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Invasive earthworm damage predicts occupancy of a threatened forest fern: Implications for conservation and management

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ABSTRACT

Adequate detection and monitoring of threatened, endangered, and sensitive species presents a challenge to forest managers seeking to balance management activities with conservation and forest health. This is especially true for rare, cryptic plant species that are difficult to detect, like goblin fern (*Botrychium mormo*), which is small and does not emerge from the duff layer of the rich hardwood forests it inhabits every year, even when present. Imperfect detection of this species makes it difficult to monitor, because lack of plants detected at a specific site does not necessarily indicate that the species has been extirpated there. In this study, 80 historic locations of *B. mormo* were surveyed for occurrence over three consecutive years to assess probability of occupancy and environmental factors expected to impact occupancy, including earthworm damage and canopy closure, while accounting for detectability. We found that probability of occurrence is most strongly related to earthworm damage and were able to identify levels of earthworm damage at which the species is more likely to remain present or be extirpated. These results suggest that use of a simple metric for quantifying ecological impact of earthworm damage can be used during monitoring to assess the likelihood that *B. mormo* is still present. With this information, forest managers can prioritize sites for habitat preservation and better shape policy and management decisions to protect and enhance habitat for this species. In addition, our study demonstrates the utility of occupancy modeling for management and conservation of rare and elusive plant species.

1. Introduction

Consideration of management impacts to threatened, endangered, and sensitive (TES) species is critical to forest management, especially for agencies that are under regulatory obligation to protect them (USDA). Developing appropriate policies and management strategies related to TES and other vulnerable species depends on precise knowledge of population locations, population viability, and factors contributing to any population declines. Inventory and monitoring programs are often designed to answer questions related to where populations are and how they are trending, but typically cannot identify causal agents of those trends (Elzinga et al., 1998). Further, traditional inventory and monitoring approaches may not be sufficient to adequately address any of these issues for elusive species that are difficult to detect.

Increasingly, imperfect detectability is recognized as an important factor to account for in research and monitoring (Kéry and Schmid, 2004). The assumption that a species is not present or has been extirpated at a site where it isn't detected often does not hold, since populations or individuals can be missed during surveys (Kéry, 2004). Detectability estimates are now routinely incorporated into analysis of occupancy and abundance data for animals (MacKenzie et al., 2017). Although this approach has been used less frequently in plants and other sessile organisms (but see: Alexander et al., 2009; Berberich et al., 2016; Emry et al., 2011), detectability in plant surveys is typically less than one, and therefore important to account for (Chen et al., 2013). Without perfect detection, "false zeros" recorded when a species is present but not detected in a monitoring dataset can lead to biased under-estimates of occupancy (and over-estimates of extirpation) and misleading or incorrect results regarding the factors influencing these occupancy states (Chen et al., 2013; MacKenzie et al., 2017). Thus, using inferences from analyses based on inventory and monitoring programs that don't incorporate detectability to inform policy and management decisions may be highly problematic (Guillera-Arroita et al., 2014). Utilizing occupancy models that incorporate presence/absence data, while accounting for imperfect detectability and factors contributing to heterogeneity in detectability and occupancy, can be a valuable tool for overcoming these common obstacles in analysis of rare plant monitoring data.

Botrychium mormo (goblin fern), is an example of a rare species of

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conservation concern that is of particular importance to forest management in the Great Lakes states, but is difficult to monitor due to its small size and the fact that it does not emerge from the duff every year. It is endemic to the rich northern hardwoods of the western Great Lakes region including Minnesota, Wisconsin, and Michigan in the USA, and has one recorded occurrence in Quebec, Canada (USDA NRCS, 2018; Wagner Jr. and Wagner, 1993). The majority of known extant populations are concentrated in north-central Minnesota within the Chippewa National Forest, which overlaps 90% of the Leech Lake Reservation (Johnson-Groh and Lee, 2002; Mortensen and Mortensen, 1998). In the Chippewa National Forest, the rich northern hardwood forests this species depends on account for approximately less than 1% of forested land. Surveyors have searched this habitat extensively over the past twenty years for *B. mormo*, and over 600 element occurrences have been documented in the Chippewa National Forest. The species has state conservation ranks assigned to it throughout its entire range designating it as vulnerable to extirpation in Minnesota, imperiled in Michigan, and critically imperiled in Wisconsin and Quebec (NatureServe, 2017). It has not been reviewed for the Endangered Species Act in the United States, but is listed as endangered in Wisconsin (WI DNR, 2017) and threatened in Minnesota and Michigan (Michigan Natural Features Inventory, 2017; MN DNR, 2013).

The life history of *B. mormo* makes it particularly difficult to detect and verify occupancy. It is a small perennial fern that is known to lie dormant or fail to emerge from the duff in some years, likely due to unsuitable conditions such as drought (Wagner and Wagner, 1981), even when there is a thriving population of immature and mature plants below-ground (Johnson-Groh, 1998). Because of this, abundance of above-ground plants can vary significantly from year to year, which does not necessarily correlate with total abundance of above- and below-ground plants, and individuals or all plants from a population may fail to emerge in a given year (Johnson-Groh and Lee, 2002; Johnson-Groh et al., 2002). Thus, monitoring above-ground plant number, especially for only one year, would yield poor estimates of abundance and underestimates of occupancy. Incorporating detectability estimates derived from surveys over multiple years into occupancy models is one way to obtain unbiased estimates of probability of occurrence within sites, and can also be used to assess the effect of factors that may influence probability of occurrence (MacKenzie et al., 2017).

