2
2007

This is to certify that the
thesis entitled

SPATIAL INTEGRATION OF THREATENED
OR ENDANGERED SPECIES AND TART
CHERRY ORCHARD LOCATIONS IN MICHIGAN

presented by

CORINNA NICHOLE RUBECK-SCHURTZ

has been accepted towards fulfillment
of the requirements for the

M.S. degree in Fisheries and Wildlife

Kelly A. Millenbah
Major Professor's Signature

7/17/07

Date

SPATIAL INTEGRATION OF THREATENED OR ENDANGERED SPECIES AND TART CHERRY ORCHARD LOCATIONS IN MICHIGAN

By

Corinna Nichole Rubeck-Schurtz

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Fisheries and Wildlife

2007

ABSTRACT

SPATIAL INTEGRATION OF THREATENED OR ENDANGERED SPECIES AND TART CHERRY ORCHARD LOCATIONS IN MICHIGAN

By

Corinna Nichole Rubeck-Schurtz

In 2003, the US Environmental Protection Agency denied tart cherry growers in Oceana County, Michigan, an experimental use permit for a "reduced risk" insecticide because of the presence of the endangered Karner blue butterfly (KBB: *Lycaeides melissa samuelis*). However, this decision was not based on orchard-specific KBB data; KBB locations were portrayed at a county scale, instead of a more biologically relevant scale. My objective was to demonstrate a process for integrating private lands commodity production with TES conservation. This was completed by producing federally threatened or endangered species (TES) habitat and tart cherry block (TCB) maps. In addition, I developed a spatial integration method to allow for better identification of potential overlap areas between pesticide drift from TCBs and TES habitat which can be useful for improving policy decisions. TCB spatial coordinates were collected through global positioning system technology, and a pesticide drift layer was created in a geographic information system (GIS). A predictive model was used to create statewide habitat-suitability maps for three TES because Michigan currently lacks statewide TES surveys. All data layers were integrated in a GIS to identify which tart cherry growers had the potential to affect TES. Two example approaches integrating the data were derived. Future work is required to determine the most appropriate habitat-suitability layer to be used in the integration process for each TES.

ACKNOWLEDGEMENTS

Thanks are extended to Project GREEEN for providing the funding to support this research project. I want to thank my major advisor Dr. Kelly Millenbah for all of her support, advice, and encouragement. My committee members Dr. Mark Whalon (Entomology), Dr. Larry Olsen (State Extension Agriculture Program Leader), and Dr. Gary Roloff (Fisheries and Wildlife) also deserve thanks for their work on the project. A thank you also goes to all those who gave me the opportunity to present this research at national and international meetings.

Acknowledgment and thanks go to the members of the ESC WG (see Key to Abbreviations, p. xi) who helped shape this project: Antonio Castro-Escobar (MDA), Mike DeCapita (USFWS), Todd Hogrefe (MDNR), Brian Hughes (MDA), Margaret Jones (USEPA), Phil Korson (CMI), Ben Kudwa (Michigan Potato Industry), Ken Rauscher (MDA), Barbara Vantil (USEPA), and Denise Yockey (Michigan Apple Committee). Perry Hedin (CIAB), the FMO, and Michigan tart cherry growers also deserve thanks for their support in collecting tart cherry block spatial locations. Thanks to Justin Booth (MSU RS & GIS), Helen Enander (MNFI), and Ed Schools (MNFI) for their GIS support and Bill McConnell (Fisheries and Wildlife) for modeling advice. Also, thanks to all fellow Biomapper users who have provided knowledge and support.

I want to thank Dana Infante for her help and advice on my thesis. Thanks also go to my fellow lab mates for their help and support throughout this process. I want to thank my family and friends for their support. Special thanks go to my husband, Kasey, who has supported and encouraged me throughout this entire process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

KEY TO ABBREVIATIONS

Absolute Validation Index	AVI
Cherry Industry Administration Board	CIAB
Cherry Marketing Institute	CMI
Circular Analysis	CircAn
Cross-Validation	CV
Contrast Validation Index	CVI
Ecogeographical Variable	EGV
Ecological Niche Factor Analysis	ENFA
Endangered Species Act	ESA
Endangered Species and Commodity Working Group	ESC WG
Environmental Systems Research Institute, Inc.	ESRI
Experimental Use Permit	EUP
Federal Marketing Order	FMO
Geographic Information System	GIS
Global Positioning System	GPS
Habitat-Suitability	HS
Indiana Bat	IB
2001 Integrated Forest Monitoring Assessment and Prescription	IFMAP
Integrated Pest Management	IPM
Karner Blue Butterfly	KBB
Michigan Department of Agriculture	MDA
Michigan Department of Natural Resources	MDNR
Michigan Natural Features Inventory	MNFI
Michigan State University	MSU
Michigan State University Remote Sensing and GIS	MSU RS & GIS
National Agricultural Statistics Service	NASS
Pitcher's Thistle	PT
Tart Cherry Block	TCB
Tart Cherry Orchard	TCO
Threatened or Endangered Species	TES
US Department of Agriculture	USDA
US Environmental Protection Agency	USEPA
US Fish and Wildlife Service	USFWS
US Geological Survey	USGS
US Geological Survey Earth Resources Observation and Science	USGS EROS
Value Attribute Table	VAT

