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Insect conservation in Michigan prairie fen: addressing the challenge of global change

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Abstract Prairie fen is a globally rare, groundwater dependent peatland community restricted to discrete portions of the glaciated north central USA. Prairie fen harbours a diverse flora composed of sedge wetland and tallgrass prairie species, which in turn support a diversity of rare insects. In Michigan, USA over 20% of the state's insects of conservation concern are associated with prairie fen, including the globally imperilled Mitchell's satyr butterfly, *Neonympha mitchellii mitchellii* (Lepidoptera: Nymphalidae). Here we investigate how global change drivers, including land use change, climate change, and invasive species, may interact to threaten this important community. Specifically, we examine how characteristics of prairie fen habitats—e.g., formation and distribution—interact with the biology of rare fen insects to suggest appropriate short to long term conservation strategies. Our results suggest that prairie fen associated insects are rare for a variety of reasons, including host plant specialization, habitat specialization, and shifting landscape context that limits opportunities for dispersal. We recommend that current conservation efforts focus on stabilization and restoration of existing prairie fens, coupled with directed surveys to monitor population change in insects of concern, and restoration of the landscape matrix to facilitate metapopulation dynamics. In the future, due to the severely fragmented nature of Michigan landscapes, captive rearing and assisted migration may be necessary to conserve some prairie fen insect species. Overall, the effective conservation of fen associated insects will require a shared vision by multiple actors and a willingness to purse that vision over a long time frame.

Keywords Insect conservation · Prairie fen · Global change · Conservation biology

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Introduction

The study and conservation of rare insects has become an important part of conservation biology. In addition to their inherent value and the fascination they hold for many observers, insects also provide critical ecosystem services such as pollination and pest suppression on which human societies rely (Losey and Vaughan 2006). Global changes, including land use change, climate change, and the impacts of invasive species, are fundamentally altering terrestrial ecosystems (Dunne et al. 2002; Tylianakis et al. 2008) in ways that pose a significant threat to rare insects and the habitats they occupy. These changes are exacerbated by the fact that biodiversity is frequently concentrated in localized areas (Brooks et al. 2006). For example, in Michigan, USA, prairie fen harbours unusually high plant and animal biodiversity (Amon et al. 2002). Fens are relatively uncommon in the USA and subject to a variety of human-induced threats (Bedford and Godwin 2003). Here we analyze the nature of the rare insect fauna of prairie fens in order to guide both short and long term conservation of this community in the face of global change.

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Prairie fens represent the historic confluence of two distinct ecosystems: sedge wetlands and tallgrass prairies. As the Laurentide ice sheet receded, sedge wetlands radiated north and west from the southeastern US, while tallgrass prairie radiated north and east from the Central US (Brown 2003; Shapiro 1970). Where these two ecosystems converged, their flora and fauna mingled and were maintained by the unique hydrology present in the formerly glaciated terrain (Pielou 1991), as such, the insect fauna of prairie fens contains specialist representatives of each parental ecosystem. Due to subsequent landscape change, prairie fens have became islands of concentrated biodiversity holding nearly 20% of the insects of conservation concern in Michigan (Kost and Hyde 2009).

Characteristics of prairie fen

Prairie fen is a disturbance-dependent habitat, historically maintained by a combination of hydrologic saturation, periodic fire, beaver flooding, and grazing (Spieles et al. 1999). Prairie fens are characterized by near constant calcareous groundwater inflow (pH 6.8–8.2) maintaining a cool and saturated root zone (Bowles et al. 2005; Moran 1981; Spieles et al. 1999). The vegetation of prairie fen is dominated by sedges and grasses but also contains high forb diversity (Curtis 1971). It is distinct from other calcareous fens in having a substantial component of its flora in common with tallgrass prairie and sedge meadow habitats (Moran 1981). Prairie fen frequently contains 3–4 distinct vegetative zones along a wetness gradient, each with its own plant community, adding to the biodiversity in these habitats (Spieles et al. 1999).

While fens of many types are relatively common in the northern hemisphere, prairie fen is almost exclusively confined to glaciated portions of the north central USA where limestone bedrock or calcareous glacial till lies close to the surface (Amon et al. 2002; Godwin et al. 2002; Spieles et al. 1999; Wilcox et al. 1986). In Michigan, prairie fens are concentrated in the Kalamazoo-Battle Creek and Jackson interlobates (Fig. 1a). The interlobates occur where the lobes of the Michigan, Saginaw and Huron-Erie glaciers met along their lateral edges (Schaetzl et al. 2009). Because the glaciers that covered Michigan passed over limestone and dolomitic bedrock, they deposited glacial till rich in calcium and magnesium carbonates. Rainfall moving through the glacial till concentrates these minerals, resulting in the relatively high pH groundwater. Where this groundwater reaches the surface, it creates a constantly wet and cool environment with low plant decomposition rates. These conditions favour the build-up of organic matter and formation of peat (Wilcox et al. 1986). The close spatial proximity to coarse textured upland soils means that fens were often associated with oak savanna, barrens or prairie communities (Curtis 1971).