One factor known to negatively impact *B. mormo* is the invasion of non-native earthworms in the northern hardwood forests that harbor this species. *Botrychium mormo* requires a thick duff layer and organic soil horizon over mineral soil that is well to moderately well-drained and has loamy to silty texture (Casson et al., 2001). Personal field observation (Henderson) and Natural Resource Conservation Service (NRCS) soils mapping further indicate goblin fern hot spots typically have well-drained fine sandy loam to fine loamy sand soil textures, and are nearly level to undulating with 1–8 percent slopes (Soil Survey Staff). Within the humus layer, this species is dependent on associations with mycorrhizal fungi to obtain nutrients and water, as are other *Botrychium* species (Berch and Kendrick, 1982; Whittier, 1984; Winther and Friedman, 2007). Earthworms, especially *Lumbricus* spp., rapidly reduce organic soil layers to the detriment of *B. mormo* and other plants dependent upon intact soil O horizons in northern hardwood systems (Gundale, 2002; Hale et al., 2005a, 2006, 2008; Mortensen and Mortensen, 1998). While we know that earthworms have a significant adverse effect on this species, the level of worm damage necessary to make habitat unsuitable for *B. mormo* has not yet been quantified. This information would be highly valuable for managers to help determine when the species is likely extirpated from sites, as not finding plants on a given monitoring visit does not necessarily mean the species is absent.

In addition to soil characteristics, another factor that may influence *B. mormo* occupancy is canopy closure. This species has only been observed in forests with a relatively closed canopy (Casson et al., 2001). Shade is hypothesized to be important to *B. mormo* spores, which only germinate in the dark (Whittier, 1973), and to maintain cool, moist conditions in the duff layer (Casson et al., 2001). *Botrychium mormo* is known to be sensitive to drought conditions, and can fail to emerge during drought years (Wagner and Wagner, 1981). An open canopy can create or exacerbate dry conditions on the forest floor, impacting species dependent on moisture in the duff layer (Harpole and Haas, 1999; Semlitsch et al., 2009). Factors such as earthworm invasion and canopy closure may contribute to heterogeneity in occupancy probability, and thus are important to include in occupancy models for this species.

During this three-year study, data on *B. mormo* occupancy and covariates, including earthworm invasion stage and canopy closure, were collected from historic *B. mormo* sites to answer the following three questions: (1) How do various levels of earthworm damage influence probability of occupancy? We expect that as earthworm damage increases, occupancy probability will decrease. (2) Does canopy closure influence probability of occupancy, and if so, how? We expect that decreased canopy closure may have a negative relationship with occupancy probability. (3) Do earthworm damage and canopy closure interact? We expect that the negative effects of earthworm damage may be buffered by increased canopy closure or may be exacerbated by decreased canopy closure. Results are discussed in the context of using occupancy modeling, including detectability, in monitoring efforts to inform conservation and forest management.

2. Methods

2.1. Data collection

To assess factors that may influence occurrence of *B. mormo*, locations where the species was historically documented were monitored in 80 randomly selected sites within the Leech Lake Reservation and Chippewa National Forest. For this experiment, a “site” is defined as the area where a population of a species has been documented. Site selection was stratified by choosing 20 random sites within four time periods of original date of detection (1994–1997, 1998–2002, 2003–2007, 2008–2011; Fig. 1). Because historical sites were used, our results apply to the population of sites where this species has been documented rather than the population as a whole. Sites were divided between two observers experienced in *Botrychium* surveys, who visited the same sites once per year over three years to increase likelihood of detection if the species was indeed occupying the site. Sites were relocated from original records based on GPS coordinates or coordinates inferred from field notes that identified sites based on unique features and bearings and distances from specific features (for records that originated before GPS was widely used). During initial relocation visits, a hybrid spiral/random meaner method was used for sites with coordinates. If historic occurrence sites had inferred coordinates, or had GPS coordinates but were not initially located through this method, a parallel transect method was used to more thoroughly search sites. Initial relocation efforts ranged from 1 to 6 h per site, with an average of 4 h per site (shorter times are associated with sites where the species was easily found near given coordinates). Surveys occurred between July and August, the time period during which above-ground abundance and individual plant size peak (Johnson-Groh and Lee, 2002).

During surveys, the following variables were recorded: presence/absence of above-ground *B. mormo*, abundance of *B. mormo* plants if detected, Invasive Earthworm Rapid Assessment Tool (IERAT) stage (Loss et al., 2013), and canopy closure (foliar volume measured with a densiometer). The IERAT stage was determined using a protocol developed by the Natural Resources Research Institute Great Lakes Worm Watch program, which takes into account several facets of worm damage to forest understories, including loss of duff layer and organic soil horizons, plant community diversity, and direct evidence of earthworms including castings, middens, and earthworms themselves, to rank ecological impact of worm invasion on a site (1–5, with 5 indicating the greatest impact; Loss et al., 2013). Canopy closure was