate moisture and complete darkness, two requirements of germination in all Botrychiums.



	Spore Bank	Gametophyte	Juvenile BGS	Adult AGS	Adult BGS
Spore Bank	P_{11}			F_4	F_5
Gametophyte	G_{12}	P_{22}		G_{42}	G_{52}
Juvenile BGS		G_{23}	P_{33}		
Adult AGS			G_{34}	P_{44}	G_{54}
Adult BGS			G_{35}	G_{45}	P_{55}

Figure 1. Generalized stage-based population dynamics model for the goblin fern (*Botrychium mormo*). The model is shown both as a graphical network (top) and as a standard projection matrix (bottom).

<u>Gametophyte</u> - Upon spore germination, cell division occurs to develop a gametophyte consisting of several cells. This early gametophyte stage requires rapid infection by mycorrhizal fungi for nutrition and allows maturation of the gametophyte. The gametophyte is a fleshy, root-like structure that becomes a parasite of the mycorrhizal fungi, receiving all its nutrients from it, allowing further development and persistence.

Each gametophyte eventually develops a series of sex organs, both male and female. Moisture is required for the sperm to swim to the egg in the archegonium (female sex organ). Self-fertilization is the dominant mode of reproduction, although cross-fertilization does occur infrequently. All of these processes occur in the soil. A gametophyte has been known to produce a sporophyte in 12 months in laboratory culture, but development and fertilization in nature probably take 2-4 years.

Juvenile Below-Ground Sporophyte (Juvenile BGS) - Upon fertilization in the archegonium the egg becomes an embryo which develops into a juvenile sporophyte. Initially, root development occurs before any leaf development. The roots must develop a connection with the mycorrhizal fungi early on to establish a nutrient source. It seems probable that the gametophyte provides nutrients to the sporophyte until this root/fungi relationship is established.

The initial leaf formation is undifferentiated tissue with no trophophore or sporophore. The sporophyte develops a series of these undifferentiated primordial leaves, each enclosing the other. Up to six such leaves are developed at the stem apex. Ultimately, as the plant continues to develop, primordial leaves will develop annually into fully developed leaves with a trophophore and a sporophore. Sporophyte development through these stages probably requires several years before the first above-ground leaf is produced.

Adult Above-Ground (Adult AGS) and Below-Ground (Adult BGS) Stems - At the time the plant develops its first trophophore, sporophore and spores, it becomes classified as an adult plant. In any given year, the plant may produce an aboveground leaf or it may remain belowground. Belowground plants are typically very small and produce very few, if any, sporangia. Aboveground plants may also be small, but approximately 5-10% will develop into larger plants with 20 and 50 sporangia.

Several extrinsic factors affect whether a plant remains small, either aboveground or belowground, or fully develops into a large plant. These include deterministic factors such as the health of the mycorrhizal fungi, the connection between the plant and the fungi, the age and health of the plant, and adverse climatic conditions such as drought or flooding. These and probably other factors cause adult plants to vary annually in size and presence. Some plants may remain belowground for a few years before re-emerging above ground. Limiting factors such as amount of suitable habitat (loss of litter), fungal presence and development, water relationships such as drought and flooding, predators such as small mammals and insects, fungal and bacterial diseases, plant age, and indirect effects such as those which affect the health of the mycorrhizal fungi all affect whether a plant remains small or develops into a larger plant.

The size of the plant determines the number of sporangia developed and ultimately how many spores are produced, i.e., fecundity. In a population, the fecundity determines the annual contribution to the spore bank. We estimate that an average above-ground plant produces about 10 sporangia.

The stage-based model can be described in a number of ways, including a graphical depiction of the transitions observed both within and between stages, a traditional matrix view showing the stage-transition matrix (also known as a Lefkovitch matrix) of transition probabilities, and by a series of equations relating the abundance in a given stage in year $t+1$ to the abundances in all other stages in year t. Refer to Figure 1 in this section for the network and a depiction of the transition probabilites within a given stage (labeled P_{ii}) and the transitions between stage i and stage j (labeled G_{ij}). A discussion of the numerical estimates of these transition probabilities is given below.

Input to Simulation Models

Data appropriate to this analysis were collected by Johnson-Groh and her colleagues across five permanent monitoring plots in northern Minnesota beginning in 1992. Reports of this research were the primary source of information used in developing transition probabilities between and within stages.

The equations describing these transitions are listed below, where the numerical abundance within a given stage is depicted as [stage]:

[Bank] = 22500[Adult AGS] + 128[Adult BGS] + 0.50[Bank]
[Gametophyte] = 0.0012[Bank] + 0.00007[Adult AGS] + 0.0004[Adult BGS] + 0.34[Gametophyte]
[Juvenile BGS] = 0.36[Gametophyte] + 0.50[Juvenile BGS]
[Adult BGS] = 0.002[Juvenile BGS] + 0.52[Adult AGS] + 0.60[Adult BGS]
[Adult AGS] = 0.016 [Juvenile BGS] + 0.15[Adult BGS] + 0.47[Adult AGS]

As an example of reading this terminology is in order. The number of spores in the spore bank in year t +1 (designated by [Bank] on the left side of the topmost equation) is determined by the total spore production by all adult sporophytes present in year t (itself a function of the total number of adult sporophytes—[Adult AGS] + [Adult BGS]—and the number of spores produced per plant—22500 and 128, respectively—and by the number of spores present in year t that have remained viable through to the next year in the bank, in this case, 50%. Furthermore, it is estimated that the germination rate for these spores is 0.12% ([Gametophyte] = 0.0012[Bank]).

The justification for these values is described in greater detail below.

<u>Spore Bank</u>
Contributions are made to the spore bank by adult sporophytes both above and below ground. The number of spores produced by an aboveground sporophyte is based on the assumption that each plant produces an average of 10 sporangia with each sporangium holding about 3000 spores. If it is further assumed that about 14% of spores are lost directly through herbivory and an additional 11% are lost through dispersal outside the local population, the total annual spore production becomes 22,500 spores per plant. For the populations for which empirical data are available, the sporophyte density is estimated at 10 aboveground plants per square meter.

Belowground sporophytes were also thought to possibly contribute to the spore bank. While most plants in this stage do not produce sporophores, H. Wagner has observed a few such instances in which a very small number of spores have been produced underground. It seems possible that some of these spores which are released underground in the vicinity of the mycorrhizae and which do not need to filter down through the litter and duff layers are essentially in the sporebank the concurrent and following years. The mean number of spores contributed to the bank by this underground stage was estimated at 128 spores per plant.

We estimated that half of the spores remained in the spore bank annually (the remainder succumbing to mortality due to desiccation, herbivory, etc.), thus the probability of a spore in year t remaining as a spore in year t +1 was 0.5. This assumption was based on an estimated 5-

year residency time of spores within the bank, (i.e., it takes 5 years for spores to filter down to the mineral soil after deposition on the litter surface) and the number of observed gametophytes eventually produced by these spores.

Based on the estimated residency time of spores within the bank and a sporophyte density of 10 / m^2, the total number of spores in the bank at a given time was estimated to be 500,000 / m^2.

<u>Gametophyte</u>
Based in part on the estimated number of 700 gametophytes / m^2 observed by Johnson-Groh and Farrar in their Chippewa National Forest study plots, the germination rate to production of detectable gametophytes of spores in the bank was estimated to be 0.0012 (Germination is measured by the production of detectable gametophytes.). The low germination rate may be limited primarily by the need to establish a mycorrhizal partner during the germination process.

In addition to those gametophytes arising from germination of banked spores, some adult sporophytes (especially those that fail to emerge from the duff) may produce spores that, due to particularly favorable conditions (and a bit of good luck), germinate immediately to produce gametophytes the same season or the year following spore production. Sporophytes below ground generally do not produce sporophres; however, Wagner has observed a very few producing a small number of spores underground, presumably due to unfavorable conditions for sporangia production aboveground. It seems possible that some of these spores which are released underground in the vicinity of the mycorrhizae and which do not need to filter down through the litter could germinate immediately the same season or the next year. We estimated the probability of the few spores released belowground germinating immediately to be 0.0004. Along the same logic, aboveground sporophytes can release spores that germinate within the following year, although this process has not been observed and is considered to be unlikely since the spore would have to be released and filter down to the soil and germinate within the same growing season. We set this probability at 0.00007.

We estimated the residency time in the gametophyte stage to be 3 years. In other words, it takes 3 years for a germinating spore to develop to the point of producing sporophytes. This residency time estimate is based on laboratory results of Whittier (1992) in which gametophytes cultured under ideal lab conditions require one year to germinate and produce sporophytes. It is estimated that this process takes about three times longer under natural conditions. Based on this information and assuming negligible mortality, we estimated the within-stage transition probability to be 0.34.

<u>Juvenile Belowground Sporophyte</u>
Based on direct field observations from Johnson-Groh and Farrar's 1995 plots, a density of juvenile belowground sporophytes of about 250 / m^2 was observed. From these observations, we estimated that, on average, about 36% of gametophytes within a given year produce belowground sporophytes the following year. Additionally, we estimated the within-stage transition to be 0.5 based on a fixed number of aboveground sporophytes observed in study plot 4 of the Chippewa National Forest and the number of juveniles observed belowground.

Adult Aboveground Sporophytes

Johnson-Groh and Farrar observed an average of 10 aboveground sporophytes / m^2 in study plot 4 of the Chippewa National Forest site from 1994 through 1997. Adult aboveground sporophyte transition probabilities were calculated in order to account for the observed density of adults in this stage. The rate at which adult belowground sporophytes return as aboveground adults the following year was estimated to be 0.15 annually. This is based on an average return rate among 527 plants monitored over 5 study plots for 3 years by Johnson-Groh and Farrar. These same data indicated that the estimated rate at which aboveground plants in year t return as aboveground plants in year t+1 is 0.47. From these more direct estimates, an indirect estimate can be made of the rate at which juvenile sporophytes can develop into aboveground sporophytes. The annual rate at which this occurs was estimated to be 0.016.

Adult Belowground Sporophytes

Juvenile sporophytes may develop into adult sporophytes that, perhaps due to adverse environmental conditions within a given year (e.g., lack of moisture or mycorrhizae), do not appear aboveground during their first year in that stage. We estimated this probability to be 0.002.

Sporophytes that were observed aboveground in year *t*-1 but are absent in year *t* are all considered to have gone "belowground". This can, or course, include plants that in reality died in addition to those that simply survived but did not produce an aboveground leaf; from the perspective of the model, these two fates are indistinguishable. The probability that an aboveground sporophyte does not return the following year was estimated at 0.52. This estimate is based on an average return rate among 527 plants monitored over 5 study plots for 3 years by Johnson-Groh and Farrar. Based on these figures, the within-stage transition probability was estimated at 0.60 annually.

A summary of the baseline model input parameters is presented in the standard projection matrix below.

	Spore Bank	**Gametophyte**	**Juvenile BGS**	**Adult AGS**	**Adult BGS**
Spore Bank	0.50			22500	128
Gametophyte	0.0012	0.34		0.00007	0.0004
Juvenile BGS		0.36	0.50		
Adult AGS			0.016	0.47	0.15
Adult BGS			0.002	0.529	0.60

The initial models introduced above began as strictly deterministic in nature; in other words, transition probabilities were fixed and did not vary stochastically over time. These initial models were subsequently modified to account for stochastic variation estimated from the field studies of Johnson-Groh and Farrar. All of the estimates of environmental variation are described statistically as lognormal distributions with the exception of fecundity, which is distributed as a Poisson variable. All estimates of variation were in accord with an assumed coefficient of variation (CV, or standard deviation expressed as a percentage of the mean) equal to 25%.

Density Dependence (Carrying Capacity)

There was a general consensus among the group that some form of density dependent process operates in goblin fern populations to regulate their growth. We assume that this density dependence is shown in the form of a ceiling or carrying capacity. Moreover, this carrying capacity is based on the total number of adult sporophytes, both aboveground and belowground. These stages were thought to take up the greatest proportion of habitat resources. Whenever the total number of adult sporophytes exceeds the carrying capacity, the fecundity of adult aboveground sporophytes (F_4) is decreased by an amount proportional to the extent of exceedence. Only the mean rate was modified, so annual variability could continue to make some fecundities larger or smaller. It was therefore possible for the abundance to increase above the carrying capacity, so the ceiling was not excessively strict. Carrying capacities of 50, 25, 10, and 5 total adult sporophytes were chosen in an attempt to assess the extinction risks among populations of different sizes. Some populations may in fact be larger, consisting of up to 50 adult sporophytes per m^2, but we focused initially on the smaller populations presumably at larger risk.

Catastrophes

Beyond normal annual variation in environmental conditions, the group felt that extreme conditions could infrequently occur which may have considerable impacts on goblin fern populations. Data presented at the workshop suggested that severe drought occurs in the upper Midwest on average every eleven years, and this type of event would target spore production in the affected population. Therefore, a subset of models included a catastrophic drought with an annual probability of occurrence of 9.09% and, if it occurred, it would reduce fecundity of adult aboveground sporophytes (F_4) by 70% in that particular year. An additional, more severe drought event was simulated with an annual probability of occurrence of 5.0% (occurring once on average every 20 years). In the year of such a catastrophic drought, the abundances of all stages except the spore bank were reduced by 50%, 75% or 100% (self-sufficient encapsulated spores were thought to be immune from drought effects). Because of the independent, probabilistic nature of these event, it is possible that a drought could occur in two successive years, or it may not occur for extended periods of time.

All model projections were iterated 1000 times, each with a duration of 50 years.

Results from Simulation Modelling

Deterministic Model Results

The long-term deterministic population growth rate, or λ (lambda), can be calculated using standard life-table analysis. These calculations assume that there is no annual variation in birth and death rates (resulting from either random environmental fluctuations or from stochastic demographic variation), that the availability of gametophytes with sex organs is never a limiting factor, and that the stage-specific abundances are at an equilibrium, stable state. Populations with $\lambda > 1.0$ are increasing over time while those with $\lambda < 1$ are decreasing over time. Given these assumptions, and our best estimates of the life-history parameters for this species, the goblin fern baseline model shows the capacity for strong annual growth with $\lambda = 1.132$ (Table 1). **In other**

words, this simulated population is expected to grow, in the absence of stochastic variation in vital rates, at a rate of 13.2% per year.

It is important to remember during the evaluation of these results that the growth rates calculated in these initial models are based on a number of best-guess estimates for life-history parameters. *As a result, the absolute value of λ should not be taken as an exact predictor of current population performance*, although the general trend may be considered reliable within the context of our assumptions. Perhaps of greater value in this process is the analysis of changes in relative population performance resulting from perturbations made to individual life-history parameters such as spore set, spore germination rate, or spore bank characteristics as these are parameters for which only scant data are available. This type of sensitivity analysis allows us to evaluate the consequences of our "ignorance" of accurate estimates of various life-history parameters.

Towards this end, considerable insight into the nature of goblin fern population dynamics can be gained by studying the *elasticities* of the baseline projection matrix. The elasticity of a projection matrix is basically a measure of the contribution of a particular matrix element to the magnitude of λ calculated from that matrix. Consequently, changes made to matrix elements with high elasticity result in proportionally larger changes in λ. As can be seen from Table 2, the projection elements with the highest elasticities are related to spore set (F_4, F_5), spore germination (G_{12}), and development (G_{23}) of gametophytes into juvenile belowground sporophytes.

Table 1. Goblin fern (*Botrychium mormo*) population viability. Output for the deterministic and stochastic models with habitat carrying capacity (*K*) = 50 adult sporophytes (see text for a description of model conditions). The population growth rate per generation is given by λ, while P(E) is the probability of population extinction within the 50-year duration of the simulation and N_{50} is the number of adult aboveground sporophytes extant at the end of the simulation. See Figure 1 for graphical definitions of the stated transition probabilities.

Model Conditions	λ	P(E)	N_{50} (SD)
Baseline	1.132	0.0	57 (17)
$P_{11} = 0.25$	1.084	0.0	40 (10)
$P_{11} = 0.125$	1.065	0.0	33 (9)
$G_{12} = 0.0006$	1.043	0.0	27 (10)
$G_{12} = 0.0003$	0.973	0.203	3 (2)
$F_4 = 16{,}875$	1.093	0.0	44 (12)
$F_4 = 11{,}250$	1.044	0.0	29 (8)
$G_{45} = 0.40$	1.121	0.0	58 (17)
$G_{45} = 0.27$	1.111	0.0	59 (18)

The effects of changes to those transitions with different elasticities are demonstrated in the second column of Table 1. A series of models were run with spore bank residency, spore germination rate, and aboveground sporophyte fecundity each systematically reduced by biologically reasonable proportions. As can be seen from the results in the table, the growth rate is reduced by more than 50% when the spore bank residency is reduced from $P_{11} = 0.5$ (13.2%) to $P_{11} = 0.125$ (6.5%). Reducing aboveground sporophyte fecundity by 50% also leads to a strong decrease in population growth (F_4 = 11,250: λ = 1.044). This decrease is mirrored very closely by a 50% reduction in spore germination rate (G_{12} = 0.0006: λ = 1.043), as is expected since these two transitions have very similar elasticities (0.1262 v. 0.1254). It is useful to note that, under extreme conditions of low spore germination, the dynamics of the population may change from one characterized by growth to one of decline (G_{12} = 0.0003: λ = 0.973). It is also possible that models incorporating uncertainty in more than one parameter (e.g., low germination combined with decreased spore bank residency) would result in similar switches in population behavior and most likely represents a more realistic scenario. Finally, as expected, changes made to those transitions with low elasticities, such as the "disappearance rate" of aboveground sporophytes, G_{45}, result in a much smaller change in λ (see bottom of Table 1).

Table 2. Elasticities calculated from the baseline population model for the goblin fern (*Botrychium mormo*). Changes made to transition probabilities with larger elasticity result in proportionally larger changes to the long-term population growth rate (λ).

	Spore Bank	Gametophyte	Juvenile BGS	Adult AGS	Adult BGS
Spore Bank	0.0999			0.1254	0.0008
Gametophyte	0.1262	0.0542		0.0	0.0
Juvenile BGS		0.1262	0.0999		
Adult AGS			0.1218	0.1156	0.0410
Adult BGS			0.0044	0.0374	0.0472

These simple deterministic models suggest that, given our best estimates of life-history parameters for this species, goblin fern populations have the potential for vigorous positive growth under normal environmental conditions, i.e., no outside human-mediated disturbance to *B. mormo* habitat. However, high levels of uncertainty associated with these estimates makes precise predictions of future population projections very difficult to compute. In other words, we must remember that our baseline projection of 13% annual population growth may come with considerable imprecision that could be removed only through increased field study efforts.

Stochastic Model Results

Simple analysis and comparison of deterministic, long-term growth rates does not take into account the variation in those rates that may occur because of variation in environmental conditions or the stochastic variation inherent to vital rates governed by so-called "binomial processes", i.e., birth, death, sex determination, etc. When some or all of these sources of stochastic variation are added to deterministic models of population dynamics, a picture of risk emerges where our predictions about the fate of populations may differ dramatically from simpler deterministic analyses. For example, 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 vital rates is sufficiently large. This is particularly true in smaller populations or in those species with wide fluctuations in vital rates brought on by environmental fluctuations. In other words, it may be likely that a population would grow in size over the long term, but it could be possible that the same population could go extinct if hit by a particularly nasty bout of bad luck.

A series of stochastic models were developed for the goblin fern that included annual variation in stage-specific transition probabilities resulting from environmental variation. The output from these models is presented here as the probability of aboveground sporophyte extinction (other stages may or may not be present) and the total number (actual, mean and standard deviation) of aboveground sporophytes present at the end of the 50-year simulation. As stated before, because of the number of imprecise estimates that were required in our model construction it is perhaps more appropriate to observe the differences in outcome between sets of models than to interpret specific model outcomes as precise representations of reality.

The initial baseline model was run under the range of carrying capacities previously described. The results of these models are shown in the top row of Tables 1 and 3-5 and in Figure 2. True to expectations based on the deterministic growth rate, the average population size easily reaches the ceiling and remains there for the duration of the simulation. The significant extent of variation about the mean population size due to demographic and environmental stochasticity, particularly when the mean is relatively large, is plainly evident in Figure 2. **Despite this variation, the risk of population extinction under these baseline conditions is negligible because of robust population growth, even at very low population numbers.**

Table 3. Goblin fern (*Botrychium mormo*) population viability. Output for the deterministic and stochastic models with habitat carrying capacity (*K*) = 25 adult sporophytes (see the text for a description of model conditions). See Table 1 for additional definitions.

Model Conditions	λ	P(E)	N_{50} (SD)
Baseline	1.132	0.0	29 (9)
$P_{11} = 0.25$	1.084	0.0	19 (5)
$P_{11} = 0.125$	1.065	0.0	16 (5)
$G_{12} = 0.0006$	1.043	0.0	14 (5)
$G_{12} = 0.0003$	0.973	0.264	2 (2)
$F_4 = 16{,}875$	1.093	0.0	22 (6)
$F_4 = 11{,}250$	1.044	0.0	15 (5)
$G_{45} = 0.40$	1.121	0.0	29 (8)
$G_{45} = 0.27$	1.111	0.0	30 (8)

Tables 1 and 3-5 also show the consequences of changing various demographic parameters on those population characters influenced by stochastic processes, such as the probability of population extinction. For example, when K = 50 (Table 1), final population size (N_{50}) can be affected dramatically through changes in spore germination rate (G_{12}) or adult sporophyte fecundity (F_4). A graphical depiction of this sensitivity analysis in terms of its effect on final population size is shown in Figure 3. Note the relatively greater sensitivity of the simulated population to changes in spore germination (G_{12}) and adult sporophyte fecundity (F_4) compared to spore bank residency (P_{11}) and disappearance of adult sporophytes belowground (G_{45}).

Table 4. Goblin fern (*Botrychium mormo*) population viability. Output for the deterministic and stochastic models with habitat carrying capacity (K) = 10 adult sporophytes (see the text for a description of model conditions). See Table 1 for additional definitions.

Model Conditions	λ	P(E)	N_{50} (SD)
Baseline	1.132	0.0	12 (3)
$P_{11} = 0.25$	1.084	0.0	8 (2)
$P_{11} = 0.125$	1.065	0.0	7 (2)
$G_{12} = 0.0006$	1.043	0.0	6 (2)
$G_{12} = 0.0003$	0.973	0.64	1 (1)
$F_4 = 16{,}875$	1.093	0.0	9 (2)
$F_4 = 11{,}250$	1.044	0.0	6 (2)
$G_{45} = 0.40$	1.121	0.0	11 (4)
$G_{45} = 0.27$	1.111	0.0	12 (4)

Table 5. Goblin fern (*Botrychium mormo*) population viability. Output for the deterministic and stochastic models with habitat carrying capacity (K) = 5 adult sporophytes (see the text for a description of model conditions). See Table 2 for additional definitions.

Model Conditions	λ	P(E)	N_{50} (SD)
Baseline	1.132	0.0	6 (2)
$P_{11} = 0.25$	1.084	0.0	4 (1)
$P_{11} = 0.125$	1.065	0.0	3 (1)
$G_{12} = 0.0006$	1.043	0.002	3 (1)
$G_{12} = 0.0003$	0.973	0.87	1 (1)
$F_4 = 16{,}875$	1.093	0.0	4 (1)
$F_4 = 11{,}250$	1.044	0.0	3 (1)
$G_{45} = 0.40$	1.121	0.0	6 (2)
$G_{45} = 0.27$	1.111	0.0	6 (2)

Only through a 75% reduction in spore germination rate does an extinction risk become evident in these simulated populations. When K = 50, this risk is nearly 15% (Table 1); however, as carrying capacity decreases, the risk increases sharply to nearly 80% when K = 5 (Table 5). This result is dramatic evidence that smaller populations are at risk of extinction precisely because they are small and therefore susceptible to the detrimental effects of random variation in demographic processes.

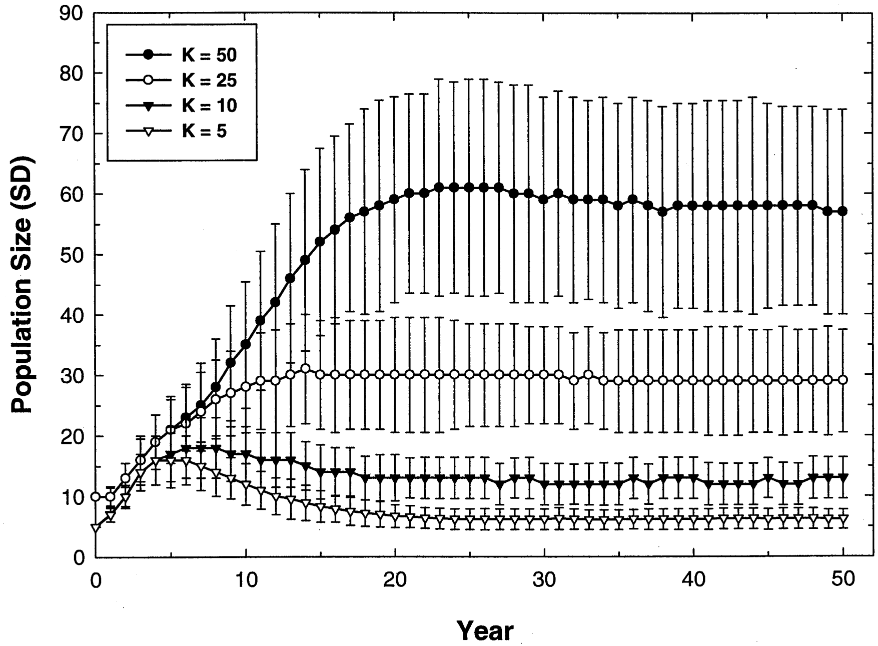


Figure 2. Fifty-year projection (mean ± standard deviation) of simulated goblin fern (*Botrychium mormo*) populations under baseline conditions (see text for a description of baseline parameters). Carrying capacity (K) is defined in terms of the total number of adult sporophytes, both above and belowground.

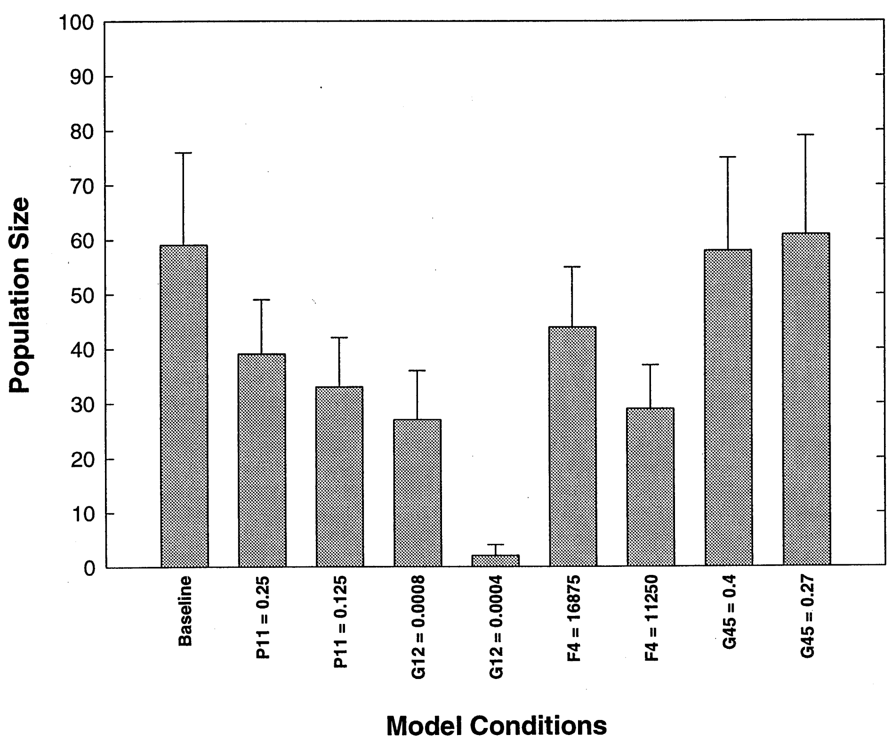


Figure 3. Final population size (mean ± standard deviation) of initial goblin fern baseline model and subsequent models incorporating the indicated change in a single demographic parameter.