Threats to prairie fen

The main threats to fens globally include: habitat conversion and fragmentation (van Diggelen et al. 2006), changes in hydrology (Amon et al. 2002), alteration of disturbance regimes (Middleton et al. 2006), invasive species (Bowles and Jones 2006), and changes in nutrient inputs (Panno et al. 1999). In many cases these factors interact to influence prairie fen insect communities. Moreover, all of these existing threats occur within the context of a changing climate. Predictions for Michigan suggest an increase in annual temperatures of 3.5–4°C by the end of the

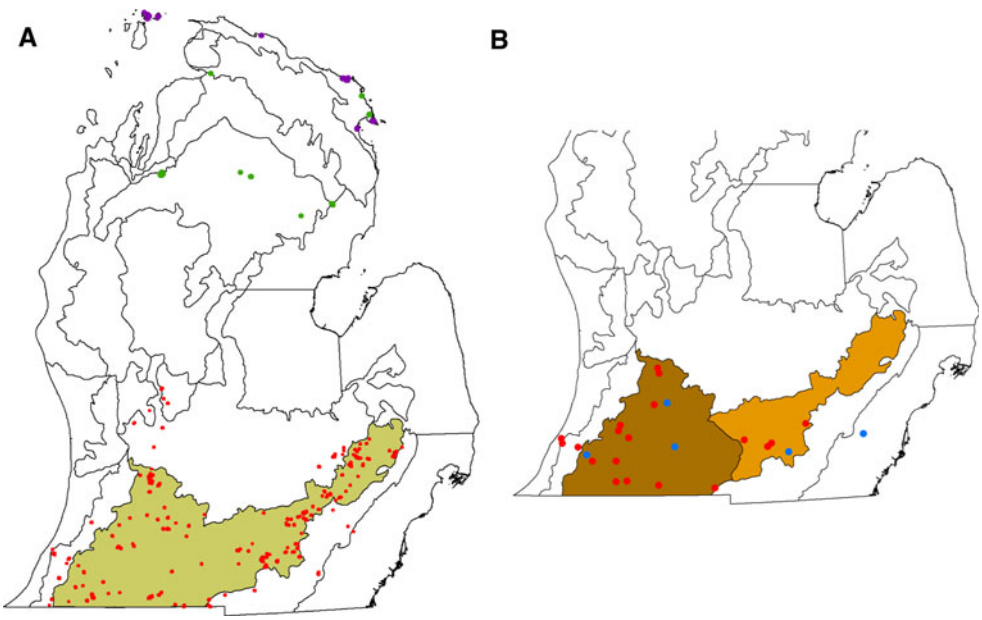

Fig. 1 Map of Michigan, USA showing locations of fens overlaid on ecoregions *sensu* Albert (1995). **a** mapped prairie fens (in *red*), northern fens (in *green*) and coastal fens (in *purple*) shown with the combined interlobate regions highlighted. **b** Current (*red*) and historic (*blue*) distribution of Mitchell's satyr with the Kalamazoo interlobate (*left*) and the Jackson interlobate (*right*) highlighted

twentyfirst century, with greater increases in the winter (4–5°C) than summer months (3.5–4°C) (Solomon et al. 2007). Over the same time frame, precipitation is projected to increase 5–10% with greater increases in the winter (10–15%) than summer months (0–5%) (Solomon et al. 2007). Overall, increased temperatures will lead to higher evapotranspiration and reduced groundwater recharge, resulting in a drying of headwater streams such as those arising from fens. They further predict increases in spring runoff and summer storm events that carry excess nutrients into wetland systems (Kling et al. 2003, Pileus Project 2007). Such detrimental impacts on prairie fen hydrology and water quality suggest additional negative pressures on rare fen insects.

Insects in prairie fen

Panzer et al. (1995) documented 256 remnant-dependent insects associated with savanna-prairie ecosystems in the Chicago region. While studies specifically examining prairie fen arthropod communities are relatively rare, they include studies of ants (Kannowski 1956, Lesica and Kannowski 1998), leafhoppers (Cwikla 1987), cursorial spiders (Bultman 1992), midges (Lammers-Campbell 1998), Lepidoptera, and Homoptera (Summerville and Clampitt 1999). The Michigan Natural Features Inventory (MNFI) currently lists 26 insect species of conservation concern that use prairie fen and associated aquatic habitats (Table 1).

Table 1 Insects of conservation concern in prairie fen and associated aquatic communities in Michigan, USA