INTRODUCTION

Need for Project

The Endangered Species Act (ESA; 16 U.S.C. 1531 et set.) seeks to protect threatened or endangered species (TES) and the essential habitat of the species (USFWS 1996), and its rules and regulations can influence commodity producers whose economic livelihoods may be affected by TES on or near their property. While many people acknowledge the importance of protecting TES from extinction, opinions on conservation approaches differ when TES protection impacts people's jobs or livelihoods. For example, in New Mexico, a difference of opinion occurred between farmers needing to irrigate crops and environmentalists (Scharpf 2001). The farmers claimed rights to the water while environmentalists believed the river should be managed in a way that ensured the survival of the Rio Grande silvery minnow (*Hybognathus amarus*). This same type of discord has occurred with other TES conservation activities including the threatened northern spotted owls (*Strix occidentalis caurina*) in the forests of the Pacific Northwest (Freudenburg et al. 1998, Carroll et al. 1999) and gray wolves (*Canis lupus*) in the western US (i.e., Idaho, Montana, Yellowstone Ecosystem) (Hardy-Short and Short 2000). To ensure that people's livelihoods and TES are protected there is a need for open communication among all stakeholder groups (i.e., commodity producers, private landowners, agencies) to ensure that the most accurate and relevant information is available for decision-making.

In Michigan, tart cherries are an important commodity that could potentially be impacted by TES. Recently, some of Michigan's tart cherry growers were denied a pesticide experimental use permit (EUP) because of potential harm to a TES (pers. comm., M. Whalon, Department of Entomology, Michigan State University (MSU), pers. comm., P. Korson, Cherry Marketing Institute (CMI), Project GREEEN 2005). This situation highlighted a need to develop a process that could identify the spatial locations near tart cherry orchards (TCO) where pesticide application could potentially impact TES. Such a process would help identify areas where mitigation efforts for TES protection could be directed.

Project Background

Benefits of Pesticides to Tart Cherry Growers

Commodity producers experience benefits from the use of pesticides including higher crop yields and higher quality crops by reducing diseases, pest insects, and competition with weeds (Pope et al. 1998; Ragsdale 1999; Tart Cherry Pest Management Strategic Plan 2000, 2006; USEPA 2006). In Michigan, the tart cherry commodity provides income for a large number of Michiganders and produces a plethora of tart cherry products for the US. Michigan leads the nation in tart cherry production, and in 2004, produced 149 million pounds, or 70%, of the US tart cherry product, followed by 208 million pounds, about 77%, in 2005 (Pollack and Perez 2006). The next two highest tart cherry producing states for 2004 and 2005 included Utah, which produced 22 million and 28 million pounds, respectively, and Washington, which produced 17.5 million and 16.5 million pounds, respectively (Pollack and Perez 2006).

In Michigan, tart cherry growers use pesticides to protect their crops from damage. Some insecticides are used to protect tart cherries from plum curculio (*Conotrachelus nenuphar*) and cherry fruit fly (*Rhagoletis cingulata* and *Rhagoletis* *fausta*) larvae damage (Tart Cherry Pest Management Strategic Plan 2000, 2006; USEPA 2001). Infestations can prevent a crop from going to market and if a cherry is found to contain either pest the grower's fruit can be denied for sale (Whalon et al. 1999; Tart Cherry Pest Management Strategic Plan 2000, 2006; USEPA 2001). Other protective measures include the use of herbicides which can be used to reduce the amount of competition for nutrients between tart cherry trees and other plants (e.g., weeds) (Tart Cherry Pest Management Strategic Plan 2000, 2006). Fungicides can also be used to prevent outbreak of disease (e.g., American brown rot (*Monilinia fructicola*), cherry leaf spot (*Blumeriella jaapii*)), in TCOs that could damage the fruit or the tree (Tart Cherry Pest Management Strategic Plan 2000, 2006).

While use of pesticides benefit crops by protecting them from disease, competition, and pest insects, proactive steps are already being taken in Michigan to reduce the potential for interactions between pesticides and the environment. For example, Michigan's tart cherry grower community is part of an integrated pest management (IPM) program (Tart Cherry Pest Management Strategic Plan 2000, 2006). This program allows tart cherry growers to produce a high-quality product, but also to reduce pesticide use and potential negative effects on the environment and workers in the orchards (Tart Cherry Pest Management Strategic Plan 2000, 2006). Some examples of IPM practices and research occurring in TCOs include using organophosphate alternatives to control pests, adjusting pesticide application methods, changing pesticide application equipment, using models to help determine when to apply pesticides, and improving pest monitoring methods (Tart Cherry Pest Management Strategic Plan 2000, 2006; Tart Cherry Integrated Orchard Management 2006).