Perhaps some of this risk of population extinction under conditions of low spore germination is due to the susceptibility of goblin fern populations to drought conditions. An attempt was made to assess this possibility by repeating the models shown in Tables 4 and 5 (the smaller populations with K = 10 and 5) but with the catastrophic event removed from the simulations. Through this process, in which all other parameters and their subsequent modifications are held constant, the direct effect of the catastrophe can be evaluated. The results are presented in Tables 6 and 7.

As can be seen from the tabulated results when compared to those in Tables 4 and 5, the simulated catastrophic drought had relatively little detrimental impact on the simulated populations. A 70% decrease in the number of spores produced per sporophyte in a given "catastrophe" year was not seriously harmful to these populations in terms of either final population size or risk of population extinction. Perhaps the catastrophic event is not being simulated correctly with respect to what component of the fern's life cycle it most acutely affects or its severity. On the other hand, it is possible that this type of event does in fact have relatively little impact on goblin fern population dynamics, at least in the long-term. Additional field data are needed to resolve this issue.

Table 6. Goblin fern (*Botrychium mormo*) population viability. Output for the deterministic and stochastic models with habitat carrying capacity (*K*) = 10 adult sporophytes and no catastrophes (see the text for a description of model conditions). See Table 2 for additional definitions.

Model Conditions	λ	P(E)	N_{50} (SD)
Baseline	1.132	0.0	13 (3)
$P_{11} = 0.25$	1.084	0.0	8 (2)
$P_{11} = 0.125$	1.065	0.0	7 (2)
$G_{12} = 0.0006$	1.043	0.0	6 (2)
$G_{12} = 0.0003$	0.973	0.49	1 (1)
$F_4 = 16,875$	1.093	0.0	9 (2)
$F_4 = 11,250$	1.044	0.0	6 (2)
$G_{45} = 0.40$	1.121	0.0	12 (3)
$G_{45} = 0.27$	1.111	0.0	13 (4)

Table 7. Goblin fern (*Botrychium mormo*) population viability. Output for the deterministic and stochastic models with habitat carrying capacity (*K*) = 10 adult sporophytes and no catastrophes (see the text for a description of model conditions). See Table 2 for additional definitions.

Model Conditions	λ	P(E)	N_{50} (SD)
Baseline	1.132	0.0	6 (2)
$P_{11} = 0.25$	1.084	0.0	4 (1)
$P_{11} = 0.125$	1.065	0.0	4 (1)
$G_{12} = 0.0006$	1.043	0.015	3 (1)
$G_{12} = 0.0003$	0.973	0.81	1 (1)
$F_4 = 16,875$	1.093	0.0	5 (1)
$F_4 = 11,250$	1.044	0.0	3 (1)
$G_{45} = 0.40$	1.121	0.0	6 (2)
$G_{45} = 0.27$	1.111	0.0	6 (2)

Additional models were developed that incorporated a more serious drought, which affected the abundances of all life stages (except the spore bank) during the drought year. The results of these models are shown in Table 8 and Figure 4. A 50% reduction in stage-specific abundances has relatively little effect, even at small carrying capacities, although a slight extinction risk does occur when K = 5. More serious consequences result when at least 75% of individuals in all non-spore stages do not survive a given drought year. Particularly striking are the results of a very severe event, marked by 100% mortality of individuals during the year. Even the largest population (K = 50) shows a 20% risk of extinction while the smallest (K = 5) suffers from a risk approaching 50% over 50 years. Moreover, populations are reduced to about 50% of their maximum size if extinction is not seen during the timespan of the simulation.

Table 8. Goblin fern (*Botrychium mormo*) population viability. Output for stochastic models with severe drought under different habitat carrying capacities (K). Severity is defined in terms of the percent reduction in abundance of all non-spore life stages during a drought year. Extinction probabilities and final population sizes are for above ground sporophytes only. Demographic parameters for all models as per the baseline model (see table 1 for additional information).

K	Drought Severity (%)	P(E)	N_{50} (SD)
50	50	0.0	48 (19)
	75	0.01	40 (25)
	100	0.19	25 (25)
25	50	0.0	25 (10)
	75	0.05	21 (12)
	100	0.24	12 (12)
10	50	0.0	10 (4)
	75	0.03	8 (5)
	100	0.33	5 (5)
5	50	0.01	5 (2)
	75	0.10	4 (2)
	100	0.46	2(2)

It is important to remember that we have been defining "extinction" of a population of goblin ferns in terms of the absence of a single stage, namely adult aboveground sporophytes, at the end of a 50-year simulation. In the absence of these individuals, it is still possible that a number of individuals within other stages are still present. We wanted to investigate the capacity of this severe drought to eliminate a larger proportion of a simulated population. All individuals beyond the gametophyte stage were collectively labeled as "Plants" and were tallied at the end of the models shown in Table 8 and Figure 4 (Data for "Plants" tally not shown). When considering total "Plant" population size in these drought models, a picture nearly identical qualitatively to that in Figure 4A emerged, i.e., population size was relatively unaffected by a drought of 50% severity while a very serious drought reduced final population size by about 50%. A risk of "Plant" population extinction, leaving only a small set of gametophytes and the spore bank, was restricted to the very severe drought (100% severity). This risk ranged from 9% in the largest populations (K = 50) to 13% in the smallest populations (K = 5).

Taken in total, it is clear that this type of severe drought, under the set of assumptions built into these models, can have a considerable impact on the capability of goblin fern populations to persist. It therefore becomes of paramount importance to understand the nature and extent of microsite variation across *B. mormo* habitat and the consequences of this variation for susceptibility to the detrimental effects of drought across the species' distribution.

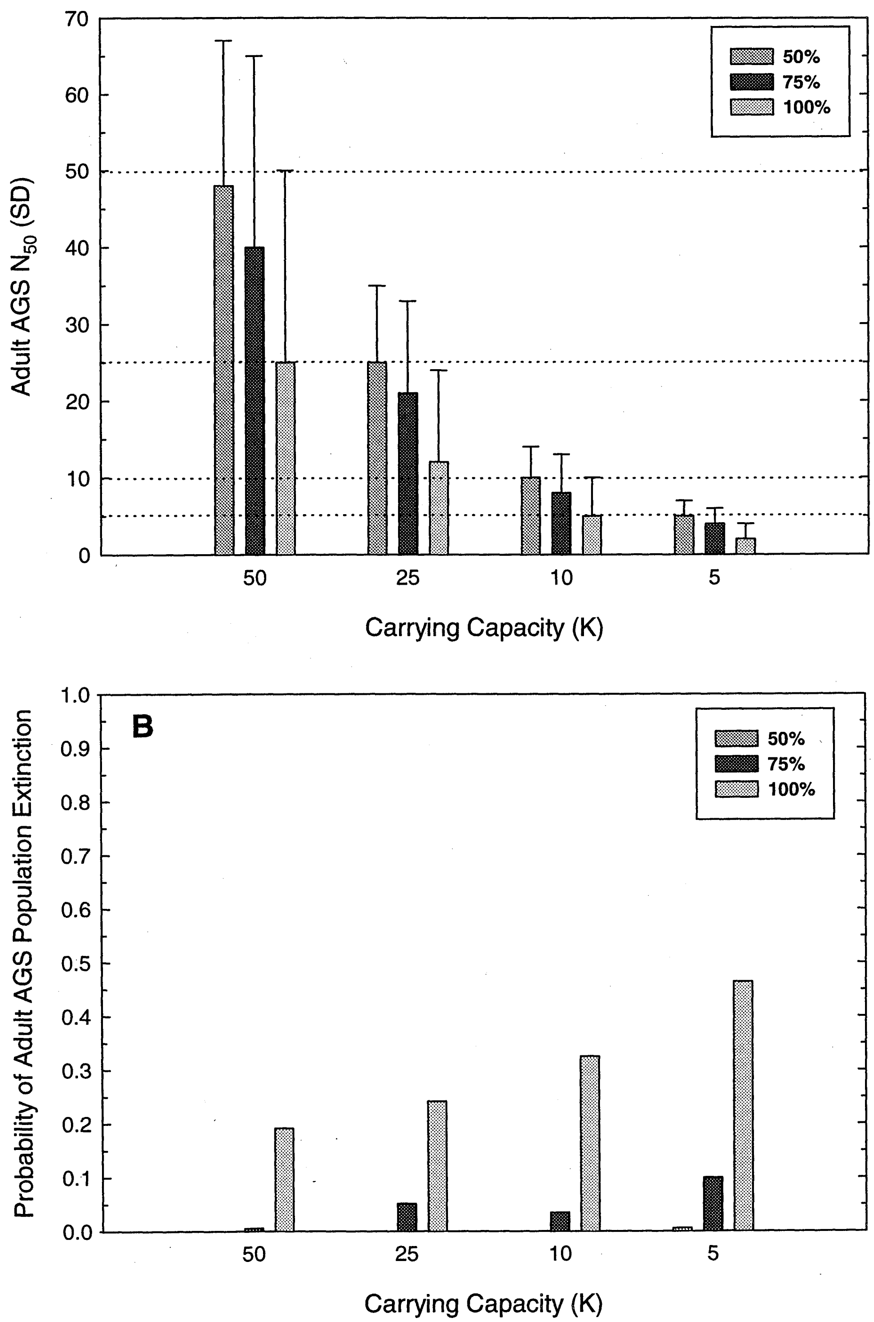


Figure 4. A, Final population size (mean ± standard deviation) and **B,** extinction probability of adult sporophytes aboveground in simulated goblin fern populations under severe drought conditions. Numbers in legend indicate alternative drought severities, defined by percent reductions in all non-spore stage abundances. Dotted lines in **A** identify different carrying capacities.

An attempt was also made to investigate the response of goblin fern populations to environmental variation. In addition to the standard models in which the effect of environmental variation was set at approximately 25% of the mean parameter, an additional set of models was developed in which the variation was set at 35% of the mean. Only those models with K= 10 and K = 5 were included in this analysis as the extinction risk for larger populations, based on previous estimates of population growth, was assumed to be negligible.

Table 9. Goblin fern (*Botrychium mormo*) population viability. Output for the deterministic and stochastic models with habitat carrying capacity (*K*) = 10 adult sporophytes and larger environmental variation (CV = 35%) (see the text for a description of model conditions). See Table 1 for additional definitions.

Model Conditions	λ	P(E)	N_{50} (SD)
Baseline	1.132	0.0	12 (5)
$P_{11} = 0.25$	1.084	0.0	8 (3)
$P_{11} = 0.125$	1.065	0.0	7 (3)
$G_{12} = 0.0006$	1.043	0.0	6 (2)
$G_{12} = 0.0003$	0.973	0.676	1 (1)
$F_4 = 16,875$	1.093	0.0	19 (3)
$F_4 = 11,250$	1.044	0.0	6 (2)
$G_{45} = 0.40$	1.121	0.0	12 (5)
$G_{45} = 0.27$	1.111	0.0	12 (5)

Table 10. Goblin fern (*Botrychium mormo*) population viability. Output for the deterministic and stochastic models with habitat carrying capacity (*K*) = 5 adult sporophytes and larger environmental variation (CV = 35%) (see the text for a description of model conditions). See Table 1 for additional definitions.

Model Conditions	λ	P(E)	N_{50} (SD)
Baseline	1.132	0.0	6 (2)
$P_{11} = 0.25$	1.084	0.0	4 (1)
$P_{11} = 0.125$	1.065	0.001	3 (1)
$G_{12} = 0.0006$	1.043	0.035	3 (1)
$G_{12} = 0.0003$	0.973	0.867	1 (1)
$F_4 = 16,875$	1.093	0.001	4 (2)
$F_4 = 11,250$	1.044	0.009	3 (1)
$G_{45} = 0.40$	1.121	0.0	6 (2)
$G_{45} = 0.27$	1.111	0.0	6 (2)

The results of these models presented in Tables 9 and 10 clearly indicate that goblin fern populations subjected to increased levels of annual environmental variation are at greater risk of population decline and extinction. When comparing these results to those in Tables 4 and 5, it is important to observe that while the mean final population sizes are nearly identical, the extent of dispersal around that mean as shown by the standard deviation is greater when the environmental variation is higher. Moreover, this increased variation in final population size leads to an increased risk of population extinction (e.g., compare $G_{12} = 0.0006$ models in Tables

5 and 10).

Instead of focusing solely on the risk of population extinction, defined here as less than one aboveground sporophyte present at the end of the simulation, it may be instructive to think in terms of the risk of *quasi-extinction* in a goblin fern population. Quasi-extinction is defined as the decrease in population abundance to some specified level. If that level is deemed to be zero, then this becomes true local extirpation of the population. The probability that a population declines to a given level or below is then called the quasi-extinction risk. An example of this concept is given in Figure 5 for the model with a carrying capacity of 25 adult sporophytes and a low spore germination rate (G_{12} = 0.0003; Table 3). While the probability that the population, initiated with 10 aboveground sporophytes, will decline to less than one individual is about 26%, there is a 62% risk that the population will decline to no more than two individuals and a 90% chance it will decline to four individuals. The decision as to whether risk is defined as total extinction or quasi-extinction is ultimately a management-based decision and a target threshhold must therefore be specified by those responsible for species monitoring and management.

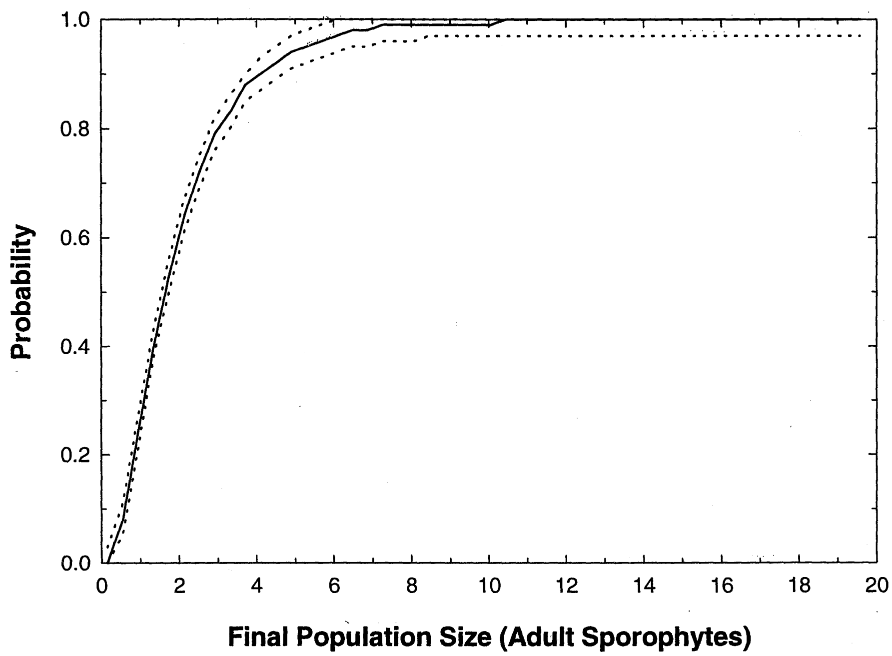


Figure 5. Probability of quasi-extinction in a simulated goblin fern population with carrying capacity (K) = 25 adult sporophytes and low spore germination rate (G_{12} = 0.0003). The plot shows the probability (mean ± standard deviation) that the population will fall to or below the specified number of individuals at the end of the 50-year simulation. In this case, the probability of extinction, defined as falling below one individual is 0.16.

Conclusions and Recommendations

A series of deterministic and stochastic models were developed for populations of the goblin fern (*Botrychium mormo*) as a tool to investigate the current state of knowledge of the population biology of the species. Using a stage-based modeling approach, sensitivity analysis was used to assess the relative impact on population dynamics of changes to individual stage-specific transitions for which scant field or laboratory data are available. In general, the sensitivity these populations exhibit is largely manifest in those stages we know the least about: viable spore set per sporophyte, the nature and extent of any spore bank, and the spore germination rate. In contrast, many of the transitions involving more advanced stages of the life cycle appear, at least in the context of the model developed herein, to have comparatively less influence on the overall population dynamics of the species.

While the baseline goblin fern model indicates the capacity for vigorous population growth under undisturbed conditions, it is critical to remember that despite the considerable intellectual processes brought to bear on the estimation of the necessary demographic parameters, considerable error may be associated with some of these estimates. Sensitivity analysis allows us to assess the consequences of these errors and act accordingly during any risk assessment process.

Small populations are, almost by definition, at risk of extinction through the action of stochastic variation from year to year in demographic parameters such as those listed above. Moreover, the risk of extinction is increased if environmental variability increases. It appears imperative, therefore, to limit those human-mediated forces that act to reduce the amount of habitat available for goblin ferns. This will reduce the gradual erosion of carrying capacity and, by extension, the reductions in population size below which stochastic population fluctuations play a major role in the prospects for persistence.

Finally, it is vital to stress that these models are exploratory and preliminary. Despite the limitations of the process, a considerable amount of information has been obtained through comparative modeling and sensitivity analysis. This has led to the development and enumeration of the following recommendations, designed to prevent further degradation of the habitat or species decline:

1. **Maintain sufficient northern hardwood habitat.**
   This would allow for the maintenance of goblin fern populations sufficiently large to overcome some of the effects of random variation in annual population growth.

2. **Preserve significant *B. mormo* sites such as Ottertail Peninsula and others as they are located in the future.**
   The total number of individuals and the proportion of the total population of *B. mormo* contained therein are significant features of existing populations. We recommend that the largest population currently studied, the Ottertail population may provide research opportunities, candidates for translocation and represents a largely undisturbed site.

3. **Monitor the demographics of natural populations through permanent plots.**
   This would increase our understanding of *B. mormo* population dynamics in the absence of human disturbance and improve our modeling capabilities.

4. **Monitor the demographics of disturbed populations (e.g., earthworms, timber harvesting) through permanent plots.**
   This would increase our understanding and appreciation of the various disturbance agents and would greatly improve our risk estimation capabilities, and ultimately allow us to predict the MVP more accurately.

5. **Search for additional occurrences of *B. mormo* in all habitats including less likely (and previously less intensively searched) sites.**

6. **Study underground biology of *B. mormo* in normal and disturbed communities.**
   A more comprehensive understanding of belowground population processes would markedly improve our understanding of the total species life cycle. The data incorporated in this model is derived from one site and may not accurately represent other populations.

7. **Study spore dispersal strategy, including the distance dispersed and agents.**
   Our definition of a goblin fern population in part rests on our understanding of dispersal in this species, so additional information could have very important implications for both research and management.

8. **Conduct transplant experiments with *B. mormo*.**
   Such research could greatly accelerate our learning process with respect to the species' biology and its requirements for successful establishment and persistence.

9. **Study unknown mycorrhizal components of population dynamics such as the presence or absence with regard to habitat type and disturbance.**
   Because the processes operating belowground appear to largely determine population growth, understanding the nature of the mycorrhizal association is vital.

10. **Study ecophysiology including contribution of photosynthesis to overall energy budget.**
    Additional research like this would potentially help in the identification of appropriate sites for monitoring, etc.

11. **Examine the potential importance of *B. mormo* to the entire community including other species of *Botrychium*.**
    The appreciation of the conservation of this species in the context of overall ecosystem viability will help to maximize our likelihood of successful recovery.

12. **Maintain sufficient northern hardwood habitat.**
    This would allow for the establishment of new populations and for the maintenance of existing goblin fern populations sufficiently large to overcome some of the effects of random variation in annual population growth.

13. **Preserve significant *B. mormo* sites such as Ottertail Peninsula and others as they are located.**

Of significance here is the total number of individuals and the proportion of the total population of *B. mormo* contained therein. Perhaps the largest population currently studied, the Ottertail population may provide research opportunities as well as candidates for translocation.

14. **Monitor the demographics of natural populations through permanent plots.**
This would increase our understanding of *B. mormo* population dynamics in the absence of human disturbance and improve our modeling capilities.

15. **Monitor the demographics of disturbed populations (e.g., earthworms, timber harvesting) through permanent plots.**
This would increase our understanding and appreciation of the effects of various disturbance agents and would greatly improve our risk estimation capabilities.

16. **Search for additional occurrences of *B. mormo* all habitats, including less likely sites.**

17. **Study underground biology of *B. mormo* in normal and disturbed communities.**
A more comprehensive understanding of belowgrouns population processes would markedly improve our understanding of the total species life cycle.

18. **Study spore dispersal strategy, including the distance dispersed and agents of dispersal.**
Our definition of a goblin fern population in part rests on our understanding of dispersal in this species, so additional information could have very important implications for both research and management.

19. **Conduct transplant experiments with *B. mormo*.**
Such research could greatly accelerate our learning process with respect to the species' biology and its requirements for successful establishment and persistence.

20. **Study unknown mycorrhizal components of population dynamics such as its presence or absence with regard to habitat type and disturbance.**
Because the processes operating below ground appear to largely determine population growth, understanding the nature of the mycorrhizal association is vital.

21. **Study ecophysiology including contribution of photosynthesis to overall energy budget of *B. mormo*.**
Additional research like this would potentially help in the identification of appropriate sites for search, transplanting, and understanding the role of the mycorrhizae.

22. **Examine the potential importance of *B. mormo* to the entire community including other species of *Botrychium*.**
The appreciation of the conservation of this species in the context of overall ecosystem viability will help to maximize our likelihood of successful recovery.

Because of the similarity among species, data obtained for *B. mormo* will be transferable to management of other rare species of *Botrychium.*

RAMAS/stage input file (1.4) 22

Goblin fern (*Botrychium mormo*) population model Stage-based STOCHASTIC model from the B. mormo PHVA Workshop held 6-9 October 1997, Leech Lake, MN. Data for model derived primarily from the field studies of Cindy Johnson-Groh, Don Farrar, and Herb Wagner.

1000	*Number of simulations*
50 years	
-Drivers-	
13	
p11	*Transition name*
3	*Indicates lognormal distribution*
.5	*Mean*
.0156	*Variance*

p22
3
.34
.0072

p33
3
.5
.0156

p44
3
.47
.0156

p55
3
.6
.0225

g12
3
.0012
0.00000009

g23
3
.36
.007

g34
3
.016
.000016

g35
3
.002
.0000025

g45
3

.529
.0175

g42
3
.0001

g52
3
.0004

g54
3
.15
.0014

-Parameters-
3
cat1 *Base Catastrophe*
if1(uni(0,1)+1/11,0.3,1.0)

cat2 *Severe Catastrophe*
if1(uni(0,1)+1/20,0.0,1.0)

dd *Density dependence (Carrying capacity) function; here K = 50*
(1/50)*([Adult AGS] + [Adult BGS])
-Stages-
5
Bank
500000
[p11]*{Bank}+(if1([dd],1/[dd],1)*poi(22500*{Adult AGS}))*[cat1]+(if1([dd],1/[dd],1)*poi(128*{Adult BGS}))
Gameto
700
([g12]*{Bank}+[p22]*{Gameto}+[g42]*{Adult AGS}+[g52]*{Adult BGS})*[cat2]
Juvenile
250
([g23]*{gameto}+{p33}*{juvenile})*[cat2]
Adult AGS
5
([g34]*{Juvenile}+[p44]*{Adult AGS}+[g54]*{Adult BGS})*[cat2]
Adult BGS
5
([g35]*{Juvenile}+[g45]*{Adult AGS}+[p55]*{Adult BGS})*[cat2]
-Tallies-
2
Adults Above Ground *This is the unit of population count summarized in the text*
1 *Tally taken annually*
[Adult AGS]
10

Spores
1
[Bank]
-Views-
1
2
1
1

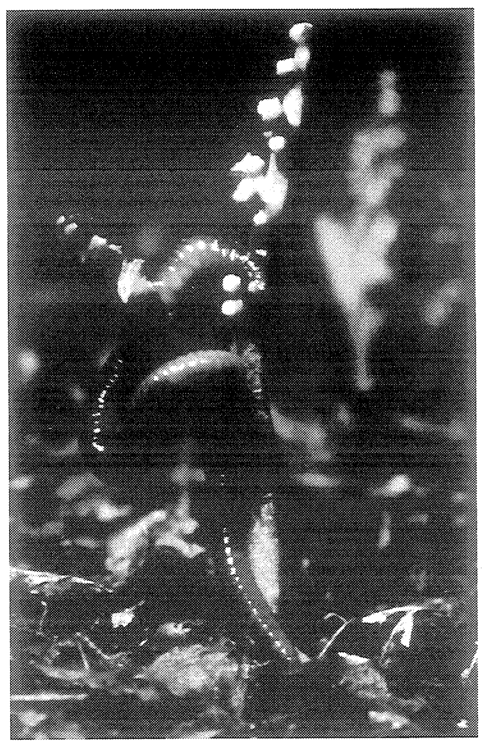
2.234
15.469
0
0.99
0
-End of file-

Participants: John Casson, June Dobberpuhl, Don Farrar, Ann Hoefferle, Cindy Johnson-Groh, Henry Peters, Herb Wagner, Florence Wagner, Candy Westfield, Phil Miller

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE GOBLIN FERN
(*Botrychium mormo*)

Horseshoe Bay Resort
Walker, Minnesota
6 - 9 October 1997

Final Report
January 1998



SECTION 3
THREATS AND RISK WORKING GROUP REPORT

THREATS AND RISK WORKING GROUP REPORT

Introduction

The Threats and Risks Working Group was assigned the task of identifying and ranking potential risks to *Botrychium mormo* plants and *B. mormo* habitat. We needed to identify the risks so that mitigation options could be examined, research needs for management could be determined, and population growth scenarios could be simulated. The group discussed various methods to complete this task, and received suggestions from the other working groups. We selected one of several possible methods, which we believed would provide the most practical information for land managers.

We chose to provide our threat assessment in a matrix with explanatory text. In order to keep the matrix legible and usable, it does not include our assumptions, definitions, or rationale. Therefore, it is imperative that the user of this information carefully read the accompanying text.

Threats were grouped by activity/event type into the following categories: exotics, forestry practices, other development/land use, and other threats. We aimed for an inclusive list without redundancy; however, we may have missed some threats. Land use activities not listed may also cause adverse changes in the physical or biological parameters essential for the fern or the mycorrhizae on which it depends. These activities should be evaluated as they are identified.

For each threat, we gave ratings on a scale of 1 (least) to 5 (greatest) for likelihood of occurrence, duration, frequency, intensity, and extent of threat (see definitions below). We added these ratings to give a total score to each threat. We also rated the need for research relative to management for each threat, but did not use these numbers in the total score. Lastly, we provided information on each threat as to repetition interval (for cyclical threats), land ownership primarily impacted by the threat (public or private), and miscellaneous comments such as research specific needs.