Order	Family	Scientific name	Common name	Rank		
Odonata						
	Cordulegastridae	*Cordulegaster erronea* Hagen	Tiger spiketail	SC	S1S2	G4
	Corduliidae	*Williamsonia fletcheri* Williamson	Ebony boghaunter	SC	S1S2	G3G4
Homoptera						
	Cercopidae	*Lepyronia angulifera* Uhler	Angular spittlebug	SC	S1S2	G3
	Cercopidae	*Prosapia ignipectus* (Fitch)	Red-legged spittlebug	SC	S2S3	G4
	Cicadellidae	*Dorydiella kansana* Beamer	Kansan leafhopper	SC	S1S2	GNR
	Cicadellidae	*Flexamia huroni* Bess & Hamilton	Huron river leafhopper	SC	S1	GNR
	Cicadellidae	*Flexamia reflexus* Osborn & Ball	Leafhopper	SC	S1	GNR
Orthoptera						
	Acrididae	*Paroxya hoosieri* (Blatchley)	Hoosier locust	SC	S2S3	G5
	Gryllidae	*Oecanthus laricis* Walker	Tamarack tree cricket	SC	S1S2	G1G2
	Tettigoniidae	*Neoconocephalus lyristes* (Rehn & Hebard)	Bog conehead	SC	S1S3	GNR
	Tettigoniidae	*Orcheliumum concinnum* Scudder	Red-faced meadow katydid	SC	S2S3	GNR
Coleoptera						
	Dytiscidae	*Liodessus cantralli* (Young)	Cantrall's bog beetle	SC	S1S3	GNR
	Elmidae	*Stenelmis douglasensis* Sanderson	Douglas Stenelmis riffle beetle	SC	S1S2	G1G3
Lepidoptera						
	Hesperiidae	*Euphyes dukesi* (Lindsey)	Duke's skipper	T	S1	G3
	Hesperiidae	*Oarisma poweshiek* (Parker)	Poweshiek skipperling	T	S1S2	G2G3
	Noctuidae	*Meropleon ambifusca* (Newman)	Newman's brocade	SC	S1S2	G3G4
	Noctuidae	*Papaipema beeriana* Bird	Blazing star borer	SC	S1S2	G3
	Noctuidae	*Papaipema cerina* Grote	Golden borer	SC	S1S2	G4
	Noctuidae	*Papaipema maritima* Bird	Maritime sunflower borer	SC	S1S2	G3
	Noctuidae	*Papaipema sciata* Bird	Culver's root borer	SC	S2S3	G4
	Noctuidae	*Papaipema silphii* Bird	Silphium borer	T	S1S2	G3G4
	Noctuidae	*Papaipema speciosissima* (Grote & Robinson)	Regal fern borer	SC	S2S3	G4
	Noctuidae	*Spartiniphaga inops* Grote	Spartina moth	SC	S1S2	G2G4
	Nymphalidae	*Neonympha m. mitchellii* French	Mitchell's satyr	E	S1	G1G2
	Riodinidae	*Calephelis mutica* McAlpine	Swamp metalmark	SC	S1S2	G3
	Saturniidae	*Hemileuca maia* (Drury)	Barrens buckmoth	SC	S2S3	G5

Data from Michigan Natural Features Inventory Rare Species Explorer and species Abstracts. Ranks represent (left to right) state status, state rank, and global rarity rank. State status: SC: special concern (no legal protection) T: threatened, E: federally endangered. State and global ranks use the same system: NR: not ranked, G/S5: secure, G/S4: apparently secure, G/S3: vulnerable, G/S2: imperiled, G/S1: critically imperiled

Mitchell's satyr butterfly, *Neonympha mitchellii mitchellii*, is a globally rare species that typifies concerns about insect conservation in prairie fen (Greenberg 2002). First described from a Michigan fen by French (1889), the highest concentration of extant populations occurs in southern Michigan and a single site in northern Indiana. Formerly known from Ohio, Wisconsin and New Jersey as well, Mitchell's satyr has been extirpated in those states (Shuey et al. 1987; Shuey 1997). Throughout its range, Mitchell's satyr occurs in highly localized wetland habitats including prairie fens and sedge-dominated wetlands. In addition to the risks posed by habitat loss, the low population sizes of Mitchell's satyr in many of these sites calls into question their continued persistence (Szymanski et al. 2004). For example, in the 20 years in which surveys have been conducted in Michigan and Indiana, Mitchell's satyr has apparently been lost from nine of 28 formerly occupied sites. It is now known from only 18 sites in Michigan and one in Indiana, many of which have 30 or fewer individuals observed per season (D. Hyde, Personal Communication).

Given the overall rarity of prairie fen habitats, the concentration of rare insects they harbour, and the significant threats to their continued persistence, there is a critical need to develop clear strategies and recommendations for their conservation. Specifically, in this paper we: 1) examine characteristics of prairie fen in Michigan, including their distribution, quality, and landscape context that contribute to their vulnerability, 2) examine the conservation status, life history traits and habitat use of rare insects that occur in prairie fen, and 3) use this information to recommend short, medium, and long term conservation actions.

Methods

Distribution and landscape context of fens

The MNFI natural heritage database (MNFI 2009) was used to determine the current distribution of mapped prairie fens, northern fens, and coastal fens in Michigan as described by Kost et al. (2007), as well as the current and historic distribution of Mitchell's satyr. These occurrences were mapped against the ecoregional subsections of Michigan (Albert 1995). For prairie fens, we used their reported size and element occurrence ranking (NatureServe 2002) to assess size/quality relationships. Prairie fen occurrences were contrasted to the historic (*circa* 1800) distribution of prairie and savanna (Comer et al. 1995) as well as threats and opportunities for conservation lands in Michigan. Specifically, we examined the extent of agricultural production throughout the Michigan Lower Peninsula using remote sensed Thematic Mapper imagery (30 × 30 m pixels) from the Integrated Forest Monitoring Assessment and Prescription Landuse/Landcover data layer (MDNR 2003). We also used predicted housing density increases (homes/km^2) in modified U.S. Census Bureau divisions provided by University of Wisconsin (Hammer et al. 2004; Radeloff et al. 2005) to visualize areas expected to see higher than the state-wide average housing density increase between 2010 and 2020. Finally, we used the distribution of conservation lands in Michigan from the Conservation and Recreational Lands (CARL) database (http://glaromaps.ducks.org/carl/) to assess the degree to which extant prairie fens receive conservation protection. Within CARL, we used conservation lands (Scott et al. 1993) generally owned by federal, state, municipal and non-governmental entities, within which management status ranges from full biodiversity protection (Gap status 1) to "multiple use" conservation management (Gap status 3). We evaluated the degree to which prairie fens were represented within these lands by overlaying protected areas on fen polygons as represented in the MNFI natural heritage database (2008 version), omitting fens not validated since 1983 ($n = 128$ prairie fen occurrences). Finally, we reviewed conservation action plans (CAPs) for nine areas in southeast Michigan in which prairie fens and/or fen dependent insects were focal conservation targets and which ranked specific conservation threats (ConPro 2009). Threat ranks across the nine CAPs were aggregated using a weighted scoring approach (4 points for Very High, and 3, 2, or 1 point for High, Medium, or Low, respectively) to produce an overall rank.