Threat ratings were determined by group members, with as many members providing input as had knowledge on a given threat. That is, we wanted to avoid biasing ratings by ignorance, although we recognize that there is not much information available for some of the threats. Indeed, we considered lack of biological knowledge as a threat by itself. We abstained from classifying a few threats for which our knowledge gap was too great.

During this process, we made many assumptions. Assumptions specific to threat category are discussed below, along with detailed information for each threat rating. Overall, we assumed that the following items are detrimental to *B. mormo* or its habitat, regardless of the activity causing them, via direct or indirect effects: soil compaction; loss of soil nutrients; loss of duff layer (O horizons); loss of darkness provided by the duff layer or forest canopy; changes to moisture regime (drying, such as by canopy removal, or flooding); changes in soil characteristics (pH, aeration, structure); and inhibition of spore dispersal.

We were assisted in making this assumption by the Life History Group, which determined limiting factors for *B. mormo*. To accommodate a request from the Life History Group, we also provided our threat assessment in a second format, based on these factors. The second format (Table II) allows the reader to see which threat potentially may cause these critical changes.

We also assumed, after discussion with the Life History Group, that *B. mormo* may tolerate some disturbance (extent unknown), but does not specifically require disturbance, unlike other *Botrychium* species.

Our total scores for the 45 threats listed (Table I) ranged from 5 (mine fumes and temporary flooding) to 25 (earthworms, lack of biological knowledge, human population growth). We believed certain threats, such as global warming or acid rain, to be beyond the scope of our assessment since these changes would occur gradually and over a long time scale. We further recognize that managers can exert a greater degree of control over some of the threats than others. Clearly, the ones well under managers' control provide the best opportunities for mitigation of impacts to *B. mormo* or its habitat.

Definitions of Categories used in Threats Matrix

'Risk of threat' columns

<u>Likelihood of threat</u>
Probability of this particular threat happening in *B. mormo* habitat across its range
1 = low
3 = medium
5 = high, has happened

<u>Duration of threat</u>
Combined persistence of the disturbance and its consequences on a population & its habitat
1 = temporary, both population and habitat can recover in less than one year
3 = population lost, habitat recoverable
5 = permanent for the foreseeable future, population & its habitat are lost

<u>Frequency of threat</u>
Number of times disturbance occurs across its range currently or potentially
1 = rare
3 = occasional
5 = frequent

<u>Intensity of threat</u>
Degree to which the activity adversely affects the numbers of plants at a given site
1 = minor
3 = moderate
5 = species irradicated

Extent of threat
Potentially, politically and ecologically realistic range of disturbance
1 = the smallest unit, e.g.: colony, stand, phase unit, etc.
2 = bigger than one or smaller than 3
3 = a larger unit: national forest, state forest, political unit, tribal
4 = state, ecoregion
5 = rangewide or at sites distributed across the range

Total score
Sum of scores for each threat-ranking criterion

'Information' columns

Need for research related to management
This category serves to assist with the prioritization of research needs
1=can't be studied, much already known, or not as important for management
3=needs study, important for management
5=critical need for research for management decisions

Threat interval
An informational column providing an estimate of years between occurrences of the threat at a particular location.

Primary land ownership impacted
Private, public or both

THREAT MATRIX SEE DOCUMENTATION FOR RATING SCALES	LIKELIHOOD OF THREAT	DURATION OF THREAT	FREQUENCY OF THREAT	INTENSITY OF THREAT	EXTENT OF THREAT	**TOTAL SCORE**	NEED FOR RESEARCH REL. TO MGMT.	INFORMATIONAL COLUMNS THREAT INTERVAL (yrs)	PRIMARY LAND OWNERSHIP IMPACTED (private/public)
EXOTICS									
earthworms	5	5	5	5	5	**25**	5		pr/pu
sowbug/slug	3	3	4	2	5	**17**	3		pr/pu
garlic mustard	5	2	4	1	4	**16**	2		pr/pu
gypsy moth	4	1	2	3	4	**14**	1		pr/pu
Dutch elm disease	3	2	2	1	3	**11**	1		pr/pu
unknown future invasive aggressive exotic		cannot classify at this time							pr/pu
FORESTRY PRACTICES									
clearcutting	5	4	5	5	4	**23**	4	40-60	pu
market-driven stand type misinterpretation	4	5	4	5	4	**22**	1		pu
inappropriate rotation age (ave. 40 yrs on CNF)	4	5	4	5	3	**21**	4		pu
conversion to even-aged aspen	4	5	4	5	3	**21**	4		pu
intermediate harvest (thinnings)	5	3	5	3	4	**20**	4	10-20	pu
single tree selection	5	3	5	3	4	**20**	4	10-20	pu
group selection	5	3	5	3	4	**20**	4	10-20	pu
roads, landings, skid trails, accesses	5	5	5	2	2	**19**	1		pu
salvage sales	5	4	3	4	2	**18**	4		pu
white pine/hemlock/yellow & paper birch restoration/scarification	2	3	2	4	2	**13**	4		pu
lack of adequate buffer around *B. mormo* plants		cannot classify without more info: e.g. edge effects					5		pu
old growth designation		this is not a threat, and may be an enhancement					1		pu
									pu
OTHER DEVELOPMENT/LAND USE									
public roads, ROW	4	5	2	5	2	**18**	1		pr/pu
powerline, utility corridor constr. and maint.	3	5	2	5	2	**17**	3		pr/pu
housing developments	3	5	1	5	1	**15**	1		pr
vacation/lakeshore development	3	5	1	5	1	**15**	1		pr
recreation sites, public lands	3	5	1	5	1	**15**	1		pu
direct mining impacts: roads, tailings, equip.storage	2	5	1	5	2	**15**	1		pu
anthropogenic alteration of water levels	2	5	3	4	1	**15**	1		pr/pu
pipeline construction and maintenance	2	5	1	5	2	**15**	5		pr/pu
snowmobile trails	1	4	1	5	1	**12**	1		pu
ATV use in sugarbush	2	2	1	2	2	**9**	1	1	pr/pu
grazing (incl. soil compaction, plant spp. change)	1	2	1	3	1	**8**	1		pr/pu
mine runoff	2	1	1	1	1	**6**	1		pu
mine fumes	1	1	1	1	1	**5**	1		pu

OTHER THREATS									
lack of biological knowledge	5	5	5	5	5	**25**	5		pr/pu
human population increase	5	5	5	5	5	**25**	1		pr/pu
deer impacts to forest structure	5	2	5	1	5	**18**	2		pr/pu
beaver induced flooding	2	5	3	4	1	**15**	1		pr/pu
herbivory on *B. mormo* plants	5	1	3	1	5	**15**	4		pr/pu
Drought	4	1	1	3	5	**14**	2	11 (minor) 22 (major)	pr/pu
wildfires	2	3	1	4	1	**11**	1	25-150	pr/pu
B. mormo survey practices	5	1	3	1	1	**11**	3		pr/pu
natural windthrow	4	1	3	1	1	**10**	2	100	pr/pu
nitrates (e.g. fertilizer application)	1	1	1	3	1	**7**	2		pr/pu
flooding (temporary, storm-related)	1	1	1	1	1	**5**	1		pr/pu
decline in numbers of dispersal agents	cannot classify without more info on dispersers						5		pr/pu
unknown future potential diseases of *B. mormo*	cannot classify at this time						1		pr/pu
unspecified threats to mycorrhizae	cannot classify at this time						5		pr/pu

THREAT MATRIX SEE DOCUMENTATION FOR RATING SCALES	COMMENTS
EXOTICS	
earthworms	
sowbug/slug	
garlic mustard	
gypsy moth	
Dutch elm	research whether elm mycorrhizae important to *B. mormo*; evidence suggests this is unlikely
unknown future invasive aggressive exotic	
FORESTRY PRACTICES	
clearcutting	research on buffers and when/if *B. mormo* comes back after timber harvest
market-driven stand type misinterpretation	
inappropriate rotation age (ave. 40 yrs on CNF)	mitigation by increasing rotation age; do we know *B. mormo* does not occur in 40 yr old stands?
conversion to even-aged aspen	
intermediate harvest (thinnings)	
single tree selection	tree selection may mimic nature, but ground impact would not
group selection	
roads, landings, skid trails, accesses	skid trails may recover
salvage sales	check with timber specialist re salvage specifics
white pine/hemlock/yellow & paper birch restoration/scarification	MI/WI folks comments?; research under uneven-age mgmt research
lack of adequate buffer around *B. mormo* plants	
old growth designation	
OTHER DEVELOPMENT/LAND USE	
public roads, ROW	
powerline, utility corridor constr. and maint.	
housing developments	
vacation/lakeshore development	
recreation sites, public lands	
direct mining impacts: roads, tailings, equip.storage	
anthropogenic alteration of water levels	
pipeline construction and maintenance	
snowmobile trails	
ATV use in sugarbush	
grazing (incl. soil compaction, plant spp. change)	
mine runoff	
mine fumes	is this even a threat?
OTHER THREATS	
lack of biological knowledge	
human population increase	
deer impacts to forest structure	
beaver induced flooding	
herbivory *on B. mormo* plants	
drought	
wildfires	
B. mormo survey practices	

natural windthrow nitrates (e.g. fertilizer application) flooding (temporary, storm-related) decline in numbers of dispersal agents unknown future potential diseases of *B. mormo* unspecified threats to mycorrhizae	research on pit and mound potential correlation

DIRECT EFFECTS OF THREATS ON LIMITING FACTORS FOR *B. MORMO*

Critical changes: Threats:	SOIL COMPACTION	LOSS OF SOIL NUTRIENTS	CHANGES IN MOISTURE REGIME	INHIBITION OF SPORE DISPERSAL	LOSS OF DARKNESS	CHANGES IN SOIL CHARACTERISTICS	LOSS OF DUFF LAYER (O horizon)
EXOTICS							
earthworms	X	X	X	X	X	X	X
sowbug/slug		X		X		X	X
gypsy moth		X	X		X		X
garlic mustard		X	X	X			
Dutch elm disease		X	X		X		X
unknown future invasive aggressive exotic	?	?	?	?	?	?	?
FORESTRY PRACTICES							
clearcutting	X	X	X	?	X		X
intermediate harvest (thinnings)	X	X	X	?	?		?
single tree selection	X	X	X	?	?		?
group selection	X	X	X	?	?		?
salvage sales	X	X	X	?	X		X
roads, landings, skid trails, accesses	X	X	X	X	X	X	X
inappropriate rotation age (ave. 40 yrs on CNF)	X	X	X				
conversion to even-aged aspen	X	X	X		X		X
market-driven stand type misinterpretation	X	X	X				
w pine/hemlock/y&p birch restoration/scarification	X	X	X	X	X	X	X
lack of adequate buffer around *B. mormo* plants			X	X	X	X	
old growth designation							
OTHER DEVELOPMENT/LAND USE							
housing developments	X	X	X	X	X	X	X
vacation/lakeshore development	X	X	X	X	X	X	X
recreation sites, public lands	X	X	X	X	X	X	X
public roads, ROW	X	X	X	X	X	X	X
ATV use in sugarbush	X			X	X		X
snowmobile trails	X		X	X	X		X
direct mining impacts: roads, tailings, equip.storage	X	X	X	X	X	X	X
mine fumes							
mine runoff		X	X			X	
anthropogenic alteration of water levels		X	X	X	X	X	X
pipeline construction and maintenance	X	X	X	X	X	X	X
powerline, utility corridor constr. and maint.	X	X	X	X	X	X	X
grazing (incl. soil compaction, plant spp. change)	X		X	X	X	X	X
OTHER THREATS							
natural windthrow			X	X	X	X	X
beaver induced flooding		X	X	X	X	X	X
decline in numbers of dispersal agents				X			

deer impacts to forest structure				X	X		X
unknown future potential diseases of *B. mormo*				X			
unspecified threats to mycorrhizae		X	X	X		X	
lack of biological knowledge	X	X	X	X	X	X	X
wildfires		X	X	X	X	X	X
herbivory on *B. mormo* plants				X			
drought		X	X	X		X	
nitrates (e.g. fertilizer application)				X?		X	
B. mormo survey practices	X		X	X	X		X
flooding (temporary, storm-related)		X	X	X		X	
human population increase	X	X	X	X	X	X	X

Threats from Exotics

With over forty percent of extinctions having exotic species as a primary cause (World Conservation Monitoring Centre, 1992, *Global Biodiversity: Status of the Earth's living resources*. Chapman & Hall, London), it is important to consider the role of exotics in relation to the viability of the goblin fern, *B. mormo*. This is especially true when considering the available data on the impact of non-native earthworms in *B. mormo* sites and what is becoming a ubiquitous distribution of the earthworms within the range of *B. mormo*.

Earthworms and other exotics need to be taken into account in all studies and monitoring of *B. mormo*. Earthworms appear to be having a great negative effect on the goblin fern on the Ottertail Peninsula by impacting the soil, especially by eliminating the O horizons, which is critical to the fern's survival. Whether the apparent loss of *B. mormo* in the impacted area is permanent, temporary, or only apparent, remains an unanswered question.

The biology of the invasiveness and damage by the earthworms and other exotic species is poorly known. It is critical that research studies be conducted to determine how the invasions impact the communities, and how the impact may be mitigated or eliminated. The deleterious effects of exotic species often are quite specific, such as sowbugs eating mycorrhizae.

The likelihood that some exotic species considered will occur and cause harm to *B. mormo* populations is quite high. Exotics are able to spread quite widely, become established and exert long lasting effects. How damaging, the intensity of the exotic threat, depends on whether the establishment is permanent (as in earthworms) or with transitory establishment (Dutch elm disease and gypsy moth).

Because exotics are quite widespread, they probably have (or will have) effects throughout the range of *B. mormo*. In this way, their threat may be quite severe, and has the potential to exert disturbance in all *B. mormo* areas.

The tremendous impact that seems to be occurring with the invasion of earthworms in *B. mormo* habitats necessitates a greater understanding of the processes and damage. The potential of earthworms to cause, directly or indirectly, the extinction of *B. mormo* appears to be great and requires both research and monitoring efforts. These need to occur quickly and need proper funding.

Exotics Recommendations

Because of the potentially great threat, including potential extinction, to the viability of *B. mormo* from earthworms it is critical to study earthworm impact. Therefore, other potential impacts on *B. mormo* should be avoided for the next 24 months to allow estimation of the earthworm threat.

1. The impact of earthworms on *B. mormo* and the forest community needs to be studied immediately. These studies should include:

- soil changes, especially on the O horizon layer
- plant and animal community changes following invasion
- impact on *B. mormo* and its supporting mycorrhizae
- which earthworm species cause which changes
- how quickly and by what means do the earthworms invade
- how do earthworms spread across and through habitats
- source of earthworm invasion
- standardization of sampling techniques
- importance of corridors and disturbance in worm dispersal

2. The impact of other exotic/invasive species should be studied.
    - what is the effect of sowbugs and slugs following or preceding earthworm invasion
    - do sowbugs and slugs eat/impact mycorrhizae
    - will exotic plants invade following earthworm-caused disruption of the native plant community

3. Training and education for professional and public parties needs to be developed including:
    - standardization of identification and sampling methodologies
    - training of professionals
    - preparation of articles and educational brochures for the public

4. In order to determine the range wide impact on *B. mormo* it is important to survey all (most) sites to determine the presence or proximity of the earthworm threat.

5. Methods to prevent the spread of earthworms and to control them in *B. mormo* sites must be studied. Possible methods may include:
    - chemical extraction
    - specific vermicides
    - physical barriers

Forest Practices

This working group originally created a list of potential threats to *B. mormo* related to forestry practices. We reviewed the list and combined the threats into seven major categories: clearcutting, intermediate harvests (thinnings), salvage sales, roads/landings/skid trails/accesses, logging policy, stand type interpretation, restoration activities including white pine, eastern hemlock, yellow or paper birch restoration activities. These threats may be broken into additional components to further define where or how the risks to this species are expressed. For instance brush disposal, timber stand improvement, or site preparation activities may occur under any of the harvest regimes depending on the goal for the forest stand. Since these are usually considered part of the harvest 'package of activities' we did not break them out as separate threats in and of themselves.

Harvest Practices
We identified 5 major harvest regimes commonly used range-wide on forestland where *B. mormo*

occurs. We recognize that our descriptions of these harvest types may be oversimplified. The five regimes are clearcutting, intermediate harvests (thinnings), single tree selection (also an intermediate harvest), group selection, and salvage harvests to recover dead or down trees.

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 harvest are similar to clearcuts but at a smaller scale. Patches of trees from .1 to .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, environmental 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, Skid trails, Accesses

Access for harvests and timber removal is common to all harvest methods. System roads including state, county, and federal roads are a permanent fixture on the landscape once they are built. They are necessary to transport the timber resource to the mill. Landings, skid trails, and other accesses are more 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. Temporary roads and landings may persist on the land for many years following construction.

Policy Driven Impacts

Natural resource policy on public forest land in the Lakes States works against maintenance or development of forest habitat suitable for *B. mormo*. Public land management agencies generally emphasize even-aged aspen over a large portion of their landbases, even though management plans may allow for more flexible approaches to forest management. With this single species emphasis comes a short rotation age (as young as 40 years), the conversion of mixed hardwood stands to even-aged aspen, and market driven stand type misinterpretation. Each of these work against maintaining or developing suitable habitat for this species.

Site Preparation or Restoration

With the emphasis on ecosystem management on public lands, attention has been given to tree species that were formerly more common than they currently are. These 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*. Each of these has their own unique problems for regeneration, but share a need for a soil disturbance to successfully establish seedlings. This is done artificially by scarification with heavy equipment. The organic layer and soil are severely disrupted.

Buffer Areas

Protective buffers may be implemented around known *B. mormo* colonies in order to mitigate the detrimental effects of an adjacent timber harvest. Buffers of 100 to 300 feet have been suggested to maintain *B. mormo* colony conditions. The working group did not evaluate this practice because we felt there was not enough information to determine their effectiveness. More work would need to be completed on edge effects with regard to physical or biological changes within the buffer and the effect on *B. mormo*.

Old Growth Designation

The working group felt that designation of old growth reserves or complexes were not a threat to *B. mormo*. This species does not appear to require disturbance for its life history though this has not been documented. Northern hardwood forests suitable for old growth designation may experience very little disturbance over several hundred years. Consequently, this type of forest stand may be highly suitable for this species.

We did not evaluate winter vs. summer logging because we believe harvest practices are the threat, not the seasonality. Nevertheless, it is possible that logging over snow cover on frozen ground may have less direct impact on litter compaction and destruction than summer logging. We also did not evaluate prescribed fire as it would not be ecologically appropriate or practical on these normally moist sites.

Forest Practices Recommendations

1. Emphasis on aspen regeneration on forest lands range-wide has caused conflicts with *B. mormo* habitat and colonies due to inappropriate rotation age, conversion to aspen or overemphasis on aspen, and slanting timber typing to favor aspen. Feasibility of changes in species emphasis or harvest method to practices that do not impact *B. mormo* habitat should be investigated.

2. Increase the rotation age by at least 20 years on LTAs or forest cover suitable for *B. mormo*.

3. Collect quantitative forest data to reflect actual species composition in *B. mormo* stands for decision making.

4. Harvest operations, including clearcutting, even-aged methods (shelterwood), and intermediate harvests, could adversely affect key life requirements for *B. mormo* by changing the moisture, light, forest floor and mycorrhizal regime. This likely results in loss of viability of colonies in areas where these practices occur. Answers to the following research questions are needed:
   a. What are the effects of various harvest methods (e.g. clearcutting, group selection harvest, intermediate harvests) on site level viability to *B. mormo*?
   b. Do buffers (100 feet, 250 feet, or LTA phase level) around known *B. mormo* sites effectively maintain colony viability?
   c. Will maintaining a buffer around known *B. mormo* colonies at the LTA phase level, at minimum, provide for habitat at a meaningful ecological level?
   d. Does *B. mormo* occurs in younger stands; i.e. less than the mean stand age (~70 years old)?

Other Developments/Land Use

All potential threats in this category result from human decisions or actions regarding land use; none are natural or otherwise uncontrollable phenomena. This section includes those land use actions and decisions not related to forestry or silvicultural practices.

Each potential threat would operate via at least one of the biological means identified by this PHVA's Life History working group. The potential threats were ranked by the Threats and Risk Working Group's criteria for ranking all threats and are presented on pages 50 and 51.

Eight of the 13 potential threats received 15 through 18 total point scores. These eight had common characteristics that separated them from the five presumptively less dire potential threats in this category. The eight "more dire" potential threats scored 5 points, the maximum, for Duration of Threat, meaning the consequence of actualized threat was considered to be permanent loss of *B. mormo* and its habitat in the action/project impact area. Similarly, and with only one potential threat's exceptional score of 4, these same eight potential threats scored 5 points each for Intensity of Threat, i.e., all plants in the impacted area would be lost. Since they are unlikely to impact all sites rangewide, these eight threats received low to moderate scores for Frequency of Threat and Extent of Threat.

In summary, the more dire eight's threats are devastating to *B. mormo* where they impact it, but they are unlikely to impact most sites. This is true in large part because almost all *B. mormo* sites are on public land where they are not as likely to receive these impacts. The less dire five potential threats in the Other Development/Land Use category generally had low scores in all five threat ranking categories. This reflected the Threat Group's judgement that these five threats generally had low likelihood of occurring in *B. mormo* sites and were less likely to devastate a site, should they occur.

All 13 potential threats are functions of human land use choices and largely controllable by humans; there is thus every reason for optimism and belief that practical, effective measures can be developed and implemented to minimize the adverse impacts of all 13 Other Development/Land Use potential threats.

Other Developments/Land Use Recommendations

1. Various State and Federal permits or licenses are required for public and private activities/projects that can contain these threats, *e.g.*, Federal Energy Regulatory Commission license of hydropower dams, power lines, and gas and oil pipelines; Corps of Engineers permits for dredge, fill, and construction (*e.g.*, roads/bridges) in waters of the U.S.; EPA Clean Water Act (sect. 401 state certification); and various similar State government permits and licenses. State and Federal environmental laws (*e.g.*, National Environmental Policy Act, Fish and Wildlife Coordination Act and similar State laws) allow State and Federal natural resource agencies to review and recommend permit denial or recommend conditions to the licensing and permitting agencies. State and Federal natural resources agencies' recommendations are not restricted to project impacts to formally listed endangered or threatened species -- the recommendations can be for protection and conservation of many natural resource values, including unlisted species (*e.g.*, sportfish, wetlands, waterfowl, and special plant or animal communities). It is recommended that state and federal natural resource agencies and licensing and permitting agencies use their authorities to (1) require or recommend, as appropriate, pre-project surveys for *B. mormo*, and (2) recommend conservation and protection conditions for any permits and licenses issued.

2. Undertake surveys of historic, current and potential sites; provide survey data to state natural heritage programs; to state, local and federal development entities to environmental consultants. Knowledge of *B. mormo* site locations would enable planners to avoid or otherwise provide for site conservation.

3. Since many private landowners are very willing to conserve rare natural features/species on their land, it is recommended that we support and work with this willingness by providing landowners information on *B. mormo* and assist them in developing site protection measures, as through the TNC registry program or via other voluntary site protection plans.

Other Threats

Natural windthrow
Natural windthrow could result in loss of all or part of a population, depending on the population's size. It is probably very unlikely to seriously affect most populations. Windthrow is part of a naturally functioning forest.

Beaver induced flooding
Beaver numbers have increased dramatically in the last 20 years due to reduced trapping and possibly the conversion of riparian areas to aspen. This increases the potential for beavers to impound water in areas that might affect *B. mormo*. However, we view this threat as a relatively minor one, as most of the large *B. mormo* sites are on higher ground and in cover types that are not particularly attractive to beaver.

Decline in numbers of dispersal agents
Little is known about the dispersal agents of *B. mormo*. It has been speculated that, due to the thick spore coat, they may be capable of passing through the gut of insects and small rodents and would then be dispersed in the insects' or rodents' droppings. If insects and small rodents prove to be dispersal agents, declines in their populations could result in reduced spore dispersal and therefore fewer new plants or inability to colonize new areas.

Deer impacts on forest structure
White-tailed deer are known to have a profound effect on forest habitats due to their browsing of shrubs and herbaceous vegetation. Over parts of *B. mormo* range deer were uncommon or even rare prior to the extensive logging around the turn of the century that converted mature forests to younger second growth. Deer could have an impact on *B. mormo* if their browsing alters the forest vegetation or the mycorrhizal interactions with *B. mormo* and other forest plants.

Potential unknown future diseases of B. mormo
Nothing is known about diseases of *B. mormo* or of its mycorrhizae. We have observed, however, that within monitored populations, occasionally all plants in a section of the population fail to reappear. This suggests a systematic problem such as disease, possibly acting through effects on the mycorrhizae. Due to the plant's rarity, a disease that would inflict a high mortality across part of the range (Ottertail Point, for example) could have a serious impact on the viability of the species. It is suspected that species are more vulnerable to catastrophic disease when they are already stressed.

Unspecified threats to mycorrhizae
B. mormo is dependent on mycorrhizae for its survival. Should some event or forestry practice significantly alter this relationship, *B. mormo* could undergo a significant population decline.

Lack of biological knowledge
We are woefully lacking in certain aspects of basic biological knowledge about *B. mormo* that would enable us to make well-informed decisions that insure the survival of the species. Due to its rarity and to the peculiar life history of *B. mormo*, we are forced to make habitat management

decisions with incomplete knowledge of its requirements.

Wildfires
B. mormo lives in forest types that are not prone to wildfires. Only in the event of an intense drought would this habitat become dry enough to carry a fire. Because of this, in addition to active fire suppression, it is unlikely that wildfires would significantly reduce *B. mormo* populations.

Herbivory on B. mormo plants
It is suspected that *B. mormo* is eaten by insects and small mammals. Although this may reduce or eliminate the sporophore and/or trophophore for that particular year, this is not believed to significantly affect the plant other than to prevent spore development for that individual in that year. In fact if it occurs after spores have matured, herbivory may be a means of spore dispersal for the species, in which case it may be necessary for the dispersal of the species. For these reasons it is not considered to be a significant threat to the plant.

Drought
Drought is a natural but infrequent phenomenon for the range of *B. mormo*. It seems likely that the plant has evolved to tolerate a certain amount of unfavorable weather. However, prolonged drought or drought in combination with other stresses could threaten the viability of the species as has been shown for prairie *Botrychium.*

Nitrates
Nitrates, such as those used in chemical fertilizers, probably to reduce spore germination. The use of nitrates near a population of *B. mormo* could eventually reduce the viability of the population.

B. mormo survey practices
We hope our monitoring methods have little impact on the species or community we're working with, but we need to recognize that disturbing the leaf litter or duff layer could have a negative effect on *B. mormo*.

Flooding (temporary, storm-related)
Temporary flooding due to rain or snow melt could raise water levels and affect plants growing at the edge of a wetland or ephemeral pool, but unless the flooding was prolonged, the plants would probably recover and the effect on the population would be minimal.

Human population increase
Exponential increase in the human population and the demands this places on the earth's natural resources will make it increasingly difficult to preserve rare species and communities.

Other Threats Recommendations

Because of the symbiotic relationship of the mycorrhizae with *B. mormo*, research on the life cycle of the mycorrhizae should be conducted. Outcomes of the study should include answers to the following:

a. The species of fungus involved in this relationship (Per D. Farrar: Francisco Comacho, a graduate student in Oregon, is currently working on identifying the mycorrhizae of Botrychium; this research should be supported before allocating funds to what could be a duplication of effort.);
b. The factors threatening the existence of the mycorrhizae;
c. The carbohydrate donor plant that the mycorrhizae uses to transfer carbohydrates to the gametophyte and sporophyte of *B. mormo*; and
d. How management practices effect the survival of the mycorrhizae.

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POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE GOBLIN FERN
(*Botrychium mormo*)

Horseshoe Bay Resort
Walker, Minnesota
6 - 9 October 1997

Final Report
January 1998

SECTION 4
MANAGEMENT AND SOCIAL ISSUES WORKING GROUP REPORT

MANAGEMENT AND SOCIAL ISSUES WORKING GROUP REPORT

Working Group Goal: Develop a collaborative strategy for adaptive management for *B. mormo* viability.

Ideas surrounding this goal

A collaborative approach will include all stakeholders. It will provide the opportunity for participation from stakeholders at all stages and levels of planning and implementation. Informed consensus will be sought.

An adaptive approach will address new technology, maintain options and allow experimentation. As new knowledge is gained, management options may change.

Management is a conscious decision for action or non-action. All alternatives should be considered and the risk of each option should be assessed. Currently, *B. mormo* is listed as a state species of special concern and it is on the Forest Service Regional Forester's list due to its TNC rank. (*Botrychium mormo* is currently ranked as rare or uncommon (G3) by The Nature Conservancy.) A successful management strategy will ensure continued range-wide existence of *B. mormo*. The management goal is to maintain a secure population level (G4) across the range of *B. mormo*. More information about the species and its habitat requirements are needed to re-assess the status of the species. It is necessary to consider other ranking systems' (e.g. USFWS, State) influence on management.

The Management and Social Issues Working Group addressed three categories of action for reaching the stated goal and recommended: management guidelines; monitoring and research; and increased stakeholder involvement.

Management Guidelines

In order to take a proactive approach to maximize the viability of *B. mormo,* at the least cost, the recommendation is to use an ecological hierarchy to identify areas with the highest potential for maintaining this species within its range. While this approach focuses on *B. mormo* and its habitat, it should also provide for long-term viability of a wide variety of plant and animal species in this habitat.

Range-wide Level
Step-wise recommendations are outlined to protect species and habitat viability across the range of *B. mormo*. Known range and habitat characteristics are explained in the distribution and life history sections of this report.

1. Plot geomorphic region equivalents (e.g. Land Type Associations - LTA) across the entire range of *B. mormo*. An LTA is a Land Type Association in the ecological classification system

(R. Bailey) used by the Forest Service, the Natural Resources Conservation Service (NRCS), and some states. This system is based roughly on geomorphic regions (glacial landforms, vegetation).

2. Select those LTA's that hold the largest number of known *B. mormo* occurrences and/or have the greatest potential for *B. mormo* occurrence or habitat. Based on known habitat requirements, managers should select an adequate number of LTAs to protect a viable population of *B. mormo* across its range. (Three in Minnesota, two in Wisconsin and two in Michigan has been suggested.)

3. 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 throughout its range.

4. Develop a range-wide communication network to track status, distribution, new technology, biology, research findings, data collection techniques and monitoring results.

<u>Landscape Level</u>

1. Within the selected LTAs (Fig. 1), further identify and designate the landscapes which are, or recently were dominated by forests with a maple-basswood-beech component as *B. mormo* habitat management areas (BMHMAs).

2. Implement landscape level land management strategies on these BMHMAs designed to maintain or promote the composition, structure and historic disturbance regime associated with these forest habitats. Management strategies most compatible with this include uneven-aged silvicultural systems designed to maintain or promote a large proportion of the LTA in older, multi-aged forest. Suggested uneven-age techniques include: single tree or group selection to 80-90% canopy cover; group openings no larger than a tree and a half in diameter; individual tree selection that maintains forest composition without high-grading; infrequent harvests (20-30 year rotation).

3. Within the BMHMAs (10,000+ acres), designate large areas (300-3000 acres) for a high level of protection for *B. mormo* and associated species. These high protection areas may surround or be associated with a Research Natural Area (RNA), Special Management Area (SMA), designated old growth or other form of protected area with minimal tree harvest allowed for habitat maintenance only.

4. Infrequent prescribed fires (for pine regeneration) in forests holding *B. mormo* should be rare events.

5. Large public landowners have the greatest opportunity - and responsibility- for managing landscapes for *B. mormo* and other associated species. Promote multi-agency management compatible with habitat objectives within BMHMAs that provide for maintenance of viable populations.

Site/Stand Level
The goal of this approach is to provide for the long term viability of the *B. mormo* in areas of suitable habitat within the selected LTAs.

1. Within the BMHMAs, for stands without *B. mormo* occurrences, two recommended management options are: defer harvest; or implement uneven-aged silvicultural practices (single-tree or group selection).

2. Within the BMHMAs, for stands with *B. mormo* occurrences, recommended management options are: defer harvest in the stand; or permit single tree or group selection beyond 300 feet* of known occurrence in the remainder of the stand.

3. For known *B. mormo* occurrences outside the BMHMAs and within the selected LTAs, the recommended management options are: defer from harvest land type phase or stand; or allow any harvest greater than 300 feet* from an occurrence.

4. For known *B. mormo* occurrences outside the selected LTAs, the recommended management options are: defer the stand from harvest; or allow harvest beyond 300 feet of known occurrence.

*This buffer distance is subject to change as new information is gained.

It is assumed that after a certain population level across the range is secure, some populations are potentially expendable and silvicultural practices which create a higher risk to *B. mormo* plants will be allowed. Silvicultural practices should be designed and monitored carefully and creatively by a multidisciplinary team that includes biological and botanical experts.

Information and Monitoring Needs

Priorities for research and monitoring were grouped into four categories, in order of management importance: species location and re-occurrence; effects of management activities; identifying limiting factors; regeneration research. Specific recommendations follow.

1. Update, integrate and share all information range-wide across all agencies and interested parties. Currently, State Natural Heritage Programs (NHP), the Forest Service, and The Nature Conservancy maintain databases. Current range-wide information needs to be integrated and then, updated and shared with all agencies and interested parties *annually*. Suggested Responsibility: State National Heritage Program (NHP) Botanists

2. Continue Forest Service pre-management (project level) inventories and encourage other landowners (state, county, tribal and private) to do the same. Currently, project level inventories are performed on all Forest Service sites. In Minnesota, there is no legal mandate to inventory prior to management activities for Special Concern species. In Wisconsin and Michigan *B. mormo* (and other EO) data is forwarded to NHP following these pre-management surveys. It is recommended that USFS surveys continue and voluntary state level inventories in appropriate

habitats should be encouraged. Responsibility: US Forest Service, States

3. Seek grants and partnerships to support proactive range-wide inventories of *B. mormo* and associated habitat. Currently, the Minnesota County Biological Surveys include intensive inventories, county by county. Wisconsin has done such surveys in the Crandon Mine Area. Michigan and the Forest Service do not have proactive inventories. It is recommended that grants be secured for $60K to conduct range-wide proactive surveys for *B. mormo*. A field inventory of three states by three persons (L.Gerdes?) for four months to collect information on location, number, soils, Ecological Land Type Phase, moisture, duff characteristics and other réleve data is suggested. Responsibility: Mighton? Zeman?

4. Summarize all existing monitoring studies range-wide, including study objectives and progress and subsequently share this information with all agencies and interested parties. Currently, data exist from a Chippewa National Forest administrative study, the Leech Lake Reservation, Johnson-Groh and Farrar study and Crandon mine site monitoring. Future needs should be identified and shared through the recommended range-wide communication network. Responsibilities: Johnson-Groh, Farrar, Mortinsens, Casson, Tans, other researchers.

5. Seek grants and partnerships to support studies to evaluate the effects of clear-cutting and intermediate timber harvest on *B. mormo*. Currently, a Chippewa National Forest administrative study is investigating management effects on *B. mormo.* Further research is recommended through a DNR/FS partnership or grant ($1-10K/year for 6 years) to evaluate effects of clear-cutting and intermediate harvest. Test for *B. mormo* presence, reoccurrence, site characteristics (e.g. duff, structure, function, composition). Evaluate cumulative effects of harvest techniques. Responsibility: Cindy Johnson-Groh, Zeman, Forest Service Research, DNR Forestry.

6. Conduct studies to thoroughly research site and plant characteristics in specified locations. Currently, there is limited or no information regarding site conditions associated with *B. mormo*. Refer to the life history section for specific research recommendations.

7. Conduct studies to provide information on *B. mormo* life history. Specific research requirements are outlined in the life history section of this report.

8. Monitor and control earthworms. Specific research requirements are outlined in the threats section of this report.

NOTE: Research into the effects of other land management activities (e.g., mining, pit development, trail and road construction) are not included here but should be evaluated where applicable. Forest Service prescribed fire plans require consideration for threatened and endangered species monitoring and need not to be addressed here. It is recommended that other agencies follow the same procedures.

Acceptance and development of a collaborative strategy

Stakeholders in a region-wide viability assessment for *B. mormo* were identified. Participation of all affected groups at all stages and levels of planning and implementation is imperative. A paired-ranking system was used to identify the integral stakeholders. Based on this ranking, the level of suggested participation was identified. This matrix can be used as a reference tool to insure all parties are included in the planning process. Additional information to be considered in development of a collaborative plan includes individual stakeholders' positions and rationale.

Participation Level:
CI - Continued involvement
E – Engage in an active dialog
I – Provide information and invitation for input

Stakeholder Matrix

Stakeholders	MN	WI	MI
Timber Industry	E	E	E
Mining	I	E	I
Tribal	CI+E	E	E
Superior National Forest	E	n/a	n/a
Political Delegations	I	I	I
USFS Regional Office	E		
General Public/ Environmental Education	I	I	I
TNC	E	E	E
Native Plant Societies	I	I	I
Herbarium Curators	I	I	I
Professors/Research	CI + I		
Heritage Groups	CI	CI	E
DNR – Forestry	E	E	E
County Lands	E+I	I	I
Hunting groups	I	I	I
Environmental Groups (e.g. Sierra Club, Audubon)	E	E	E
USFWS	CI+E	CI	CI
Lake State Forests	CI	CI	CI+E

Based upon the above matrix, recommendations were made to continue invitations and information updates to a wide-range of potential stakeholders. In addition, key stakeholders who were not involved in the October PHVA workshop were identified and responsibility for encouraging their participation in future planning sessions was assigned to working group members. Actions recommended are:

1. Additional stakeholders to include on the PHVA mailing list were identified: Timber Industry Wisconsin and Michigan; Political delegations, Michigan and Wisconsin Native Plant Societies; additional herbarium curators; DNR Forestry; County Land Departments in Minnesota, Wisconsin and Michigan; environmental groups from Minnesota, Wisconsin, Michigan; and States' Departments of Transportation (Responsibility: Nancy Berlin, Colleen Matula). The invitation list for the October meeting is in Appendix III. A general letter and overview of the PHVA process will be provided to updated mailing list by Nancy Berlin within two-weeks following the workshop. Copies of the participant reviewed Goblin Fern PHVA Workshop Report will be provided to all participants, critical stakeholders and anyone else expressing interest (Responsibility: CBSG).

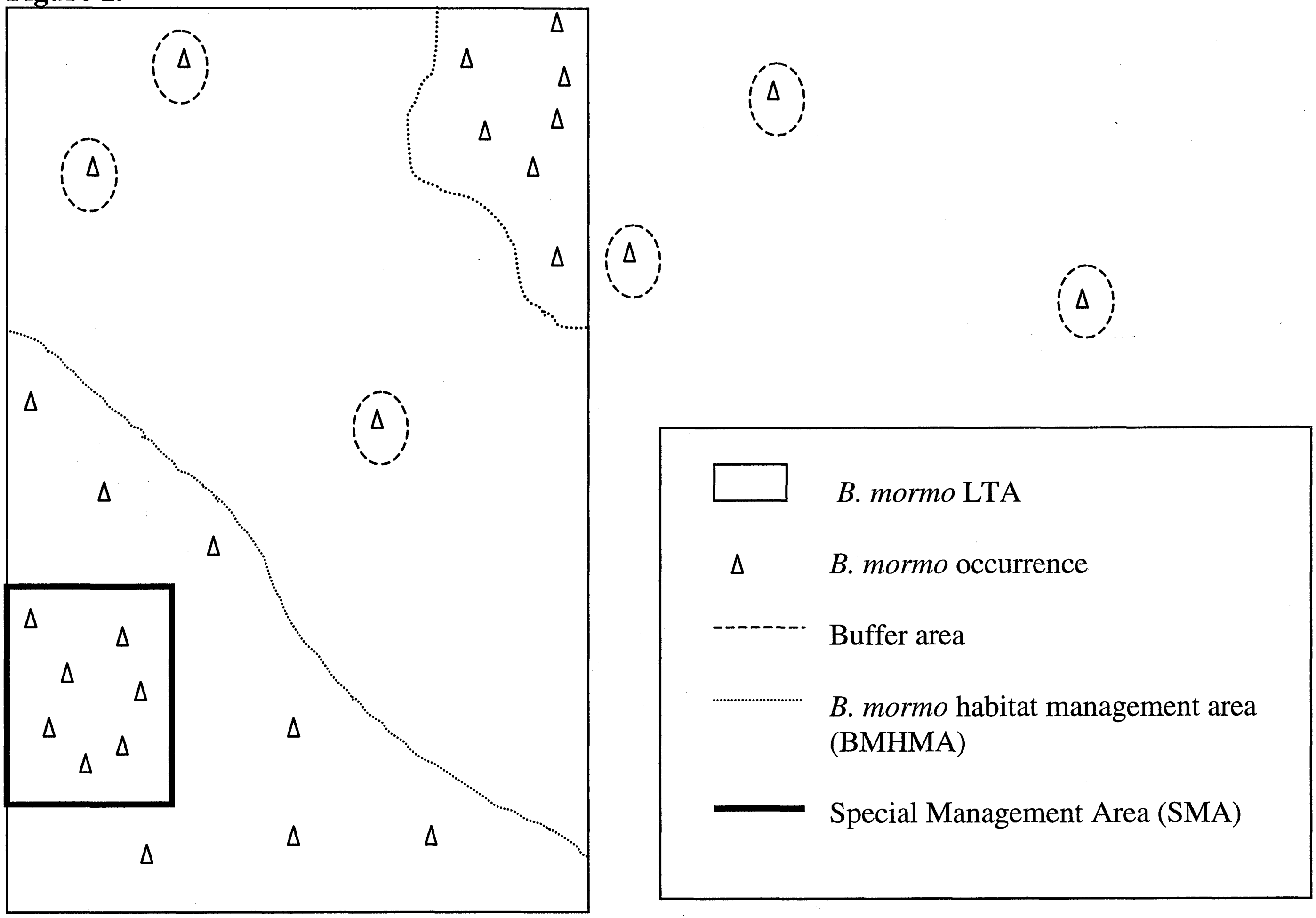
2. In order to insure collaboration in the process, it is necessary to establish personal contacts with critical stakeholders who did not attend the PHVA. Specifically, representatives from Timber Industry, Superior National Forest, USFS Regional Office, TNC, and environmental organizations (i.e. Sierra Club, Audubon) were identified. These organizations should be brought "to the table" at a one-day overview of the process in neutral location. Responsibility: Berlin, Williamson, Eubanks, Sather.

3. There is a need to continue sharing information about the goblin fern with all stakeholders. One suggested medium is to include goblin fern information on the Chippewa National Forest homepage (www.fs.fed.us/r9/chippewa); other entities can link to the site. The suggested focus is range-wide status, general life history, ongoing research and monitoring suggested throughout this report. Responsibility: Al Williamson, Nancy Berlin.

4. Another means of sharing information with a wider audience is to publish popular articles (Minnesota Volunteer, Mpls. Star Tribune-Tom Meersman) on goblin fern in general, rogue worms. Responsibility: Johnson-Groh, Sather, Mortinsen.

Participants: Nancy Berlin, Janet Boe, Marjory Brzeskiewicz, Colleen Matula, Pete Tennis, Al Williamson, (Steve Eubanks – initial stages)

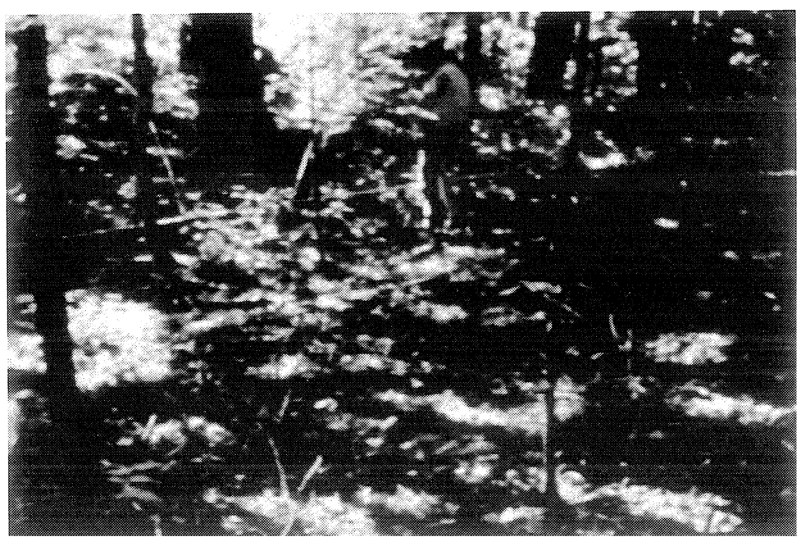
Figure 1.


B. mormo LTA
B. mormo occurrence
Buffer area
B. mormo habitat management area (BMHMA)
Special Management Area (SMA)

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE GOBLIN FERN
(*Botrychium mormo*)

Horseshoe Bay Resort
Walker, Minnesota
6 - 9 October 1997

Final Report
January 1998



SECTION 5
DISTRIBUTION AND STATUS WORKING GROUP REPORT

DISTRIBUTION AND STATUS WORKING GROUP REPORT

Introduction

At the Goblin Fern PVHA Workshop (6-9 October 1997), participants identified the need to reconcile discrepancies in Forest Service and State Natural Heritage Program data and to integrate that data rangewide to provide a current distribution summary and rangewide map based on ecological units. The distribution working group met at the CBSG office in Apple Valley, MN on 20 November 1997 to address this need. Integration of this data can be used to better understand rangewide distribution, species status and by managers in making risk assessments for management activities.

Methods

Following the October workshop, occurrence data from Minnesota, Wisconsin and Michigan were reconciled and integrated to form a database (Table 1) and map (Figure 2). The database and map were then used to evaluate and compare sites.

Each known goblin fern site was ranked for its potential contribution to a viable population across the species range. Criteria considered for evaluation were: threats to the species and its habitat; method and intensity of census; potential habitat; projection of extinction risk; location of sites; current monitoring efforts; infrastructure; site quality; fragmentation of habitat; mycorrhizae habitat requirements; currency of data; proximity to other occurrences; and reproductive status of a site. The initial evaluation of these characteristics was based on currently available information with the stated goal to maintain viable populations across the species range.

The priority criteria were then used to evaluate each known site. Table 2 summarizes the relative distribution and compares "stability" of the population as a whole.

Discussion

Results of a paired ranking technique showed threats to the species, risk of extinction, the infrastructure available for management and site quality as the priority concerns of the group in evaluating the status of each site. As illustrated (Table 2), based on the 1997 rangewide data, 51 of 191 recorded goblin fern sites are considered stable.

The following assumptions were made in defining a "secure site":

> **Population size –** Modeling of goblin fern populations based on the best available life history information from the workshop indicates that populations with fewer than five above-ground stems are at greater risk of extinction and therefore not secure. Variable survey and monitoring methods have been used to report the number of stems per site.

There is a strong likelihood that both the number of plants recorded a site and the number of sites within a political, administrative or ecological unit are an artifact of the method and intensity of search. Some records resulted from quick walk-throughs while others involved intensively monitored plots. It is very likely that many records include more stems than are recorded because of variable survey methods, the cryptic nature of goblin fern and annual and seasonal variability. For this analysis, if only a presence/absence survey was done, it was assumed conservatively that less then five plants were present.

Threat: earthworms – Initial data presented by Wolff et al. indicated that presence of earthworms reduced the litter layer critical to the goblin fern. The distribution of exotic earthworms is unknown at this time but for this discussion is was assumed that Ottertail Peninsula sites are threatened and are not considered secure.

Threat: timber harvest and mining – Although mitigating the effects of harvest through buffering and transplant have been proposed, the effectiveness of such measures are unknown at this time. A conservative approach was applied in assessing the security of sites. The worst case scenario adopted in this analysis posits that all harvest methods have the potential of being detrimental because of their potential impact on the condition of the litter layer, that all stands typed as aspen or having a significant aspen component are likely to be harvested, and that mitigation measures could fail.

Summary and Recommendations

It is hoped that these relative comparisons may be useful to managers in prioritizing sites and making risk assessments. At this time, three-quarters of known goblin fern sites are on National Forest system lands. This may be due to habitat but also due to search effort. Other public land agencies are encouraged to search to achieve a more accurate distribution record. Ecological unit maps may aid in identifying potential habitat. From the distribution of populations in figure 1, it would appear that further search is needed in upper, lower Michigan and in ecological units 212jf, 212jb, 212nd and 212 kb.

The risk assessment models described in this report indicate that natural catastrophic events such as severe drought are primary threats to *B. mormo* populations not already impacted by human-mediated processes. This has also been identified as a general threat for *in situ* populations by Menges (1990). It therefore becomes extremely important to identify the nature and extent of suitable microsites within the 51 stable sites identified herein as well as the type of variation within these sites, particularly with respect to topography and soil characteristics as they relate to water availability. A metapopulation viability analysis can then be undertaken which focuses on the current proportional occupancy of these microsites and the minimum number of sites required to sustain a metapopulation.

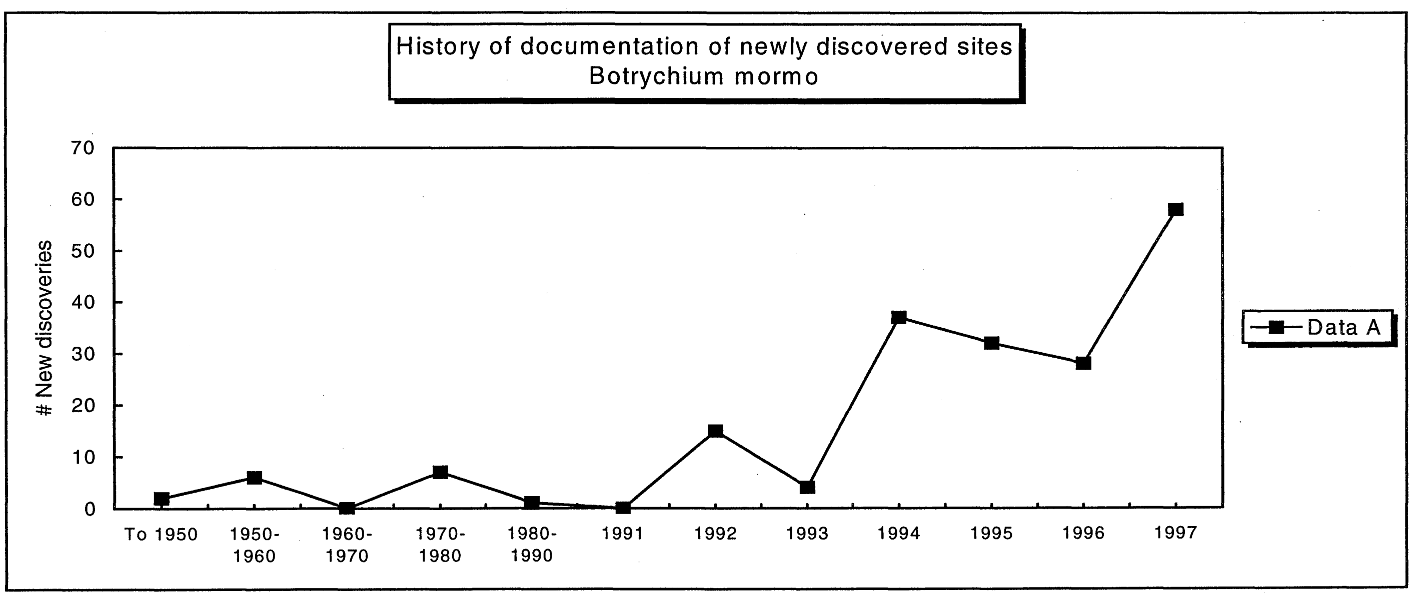
There was significant discussion of the TNC global ranking of G3 for the goblin fern. At the present time *Botrychium mormo* is ranked by The Nature Conservancy as G3. G3 species are defined as "Either very rare and local throughout its range or found locally (even abundantly at some of its locations) in a restricted range (eg. a single western state, a physiographic region in the east) or because of other factors making it vulnerable to extinction throughout its range. (21 to 100 occurrences)." TNC's Element Global Ranking form for this species was prepared in 1992. At the time *Botrychium mormo* was assigned this rank, only 16 of the 191 presently known populations had been documented, only 15 of which were reported in the EGR. At the present time 191 element occurrences have been documented throughout the range by Natural Heritage Programs and/or the US Forest Service. Of these, 51 sites are defined as "secure" by the criteria outlined in this report in seven ecoregions in both Minnesota and Wisconsin. Using the above criteria for risk and security it would seem appropriate for the global rank of the species to be changed to G4.

However, more conservative and widely accepted guidelines for viability in plant populations generally assume a MVP of 100 plants. According to this more conservative guideline for viability, only two of five populations known to be as large or larger than 100 above-ground plants are free of threat. The remainder are on the Ottertail Peninsula and run a potential risk of impact from litter alteration as a consequence of earthworm invasion. These facts suggest that the G rank should not be modified until there is better documentation of the actual size of unthreatened populations, the geographic extent and intensity of earthworm threat has been evaluated and managing agencies have developed guidelines that assure avoidance of impacts to large known populations as a result of timber harvest.

Although known sites have increased considerably in the past few years (Figure 1), TNC global rankings should consider the population and threat factors discussed above in addition to total population numbers. With more then three-quarters of the recorded goblin fern sites, National Forest conservation strategies could play a critical role in conserving the species.

Working group participants: Nancy Berlin, June Dobberpuhl, Zella Ellshoff, Nancy Sather

Figure 1. Source: MN DNR, WI DNR, Michigan Natural Features Inventory, and USFS



Legend (Table 1)

Ecological Classification System (ECS) unit:
Refer to the legend on Figure 1 for section and subsection identities.

LTA: Land type association
- G – Gutherie Till Plain
- I – Itasca Moraine
- M – Marcell Moraine
- ***B – Blackduck Till Plain***
- R – Rosey Lake Plain
- S – Bemidji Sand Plain

EO: Element Occurrence number assigned to each site in the natural heritage databases

Date of Information: most recent date a fern was observed

Threats:
- T – Timber threat
- W – Known presence of exotic earthworms in the area.
- M – Occurs on proposed mine site.
- P – Number of recorded plants at the sites is less than five.