Fen insects of conservation concern

Using MNFI's on-line databases, we developed a comprehensive list of insects of conservation concern associated with Michigan prairie fens (MNFI 2007). For purposes of further analysis, we eliminated the two dragonfly and two beetle species that primarily use open water habitats (headwater streams, lakes) associated with fens, since they are not directly dependent upon prairie fen itself. We then assembled information on their occurrence in other community types, their microhabitat requirements if known, and host plants. We assigned habitat use based primarily on MNFI species abstracts (MNFI 2007) using the plant community and ecological group naming system of Kost et al. (2007). Finally, in light of global change predictions we suggest conservation strategies to mitigate threats to these species.

Results

Distribution and landscape context of fens

The MNFI database documents 146 occurrences of prairie fen in Michigan, most of which fall within the combined

Kalamazoo-Battle Creek and Jackson interlobates (Fig. 1a). In Michigan, fens are typically small, ranging in size from less than 0.5–130 hectares, with roughly 46% less than 5 ha and 21% less than 2 ha. Only 11 (8%) of the prairie fen occurrences are ranked as high quality (A or AB rank, Table 2), with 120 (82%) being of fair quality (B–C rank) and 15 (10%) of poor quality (CD rank). High quality fens were of larger average size (mean $\geq$ 25 ha) than poor quality fens (mean $\leq$ 25 ha) and no high quality fens were smaller than 6 ha. Although small fens may harbour diverse intact plant and animal communities, they are considered to be less viable due to their small size and greater susceptibility to degradation. Mapping prairie fen occurrences against historic prairie and savanna shows that these communities were highly associated (Fig. 2a) and predominantly fall within with the interlobate regions (Fig. 1a). Much of southern Michigan, where prairie fen is concentrated, has been converted to agricultural or urban/suburban land use and strong development pressure remains (Fig. 2b, c). In contrast, conserved lands are focused in the northern portion of Michigan's lower peninsula (Fig. 2d). Finally, our analysis of current prairie fens and conservation lands shows that only 28% are well-protected (i.e., >80% of the fen area under conservation ownership), and the majority (58%) of prairie fens in Michigan remain largely unprotected (i.e., <20% of the fen area in conservation ownership; Fig. 3). Aggregated threat ranks from for nine Michigan fen networks suggest that invasive species, housing and urban areas, and fire suppression are the leading threats to fens and fen dependent insects in Michigan (Table 3).

Fen insects of conservation concern

Of the 22 species of conservation concern in Michigan prairie fen, three are wholly confined to this habitat (Table 4). *Flexamia huroni* is known from just five prairie fen sites, all within a small portion of Oakland County, Michigan (MNFI 2009). The host plant for *F. huroni* is *Muhlenbergia richardsonis* (mat muhly) which itself is known from just 16 Michigan localities including 12 prairie fen sites in southern Michigan and 4 sites in the Upper Peninsula (3 alvar sites, and 1 northern fen) (Penskar and Higman 1999). *Lepyronia angulifera* is found mostly along the Atlantic coast (Hamilton 1982) and known in Michigan from nine prairie fens. In Michigan, *Oarisma poweshiek* is highly associated with prairie fen, often occurring in only small portions of much larger fens, in areas with an abundance of either *Muhlenbergia richardsonis* or *Sporobolus heterolepis*. *Oarisma poweshiek* abundance has decreased in recent years in the tallgrass prairie portion of its range (MN, ND, SD, IA) (Selby 2005). Despite intensive searches throughout southern Michigan, recent collections of *O. poweshiek* have occurred in only five counties (MNFI 2007). Additional survey efforts are warranted for these insects and may reveal use of additional habitats.

A second group of five species are found in prairie fen and just a few closely associated habitats. These include *Flexamia reflexus* which occurs in prairie fen and wet prairies and *Oecanthus laricis* which occurs in fen and tamarack swamp. *Euphyes dukesi* and *Papaipema speciosissima* occur in fen but prefer somewhat more wooded habitat, while *Neonympha m. mitchellii* prefers open areas of fen with nearby woody vegetation.

A third group of species occurs in prairie fen as well as other permanent or seasonally wet habitats ranging from marsh and bog to wet and wet-mesic prairies. These include eight species: *Calephelis mutica*, *Paroxya hoosieri*, *Orcheliumum concinnum*, *Dorydiella kansana*, *Neoconocephalus lyristes*, *Papaipema maritima*, *Meropleon ambifusca*, and *Papaipema cerina*, that feed on plants common in a variety of wet to wet-mesic habitats types including sedges and rushes.