FS: Forest service unit number

Habitat:
- MB – Maple/Basswood
- **NH – Northern Hardwood**
- A – Aspen

Table 1: Known goblin fern sites (data sources: National Forest databases; Michigan, Minnesota and Wisconsin Natural Heritage databases).

State	Admin. Unit	ECS section	LTA	EO#	# plants/EO recorded	Date of information	Relative Intensity	Threats	FS	Habitat	*Comments*
MI	Priv	212Nb		1	?	09/05/51				old rd. shaded clearing	ASSUME EXP
MI	SF	212Nb	MI	2	?	08/22/51				old rd	ASSUME EXP
MI	Priv	212Nb		3	?	08/20/88				MB beech	ASSUME EXP
MI	Priv	212Nd		4	?	7/ /1952				ls ravine	ASSUME EXP
MI	Priv	212Hi		5	?	09/01/51				mesic for	ASSUME EXP
MI	Priv	212Nd		6	?	08/16/54				maple ls.	ASSUME EXP
MI	priv/state	212Nc		7	>1	07/17/52				NH, ls	ASSUME EXP
MI	NPS	212Kb		8	>1	08/21/51		P		mix wd,dune	
MI	Ottawa NF	212Jb		9	13	08/29/95		T		MB fir	
MI	Ottawa NF	212Jl		new	10?	/ /1997		T		MB	Matula
MI	Ottawa NF	212Jc		new	10?	/ /1997		T		MB	Matula
MI	Hiawatha NF	?		new		/ /1997		T		?	Schultz--identification uncertain, Grand Island
MN	?	212Jl		new	>36	08/06/97				MB	Dahle & Engels
MN	CNF	212Na	G	2	>1	8/ /1975		W,P	2001	MB	
MN	CNF	212Na	G	8	4	1973?		P	202	MB	
MN	CNF	212Na	I	9	>1	09/09/92		P	5001	MB	
MN	CNF	212Na	G	10	>1	09/09/92		P	2003	MB, MO, Cedar	
MN	CNF	212Na	G	11	>1	08/25/92		P	2004	MB, Cedar	
MN	CNF	212Na	G	12	150	08/25/92		W	2005	MB	
MN	CNF	212Na	G	13	10?	10/08/92		P	2006	M	
MN	CNF	212Na	G	14	10?	08/25/92		W,T	2007	MB	
MN	CNF	212Na	G	15	10?	10/08/92		W,T	2008	MB	
MN	CNF	212Na	G	16	10?	10/08/92		W	2009	NH	
MN	CNF	212Na	G	17	10?	10/08/92		W	2010	NH	
MN	CNF	212Nb	M	19	3	10/03/92		P	4001	MB	
MN	CNF	212Nb	B	20	2	08/31/92		P	4002	NH	
MN	CNF	212Na	R	23	7	8/ /1994			3004	MB	

State	Admin. Unit	ECS section	LTA	EO#	# plants/EO recorded	Date of information	Relative Intensity	Threats	FS	Habitat	*Comments*
MN	CNF	212Na	G	24	>100	07/01/94		W	2015	MB	
MN	CNF	212Na	G	25	6	08/01/94		W	2026	MB	
MN	CNF	212Na	G	26	>25	07/27/95		W	2013	MB	
MN	CNF	212Na	G	27	>10	08/01/97		W	2012	MB	
MN	CNF	212Na	G	28	5	08/02/94		W	2011	MB	
MN	CNF	212Na	R	29	10?	08/01/94			3003	MB	
MN	CNF	212Na	S	30	4	08/08/94			3001	MB	
MN	CNF	212Na	S	31	1	08/30/94		P	3002	MB	
MN	CNF	212Na	M	32	1	08/30/94		T,P	4003	MB	
MN	CNF	212Na	B	33	>50	09/01/94			1006	M W Cedar	
MN	CNF	212Na	B	34	2	09/11/94		P	1005	NH mix	
MN	CNF	212Na	B	35	2	07/26/94		T,P	1004	NH aspen	
MN	CNF	212Na	B	36	>10	08/17/94		T	1008	Aspen	
MN	CNF	212Na	B	37	1	09/07/94		P	1009	Red M/B	
MN	CNF	212Na	B	38	3	08/31/94		T,P	1014	NH mix	
MN	CNF	212Na	B	39	2	09/03/94		T,P	1013	NH mix	
MN	CNF	212Na	B	40	>1	09/08/94		T,P	1012	MB aspen	
MN	CNF	212Na	B	41	>15	08/23/94		T	1003	NH	
MN	CNF	212Na	B	42	3	09/02/94		T,P	1001	Aspen	
MN	CNF	212Na	B	43	2	09/02/94		T,P	1010	Asp, W M	
MN	CNF	212Na	B	44	>1	08/29/94		T,P	1011	NH	
MN	CNF	212Na	B	45	>1	08/29/94		T,P	1007	Asp	
MN	CNF	212Na	R	46	8	09/06/94		T	3005	MB	
MN	CNF	212Na	G	56	>20	08/21/96			2020	MB	
MN	CNF	212Na	B	57	5	09/16/96		T,P	3007	MBaspen	
MN	CNF	212Na	B	58	>25	08/07/96		T	3006	Basswd balsam	
MN	CNF	212Na	B	59	15	08/06/96		T	1002	NH	
MN	CNF	212Na	B	60	>15	09/02/94		T	1018	MBA	
MN	CNF	212Na	B	61	80	08/13/96			1017	MB	
MN	CNF	212Na	B	62	15	08/13/96		T	1021	MB	

State	Admin. Unit	ECS section	LTA	EO#	# plants/EO recorded	Date of information	Relative Intensity	Threats	FS	Habitat	*Comments*
MN	CNF	212Na	B	63	20	8/13/96		T	1019	HDMIX	
MN	CNF	212Na	B	64	3	8/--/96		T,P	1020	OA	
MN	CNF	212Na	B	65	5	8/--/96			1022	MBA	
MN	CNF	212Na	B	66	1	8/--/96		P	1023	?	
MN	CNF	212Na	B	67	28	08/20/96		T	1024	MBA	
MN	CNF	212Na	B	68	13	08/14/96		T	1015	MBA	
MN	CNF	212Na	B	69	1	08/08/96		T,P	1016	Asp NH	
MN	CNF	212Na	B	70	>1	08/27/96		T,P	1026	CED/FI/AS	
MN	CNF	212Na	B	71	3	08/21/96		T,P	1027	MB FIR	
MN	CNF	212Na	B	72	1	08/26/96		T,P	1028	AB	
MN	CNF	212Na	R	73	24	08/12/96		T	1029	HDMIX	
MN	CNF	212Na	R	74	>1	08/12/96		T,P	1030	MBA	
MN	CNF	212Nb	M	75	2	08/31/96		P	4004	MB	
MN	CNF	212Na	G	76	>1	07/16/96		P	2018	HDMIX	
MN	CNF	212Na	G	77	32	09/16/96			2019	MB	
MN	CNF	212Na	M	78	1	08/10/94		T,P	4005	NH	
MN	CNF	212Kb		79	>2	08/08/96				MB	
MN	CNF	212Na	R	80	2	07/31/97		T,P	1032	Asp mix	
MN	CNF	212Na	R	81	9	09/02/97		T	1035	Asp mix	
MN	CNF	212Na	R	82	10	07/14/97		T	1033	NH mix	
MN	CNF	212Na	R	83	>50	07/16/97		T	1031	MB	
MN	CNF	212Nb	M	84	1	08/06/97		?P	4008?	MB	
MN	CNF	212Nb	M	85	>100	08/12/97			4010	NH	
MN	CNF	212Na	D	86	1	07/10/97		T,P	1034	MB Aspen	
MN	CNF	212Nb	M	87	1	08/10/97		P	4011	MB	
MN	CNF	212Nb	M	88	1	09/03/97		P	4012	MB	
MN	CNF	212Na	G	89	6	07/08/97			2021	MB	
MN	CNF	212Na	G	90	>20	07/02/97			2022	MB OG	
MN	CNF	212Na	G	92	>1	8/ /1997		W	2027	?	
MN	CNF	212Na	G	94	2	06/30/97		P	2023	MB	

State	Admin. Unit	ECS section	LTA	EO#	# plants/EO recorded	Date of information	Relative Intensity	Threats	FS	Habitat	*Comments*
MN	CNF	212Na	G	95	20	06/30/97			2024	MB	
MN	CNF	212Na	R	96	1	06/25/97		P	2025	MB	
MN	CNF	212Na	P	97	2	08/13/97		P	3010	MB	
MN	CNF	212Na	P	98	2	08/13/97		T,P	3009	MB	
MN	CNF	212Na	R	99	1	08/13/97		P	3012	MB	
MN	CNF	212Na	R	100	1	08/13/97		P	3011	MB	
MN	CNF	212Nc	I	101	3	07/18/97		P	5003	ASPMIX	
MN	CNF	212Nc	I	104	1	07/15/97		P	5002	MB	
MN	CNF	212Jf	M	new	2	09/03/97			4008	MB	
MN	CNF	212Hp	M	new	11	08/18/97			4009	MB	
MN	CNF	212Jf	M	new	3	08/14/97		P	4007	MB/cedar	
MN	CNF	212Na	B	new	1	08/13/97		P	3009	MB	
MN	CNF	212Na	B	sight	1	07/10/97		P	1034	MBA	
MN	CNF	212Na	R	sight	9	09/02/97			1035	MBA	
MN	CNF	212Na	R	sight	50	07/16/97			1031	MBB	
MN	CNF, PRIVATE	212Na	G	91	1	8/ /1997		W,P	2028-9	Aspen	
MN	County	212Jf		new	6	08/02/97				NH mix	Delaney
MN	DNR			new	7	07/30/97			NA	MB	J Boe
MN	DNR			new	7	08/21/97			NA	MB	J Boe
MN	FS, Indian, State	212Na	G	103	>300	9/ /1997		W	2030,31,32	MB	
MN	Hagen WPA	222Ma		22	12	10/03/92				MB	
MN	Hagen WPA	222Ma		48	23	09/13/94				MB	
MN	Indian	212Na	G	49	5	07/22/93			2017	MB	
MN	Indian	212Na	G	50	>1?	08/07/95		W	2016	MB	
MN	Indian	212Na	I	51	23	9/ /1997			5004	Maple	
MN	Itasca	212Nc		1	>1	1973				MB	
MN	Itasca	212Nc		5	>1	1973				MB	ASSUME EXP
MN	NWR	212Jf		new	16	08/23/97				MB	Gerdes
MN	NWR	212Jj		new	2	09/10/97				NH mix	Dahle & Engels
MN	private	212Nc		6	>1	1973				NH mix	

State	Admin. Unit	ECS section	LTA	EO#	# plants/EO recorded	Date of information	Relative Intensity	Threats	FS	Habitat	*Comments*
MN	private	222Ma		7	>1	1973				field	ASSUME EXP
MN	private	212Na		50	>1?	9/ /97		W	2033	MB	
MN	private	212Na	G	93	>1	8/ /1997		W	2014	?	
MN	private	212Na	G	102	>1?	9/ /97		W	2034	MB	
MN	private	222Ma		105	25	08/21/97				OA MESIC	M Lee
MN	private - moley	222Ma		52	>5	08/02/95		T		MB	
MN	private - moley	222Ma		53	3	08/27/95		T		MB	
MN	Red Lake	212Mb		4	>1	1976		P		MB	ASSUME EXP
MN	Rice Lake NWR	212Kb		55	>1	07/31/96		P		MB	
MN	Sav SF	212Nd		54	3	06/24/96		P		MB	
MN	state for	212Jl		new	>5	09/03/97				NHmix	Dahle & Engels
MN	state for	212Jl		new	2	08/20/97		P		MB	Dahle & Engels
MN	state for	212Jl		new	10	07/10/97				MBaspen	Dahle & Engels
MN	Superior	212Lc		18	15	08/25/92				NH	
MN	Superior	212Lc		21	20	08/27/92				NH	
MN	WMA	212Nc		47	11	09/07/94				NH	
MN	WMA	212Jl		new	6	07/21/95				MB	Delaney
sight record	private		G						2033	MB	
sight record	private		G						2034	MB	
WI	?	212Kb		5	22?	10/13/93				MB	no aspen
WI	?	212Jc		7	?	09/06/95				NH	
WI	?	212Jl		16	72	08/25/94		M		NH	Hemlock Ck. mining threat
WI	?	212Jl		17	4	09/08/94		P		MB	
WI	?	212Jl		18	53	09/13/94				MB	count is from 1996, 11 in 1994
WI	?	212Jl		19	43	09/28/95				MB	
WI	Che NF	212Hj		1	2	/ /97		T		NH MIX	>1000 in '79, 23 in '93
WI	Che NF	212Kb		6	>20	07/22/92		T		MB	
WI	Che NF	212Jc		8	1	09/26/94		P		MB	no logging planned
WI	Che NF	212Jl		10	3	09/22/93		T,P		MB	ATV, id for harvest
WI	Che NF	212Jl		14	8	07/24/95		T		MB	id for harvest

State	Admin. Unit	ECS section	LTA	EO#	# plants/EO recorded	Date of information	Relative Intensity	Threats	FS	Habitat	*Comments*
WI	Che NF	212Jl		56	20	08/07/97		T		MB	survey prior to possible cut
WI	Co. Pk.	212Kb		2	?	09/15/15				NH Mix	searched 97 none found; Park
WI	Crandon	212Kb		21	16	08/24/94		M		NH	not seen 1995
WI	Crandon	212Jl		22	23	08/22/94		M		NH	mine threat
WI	Crandon?	212Jl		23	1	09/06/94		P		NH	
WI	Crandon?	212Jl		24	4	09/28/94		P		2nd map	
WI	Crandon?	212Jl		25	5	09/30/94				2nd map	
WI	Crandon?	212Jk		26	3	10/05/94		P		2nd ,map	
WI	Crandon?	212Jl		27	5	1994		M		MB	mine threat
WI	Crandon?	212Jl		29	1	08/08/95		P		?	
WI	Crandon?	212Jl		30	1	08/08/95		P,?T		popple marsh hardwoods	
WI	Crandon?	212Jl		32	123	08/14/95				?	
WI	Crandon?	212Jl		33	2	08/30/95		P		?	
WI	Crandon?	212Jl		41	10	09/02/95		?T		?	
WI	Crandon?	212Jl		42	5	08/22/95		?T		?	
WI	Nic NF	212Hb		11	2	09/01/95		T,P		MB	id for harvest
WI	Nic NF	212Jc		12	30	07/17/97				MB	RNA
WI	Nic NF	212Jl		13	57	07/21/97				MB	RNA
WI	Nic NF	212Jc		15	11	08/04/97		T		MB	id for aspen harvest
WI	Nic NF	212Jl		28	4	08/10/95		P		?	
WI	Nic NF	212Hm		31	1	08/29/95		P		?	
WI	Nic NF	212Jl		35	3	08/31/95		P		?	
WI	Nic NF	212Jl		36	34	08/31/95		?T		?	
WI	Nic NF	212Jl		37	17	08/30/95		?T		?	
WI	Nic NF	212Jl		38	7	08/22/95		?T		?	
WI	Nic NF	212Jl		39	34	08/14/95		?T		?	
WI	Nic NF	212Jl		40	60	08/25/95		?T		?	
WI	Nic NF	212Jl		43	34	08/24/95		?T		?	
WI	Nic NF	212Hm		44	40	08/24/95		?T		?	
WI	Nic NF	212Jl		45	11	08/11/95		?T		?	

State	Admin. Unit	ECS section	LTA	EO#	# plants/EO recorded	Date of information	Relative Intensity	Threats	FS	Habitat	*Comments*
WI	Nic NF	212Jl		46	20	09/10/97		?T		NH/hemlock	
WI	Nic NF	212Jl		47	2	08/11/95		P		?	
WI	Nic NF	212Jl		48	2	08/09/95		P		?	
WI	Nic NF	212Jl		49	4	08/10/95		P		?	
WI	Nic NF	212Jl		50	2	07/25/96		P		2nd map	
WI	Nic NF	212Jl		51	13	08/13/96				MB	very small area, actively mg. stand, no threat
WI	Nic NF	212Jl		52	16	08/21/96				MB	cut in past, not threatened now
WI	Nic NF	212Jl		53	6	08/27/96				MB	
WI	Nic NF	212Jl		54	25	1995		?T		?	Crandon?
WI	Nic NF	212Jl		55	1	1995		P		?	Crandon?
WI	priv	212Hj		3	?	07/09/38				MB	not seen 1993; development
WI	priv	212Jc		20	3	09/14/94		P		MB	
WI	USFS	212Jl		9	4	10/14/93		T,P		MB	
WI	USFS	212Jl		34	34	09/18/97		?T		MB	actively managed hardwood, no threats

Table 2: Summary of rangewide site characteristics.

Administrative Unit	Total # of Identified Sites	# Secure Sites	# Sites w/ <5 plants	# Sites w/ Known Earthworm Threat	# Sites w/ Timber Threat	Other comments
Michigan	**12**	**0**	**1**	**0**	**4**	**7 Assume Exp**
Hiawatha NF	1	0	?	0	1	i.d. uncertain
NPS	1	0	1	0	0	
Ottawa NF	3	0	0	0	3	
Private	6	0	0	0	0	6 Assume Exp
State Forest	1	0	0	0	0	1 Assume Exp
Minnesota	**124**	**38**	**54**	**18**	**38**	
CNF	90	17	48	13	36	
County	1	1	0	0	0	
DNR	2	2	0	0	0	
Hagen WPA	2	2	0	0	0	
Indian	4	2	0	2	0	
Itasca	2	0	2	0	0	1 Assume Exp
NWR	2	2	0	0	0	
Private	10	5	0	3	2	1 Assume Exp
Red Lake	1	0	1	0	0	1 Assume Exp
Rice Lake	1	0	1	0	0	
Sav SF	1	0	1	0	0	
State forest	3	2	1	0	0	
Superior	2	2	0	0	0	
WMA	2	2	0	0	0	
New record	1	1	0	0	0	8/6/97
Wisconsin	**55**	**13**	**11**	**0**	**22**	
Cheq NF	6	0	2	0	5	
County Park	1	1	0	0	0	
Crandon mine	13	2	6	0	3	3 mining
Nicollet NF	25	5	9	0	12	
Private	2	1	1	0	0	1 development
USFS	2	0	1	0	2	
?	6	4	1	0	0	1 mining
Range Total:	**191**	**51**	**66**	**18**	**64**	

Figure 2.
Map Legend

200 HUMID TEMPERATE DOMAIN

210 WARM CONTINENTAL DIVISION

212 LAURENTIAN MIXED FOREST PROVINCE

212H NORTHERN GREAT LAKES SECTION

212Ha Gwinn-Deerton Outwash and Sand Ridges Subsection
212Hb West Green Bay Till Plain Subsection
212Hc Green Bay Clayey and Silty Lake Plain Subsection
212Hd Manitowoc Till Plain Subsection
212He Door and Escanaba Penisulas and Lake Plains Subsection
212Hh Seney Sand Lake Plain Subsection
212Hi Grand Marais Sand End Moraine and Outwash Subsection
212Hj St. Ignace Lake Plain Subsection
212Hk Rudyard Clay Lake Plain Subsection
212Hl Cheboygon Lake Plain Subsection
212Hm Harrisville Moraines Subsection
212Hn Stutsmanville Sand Ridges Subsection
212Ho Traverse City Drumlin Fields Subsection
212Hp Vanderbilt Moraines Subsection
212Hq Mio Outwash Plains Subsection
212Hr Tawas Lake Plain Subsection
212Hs Cadillac End Moraines Subsection
212Ht Big Rapids Loamy Moraines Subsection
212Hu Newago Outwash and Ice Contact Subsection
212Hv Wellston Outwash and Ice Contact Subsection
212Hw Manistee Outwash and Lake Sands Subsection
212Hx Hart Outwash and Lake Sands Subsection
212Hy Kalkaska Moraines Subsection

212I LAKE SUPERIOR SECTION

212Ia Lake Superior and Islands Subsection
212Ib Isle Royale Subsection

212J SOUTHERN SUPERIOR UPLANDS SECTION

212Ja Lake Superior Clay Plain Subsection
212Jb Gogebic-Penokee Iron Range Subsection
212Jc Winegar Moraines Subsection
212Jd St. Crois Moraine Subsection
212Je Central-Northwest Wisconsin Loess Plains Subsection
212Jf Perkinstown End Moraine Subsection
212Jg Lincoln Formation Till Plain, Mixed Hardwoods Subsection
212Jh Neilsville Sandstone Plateau Subsection
212Ji Rib Mountain Rolling Ridges Subsection
212Jj Green Bay Lobe Stagnation Moraine Subsection
212Jk Spread Eagle-Dunbar Barrens Subsection
212Jl Brule and Paint Rivers-Drumlinized Ground Moraine Subsection
212Jm Northern Highlands Pitted Outwash Subsection
212Jn Baraga-Keweenaw Coarse Rocky Till Subsection
212Jo Ewen Dissected Lake Plain Subsection
212Jr Michigamme Highlands Subsection
212Js Lincoln Formation Till Plain-Hemlock-Hardwoods Subsection

212K WESTERN SUPERIOR UPLANDS SECTION

212Ka Bayfield Sand Plains Subsection
212Kb Mille Lacs Uplands Subsection

212L NORTHERN SUPERIOR UPLANDS SECTION

212La Border Lakes Subsection
212Lb North Shore Highlands Subsection
212Lc Laurentian Highlands Subsection
212Ld Toimi Uplands Subsection

212M NORTHERN MINNESOTA AND ONTARIO SECTION

212Ma Littlefork-Vermillion Uplands Subsection
212Mb Agassiz Lowlands Subsection

212N NORTHERN MINNESOTA DRIFT AND LAKE PLAINS SECTION

212Na Chippewa Plains Subsection
212Nb St. Louis Moraines Subsection
212Nc Pine Moraine and Outwash Plains Subsection
212Nd Tamarack Lowlands Subsection

212O LAKE MICHIGAN SECTION

212Oa Lake Michigan and Islands Subsection
212Ob Green Bay Subsection
212Oc Grand Traverse Bay Subsection

212P LAKE HURON SECTION

212Pa Lake Huron and Islands Subsection
212Pb Saginaw Bay Subsection

220 HOT CONTINENTAL DIVISION

222 EASTERN BROADLEAF FOREST (CONTINENTAL) PROVINCE

222H CENTRAL TILL PLAINS, BEECH-MAPLE SECTION

222Ha Bluffton-Ann Arbor Till Plains Subsection

222I ERIE AND ONTARIO LAKE PLAIN SECTION

222If Maumee Lake Plain Subsection
222Ig Lake Erie Sand Plain Subsection

222J SOUTHEASTERN GREAT LAKES SECTION

222Ja Southeast Lake Michigan Plains and Dunes Subsection
222Jb Southeast Lake Michigan Moraines Subsection
222Jc Iona Moraines Subsection
222Jd Saginaw Clay Lake and Till Plain Subsection
222Je Huron Clay Lake and Till Plain Subsection
222Jf Lum Interlobate Moraine Subsection
222Jg Jackson Interlobate Moraine Subsection
222Jh Kalamazoo-Elkhart Moraines and Plains Subsection
222Ji Steuben Interlobate Moraines Subsection
222Jj Southeast Lake Michigan Plains and Dunes Subsection

222K SOUTHWESTERN GREAT LAKES MORAINAL SECTION

222Ka Central Wisconsin Sand Plain Subsection
222Kb Central Wisconsin Moraines and Outwash Subsection
222Kc Lake Winnebago Clay Plain Subsection
222Kd South Central Wisconsin Prairie and Savannah Subsection
222Ke Southern Green Bay Lobe Subsection
222Kf Geneva-Darien Moraines and Till Plains Subsection
222Kg Kenosha-Lake Michigan Plain and Moraines ? Subsection
222Kh Rock River Old Drift Country Subsection

222L NORTH CENTRAL U.S. DRIFTLESS AND ESCARPMENT SECTION

222La Menominee Eroded Pre-Wisconsinan Till Subsection
222Lb Melrose Oak Forest and Savannah Subsection
222Lc Mississippi-Wisconsin River Ravines Subsection
222Ld Kickapoo-Wisconsin River Ravines Subsection
222Le Mineral Point Prairie-Savannah Subsection
222Lf Western Paleozoic Plateau Subsection

222M MINNESOTA AND NORTHEAST IOWA MORAINAL SECTION

222Ma Alexandria Moraine-Hardwood Hills Subsection
222Mb Big Woods Moraines Subsection
222Mc Anoka Sand Plain Subsection
222Md Rosemont Baldwin Plains and Moraines Subsection
222Me Oak Savannah Till and Loess Plains Subsection

222N LAKE MODIFIED TILL SECTION

222Na Aspen Parklands Subsection

222Q LAKE ERIE SECTION

222Qa Lake Erie/Bays and Islands Subsection
222Qb Lake St. Claire Subsection

250 PRAIRIE DIVISION

251 PRAIRIE PARKLAND (TEMPERATE) PROVINCE

251A RED RIVER VALLEY SECTION

251Aa Lake Agassiz Plain Subsection

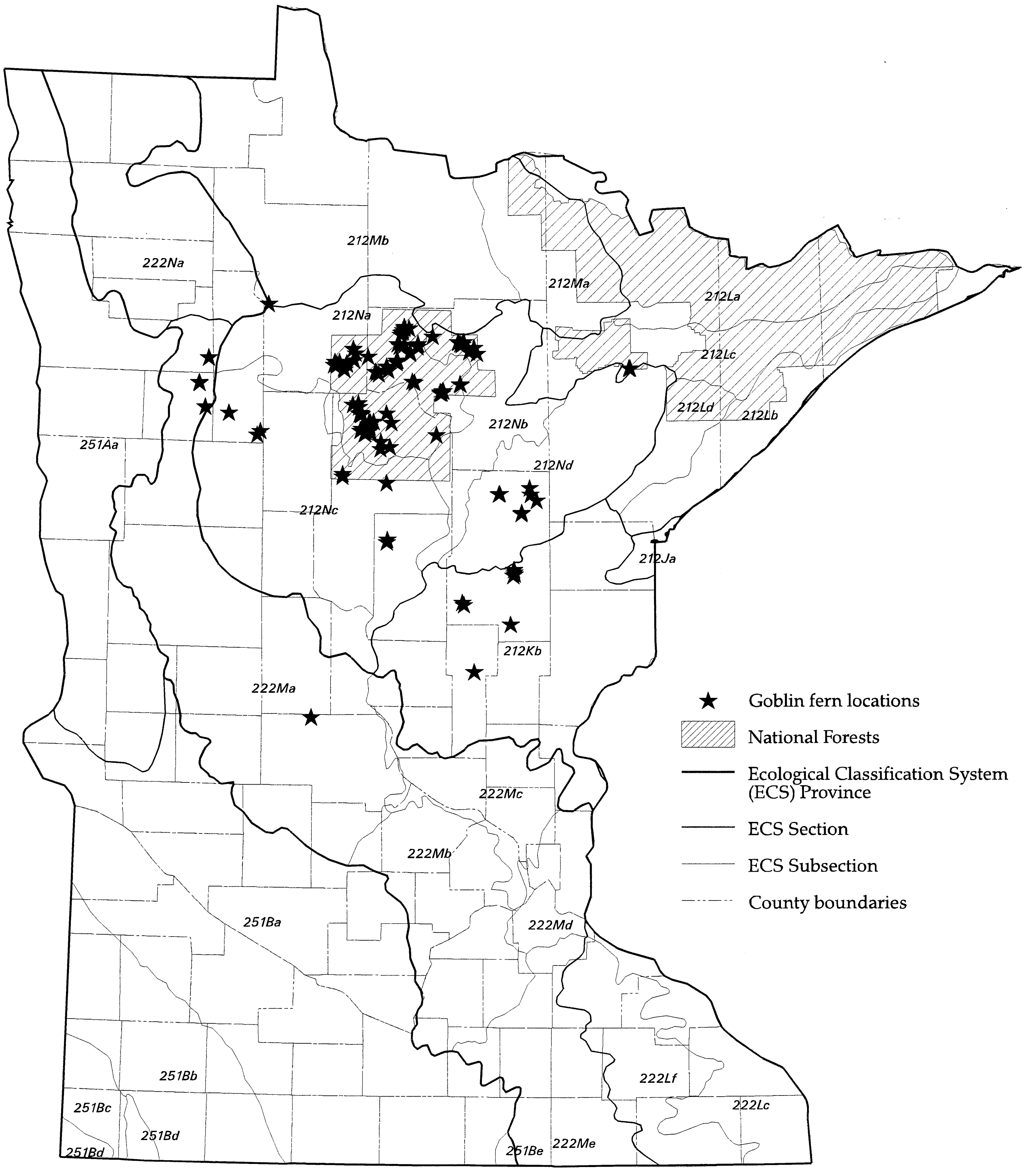
251B NORTH CENTRAL U.S. MORAINAL AND TILL PLAINS SECTION

251Ba Upper Minnesota River-Des Moines Lobe Subsection
251Bb Outer Coteau des Prairies Subsection
251Bc Inner Coteau des Prairies Subsection
251Bd Northwest Iowa Plains Subsection
251Be Southern Des Moines Lobe Subsection

Known and reported locations of Goblin fern *(Botrychium mormo)* in Michigan as of November 1997

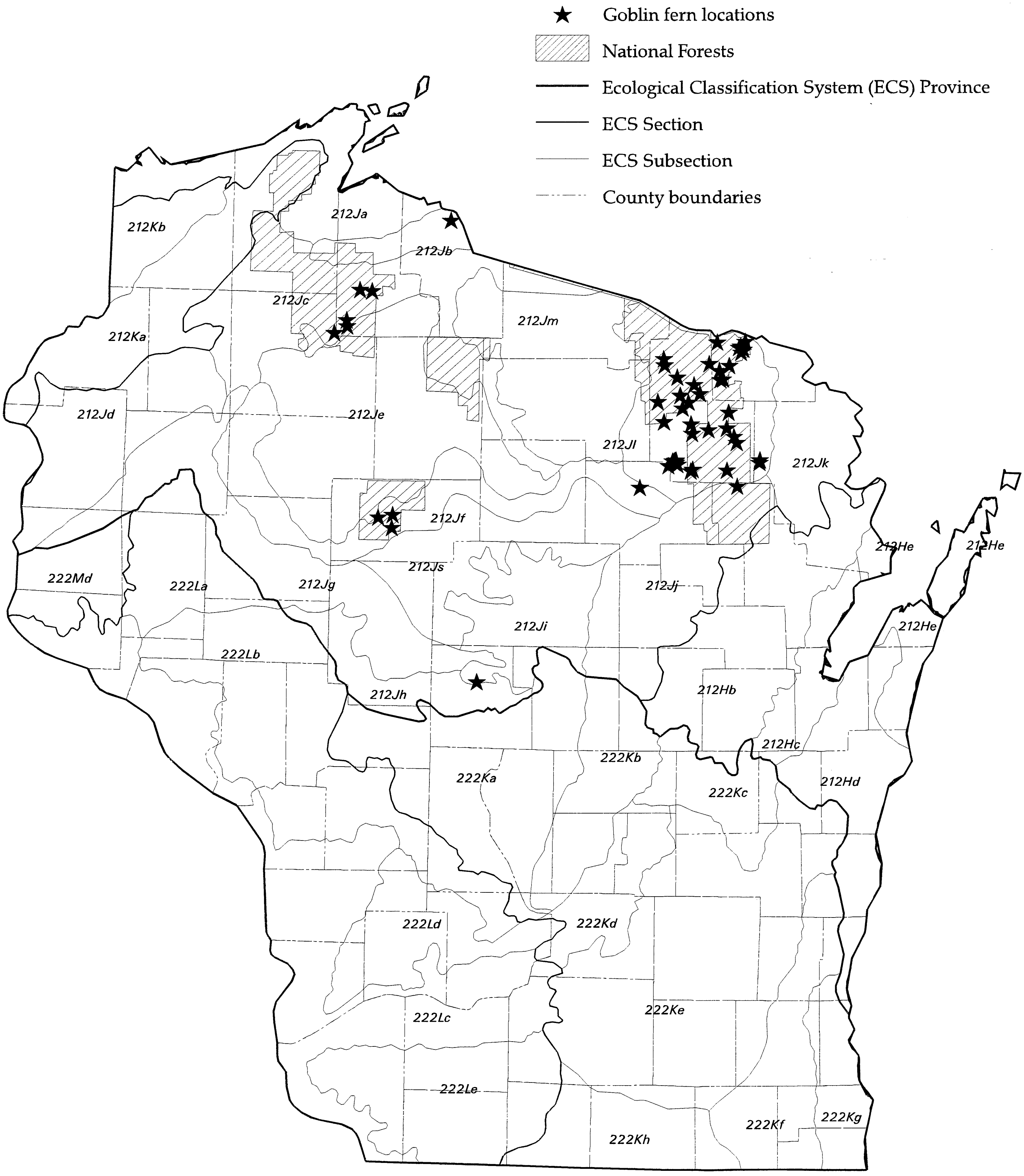
Data compiled and map produced February 03, 1998, by the Minnesota Natural Heritage and Nongame Research Program based on 1997 data provided by the Michigan Rare Features Inventory and the Ottawa National Forest.

Known and reported locations of Goblin fern *(Botrychium mormo)* in Minnesota as of November 1997



Data compiled and map produced February 03, 1998, by the Minnesota Natural Heritage and Nongame Research Program based on 1997 data provided by the Chippewa National Forest and the Minnesota Natural Heritage Information System.

Known and reported locations of Goblin fern *(Botrychium mormo)* in Wisconsin as of November 1997



Data compiled and map produced February 03, 1998, by the Minnesota Natural Heritage and Nongame Research Program based on 1997 data provided by the Wisconsin Natural Heritage Program.

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE GOBLIN FERN
(*Botrychium mormo*)

Horseshoe Bay Resort
Walker, Minnesota
6 - 9 October 1997

Final Report
January 1998

APPENDIX I.
WORKSHOP PRESENTATIONS

A Background for the Study of Moonworts
Dr. Herb Wagner

The moonworts are a subgenus of the genus of grapeferns, *Botrychium*, of the family of adder's tongues, Ophioglossaceae. Probably the best-known and most common grapefern in the world is the plant known in North America as rattlesnake fern, *Botrychium virginianum* which ranges around the globe in the north latitudes, and in the New World into the mountains of South America, at least as far south as Bolivia and Peru. The typical moonworts are also mainly in the North Temperate Zone, but they are usually much smaller than rattlesnake ferns, and frequently difficult to find and often very rare. To discover them, we often have to crawl along the ground underneath shrubs and grasses. A search image can be acquired making it possible to separate the moonworts from young seedlings of flowering plants. The original moonwort (the one described by Linnaeus and most familiar to Europeans) was named *Botrychium lunaria*, and is a spectacular plant because the leaflets are shaped like a half moon. It is also one of the largest moonworts. Like all Ophioglossaceae, the leaf is unique among all higher plants in that the leaf has two parts, one the photosynthetic blade part (the sterile segment of trophophore) and the spore-producing non-bladed part (the fertile segment or sporophore). The roots and stem are both underground. The roots are fleshy and only slightly branched and they lack root hairs. Fungi live in association with the roots, and provide at least some of the nourishment for the plant. The stems are buried in the ground and basically unbranched, like a vertical rod. The new leaves arise underground, at the top of the stem, the oldest leaf embracing the next lower leaf with its basal sheath, and the next lower embraced similarly the leaf below it, and so on. Only the top leaf appears above the ground, the remainder of the leaves (several, up to five) remain each enclosed by the one above it, and these enclosed leaves (those below the top leaf) stay in the embryonic state until their year of appearance arrives. Thus a plant has but a single leaf per year above ground, but underground there is a storehouse for up to five leaves for the future five years. In the typical moonworts, all leaves, mature or embryonic, bear sporophores and trophophores, but in typical grapeferns, like the evergreen species, and the rattlesnake, often lack or abort the fertile part, being entirely vegetative. In all members of the genus *Botrychium*, animals may eat off the fertile parts present, and there is a suspicion that animals spread spores in addition to wind. Howsoever the spores are dispersed, in order for them to germinate and form the sexual plants, it is necessary for them to percolate down into the soil one to several inches, where they become infected with the fungi. To keep the spores from germinating prematurely, it was discovered by Dr. Dean Whittier of Vanderbilt University that the spores will not germinate in the light. They must penetrate to the lower layers of soil where it is completely dark before they form the tiny "potato-like" sexual plant or gametophyte which will undergo fertilization and start the next generation. In the case of the goblin fern and its relatives, it is necessary that we become familiar with the life cycle before we can carry out proper management procedures for their survival.

The spore cases of *botrychiums* are the largest of all known ferns. Their walls are exceptionally thick for spore cases. The number of spores per spore-case is probably the highest known for vascular plants, their numbering in the thousands. The spore-cases appear like clusters of tiny grapes (creating the name *botrychium*, from *botrys*, grapes.) In most species, the sporangial opening to release the spores is over 90° between the two sides of the gap from which the spores are dispersed, but rarely it is only 30° or less, as in the goblin fern. When the spores fall onto the ground, unlike other ferns they fail to germinate, and as described above they must percolate slowly into the soil, where germination occurs. When the gametophyte matures, it bears both types of sex organs, male for production of sperms, and female for production of eggs. Currently we believe that the majority of fertilization takes place by inbreeding, the sperms swimming to the female organs of the same gametophyte. The sperms depend on moisture in the form of free water between the granules of soil. Occasionally at least, some sperms do swim to other gametophytes; these sometimes belong to other species, and thus form interspecific hybrids. Those few hybrids that do form are apparently sterile, and although they form sporophytes, the spores they produce are abortive and unable to found new populations. In the normal course of events, the new sporophytes are fertile. They first appear as embryos in the gametophytes, and then slowly become larger. The first sporophytes are underground, but after a period of months (or years?) the first leaves appear above ground. This is what makes it possible to recognize the presence of gametophytes in any given area of soil: the young sporophyte leaves indicate that there is probably a gametophyte still attached to it, and that other gametophytes, still unfertilized, are present nearby. In most members of Ophioglossaceae, the sexual plants rot away at the base of the sporophytes, but rarely they may remain, as in the goblin fern. The tendency for self-fertilization is probably one of the reasons that a number of species of moonworts may live together in the same habitat. This ability makes it readily possible to compare closely related species growing side-by-side under the same conditions in so-called "genus communities." Indeed, the student of *botrychiums* uses this method to find the rarest species. One needs only to find one or two species that attract the eye, and then by assiduous search locate other species growing with or near them.

Let us discuss some of the diversity that exists in the genus *Botrychium* and particularly the moonworts. The distinctive evergreen grapeferns (subg. *Sceptridium*) are much larger than most moonworts, and they have triangular sterile segments that last through the winter after their fertile segments have died and rotted away. They are commonly studied and collected in midwinter, during periods when snow is not covering the ground. In most of northern North America, from east coast to west, the leather grapefern (*B. multifidum*) is found, usually in open, brushy fields. In the eastern United states and Canada, we see the dissected grapefern, *B. dissectum*, which has surely one of the most variable leaves of all fern-like plants, the trophophyll varying from once- or twice-divided to finely divided with numerous linear leaflets. Another well-known wintergreen grapefern, the Oneida or blunt-lobed grapefern (*B. oneidense*) is peculiar among its congeners in being not only rare, but restricted to shady hardwood forests and swamps. A real botanist's prize is the rugose grapefern, *B. rugulosum*, that is very rare, and occurs usually in the open, shrubby fields; it occurs in a narrow east-west band, from Vermont to Minnesota, and only recently have a number of localities been discovered. The strangest of this entire group of grapeferns is the prostrate grapefern, *B. lunarioides* of the southeastern United States. It occurs, very sporadically, in a vast area from North Carolina and Arkansas to Florida and east Texas, but has been seen in the living state by very few botanists. Its leaves (often two per plant) appear above ground first in November, and then they disappear completely by the following March.

The true moonworts are so-called because of the moon-shaped pinnae of the type species, *Botrychium lunaria*. It has a very wide range and is certainly the most common for the world as a whole, ranging practically around the globe at high latitudes (45° northward), and appears again in the Southern Hemisphere in New Zealand and Australia. The four best known and practically only species in much of eastern United States are (1) the narrow lance-leaved moonwort, *B. lanceolatum*, (2) the daisyleaf moonwort, *B. matricariifolium*, (3) the dwarf moonwort, *B. simplex*, and, to the north, the mingan moonwort, *B. minganense* (Wagner and Lord 1956). Except for the last, these species extend in the Appalachian region as far south as North Carolina. Moonworts are, of course, difficult to find unless one has the "search image," and actually the best hunting usually involves several participants (most commonly college students), and sometimes requires strenuous crawling along the ground on hands and knees. The best areas for finding moonworts are the western Great Lakes (Canada: Thunder Bay District, and Algoma District; U.S. Michigan, Wisconsin, Minnesota) and the northwest (Canada: Alberta, British Columbia; U.S. Montana, Washington, Oregon). These are the "mother lodes," where practically all of the new species that have been discovered in the past two decades were found.

Of the new species, the little goblin fern, *B. mormo*, is surely one of the most interesting and distinctive. This tiny plant grows especially in rich shaded hardwoods, including sugar maples, basswoods, and white ashes. Eastwardly (east of Marquette, MI) the associated trees are joined by American beech. The soil in mormo woods is always rich and there is a leaf litter or at least decayed material on the surface. The goblin ferns are remarkable for usually maintaining their connection to the parental gametophyte underground, the gametophyte remaining alive. Commonly the youngest plants are practically invisible, sticking up very slightly above the leaf letter. Large plants, those with over forty spore cases are usually uncommon, in most stands the majority of plants having twenty or less spore cases.

The recently discovered prairie moonwort (or "dunewort"), *B. campestre*, which was named by D. F. Farrar and me, grows in much more open and disturbed sites, always in the sun and in more or less sterile but commonly alkaline soil (Wagner and Wagner 1986). It is the earliest species to appear in the spring, usually in the last half of May and first half of June. It dries up rapidly as the end of June approaches. Prairie moonwort is unusual in having special tiny, ball-like clusters of cells ("gemmae") that reproduce the plant asexually. Like all of the moonworts, this one is probably more widespread and frequent than we are presently aware.

Other interesting Great Lakes species are the rare spatulate moonwort *B. spathulatum*, a species that was confused with the much more common Mingan moonwort, *B. minganese*. It has never been found, apparently, in Minnesota, although it is well represented on the north side of Lake Superior, in western Algoma District and Thunder Bay District of Ontario.

Out west, one of the most famous (and rare and local) species is the pumice moonwort, *B. pumicola*. It is very well known and was described as long ago as 1900. The habitat is strange – on the skrees of Crater Lake, growing in dry pumice in the full rays of the sun. We have discovered that the spores are remarkable for being released from the spore capsules in loose groups of fours, i.e., as tetrads. In connection with others of our recent discoveries, we have shown that the exceedingly rare and poorly known false pinnate moonwort, *B. pseudopinnatum* (the name referring to the western *B. pinnatum*, which it resembles) has the highest number of chromosomes yet known in moonworts, a total of 270. It is known from a couple of small populations in the Thunder Bay District, and has recently been recognized by Gary Walton and Karen Myhre in Minnesota. (For further discussions of chromosomes in moonworts, see Florence S. Wagner 1993).

At this point, some readers may wonder how we can separate the species, since many of the moonworts tend to resemble each other, such as *B. lunaria* and *B. minganense*, *B. simplex* (small form) and *B. mormo*, and *B. acuminatum* and *B. matricariifolium.* In our studies we use the genus community or syntopy method (also known as microsympatric method). What this means is that if two species occur together in the same habitat, with the potentiality of hybridization, they nevertheless stay genetically separate. If they do occasionally make hybrids, these are sterile and their spores are abortive (Wagner and Wagner 1985). A related approach involves a third species which we will call "C". If species "A" grows with "C" in one place and "B" grows with "C" in another place, but "A" and "B" still maintain their recognized differences, while "C" is unchanged, then we recognize "A" and "B" as distinct species. (Paris et al. 1989, method of mutual associates).

One of the new species of moonworts we had long confused with *B. minganense* turned out to have a distinction involving a specialized feature of the surface of the trophophore involving the exaggerated development of epicuticular wax that makes it appear to be gray-green or white. We named it the pale moonwort, *B. pallidum* for its unique feature. Later Florence Wagner discovered that it was a primitive diploid with 90 chromosomes, unlike all the other minganense-like taxa.

The most extraordinary species that has been discovered in our research is a moonwort that totally lacks a photosynthetic fertile blade. The trophophore has been replaced by a sporophore, producing a leaf with two fertile spikes and no blade! We named it the paradox moonwort, *B. paradoxum.* It has now been found in a few, widely separated localities, but it is extremely rare, and most populations have only a small number of individuals. We were astonished to discover that this strange moonwort will hybridize with more normal moonworts (specifically *B. hesperium*) to produce a curious plant we have named after the locality where the hybrid is readily found, namely Waterton Parks National Park in Alberta. We call it *B. X watertonense*, the "X" indicating its hybrid nature (Wagner et al. 1984). Another peculiar moonwort, only recently recognized, is also exceedingly rare but is known from a few scattered localities from Oregon to the Gaspé Peninsula. Ed Alverson and Peter Zike, two Oregon botanists, called it skinny moonwort because of its odd linear pinnae, which led to its scientific name, *B. lineare.*

These examples illustrate the unexpected new dimensions we and our colleagues have encountered in North American moonworts, including not only the goblin fern with its peculiar habitat, periodicity, and persistent gametophytes, but the prairie moonwort with its vegetative gemmae, the pumice moonwort with its spores released as tetrads, the pale moonwort with its whitened epidermis, the paradox moonwort with two fertile spikes but no blade, and the skinny moonwort with its very narrow, linear segments. We are still finding new species of these rare plants, and only by familiarizing the naturalists and the land managers of our natural areas can we rest assured that we truly know enough to manage and preserve them in their native habitats.

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Population Demographics, Underground Ecology and Phenology of *Botrychium mormo*

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Ecological studies of *Botrychium mormo* were initiated in 1992 and complement other studies done by the author on prairie moonworts (Johnson-Groh, 1996; 1997). These previous studies have revealed the unusual biology of moonworts. *Botrychium* produces one leaf annually consisting of two portions, a trophophore, or the photosynthetic lamina and a sporophore or the spore producing lamina. Moonworts have underground gametophytes which are not photosynthetic, but are mycorrhizal. Some species of moonworts have gemmae, vegetative propagules which detach and initiate new plants (Farrar and Johnson-Groh, 1990). New plants resulting from gemmae as well as immature sporophytes apparently are maintained by the mycorrhizal relationship for a number of years before the first leaf emerges. Our studies (both *B. mormo* and prairie species) have shown that individual plants typically do not emerge annually and may "skip" years. Removal of the above ground leaf does not negatively effect the emergence in subsequent years and damage to the leaf through collection, fire, and herbivory appears inconsequential.

Three *B. mormo* plots located in northern Minnesota (Chippewa National Forest and Superior National Forests) have been monitored for four years. Two additional plots have been monitored for six years (Chippewa National Forest) and three years (Hagen Wildlife Protection Area) respectively. Each plot contains 5.7m^2 in which each individual plant is marked by a numbered tag attached to an aluminum wire inserted into the ground two centimeters north of the plant. (Negative effects of the tags have been ruled out through comparative studies on "tagless" plots.) Each tag is checked annually for presence or absence of plants. Plants are measured and notes are recorded on the degree of development (just emerging, releasing spores, etc.) as well as disturbances such as herbivory or fire damage. New plants are tagged. Subsequent years each existing tag is examined and plants are measured (if plants are emergent) and new plants are tagged. A total of 537 *B. mormo* tags were monitored in 1997.

The results of six years of monitoring reveal large differences between sites and between years. Plot 1 (Chippewa National Forest) has many more individuals than do any other sites (Figure 1). In general all the plots vary similarly on an annual basis. For example in 1996 the population numbers were high for all plots, followed by a decline in 1997 for the three plots in the Chippewa National Forest (CNF). The two plots to the east and west of CNF were stable or increased in 1997. Similar trends, that is wide variation between sites and years, have also been noted for the prairie moonworts.

In addition to the variability at the population level, there is also a great deal of variability at the individual level. Individual plants may skip years, producing no above-ground leaves in a given year, but remaining alive and producing leaves the following season (Figure 2). While new plants are annually recruited into the population, older plants may disappear or reappear after absences of 1-3 years. Further evidence of this pattern comes from eleven years of monitoring prairie moonwort species. More years of monitoring are needed to establish the details of patterns of emergence for *B. mormo.*

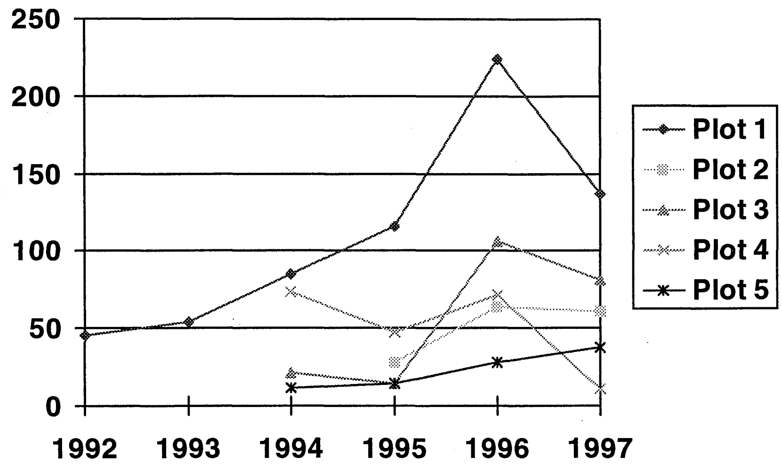

Figure 1. Population trends for *B. mormo* 1992-1997, Minnesota

It is unclear why *Botrychium* do not appear every year. It seems most probable that the health of the mycorrhizae is involved. Our assumption is that adequate mycorrhizal resources including soil moisture are not available so that moonworts do not emerge.

In order to access the impact of non-appearance of leaves in a given year, we have compared this to leaf loss through herbivory or other damage such as fire in the prairie species. It was predicted that loss of leaf tissue would decrease the photosynthetic output of the plant and thereby decrease the total vigor. If this lack of photosynthetic tissue negatively effects the plant than there should be a decline in the number or size of plants in the following year. Monitoring results indicate that loss of the leaf either through herbivory, fire or collection has no effect on the subsequent return the following year. Damaged plants are as likely as undamaged plants to return and likewise plants are equally likely of returning after non-appearance for one year as they are for years following emergence. This is also true of the prairie moonworts where we have observed severely scorched or wilted plants following burns. Such plants emerge the following year and may even show an increase in size.

Another indication that *B. mormo* depends relatively little on leaves for photosynthesis is the observation that leaves frequently do not emerge above the litter. In fact only a small proportion of the total population actually emerges from the litter (Figure 3).

So if photosynthesis is not critical for this genus and the mycorrhizae are more important in the overall energy budget, then understanding the underground biology is critically important. Indeed assumptions made about the population biology of other more normal plants may be

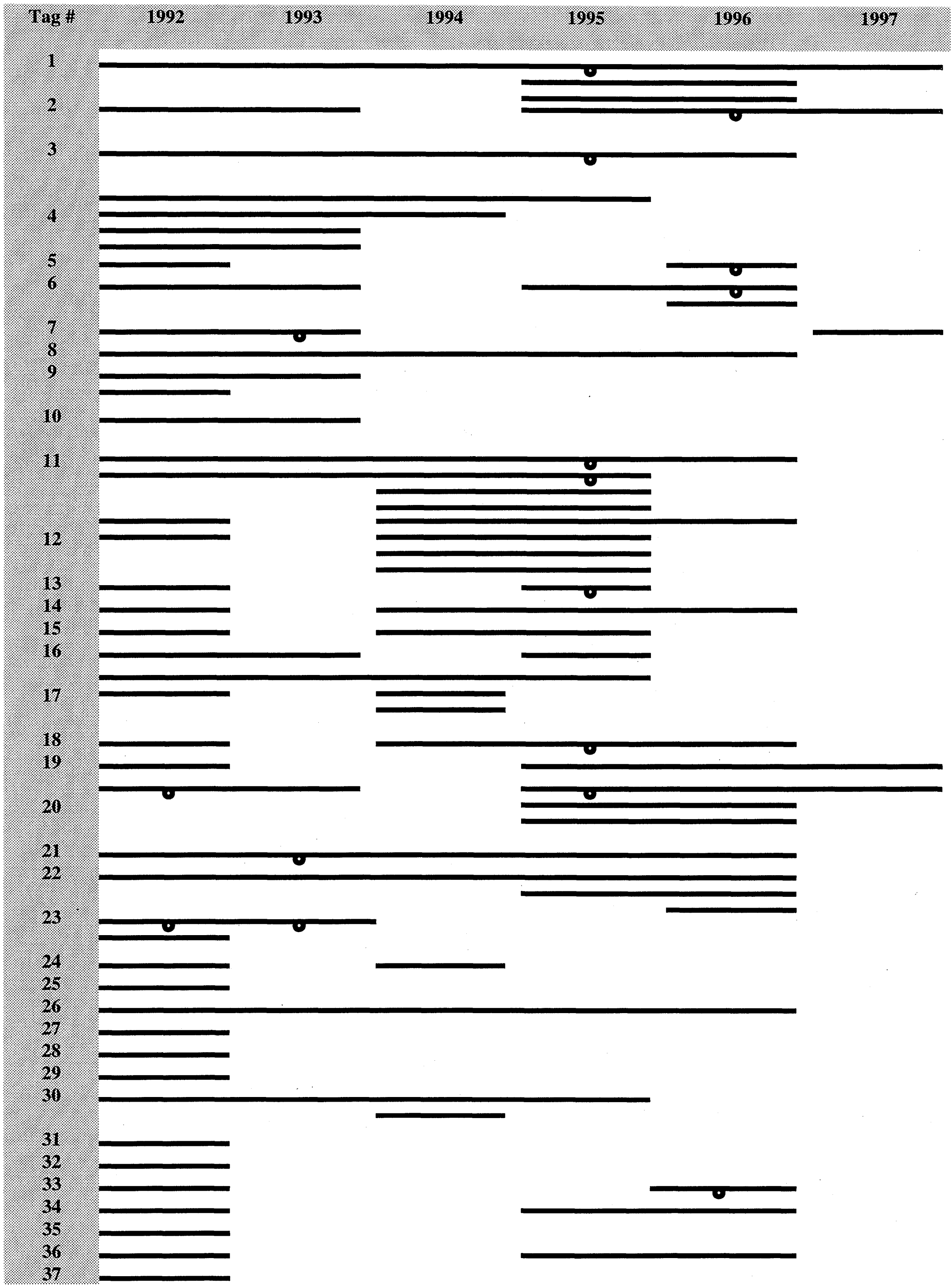

Figure 2. Emergence history of plants at tags placed in 1992 in plot 1, CNF. Lines indicate the presence of a plant and notched lines indicate that the plant was damaged (herbivory) during that particular year

irrelevant to *Botrychium*. *Botrychium* appear or disappear in accordance with the mycorrhizal health. This makes it difficult to measure simple demographics such as recruitment and mortality. Recruitment, measured as first appearance of a leaf in a new location in the plot, varies in our plots from a high of 99 new plants (plot 1, 1996) to a low of 3 (plot 5, 1997). Based on five plots studied over three years the average recruitment is 35% of the population base. However, this estimate does not include the possibility of a new individual at a spot previously marked for another individual.