A fourth group of six species occurs across a wide range of wet to very dry habitats ranging from marsh and bog to dry-mesic forest and savanna communities. These include *Spartinophaga inops*, *Papaipema silphii*, *Hemileuca maia*, *Prosapia ignipectus*, *Papaipema sciata*, and *Papaipema beeriana*.

Table 2 Quality (Element Occurrence Rank) and average size of prairie fens in Michigan, USA (MNFI 2009)

EORANK	Count	Percent of total (%)	Average size (Ha)
A	5	3.4	60.8
A?	1	0.7	97.2
AB	5	3.4	28.9
B	34	23.3	21.5
B?	3	2.1	25.3
BC	25	17.1	13.6
C	50	34.2	4.3
C?	8	5.5	9.6
CD	15	10.3	3.3
TOTAL	146	100.0	

Host plant associations

As expected, the distribution of host plants is tightly associated with the occurrence of rare insects in prairie fens. Half (11/22) of the prairie fen insects of conservation concern use one or just a few species of host plant (Table 4). Five appear to be host specialists, having only been recorded on a single species of plant, while five are oligophagous on several species within a single genus of

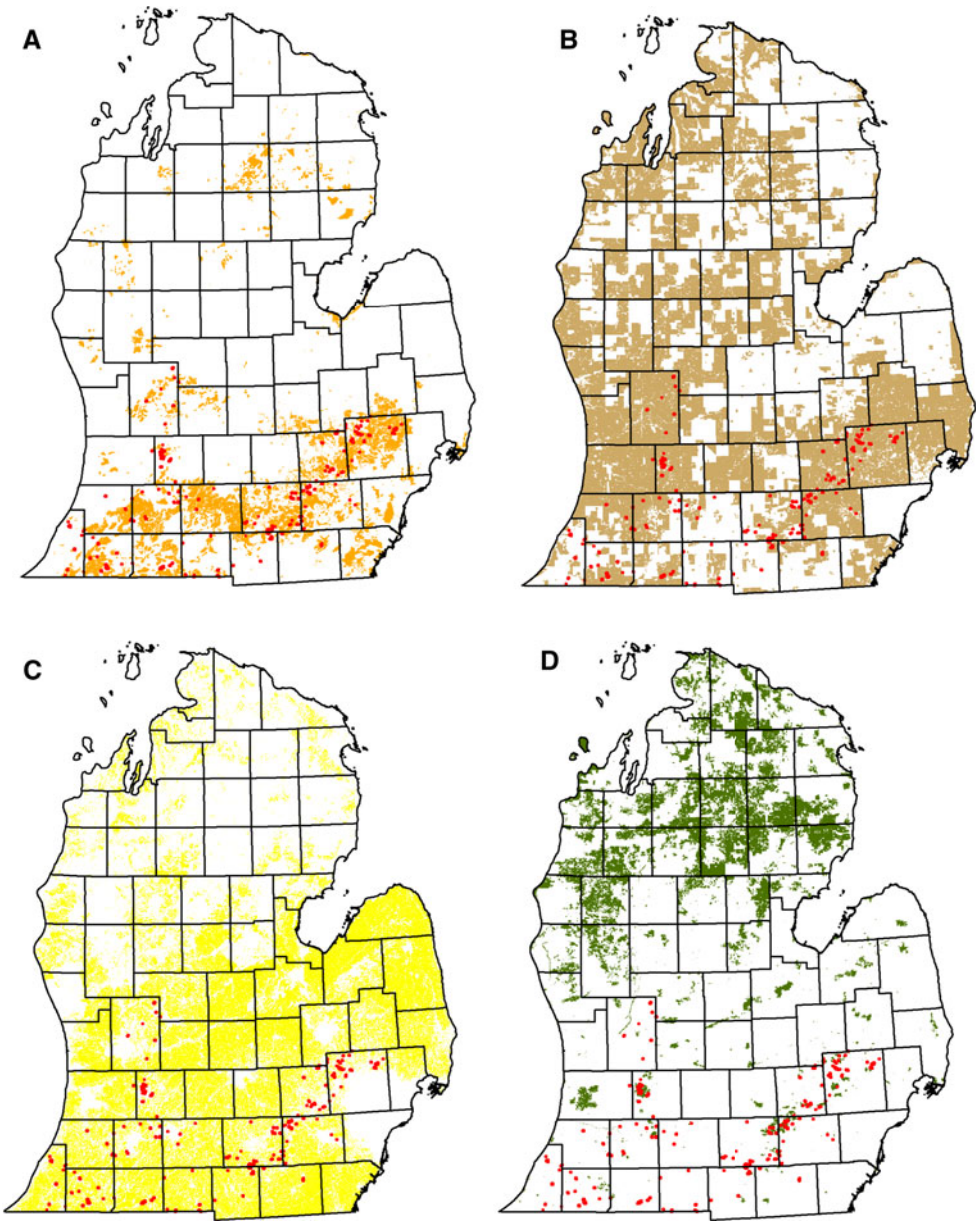

Fig. 2 Mapped prairie fens in *red circles* contrasted with **a** historic extent of prairie and savanna (*circa* 1800), **b** census divisions expected to see higher than average housing density increases in 2010–2020, **c** extent of agricultural production, **d** extent of the current conservation reserve system

host plant. *Oecanthus laricis* has only been found on *Larix laricina*, most likely due to its strong preference for ovipositing on tamarack branches (Bland 2003). *Flexamia reflexus* has only been found in association with *Sorghastrum nutans*, *P. ignipectus* on *Schizachyrium scoparium*, and *P. sciata* on *Veronicastrum virginicum*. Oligophagous insects include *P. speciosissima* on *Osmunda* spp., *C. mutica* on *Cirsium* spp., *M. ambifusca* on *Sporobolus* spp., and *S. inops* on *Spartina* spp. *Papaipema maritima* feeds on just two genera: *Helianthus* and *Cacalia*.