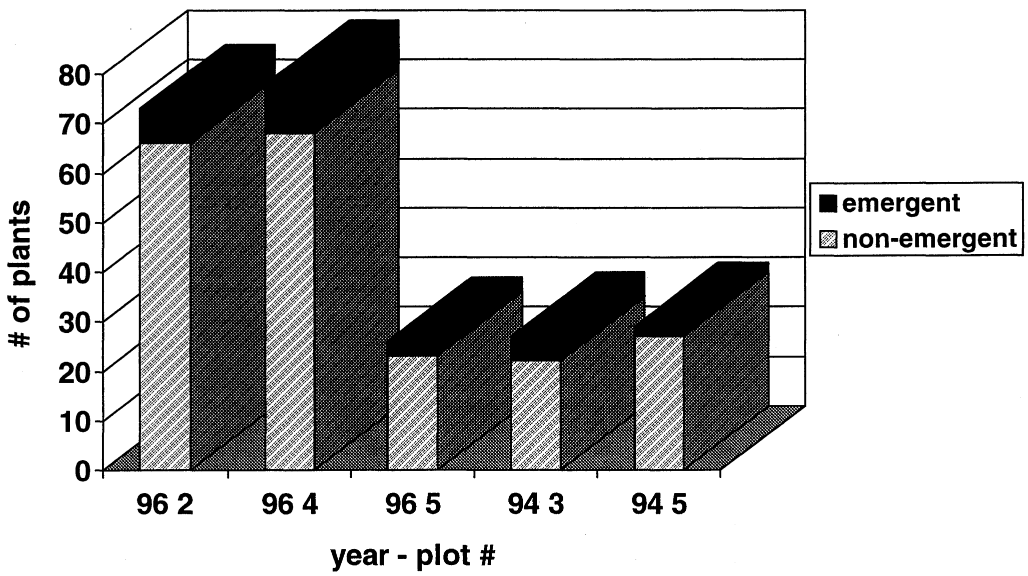

Figure 3. Number of *B. mormo* plants which are emergent and non-emergent from leaf litter in four plots monitored for two years.

Because of the possibility of annual disappearance and reappearance it is difficult to determine the longevity of these plants. Almost half (47%) of the plants observed appeared for one year above ground and then did not emerge the following year. A few plants have appeared above ground continuously for up to six years and are still going. Of the 47% which fail to emerge in a given year, only 24% reappear in a subsequent year. This only addresses the probability of reappearance of individual plants and not how long each plant was in existence above ground prior to disappearing.

The longest continued annual appearance of a plant above ground, as previously noted, is six years. However, most plants do not persist more than two years and only 24% of these return after a one year absence. Only 4% of these return after two years of absence. Thus it seems that above ground longevity for most plants of *B. mormo* is relatively short (1-2 years) as compared with the prairie moonworts in which most plants have an above ground longevity of approximately four years.

These results are all based on the assumption that plants emerging at the same tag are the same plant in successive years. Because of the small size of these plants we can only assume this to be true. Based on the exact position of a plant relative to the tag and its relative size, it seems probable that most of these are the same plants. It is possible however, to have clusters of plants within a few centimeters of one another making it difficult to trace the behavior of an individual within the group.

To understand the underground distribution of plants we conducted an experiment to examine the abundance of gametophytes and non-emergent sporophytes. Forty-nine samples of soil were collected using a bulb-digger in a spoke-like design centered on a known population of *B. mormo*. These samples were processed using a centrifugation technique which allows the lighter plant material to be separated from the soil and collected for examination under a microscope. From these samples we estimated that the average density of gametophytes was $700/m^2$ and the average density of non-emergent sporophytes was $250/m^2$. It is important to note that *B. virginianum* was also common in this area and many of the gametophytes and sporophytes are probably of this species. Additional experiments are planned to determine densities of underground plants in pure populations of *B. mormo* and to determine ways to distinguish gametophytes of *B. mormo* from *B. virginianum*.

In 1996-97 we conducted studies on *B. mormo* to determine its phenology. We visited two sites in CNF every two weeks from June 1 through October. Plots were extensively searched for reoccurring tagged plants and new untagged plants. Plants were measured and notes were recorded on the stage of development as follows:

1. Emergent. These plants had the trophophore tightly wrapped around the sporophore and were newly emerged.
2. Separation. In this stage the trophophore had begun to elongate and separate from the sporophore.
3. Spore release. The sporangia on the sporophore were yellow to brown and often slightly opened.
4. Senescence. Following spore maturation the plants yellowed and senesced occasionally rotting off at the base.

A total of 284 plants were monitored. Plants emerged earlier (June 2) than previously suggested and the population size likewise peaked earlier (July 14) than previously hypothesized. The largest plant sizes occurred late in September with an average trophophore size of 2.6 cm. Plants emerging early in the season had a prolonged "seasonspan", or period of emergence, whereas plants emerging later had a relatively short "seasonspan". Despite the short "seasonspan", plants emerging late did develop spores.

The importance of long-term monitoring of *B. mormo* is apparent from the studies described above. Because of the unusual behavior of moonworts it is important to systematically monitor these plants for an extended period of years. Little is known about their underground biology or response to management. Whereas we know something about the phenology, we have no idea how susceptible plants in different phenological stages (emergent, separation, spore release, senescence) are to timber harvest practices. Likewise little is know about the underground portion of *Botrychium* life history and its susceptibility to disturbance.

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Population Genetics of Moonwort Botrychiums

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Starch gel enzyme electrophoresis provides a method for visualizing and measuring inherited allelic variation within specific genes. Over the past decade, procedures for this analysis have been standardized and applied widely across plant and animal taxa such that variation detected within a given species or population can be compared to the "average" for similar species and populations (Wendel and Weedin, 1989; Hamrick and Godt, 1990). We have conducted starch gel enzyme electrophoresis on each of the eastern species of moonworts (*Botrychium* subgenus *Botrychium*) including *Botrychium mormo*, and applied results to questions of species relationships within this group and to relative amounts of genetic variation within species and populations. These results have bearing on the species distinctness of *B. mormo*, to its breeding behavior and dispersability, and to the question of genetic variability as a limiting factor in the species' long term survival.

We surveyed allelic diversity at 18 variable gene loci in 10 enzyme systems for each of 6 diploid species of moonworts occurring in the Great Lakes region. Comparison of alleles present and their relative frequencies between species of populations yields a measure of similarity which is termed "genetic identity" or GI. Between populations of the same species, this value is usually 90% or greater. The GI between distinct species is usually less than 70%. Comparing the genetic identities between *B. mormo* and other eastern moonworts, we find that all values are below 70%, indicating that *B. mormo* warrants recognition as a distinct species (Table 1). Comparing GI values of B. mormo with each of the other eastern moonworts, we find that it is most similar to *B. simplex*, to which it is also morphologically similar and with which it is sometimes confused. Our conclusion is that *B. mormo* is a distinct species, having approximately the same level of distinction as other recognized species of eastern diploid moonworts.

Examination of the allelic variability within each of the moonwort species, including *B. mormo*, reveals a consistent pattern of very low intraspecific variation (Table 2). The average of 1.18 alleles per locus is much lower than the average of more than 2.0 for 26 species of ferns (T. A. Ranker, Univ. of Colorado, personal communication), or of 1.96 for 473 species of seed plants (Hamrick and Godt, 1990). At 15.1%, the proportion of loci which are polymorphic (have more than one allele present) is also much lower than for ferns and seed plants in which more than 50% of the loci are usually polymorphic. *Botrychium simplex* seems to be somewhat of an exception, but when the three recognized eastern varieties of this species are treated separately, they conform to the pattern of low variability within taxa as well. In fact, these three varieties are nearly as different genetically from one another (GI values of .52 to .71) as they are from other eastern moonworts, suggesting that they might also be treated as distinct species.

Why do *Botrychium* species have such low genetic variability? A probable explanation is their tendency toward sexual inbreeding. Among seed plants, it has been demonstrated that inbreeding species have much lower genetic variability (alleles per locus = 1.69; % polymorphic loci = 41.8) than do outcrossing species (alleles per locus = 2.15; % polymorphic loci = 56.5) (Hamrick and Godt, 1990). Another indication of selfing in a species is a lower number of heterozygous individuals than expected. This is certainly true of *Botrychium* species; in fact, with over 1000 individual plants tested, we have yet to find one that is heterozygous (except for interspecific hybrids and allopolyploids). A similar observation has been reported for B. virginianum (Soltis and Soltis, 1986). Thus it seems that in *Botrychium*, self-fertilization is the rule, with outcrossing a very rare occurrence.

The propensity for self-fertilization in *Botrychium* likely is due to the fact that the sexual stage of these plants, the gametophyte, grows underground. Each gametophyte plant produces both sperm and eggs in close proximity on its surface. Given the hindrance to sperm in swimming from one gametophyte to another through the soil, it seems quite probable that each egg would first be reached and fertilized by sperm from the same plant, sperm needing to swim only a millimeter or so over the surface of the gametophyte plant.

Self-fertilization in ferns has the consequence of immediate elimination of heterozygosity in the resulting sporophyte. This is because both sperm and egg are products of the same initial cell, the spore, from which the gametophyte grew. Being a product of meiosis in the sporophyte plant, the spore and resultant gametophyte are haploid, carrying only a single set of chromosomes. By mitosis the gametophyte produces sperm and egg cells which are genetically identical. Any sporophyte resulting from self-fertilization thus has two sets of chromosomes that are identical. Sporophytes produced in this way are therefore completely homozygous; they can have no heterozygosity. Carried on for generations (the homozygous sporophyte can produce spores of only one genotype, which produce gametophytes of that same genotype, which produce additional sporophytes of the same genotype, etc.), this becomes equivalent to vegetative reproduction.

Thus, in *Botrychium*, even plants produced from spores and through the sexual process are genetically constituted as though they were produced vegetatively. This quickly leads to production of clone-like populations with each individual genetically identical to every other individual. At the species level it has also been demonstrated both empirically and through probability statistics that species relying on vegetative reproduction become genetically depauperate (Pleasants and Wendel, 1989; Hamrick and Godt, 1990).

What are the consequences of inbreeding and the resulting lack of genetic variability in *Botrychium*. On the positive side, the capacity for self-fertilization means that each spore is capable of producing a new plant. This is especially important for long-distance colonization where widely dispersed spores are likely to be isolated from one another. Thus, if a spore of *B. mormo* does get carried to a distant suitable habitat, there is a better chance of it producing a new colony of plants than there would be if the species was not capable of self-fertilization.

Low genetic variation in species or populations is often cited as a negative attribute. The assumption is that such species are less capable of changing to meet the needs of a changeable environment. In reality, this has been demonstrated to be a problem in only a few animal species; it has not been shown to be a problem in plant species (Menges, 1987, 1991). In *Botrychium*, all species seem to have extremely low genetic variability, yet most are widespread and abundant. Furthermore, the genus, *Botrychium*, surely has existed for millions of years, and there are no reasons to believe that its reproductive biology, and thus its genetic variability, has ever been different from what it is today.

From the above considerations we propose that low genetic variability is not a problem for *B. mormo* at either the population or species level. Small populations may be at risk from catastrophic disturbances (natural or man-made), and from stochastic population fluctuations, but low genetic variability should not be of concern in estimating minimum viable population sizes.

How do genetically depauperate *Botrychium* species cope with environmental change? It is probably not possible to answer this question definitively, however we speculate that, at least in part, the answer may lie in the intimate associations these plants establish with mycorrhizal fungi. The roots of *Botrychium* are few, thick and fleshy, and lack the root hairs through which other plants extract water and minerals from the soil. Instead, *Botrychium* roots are infested with fungi whose mycorrhizal filaments extend from the roots into the surrounding soil.

The role of mycorrhizal filaments in taking up water and mineral nutrients and transferring these to the host plant has been well documented (Smith and Read, 1997). It has also been demonstrated that mycorrhizae attached to two or more host plants at the same time can transfer carbohydrates from one host plant to another. This is surely the case for moonwort Botrychiums that must survive underground for years with no ability to manufacture their own carbohydrates through photosynthesis. Furthermore, in *Botrychium mormo*, the leaves of most plants, even though large and healthy, do not emerge above the leaf litter and remain white or pale yellow-green and probably incapable of contributing substantially to their own carbohydrate needs. Instead, they must rely upon their associated fungus for virtually all their nutritional needs. The mycorrhizal fungus must obtain carbohydrates from other photosynthesizing plants in the vicinity, probably species of herbaceous flowering plants, and transfer some of these carbohydrates to the non-photosynthesizing *Botrychium.*

The genetic nature of mycorrhizal fungi has not been worked out definitively, but the prevailing picture is that these are a group of common fungi belonging to a relatively few species which are broadly non-specific with regard to the plant species with which they form associations (Smith and Read, 1997). This promiscuity and their near ubiquitous presence in natural terrestrial habitats suggests that they are quite adaptable to environmental change. With such partners doing the bulk of the work in extracting a living from the environment, perhaps genetic variability in the host plant, i.e. *Botrychium*, becomes unimportant. In fact, genetic stability may be more important in assuring that the host *Botrychium* remains attractive to the mycorrhizal fungus.

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Table 1. Genetic identities among eastern diploid species of *Botrychium* subgenus *Botrychium*.

Table 1. Genetic identities among eastern diploid species of *Botrychium* subgenus *Botrychium*.

	campestre	pallidum	simplex	mormo	lance. lance.	lance. ang.
B. lunaria	.33	.29	.45	.29	.13	.19
B. campestre		.52	.41	.23	.29	.33
B. pallidum			.61	.51	.39	.09
B. simplex				.65	.15	.39
B. mormo					.28	.17
B. lance. lance.						.78

B. lanceolatum is split into eastern subspecies *angustisegmentum* and western subspecies *lanceolatum*.

Table 2. Genetic variability in eastern diploid species of *Botrychium* subgenus *Botrychium*.

Table 2. Genetic variability in eastern diploid species of *Botrychium* subgenus *Botrychium*.

	Mean sample size per locus	Mean no. of alleles per locus	Percentage of loci polymorphic
B. lunaria	41.1	1.1	11.1
B. campestre	96.9	1.2	16.7
B. pallidum	20.6	1.1	5.6
B. simplex total	96.2	1.7	61.1
var. simplex	27.0	1.1	5.6
var. tenebrosum	27.8	1.1	11.1
var. compositum	15.8	1.1	5.6
B. mormo	48.8	1.1	5.6
B. lance. lance.	24.6	1.0	0.0
B. lance. angus.	29.2	1.1	5.6

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE GOBLIN FERN
(*Botrychium mormo*)

Horseshoe Bay Resort
Walker, Minnesota
6 - 9 October 1997

Final Report
January 1998

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POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE GOBLIN FERN
(*Botrychium mormo*)

Horseshoe Bay Resort
Walker, Minnesota
6 - 9 October 1997

Final Report
January 1998

APPENDIX III.
WORKSHOP INVITATION LIST

Goblin fern mailing list

	Area	First Name	Last Name	I/R	1st Line Address	2nd Line Address	3rd Line Address	Telephone
1	~		~	INV	WISCONSIN PUBLIC SERVICE CORP	PO BOX 19002	GREEN BAY WI 54307-9002	~
2	~	~	~	INV	MINNESOTA DEER HUNTERS ASSN	~	GRAND RAPIDS MN 55744	~
3		Dennis	Albert	?	MI DNR - NAT HERITAGE PGM	MADISON BLDG BOX 30028	LANSING MI 48909	~
4		John	Almendinger	INV	MN DNR	2002 AIRPORT RD	GRAND RAPIDS MN 55744	218-327-4449
5		Dr. Bill	Alverson	?	U OF WI - DEPT OF BOTANY	BIRGE HALL 430 LINCOLN DR	MADISON WI 53706	
6		Timothy	Anderson	INV	NATURAL RESOURCE GROUP	BUTLER SQUARE SUITE 890C	MINNEAPOLIS MN 55403	612-347-6798
7		Rich	Baker	?	MN DNR - NAT HERITAGE PGM	500 LAFAYETTE RD BOX 25	ST PAUL MN 55155	
8	~	Nancy	Berlin	~	CHIPPEWA NATIONAL FOREST	RT 3 BOX 244	CASS LAKE MN 56633	218-335-8673
9	~	Janet	Boe	~	MNDNR-CBS	413 SE 13th Street	Grand Rapids, MN 55744	218-327-4449
10	~	Jenna	Borovansky	~	CBSG	12101 Johnny Cake Ridge	Apple Valley, MN 55124	612-431-9325
11		Al	Boss	INF	USDA FOREST SERVICE R9	310 WEST WISCONSIN AVE	MILWAUKEE WI 53203	414-297-1905
12		Nancy	Braker	?	THE NATURE CONSERVANCY - WI	633 WEST MAIN STREET	MADISON WI 53707	608-251-8140
13	~	Marjory	Brzeskiewicz	~	Chequamegon National Forest	1170 S. Fourth Avenue	Park Falls, WI 54552	715-762-5199
14	~	Onnie	Byers	~	CBSG	12101 Johnny Cake Ridge	Apple Valley, MN 55124	612-431-9325
15	~	Francisco	Camacho	INV	OREGON STATE UNIVERSITY	2165 MASTER PL	CORVALLIS OR 97330	547-758-0461
16	~	John	Casson	~	CASS LAKE RANGER DISTRICT	RT 3 BOX 219	CASS LAKE MN 56633	218-335-8606
17	S	Steve	Chaplin	INV	THE NATURE CONSERVANCY-REGIONL	1313 Fifth Street SE	MINNEAPOLIS MN 55414-1688	612-331-0700
18		Kim	Chapman	~	THE NATURE CONSERVANCY - MN	1315 5TH ST SUITE 320	MINNEAPOLIS MN 55155	612-331-0750
19		Anita	Cholewa	INV	U OF MN HERBARIUM 220 BIO SCI	1445 GARTNER AVE	ST PAUL MN 55128	612-625-0215
20	CS	Barb	Coffin	INV	U OF MN COLL OF NAT RES	250 NAT RES ADMIN BLDG	ST PAUL MN 55108	612-624-4986
21		Carmen	Converse	INF	MN DNR - NAT HERITAGE PGM	500 LAFAYETTE RD BOX 25	ST PAUL MN 55155	612-297-4963
22		Doug	Cornett	INV		PO BOX 122	MARQUETTE MI 49855	
23		Dr. Ed	Cushing	?	U OF M DEPT ECOL/EVOL/BEHAVIOR	1987 UPPER BUFORD CIRCLE	ST PAUL MN 55108	625-5700
24		Rolf	Dahle	INV	~	5995 MCKINLEY STREET NE	FRIDLEY MN 55432	612-571-????
25		Betsy	Daub	INV	NATL AUDUBON SOC 'MN STATE OFF	26 E EXCHANGE ST STE 207	ST PAUL MN 55101-2264	~
26		Mike	DeCapita	INV	USFWL FIELD OFFICE	1405 S HARRISON RM 302	E LANSING MI 48823	517-337-6652
27	~	June	Dobberpuhl	~	WI DNR - Bureau of Endangered	101 S WEBSTER ST BOX 7921	MADISON WI 53707-7921	608-267-5037
28	C	Bonita	Eliason	INV	MN DNR - NAT HERITAGE PGM	500 LAFAYETTE RD BOX 25	ST PAUL MN 55155	612-297-2276
29	W	Zella	Ellshoff	~	USFW ENDANGERED SPECIES	FED BLDG, 1 FEDERAL DRIVE	FORT SNELLING MN 55111-4056	612-725-3536
30		Audrey	Engels	INV	~	~	PALISADE MN 56469	218-845-????
31	~	Carol	Estes Mortensen	~	LEECH LAKE RESERVATION - DRM	Route 3 Box 100	CASS LAKE, MN 56633	218-335-7428
32	~	Steve	Eubanks	~	Chippewa National Forest	Route 3 Box 244	Cass Lake, MN 56633-8929	218-335-8600
33		Dale	Eurer	?	THE NATURE CONSERVANCY - MI	2840 E GRAND RIVER STE 5	E LANSING MI 48823	517-332-1741
34	~	Don	Farrar	~	IOWA STATE UNIVERSITY	343 BESSEY HALL - Botany	AMES, IA 50011	515-294-4846
35	~	Gary	Fewless	~	University of WI - Green Bay		Green Bay, WI 53706	414-465-2243
36			Forest Supervisor	INF	HIAWATHA NATIONAL FOREST	2727 N LINCOLN RD	ESCANABA MI 49829	906-789-3339
37	~		Forester	INV	WHITE EARTH INDIAN RESERVATION	~	DETROIT LAKES MN 55802	~
38		Lee	Frelich	?	U OF M DEPT OF FOREST RESOURCE	1530 N CLEVELAND AVENUE	ST PAUL MN 55108	624-3020
39	~	Jim	Gallagher	~	Blackduck Ranger District	HC 3 Box 95	Blackduck, MN 56630-9302	218-835-4291
40	~	Lyndes B.	Gerdes	~	Route 1 Box 88A US 41 Apt a	~	Houghton, MI 49931	~
41		Everett	Goodwin Jr.	INV	WHITE EARTH BIOLOGY DEPARTMENT	ROUTE 1 BOX 270	PONSFORD MN 56575	~
42		Phyllis	Green	INF	OTTAWA NATIONAL FOREST	E6248 US 2	IRONWOOD MI 49938	906-932-1330
43		Janet	Green	?	MN AUDUBON SOCIETY	1745 OLD NORTH SHORE DR	DULUTH MN 55804	~
44		Dave	Grigal	?	U OF MN SOIL SCIENCE DEPT	1991 UPPER BUFORD CIRCLE	ST PAUL MN 55108	~
45		Bill	Hartwig	INF	USFWS	US FEDERAL BUILDING	FORT SNELLING MN 55111	~
46		Dr. Chris	Haufler	~	UNIVERSITY OF KANSAS	~	LAWRENCE KS 66044	~
47		Warren	Haulk	inv	MISSOURI BOTANICAL GARDEN	PO BOX 299	ST LOUIS MO 63166-299	~
48		Don	Henson	INV		PO BOX 452	MANISTIQUE MI 49854	906-341-6309
49		Kim	Herman	?	MI DOT - BOTANIST	BOX 30050	LANSING MI 48909	517-373-2090
50		Phyllis	Higman	INV	MI NATURAL FEATURES INVENTORY	MADISON BLDG BOX 30028	LANSING MI 48909	517-373-1552
51	~	Ann	Hoefferle	~		904 River Street	Ontonagon, MI 49953	906-884-2547
52		Dick	Holthausen	INV	USFS SWFES FOREST SCIENCE COMP	2500 S PINE KNOLL	FLAGSTAFF AZ 86001-6381	520-556-2001
53		George	Host	?	U OF MN - DULUTH NRRI	5013 MILLER TRUNK HIGHWAY	DULUTH MN 55811	~
54	~	Mike	Houser	~	POTLATCH CORPORATION	PO BOX 504	CLOQUET MN 55720	218-879-0426
55	~	Robert	Jackson	INV	BUREAU OF INDIAN AFFAIRS	331 SECOND AVENUE SOUTH	MINNEAPOLIS MN 55401-2241	612-373-1146
56		Mark	Jaunzems	INV	~	417 E TAMARACK	IRONWOOD MI 49939	906-932-1408