Notably, a number of rare fen insects use host plants more commonly associated with prairies and savannas than wetlands. For example, *F. huroni* and *P. ignipectus* feed exclusively on the prairie grasses *S. nutans* and *S. scoparium*. In addition, several forbs that host fen insects were also historically found in prairies and grasslands including: *Liatris* spp., common in wet to very dry prairies, *V. virginicum*, a plant of wet meadows, lake plain prairies and associated savannas, *Silphium* spp., restricted to wet-dry prairies and savannas, and *Helianthus* spp., primarily plants of meadows to wet-mesic prairies. As the upland portions of these plants habitats were lost, the only remaining refuges occurred in fen and other wet habitats less suitable for agriculture or development. As such, the insects which use them are now also largely confined to the wetter portion of the host plants' habitat range.

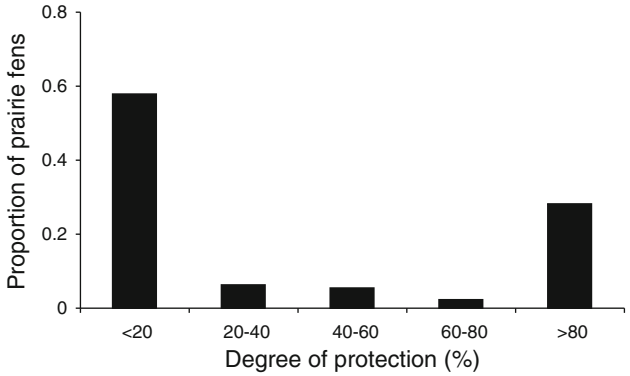

Fig. 3 Proportion of 128 prairie fens in Michigan under different levels of conservation protection. Percent protected represents the percent of each fen polygon (MNFI natural heritage database 2008) included in protected land categories in the Conservation and Recreational Lands (CARL) database

Table 3 Aggregated threat ranks for prairie fens and fen dependent insects from nine conservation areas in Michigan, USA, following the International Union for Conservation of Nature—Conservation Measures Partnership Unified Classification of Direct Threats (Salafsky et al. 2008)

Aggregated rank	Taxonomy	Threat
Very high	8.1	Invasive non-native/alien species
Very high	1.1	Housing & urban areas
Very high	7.1	Fire & fire suppression
High	4.1	Roads & railroads
High	7.2	Dams & water management/use
High	1.2	Commercial & industrial areas
Medium	2.1	Annual & perennial non-timber crops
Medium	5.1	Hunting & collecting terrestrial animals
Medium	9.1	Household sewage & urban waste water
Medium	9.3	Agricultural & forestry effluents
Low	2.3	Livestock farming & ranching
Low	9.2	Industrial & military effluents

Discussion

Prairie fens are currently nested within a complex landscape of multiple habitat types. This landscape context has exposed prairie fens to numerous interacting threats that ultimately fragment and degrade this ecosystem. Given the threats to prairie fens and prairie fen associated insects, a variety of strategies, techniques, and actors need to work in cooperation to assure their continued conservation.

Short-term recommendations

Increased survey

There is an immediate need for a comprehensive survey of fen habitats. For example, the MNFI has recorded ca. 146 prairie fens; but up to 100 more may occur (M. Kost, Personal Communication). Many of the remaining undocumented sites are likely to be on private lands and of low to moderate quality; however, some higher quality sites may yet be located. In combination with this activity, there is a clear need for increased survey efforts for virtually all of the prairie fen insects of conservation concern. Due to its federally endangered status, Mitchell's satyr has generated funds for survey and conservation efforts. As part of this work, several associated insects have also received directed attention (including *O. poweshiek* and *C. mutica, L. angulifera,* and *F. huroni*). However, despite these efforts, systematic surveys are clearly needed. For example, in 2005 a formerly unknown population of Mitchell's satyr was discovered in southwest Michigan, despite the fact that the species was first described from a nearby fen in 1889. Similarly, in 2007 four new sites with *F. huroni* were found in fens that had been known for some time. More intensive, systematic, species-focused surveys are needed for some of the more cryptic insects that are typically not collected in general insect surveys. Future survey work should be systematic and quantitative, producing long-term data sets with the goals of assessing changes in occupancy across sites, population trends within sites, and responses to habitat management.

Mapping and protection of fen hydrology

For prairie fens and fen-dependent insect communities, one key strategy is the identification of sites for acquisition and management through conservation planning (Groves 2003). Sites containing extant populations of Mitchell's satyr have received special attention and MNFI has developed conservation plans for all occupied sites. These plans suggest appropriate land protection (e.g., acquisition and easement) and stewardship actions for occupied areas and associated habitats. The fact that more than a quarter of prairie fens are >80% protected is encouraging since well under ten percent of the landscape in southern Michigan is in conservation ownership. However, fen hydrology is of fundamental importance to fen persistence, and current protection and management efforts do not fully account for threats to ground water recharge areas. This means extending the boundaries of conservation planning to include associated recharge areas and other areas that feed into the system. We have a relatively poor understanding of groundwater flow in most fen sites, so additional

Table 4 Habitat affiliations and host plants for insect species of conservation concern in prairie fen in Michigan, USA

Scientific name	Plant community or ecological group													Host plant(s)
	Marsh	Bog	Forested wetland	Shrub wetland	Southern wet meadow*	Prairie fen*	Wet prairie	Wet-mesic sand prairie*	Mesic prairie*	Mesic sand prairie*	Forest	Savanna	Dry sand prairie*	
F. huroni						x								*Muhlenbergia richardsonis*[1]
L. angulifera						x								*Eleocharis* spp.[2] *Sporobolus indicus*[3], *Cyperus swartzii*[3], *Gossypium hirsutum*[3], a variety of monocots[3]
O. poweshiek						x								*Sporobolus* spp.[3,7], *Muhlenbergia richardsonis*[8], *Eleocharis elliptica*[3], *Schizachyrium scoparium*[9,3], *Carex* spp.[8,10], *Stipa spartea*[8], *Bouteloua curtipendula*[8]
F. reflexus						x	x							*Sorghastrum nutans*[4]
O. laricis		x	x	x	x	x								*Larix laricina*[5,6]
E. dukesi			x		x	x								*Carex* spp.[11], *Scirpus cyperinus*[11], *Rhynchospora* spp.[12]
N. m. mitchellii			x	x	x	x		x						*Carex* spp.[13], *Scirpus* spp.[13,3]
P. speciosissima			x	x	x	x	x	x						*Osmunda* spp.[14]
C. mutica	x				x	x								*Cirsium* spp.[3]
P. hoosieri	x	x			x	x	x							*Typha* spp.[5], *Eupatorium maculatum*[10], *Alisma* spp.[10], *Populus heterophylla*[15]
O. concinnum	x				x	x	x							*Carex* spp.[5,16], *Eleocharis rostellata*[17], *Juncus* spp.[5,18,17], *Iris* spp.[16]
D. kansana	x					x	x	x						*Eleocharis* spp.[7,19], *Scleria* spp.[7], *Rhynchospora* spp.[19]
N. lyristes	x	x			x	x	x	x	x					*Spartina cynosuroides*[20], *Scirpus americanus*[20], *Quercus* spp.[21]
P. maritima	x				x	x	x	x	x					*Helianthus* spp.[14], *Cacalia* spp.[7]
M. ambifusca	x				x	x	x	x	x					*Sporobolus* spp.[22]
P. cerina	x		x		x	x	x				x			*Lilium* spp.[2,14], *Podophyllum peltatum*[14], *Hystrix patula*[14], *Scirpus atrovirens*[2], *Silene stellata*[14], *Iris spp.*[14]
S. inops					x	x	x	x						*Spartina* spp.[10]
P. silphii						x			x	x				*Silphium* spp.[10] *Solidago rigida*[27], *Parthenium integrifolium*[27]
H. maia				x		x						x		*Quercus* spp.[23,24,2,7], *Salix* spp.[23,24] *Populus* spp.[24], *Spiraea* spp.[24], *Lythrum salicaria*[25], *Betula* spp.[26,24], *Menyanthes trifoliata*[23]

Table 4 continued

Scientific name	Plant community or ecological group													Host plant(s)
	Marsh	Bog	Forested wetland	Shrub wetland	Southern wet meadow*	Prairie fen*	Wet prairie	Wet-mesic sand prairie*	Mesic prairie*	Mesic sand prairie*	Forest	Savanna	Dry sand prairie*	
P. ignipectus						x				x		x		*Schizachyrium scoparium*[2,3]
P. sciata						x		x			x		x	*Veronicastrum virginicum*[10]
P. beeriana						x	x	x	x	x		x	x	*Liatris* spp.[10]

Communities are roughly listed in order of decreasing wetness (left to right). Insect species are listed (top to bottom) in three broad groupings according to the moisture level of communities they occupy. Specific community names (*) follow Kost et al. (2007) or consist of groups of similar ecological communities. Host plants are listed only if the insect was observed feeding (not nectaring) on the plant species in the wild

References [1]Bess and Hamilton (1999), [2]Hamilton (1982), [3]Summerville and Clampitt (1999), [4]Hamilton (2005), [5]Bland (2003), [6]Alexander et al. (1972), [7]Panzer et al. 2006, [8]Selby (2005), [9]Shepherd et al. 2005, [10]Metzler et al. (2005), [11]Opler and Krizek 1984, [12]Scott (1986), [13]McAlpine et al. (1960), [14]Hessel (1954), [15]Blatchley (1898), [16]Hubbell (1922), [17]Thomas and Alexander (1962), [18]Pennings et al. (2009), [19]Bess (2005), [20]Fox (1917), [21]Rehn and Hebard (1915), [22]Wagner et al. (2009), [23]Legge et al. (1996), [24]Scholtens and Wagner (1995), [25]Gratton (2006), [26]Kruse (1998), [27]Andrew and Leach (2006)

monitoring, research, and modelling efforts are also needed. The legislatively mandated Michigan Groundwater Mapping Project passed in 2003 requires that groundwater be inventoried and mapped. Such efforts could add resolution to fen conservation planning by further targeting land protection and management activities in relation to the source of groundwater.