Goblin fern mailing list

	Area	First Name	Last Name	I/R	1st Line Address	2nd Line Address	3rd Line Address	Telephone
57	~	Cindy	Johnson-Groh	~	GUSTAVS ADOLPHUS	800 W COLLEGE AVE	ST PETER, MN 56082	507-933-7043
58		Kathy	Karns	INV	USFWS	1015 CHALLENGER COURT	GREEN BAY WI 54331	414-465-7440
59		Peter	Kaufman	INV	MI BOTANICAL CLUB	U OF MI - NAT SCI BLDG	ANN ARBOR MI 48109	~
60		Brian	Kernohan	INV	BOISE CASCADE	400 THIRD AVE EAST	INT'L FALLS MN 56649-2446	218-285-5670
61	~	Chuck	Kjos	~	US FISH AND WILDLIFE SERVICE	4101 E. 80TH STREET	BLOOMINGTON, MN 55425-1665	612-725-3548
62		Jerry	Knott	INF	GREAT LAKES GAS TRANSMISSIONCO	ONE WOODWARD AVE STE 1600	DETROIT MI 48226	708-239-4765
63		Frank	Koenig	INF	CHEQ/NICOLET NATIONAL FOREST	1170 4TH AVE SOUTH	PARK FALLS WI 54552	715-762-5177
64		Pat	Komer	?	MI DNR - NAT HERITAGE PGM	MADISON BLDG BOX 30028	LANSING MI 48909	~
65	~	Mark	Kuesher	INV	BIA GREAT LAKES AGENCY	615 W MAIN STREET	ASHLAND WI 54806	~
66	~	Carol	Lanphaer-Cook	INV	UNIVERSITY OF WISCONSIN	~	STEVENS POINT WI 54481	715-346-3766
67	~	Carol	Leibl	~	James Madison High School	~	~	210-637-4400
68		Betty	Les	INV	WI DNR - NAT HERITAGE PGM	101 S WESTER ST BOX 7921	MADISON WI 53707	~
69		Howard	Lipke	INV	USFWS	ROUTE 3 TOWER ROAD	DETROIT LAKES MN 56501	~
70		RALPH	Lloyd	INV	RICE LAKE NATL. WILDLIFE RFGE	ROUTE 1 BOX 67	MC GREGOR, MN 55760	218-768-2402
71		Beth	Lynch	INV	GLIFWIC - BOTANIST	PO BOX 9	ODANAH WI 54861	715-682-6619
72		Bruce	Marcott	?	USFS NWFES - BIODIVERSITY UNIT	PO BOX 3890	PORTLAND OR 97208-3890	~
73		Janet	Marr	INV	MICHIGAN TECH	BIOLOGY DEPARTMENT	HOUGHTON MI 49931	906-487-2566
74		Becky	Marty	INV	ITASCA STATE PARK		LAKE ITASCA MN 56460	218-266-3415
75	~	Colleen	Matula	~	OTTAWA NATIONAL FOREST	500 NORTH MOORE	BESSEMER, MI 49911	906-667-0261
76		Dave	McGlaughlin	INV	U OF MN COLL OF BIO SCIENCES	1445 GORTNER AVENUE	ST PAUL MN 55108	612-675-5736
77		Jill	Medland	?	USPS - GR LAKES/GR PLAINS	1709 JACKSON ST	OMAHA NE 68102	402-221-3994
78		Eric	Menges	?	ARCHIBALD BIOL STATION	PO BOX 2057	LAKE PLACID FL 33952	~
79		Don	Meyer	INF	USDA FOREST SERVICE R9	310 WEST WISCONSIN AVE	MILWAUKEE WI 53203	414-297-3766
80	~	Chuck	Meyer	INV	RED LAKE RESERVATION	PO BOX 279	RED LAKE MN 56671	218-679-3959
81	~	Steve	Mighton	~	USDA FOREST SERVICE R9	310 WEST WISCONSIN AVE	MILWAUKEE WI 53203	414-297-3612
82		Mike	Mike	INF	ONTARIO NATURAL FEATURES	PO BOX 70000	PETERSBOROUGH ONTARIO K908M5	705-755-2160
83		T. J.	Miller	INF	ECOL SERVICES	US FEDERAL BUILDING	FORT SNELLING MN 55111	612-725-3534
84	~	Dr. Phil	Miller	~	CBSG	12101 Johnny Cake Ridge	Apple Valley, MN 55124	612-431-9325
85			MN FLT	INF	CHIPPEWA/SUPERIOR NF	~	~	
86		Don	Moe	INV	CRANDON MINE	7 NORTH BROWN STREET	RHINELANDER, WI 54501	715-365-1451
87		Todd	Morrisey	?	C Y THOMPSON LIBRARY	U OF NEBRASKA	LINCOLN NE 68583	402-472-8095
88	~	Steve	Mortensen	~	LEECH LAKE RESERVATION - DRM	Route 3 Box 100	CASS LAKE, MN 56633	218-335-7423
89	~	Karen	Myhre	~	~	Route 1 Box 581	Aitkin, MN 56431	218-927-3684
90			Native Plant Society	INV	U OF M 220 BIO SCI CENTER	1445 GARTNER AVE	ST PAUL MN 55128	~
91		Corbin	Newman	INF	USDA FOREST SERVICE R9	310 WEST WISCONSIN AVE	MILWAUKEE WI 53203	414-297-3181
92		Tim	O'Hara	INF	MN FOREST IND 1015 TORREY BLDG	314 WEST SUPERIOR STREET	DULUTH MN	218-722-5013
93		Eunice	Padley	INF	USDA FOREST SERVICE R9	310 WEST WISCONSIN AVE	MILWAUKEE WI 53203	414-297-1977
94	S W	Linda	Parker	INV	CHEQ/NICOLET NATIONAL FOREST	1170 4TH AVE S	PARK FALLS W. 54552	715-762-2461
95		Brian	Parsans	?	CTR FOR PLANT CONSERVATION	HOLDEN ARB 9500 SPERRY RD	KIRTLAND OH 44094	216-256-1655
96		James	Peck	INV	U OR ARKANSAS DEPT OF BIOLOGY	2801 S UNIVERSITY AVENUE	LITTLE ROCK AR 72204	501-569-3505
97	S	Mike	Penskar	INV	MI NATURAL FEATURES INVENTORY	MADISON BLDG BOX 3002	LANSING MI 48909	517-373-1552
98	~	Henry	Peters	~		Route 1 Box 193	Ewen, MI 49925	906-988-2352
99		Sherry	Phillips	INV	SUPERIOR NF LAURENTIAN RD	318 FORESTRY ROAD	AURORA MN 55705	218-229-3371
100		Fred	Pick	INF	CHIPPEWA NATIONAL FOREST	RT 3 BOX 244	CASS LAKE MN 56633	218-335-8649
101	~	Lawrence	Puchalski	~	cancelled	37468 Fill Ave	North Branch, MN 55056	612-674-8253
102		Ron	Refsnider	?	U S FISH AND WILDLIFE SERVICE	US FEDERAL BUILDING	FORT SNELLING MN 55111	612-725-3241
103		Dr. Tony	Reznic	INV	U OF M HERBARIUM	N UNIVERSITY BLDG	ANN ARBOR MI 48109	313-764-2431
104	~	Gerald	Rose	INV	MINNESOTR DNR, Div of Forestry	500 Lafayette Road	St. Paul, MN 55155	~
105		Jim	Sanders	INF	SUPERIOR NATIONAL FOREST	8901 GRAND AVE PLACE	DULUTH MN 55808	218-626-4300
106	~	Nancy	Sather	~	MN DNR - NAT HERITAGE PGM	500 LAFAYETTE RD BOX 25	ST PAUL MN 55155	612-297-4963
107		Jim	Schlender	INF	GLIFWIC	PO BOX 9	ODANAH WI 54681	715-682-6619
108	S	Jan	Schultz	INV	HIAWATHA NATIONAL FOREST	1030 WRIGHT STREET	MARQUETTE MI 49855	906-228-8491
109	~	Ulie	Seal	~	CONSERVATION BREEDING SPEC GRP	12101 JOHHNY CAKE RIDGE	APPLE VALLEY MN 55124	612-431-9325
110		Dave	Shadis	INV	CHIPPEWA NATIONAL FOREST	RT 3 BOX 244	CASS LAKE MN 56633	218-335-8663
111		Mary	Shedd	INV	SUPERIOR NF KAWISHIWI RD	118 SOUTH 4TH AVE EAST	ELY MN 55731	218-365-7616
112		Jim	Shevock	?	USDA FOREST SERVICE R5	630 SANSOME ST	SAN FRANCISCO CA 94111	415-705-2691

Goblin fern mailing list

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113		Jim	Smalls	INF	USDA FOREST SERVICE R9	310 WEST WISCONSIN AVE	MILWAUKEE WI 53203	414-297-1371
114	C S	Welby	Smith	INV	MN DNR - NAT HERITAGE PGM	500 LAFAYETTE RD BOX 25	ST PAUL MN 55155	612-297-3733
115			Solheim	?	U OF WI - DEPT OF FORESTRY	1630 LINDEN DRIVE	MADISON WI 53706	~
116		Ron	Stag	INV	~	~	~	~
117	~	Chuck	Stone	~	~	HC 53 Box 30	Cass Lake, MN 56633	~
118		Larry	Stritch	INF	USFS MEDEWIN TALL GRASS PRAIRI	PO BOX 88	WILMINGTON IL 60481	815-423-6370
119		Paul	Strong	INF	CHEQ/NICOLET NATIONAL FOREST	68 SOUTH STEVENS STREET	RHINELANDER WI 54501	715-362-3415
120		Bill	Tans	INV	WI DNR	BOX 7921	MADISON WI 53707	608-266-3524
121	~	Pete	Tennis	~	BLACKDUCK RANGER DISTRICT	HC 3 BOX 95	BLACKDUCK MN 56630-9302	218-835-4291
122	S	Joel	Trick	INV	USFWS C/O JANET SMITH	1015 CHALLENGER COURT	GREEN BAY WI 54331	414-465-7416
123	~	Susan	Trull	~	Ottawa National Forest	E6248 U.S. 2	Ironwood, MI 49938	906-932-1330
124		Lucy	Tyrrell	?	NCFES	1992 FOLWELL AVE	ST PAUL MN 55108-6148	612-649-5031
125		Drew	Ulberg	INV	KANE CO FOREST RESERVE DIST	~	KANE CO IL 62054	847-741-9832
126		Robin	Vora	INV	SUPERIOR NF LAURENTIAN RD	318 FORESTRY ROAD	AURORA MN 55705	218-229-3371
127		Dr. Ed	Voss	INV	U OF M HERBARIUM	N UNIVERSITY BLDG	ANN ARBOR MI 48109	313-764-2431
128	~	Dr. W. (Herb)	Wagner	~	U OF MI - DEPT OF BIOLOGY	~	ANN ARBOR MI 48109-1048	313-764-1484
129	~	Florence	Wagner	~	U OF MI - DEPT OF BIOLOGY	~	ANN ARBOR MI 48109-1048	313-764-1484
130		Dr. Donald	Waller	?	U OF WI DEPT OF BOTANY	430 LINCOLN DRIVE	MADISON WI 53706	~
131		Geoff	Walsh	?	BUREAU OF LAND MANAGEMENT	7450 BOSTON BLVD	SPRINGFIELD VA 22153	703-440-1672
132	~	Gary	Walton	~	UMD Herbarium, Dept of Biology	Duluth 10 University Dr.	Duluth, MN 55812-2496	218-726-6542
133	~	Dreux	Watermolen	~	WI DNR	PO 7921	Madison, WI 53707	~
134		Tom	Weise	INV	M DNR WILDLIFE DIVISION	MADISON BLDG PO BOX 30028	LANSING MI 48909	517-373-9338
135	~	Candy	Westfield	~	Cass Lake Ranger District	Route 3 Box 219	Cass Lake, MN 56633	218-335-8606
136	~	Dean	Whittier	INV	VANDERBILT UNIVERSITY	206 BURRTICK HALL	NASHVILLE TN 37235	615-322-2241
137	~	Al	Williamson	~	CHIPPEWA NATIONAL FOREST	Route 3 Box 244	CASS LAKE, MN 56633	218-335-8651
138	~	Robert J.	Wolff	~		921 RC Thompson Road	Chesnee, SC 29323	864-578-1073
139		Fred	Young	?	USPS PICTURED ROCKS	PO BOX 40	MUNISING MI 49862	906-387-2607
140		Peter F.	Zick	?	OREGON NATURAL HERITAGE PROGRM	1205 NW 25TH	PORTLAND OR 97201	~

POPULATION AND HABITAT VIABILITY ASSESSMENT FOR THE GOBLIN FERN
(*Botrychium mormo*)

Horseshoe Bay Resort
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APPENDIX IV.
IUCN POLICY GUIDELINES

IUCN - THE WORLD CONSERVATION UNION

Re-introduction Specialist Group
Species Survival Commission

GUIDELINES FOR RE-INTRODUCTIONS
(as approved by 41st Meeting of Council, May 1995)

INTRODUCTION

These policy guidelines have been drafted by the Re-introduction Specialist Group of the IUCN's Species Survival Commission[1], in response to the increasing occurrence of re-introduction projects worldwide, and consequently, to the growing need for specific policy guidelines to help ensure that the re-introductions achieve their intended conservation benefit, and do not cause adverse side-effects of greater impact. Although IUCN developed a Position Statement on the Translocation of Living Organisms in 1987, more detailed guidelines were felt to be essential in providing more comprehensive coverage of the various factors involved in re-introduction exercises.

These Guidelines are intended to act as a guide for procedures useful to re-introduction programmes and do not represent an inflexible code of conduct. Many of the points are more relevant to re-introductions using captive-bred individuals than to translocations of wild species. Others are especially relevant to globally endangered species with limited numbers of founders. Each re-introduction proposal should be rigorously reviewed on its individual merits. It should be noted that re-introduction is **always** a very lengthy, complex **and expensive** process.

Re-introductions or translocations of species for short-term, sporting or commercial purposes - where there is no intention to establish a viable population - are a different issue and beyond the scope of these guidelines. These include fishing and hunting activities.

This document **has been written to encompass the full range of plant and animal taxa and is therefore general**. It will be regularly revised. Handbooks for re-introducing individual groups of animals and plants will be developed in future.

CONTEXT

The increasing number of re-introductions and translocations led to the establishment of the IUCN Species Survival Commission's Re-introduction Specialist Group. A priority of the Group has been to update IUCN's 1987 Position Statement on the Translocation of Living Organisms, in consultation with IUCN's other Commissions.

It is important that the Guidelines are implemented in the context of IUCN's broader policies pertaining to biodiversity conservation and sustainable management of natural resources. The philosophy for environmental conservation and management of IUCN and other conservation bodies is stated in key documents such as "Caring for the Earth" and the "Global Biodiversity Strategy," which cover the broad themes of the need for approaches with community involvement and participation in sustainable natural resource conservation, an overall enhanced quality of human life and the need to conserve and, where necessary, restore ecosystems. With regard to the latter, the re-introduction of a species is one specific instance of restoration where, in general, only this species is missing. Full restoration of an array of plant and animal species has rarely been tried to date.

Restoration of single species of plants and animals is becoming more frequent around the world. Some succeed, many fail. As this form of ecological management is increasingly common, it is a priority for the Species Survival Commission's Re-introduction Specialist Group to develop guidelines so that re-intro-ductions are both justifiable and likely to succeed, and that the conservation world can learn from each initiative, whether successful or not. It is hoped that these Guidelines, based on extensive review of case-histories and wide consultation across a range of disciplines will introduce more rigour into the concepts, design, feasibility and implementation of re-introduction despite the wide diversity of species and conditions involved.

Thus, the priority has been to develop guidelines that are of direct, practical assistance to those planning, approving or carrying out re-introductions. The primary audience of these Guidelines is, therefore, the practitioners (usually managers or scientists), rather than decision-makers in governments. Guidelines directed towards the latter group would inevitably have to go into greater depth on legal and policy issues.

1. DEFINITION OF TERMS

a) "**Re-introduction**": an attempt to establish a species[2] in an area which was once part of its historical range, but from which it has been **extirpated** or become extinct[3]. ("Re-establishment" is a synonym, but implies that the re-introduction has been successful).

b) "**Translocation**": deliberate and mediated movement of wild individuals to an existing population of conspecifics.

c) "**Re-enforcement/Supplementation**": addition of individuals to an existing population of conspecifics.

d) "**Conservation/Benign Introductions**": an attempt to establish a species, for the purpose of conservation, outside its recorded distribution but within an appropriate habitat and eco-geographical area. **This is a feasible conservation tool only when there is no remaining area left within a species' historic range.**

2. AIMS AND OBJECTIVES OF RE-INTRODUCTION

a) **Aims:** The principal aim of any re-introduction should be to establish a viable, free-ranging population in the wild, of a species, subspecies or race, which has become globally or locally extinct, or extirpated, in the wild. It should be re-introduced within the species' former natural habitat and range and should require minimal long-term management.

b) **Objectives**: The objectives of a re-introduction may include: to enhance the long-term survival of a species; to re-establish a keystone species (in the ecological or cultural sense) in an ecosystem; to maintain and/or restore natural biodiversity; to provide long-term economic benefits to the local and/or national economy; to promote conservation awareness, or a combination of these.

3. MULTIDISCIPLINARY APPROACH

A re-introduction requires a multidisciplinary approach involving a team of persons drawn from a variety of backgrounds. As well as government personnel, they may include persons from governmental natural resource management agencies, non-governmental organizations, funding bodies, universities, veterinary institutions, zoos (and private animal breeders) and/or botanic gardens, with a full range of suitable expertise. Team leaders should be responsible for coordination between the various bodies and provision should be made for publicity and public education about the project.

4. PRE-PROJECT ACTIVITIES

4a. BIOLOGICAL

(i) Feasibility study and background research

☐ An assessment should be made of the taxonomic status of individuals to be re-introduced. They should preferably be of the same subspecies or race as those which were extirpated, unless adequate numbers are not available. An investigation of historical information about the loss and fate of individuals from the re-introduction area, as well as molecular genetic studies, should be undertaken in case of doubt as to individuals' taxonomic status. A study of genetic variation within and between populations of this and related taxa can also be helpful. Special care is needed when the population has long been extinct.

☐ Detailed studies should be made of the status and biology of wild populations (if they exist) to determine the species' critical needs. For animals, this would include descriptions of habitat preferences, intraspecific variation and adaptations to local ecological conditions, social behaviour, group composition, home range size, shelter and food requirements, foraging and feeding behaviour, predators and diseases. For migratory species, studies should include the potential migratory areas. For plants, it would include biotic and abiotic habitat requirements, dispersal mechanisms, reproductive biology, symbiotic relationships (e.g. with mycorrhizae, pollinators), insect pests and diseases. Overall, a firm knowledge of the natural history of the species in question is crucial to the entire re-introduction scheme.

☐ The species, if any, that has filled the void created by the loss of the species concerned, should be determined; an understanding of the effect the re-introduced species will have on the ecosystem is important for ascertaining the success of the re-introduced population.

☐ The build-up of the released population should be modelled under various sets of conditions, in order to specify the optimal number and composition of individuals to be released per year and the numbers of years necessary to promote establishment of a viable population.

☐ A Population and Habitat Viability Analysis will aid in identifying significant environmental and population variables and assessing their potential interactions, which would guide long-term population management.

(ii) Previous Re-introductions

☐ Thorough research into previous re-introductions of the same or similar species and wide-ranging contacts with persons having relevant expertise should be conducted prior to and while developing the re-introduction protocol.

(iii) Choice of release site and type

☐ The site should be within the historic range of the species. For an initial re-enforcement there should be few remnant wild individuals. For a re-introduction, there should be no remnant population to prevent disease spread, social disruption and introduction of alien genes. In some circumstances, a re-introduction or re-enforcement may have to be made into an area which is fenced or otherwise delimited, but it should be within the species' former natural habitat and range.

☐ A conservation/benign introduction should be undertaken only as a last resort when no opportunities for re-introduction into the original site or range exist and only when a significant contribution to the conservation of the species will result.

☐ The re-introduction area should have assured, long-term protection (whether formal or otherwise).

(iv) **Evaluation of re-introduction site**

- ☐ Availability of suitable habitat: re-introductions should only take place where the habitat and landscape requirements of the species are satisfied, and likely to be sustained for the foreseeable future. The possibility of natural habitat change since extirpation must be considered. Likewise, a change in the legal/political or cultural environment since the species' extirpation needs to be ascertained and evaluated as a possible constraint. The area should have sufficient carrying capacity to sustain growth of the re-introduced population and support a viable (self-sustaining) population in the long run.

- ☐ Identification and elimination, or reduction to a sufficient level, of previous causes of decline: could include disease; over-hunting; over-collection; pollution; poisoning; competition with or predation by introduced species; habitat loss; adverse effects of earlier research or management programmes; competition with domestic livestock, which may be seasonal.

- ☐ Where the release site has undergone substantial degradation caused by human activity, a habitat restoration programme should be initiated before the re-introduction is carried out.

(v) **Availability of suitable release stock**

- ☐ It is desirable that source animals come from wild populations. If there is a choice of wild populations to supply founder stock for translocation, the source population should ideally be closely related genetically to the original native stock and show similar ecological characteristics (morphology, physiology, behaviour, habitat preference) to the original sub-population.

- ☐ Removal of individuals for re-introduction must not endanger the captive stock population or the wild source population. Stock must be guaranteed available on a regular and predictable basis, meeting specifications of the project protocol.

- ☐ Individuals should only be removed from a wild population after the effects of translocation on the donor population have been assessed, and after it is guaranteed that these effects will not be negative.

- ☐ If captive or artificially propagated stock is to be used, it must be from a population which has been soundly managed both demographically and genetically, according to the principles of contemporary conservation biology.

- ☐ Re-introductions should not be carried out merely because captive stocks exist, nor solely as a means of disposing of surplus stock.

- ☐ Prospective release stock, including stock that is a gift between governments, must be subjected to a thorough veterinary screening process *before* shipment from original source. Any animals found to be infected or which test positive for non-endemic or contagious pathogens with a potential impact on population levels, must be removed from the consignment, and the uninfected, negative remainder must be placed in strict quarantine for a suitable period before retest. If clear after retesting, the animals may be placed for shipment.

- ☐ Since infection with serious disease can be acquired *during* shipment, especially if this is intercontinental, great care must be taken to minimise this risk.

- ☐ Stock must meet all health regulations prescribed by the veterinary authorities of the recipient country and adequate provisions must be made for quarantine if necessary.

vi) **Release of captive stock**

- ☐ Most species of mammals and birds rely heavily on individual experience and learning as juveniles for their survival; they should be given the opportunity to acquire the necessary information to enable survival in the wild through training in their captive environment; a captive bred individual's probability of survival should approximate that of a wild counterpart.

- ☐ Care should be taken to ensure that potentially dangerous captive-bred animals (such as large carnivores or primates) are not so confident in the presence of humans that they might be a danger to local inhabitants and/or their livestock.

4b. SOCIO-ECONOMIC AND LEGAL REQUIREMENTS

- ☐ Re-introductions are generally long-term projects that require the commitment of long-term financial and political support.

- ☐ Socio-economic studies should be made to assess impacts, costs and benefits of the re-introduction programme to local human populations.

- ☐ A thorough assessment of attitudes of local people to the proposed project is necessary to ensure long-term protection of the re-introduced population, especially if the cause of species' decline was due to human factors (e.g. over-hunting, over-collection, loss or alteration of habitat). The programme should be fully understood, accepted and supported by local communities.

- ☐ Where the security of the re-introduced population is at risk from human activities, measures should be taken to minimise these in the re-introduction area. If these measures are inadequate, the re-introduction should be abandoned or alternative release areas sought.

- ☐ The policy of the country to re-introductions and to the species concerned should be assessed. This might include checking existing provincial, national and international legislation and regulations, and provision of new measures and required permits as necessary.

- ☐ Re-introduction must take place with the full permission and involvement of all relevant government agencies of the recipient or host country. This is particularly important in re-introductions in border areas, or involving more than one state or when a re-introduced population can expand into other states, provinces or territories.

- ☐ If the species poses potential risk to life or property, these risks should be minimised and adequate provision made for compensation where necessary; where all other solutions fail, removal or destruction of the released individual should be considered. In the case of migratory/mobile species, provisions should be made for crossing of international/state boundaries.

5. PLANNING, PREPARATION AND RELEASE STAGES

- ☐ Approval of relevant government agencies and land owners, and coordination with national and international conservation organizations.

- ☐ Construction of a multidisciplinary team with access to expert technical advice for all phases of the programme.

- ☐ Identification of short- and long-term success indicators and prediction of programme duration, in the context of agreed aims and objectives.

- ☐ Securing adequate funding for all programme phases.

- ☐ Design of pre- and post-release monitoring programme so that each re-introduction is a carefully designed experiment, with the capability to test methodology with scientifically collected data. Monitoring the health of individuals, as well as the survival, is important; intervention may be necessary if the situation proves unforeseeably favourable.

- ☐ Appropriate health and genetic screening of release stock, including stock that is a gift between governments. Health screening of closely related species in the re-introduction area.

- ☐ If release stock is wild-caught, care must be taken to ensure that: a) the stock is free from infectious or contagious pathogens and parasites *before* shipment and b) the stock will not be exposed to vectors of disease agents which may be present at the release site (and absent at the source site) and to which it may have no acquired immunity.

- ☐ If vaccination prior to release, against local endemic or epidemic diseases of wild stock or domestic livestock at the release site, is deemed appropriate, this must be carried out during the "Preparation Stage" so as to allow sufficient time for the development of the required immunity.

- ☐ Appropriate veterinary or horticultural measures as required to ensure health of released stock throughout the programme. This is to include adequate quarantine arrangements, especially where founder stock travels far or crosses international boundaries to the release site.

- ☐ Development of transport plans for delivery of stock to the country and site of re-introduction, with special emphasis on ways to minimise stress on the individuals during transport.

- ☐ Determination of release strategy (acclimatization of release stock to release area; behavioural training - including hunting and feeding; group composition, number, release patterns and techniques; timing).

- ☐ Establishment of policies on interventions (see below).

- ☐ Development of conservation education for long-term support; professional training of individuals involved in the long-term programme; public relations through the mass media and in local community; involvement where possible of local people in the programme.

- ☐ The welfare of animals for release is of paramount concern through all these stages.

6. POST-RELEASE ACTIVITIES

- ☐ Post-release monitoring is required of all (or a sample of) individuals. This most vital aspect may be by direct (e.g. tagging, telemetry) or indirect (e.g. spoor, informants) methods as suitable.

- ☐ Demographic, ecological and behavioural studies of released stock must be undertaken.

- ☐ Study of processes of long-term adaptation by individuals and the population.

- ☐ Collection and investigation of mortalities.

- ☐ Interventions (e.g. supplemental feeding; veterinary aid; horticultural aid) when necessary.

- ☐ Decisions for revision, rescheduling, or discontinuation of programme where necessary.

- ☐ Habitat protection or restoration to continue where necessary.
- ☐ Continuing public relations activities, including education and mass media coverage.
- ☐ Evaluation of cost-effectiveness and success of re-introduction techniques.
- ☐ Regular publication in scientific and popular literature.

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(1) Guidelines for determining procedures for disposal of species confiscated in trade are being developed separately by IUCN.

(2) The taxonomic unit referred to throughout the document is species; it may be a lower taxonomic unit (e.g. sub-species or race) as long as it can be unambiguously defined.

(3) A taxon is Extinct when there is no reasonable doubt that the last individual has died.

IUCN Policy Statement on Sustainable Use of Wild Living Resources
(2nd Draft -- 2 October, 1997)

1. The use of biological diversity is fundamental to the economy, culture and well being of all nations and people. People should seek to minimize losses of biological diversity when making decisions to use certain wild living resources. Use, if sustainable, can serve human needs on an ongoing basis while contributing to the conservation of biological diversity.

2. At its Session of the General Assembly (Perth, 1990) in Resolution 18.24, IUCN C The World Conservation Union recognized that the ethical, wise and sustainable use of some wildlife can provide an alternative or supplementary means of productive land-use, and can be consistent with and encourage conservation, where such use is in accordance with appropriate safeguards.

3. This position was re-affirmed in Resolution 19.54 at the following Session of the Union's General Assembly in 1994 and subsequently in Resolution 1.39 at the 1st meeting of the World Conservation Congress in 1996.

4. Analyses of uses of wild living resources in a number of different contexts demonstrate that there are many biological, social and economic factors, which combine in a variety of configurations to affect the likelihood that a use may be sustainable.

4. On the basis of these analyses, IUCN concludes that:
   a. The pursuit of sustainability is a process of continuous improvement in the management of wild living resources; and
   b. Adaptive management, which incorporates monitoring and the ability to modify management to take account of risk and uncertainty, will increase the likelihood that any use of a wild living resource will be sustainable.

6. Furthermore, consideration of the following is essential to achieve sustainability:
   a. The supply of biological products and services available for use is limited by the productivity and population fluctuations of species and the stability and resilience of ecosystems.
   b. Institutional structures of management and control require both positive incentives and negative sanctions, good governance and implementation at an appropriate scale. Such structures should include participation of relevant stake-holders and take account of land tenure, access rights, regulatory systems, traditional knowledge and customary law.
   c. Wild living resources have many values which can provide incentives for conservation. Where an economic value can be attached to a wild living resource, perverse incentives removed and costs and benefits internalized, favourable conditions can be created for investment in the conservation and the sustainable use of the resource, thus reducing the risk of resource degradation, depletion and habitat conversion.
   d. Levels and fluctuations of demand for wild living resources are affected by a complex array of social and economic factors, and are likely to increase in coming years. Thus attention to both demand and supply is necessary to ensure sustainability of uses.

7. IUCN is committed to enhancing the sustainability of uses of wild living resources and to this end it has established the Sustainable Use Initiative which incorporates regionally-structured Specialist Groups of the Species Survival Commission to:

a. to identify, evaluate and promote the principles of management that contribute to sustainability and enhanced efficiency in the use of wild living resources; and

b. to regularly communicate its findings to members and the broader community.