Medium-term recommendations

Landscape-scale conservation

In Michigan, as sedge-wetland and prairie habitats were lost to anthropogenic forces, both assemblages of insects became largely confined to prairie fens. To conserve these species in the future it will not only be vital to manage prairie fens as unique habitats, but also the surrounding areas to allow for dispersal corridors and metapopulation dynamics in sufficiently large sites. Such a landscape-scale strategy will compliment both the protection of the largest number of species possible and the security of the hydrological forces that impact prairie fens. In 2006 The Nature Conservancy, in conjunction with Michigan State University, MNFI, the Michigan Department of Natural Resources, and The Stewardship Network, initiated conservation planning and restoration at landscape levels through the Southeast Michigan Headwaters project. The project included broad examination of species of conservation concern in the southeast Michigan headwaters area, broadly concordant with the Jackson interlobate region (Fig. 1b). The goal of this planning process was to identify areas with occurrences that are most likely to be resilient, representative, restorative, and redundant. Subsequently, Conservation Area Plans (CAPs) were completed for 12 areas, many of them containing prairie fens (ConPro 2009). As a result of this prioritization, an area of approximately 2,000 hectares within the Jackson interlobate has been targeted for landscape-scale restoration. A new initiative, the Southeast Michigan Fen Collaborative, has carried on this work and is engaged in monitoring, maintenance, and restoration of fens and associated uplands in the Conservation Area. Efforts like these will also assist with medium-term persistence of rare species that are now limited to prairie fen due to the loss of upland prairies historically associated with prairie fen. This effort needs to be replicated many times and at even larger spatial scales.

Captive rearing and release

In spite of efforts to conserve them, many extant prairie fens lie in areas of high human population density, with intense agricultural production and low levels of land conservation or protection. In these areas it may well be

impossible to reconnect fens to a degree to which insect populations will remain viable. As such, inbreeding depression and other stochastic processes are anticipated to result in local extinctions. Recently, the presence of the reproductive symbiont *Wolbachia* has also been detected in Mitchell's satyr populations (Handley et al. unpublished data). The consequences of *Wolbachia* infection are potentially severe because infected populations may experience a bottleneck that reduces the number of individuals that can successfully reproduce (Nice et al. 2009). In the future, it will likely be necessary to take individuals of some fen-associated insects from the wild for captive rearing and potential re-release. Molecular data are crucial to the success of this process so that captive rearing and release can be carried out using the most appropriate subpopulations, assuring sufficient genetic variability in reintroduced populations. Techniques for captive rearing are under development for a few fen-associated species, including Mitchell's satyr and swamp metalmark.

Long-term recommendations

Perhaps the most significant long-term threat to fen communities is the predicted variability in precipitation and temperature associated with changing climate. Climate change scenarios for Michigan predict substantial warming, changes in precipitation patterns, and increased evapotranspiration (Sousounis and Bisanz 2000). Conservation planning and strategy implementation must anticipate that climate change will further stress prairie fens as temperatures increase, leading to increases in evapotranspiration rates, which will in turn interact with increasing extraction of the groundwater that feeds these systems, implying fundamental changes in groundwater flows that may be difficult to mediate.

Assisted migration

While current conservation efforts (e.g., land protection, invasive species management) may help abate current threats, the effects of climate change make it necessary to expand our conservation vision. For example, northern fen and coastal fen in northern Michigan represent structurally similar habitats that could potentially support at least a subset of the current fen-associated rare species as the climate warms. For example, northward shifts of 35–240 km were documented in some European Lepidoptera in the 1900's (Parmesan et al. 1999). This range expansion occurred with a 0.8°C increase in temperature, compared to the 2.1–4.6 predicted for the twentyfirst century. We do not know whether the ranges for the insects of conservation concern in Michigan will increase or shift northward. In addition, northward shifts in Michigan will be limited by presence of the correct host plants as well as the potential for arthropod species to disperse to these habitats. Unfortunately, while there is substantial conserved land in northern Michigan (Donovan et al. 2004), the fens occurring there are highly localized and a wide gap occurs between prairie fens in the south and potential fen habitat in the north. This suggests that natural dispersal is unlikely to represent a viable mechanism for either plant or arthropod species arrival. In such situations, the concept of managed relocation (a.k.a. assisted migration) has been explored for some species (McLachlan et al. 2007). While currently controversial, such techniques may become more widely accepted in the future.

Conclusions

Prairie fen represents a distinctive plant and animal community unique to the glaciated Great Lakes region and its associated insects of conservation concern comprise some of the rarest species in the region. Historically, prairie fen was embedded within a disturbance-dependent landscape including oak savannas and prairies. Most of the former landscape matrix has been converted to agriculture and other human land uses, making prairie fens with persistent groundwater inputs the last available habitat for many species of conservation concern. Developing a long-term strategy for conservation of these species will require a concerted effort by multiple actors. This effort has begun in Michigan, prompted in large part by the presence of the federally-listed Mitchell's satyr that has generated unique levels of interest and funding opportunities. These initial efforts need to be refined and expanded to include the entire community of rare fen-associated arthropods. Doing so successfully will require that we plan and act at much larger spatial scales, and much longer temporal time frames than currently envisioned.

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