Examples of Pesticide Effects on TES

Although pesticides protect crops they can potentially have negative effects on TES. Several examples highlight the interactions between TES and pesticide exposure. One of the better known examples involves the bald eagle (*Haliaeetus leucocephalus*). The bald eagle was listed as endangered through most of its range in 1978 because of declining populations, and one cause for these declining populations included effects from pesticides (USFWS 1983). Bald eagles ingested pesticides through consumption of contaminated prey (e.g., fish) (USFWS 2006). A study by Reichel et al. (1984) investigated 293 dead bald eagles and found all carcasses were contaminated with DDE (p,p'-dichlorodiphenyldichloroethylene). Also, dieldrin may have played a role in the death of five bald eagles as high levels of dieldrin were found in their brains (Reichel et al. 1984). Other research indicates pollutants may have led to diminished reproduction as DDE has been linked with bald eagle egg shell thinning (USFWS 1983, Wiemeyer et al. 1984, USFWS 2006). DDT (dichlorodiphenyltrichloroethane) was used to control insects that could transmit diseases along with pest insects for crops (USEPA 1972) and dieldrin was also used to control crop pest insects along with locusts, mosquitoes, and termites (USEPA 2007). Banning of the majority of uses of DDT throughout the US in 1972 in combination with other conservation activities allowed bald eagle populations to increase over time to the point where the bald eagle could be delisted (USFWS 2006).

Various studies have shown the harmful effects that pesticides have had on TES bat species. One study on the food source of endangered gray bats (*Myotis grisescens*) found that 86% of insect samples contained dieldrin and/or heptachlor epoxide (Clawson and Clark 1989). Aldrin (i.e., parent compound for dieldrin) was used to control cutworms in corn fields (Clawson and Clark 1989). Another study by Clark et al. (1978) examined the brains of 28 dead endangered juvenile gray bats from Missouri and found some contained lethal amounts of dieldrin. O'Shea and Clark (2002) reported lethal levels of dieldrin in the brains of endangered Indiana bats (IB: *Myotis sodalis*) from Missouri. Juvenile endangered gray bats are also thought to be more sensitive than adults (Clark et al. 1983), and Clawson and Clark (1989) found that two juvenile gray bats died from dieldrin poisoning likely caused by consumption of contaminated milk from their mothers.

A study by Herms et al. (1997) examined the effects of the pesticide *Bacillus thuringiensis* var. *kurstaki* (Bt) on the endangered Karner blue butterfly (KBB: *Lycaeides melissa samuelis*) larvae and found that 73% of larvae tested died at low levels of exposure (30-37 Billion International Units/ha). Herms et al. (1997) also examined the timing of KBB larvae development with regard to the temporal application of Bt and found that KBB larvae could be present at the same time Bt applications are needed to control gypsy moth (*Lymantria dispar*) outbreaks, suggesting that the KBB larvae may be susceptible to Bt exposure.

Potential Method to Spatially Identify TES and TCOs along with Spatial Data Issues

Geographic information system (GIS) and global positioning system (GPS) technologies can be used to aid decision makers, landowners, and commodity producers with TES concerns by recording and displaying spatial data. While GIS and GPS technologies are frequently used by researchers, GPS and GIS data are often lacking for TES. For example, the spatial locations for a particular TES might be recorded for only portions of its range or these data might include only presence data (i.e., area surveyed and species found) and not absence data (i.e., area surveyed and species not found). With incomplete TES spatial data, it becomes challenging to use these data for making good management or policy decisions because not all locations of species occurrences are known.

One potential mechanism to overcome a lack of TES spatial data is to model where TES potentially suitable habitats are likely to occur. Engler et al. (2004) suggested that predictive models can potentially play an important role in conserving TES, but few studies on TES have used them possibly because of a lack of information (i.e., sightings data), a lack of "defined sampling units", and a lack of absence data. Many different types of predictive models have been created including those that require only species presence data as well as others that require a combination of species presence and absence data (Guisan and Zimmermann 2000, Hirzel et al. 2001, Hirzel et al. 2002).

Besides a lack of species data, data describing environmental characteristics may also be lacking (Engler et al. 2004). Microclimate data and specific plant community type data are examples of data sources that would be useful in a GIS environment, but are hard to find or portray in a spatial environment (Engler et al. 2004). Fine scale GIS layers like these would require a considerable amount of time to collect and portray as layers. Additionally, these types of spatial data would be expensive to collect and create.

Case Study

The negative effects experienced by TES from pesticide exposure and positive effects of pesticide use for protecting commodity crops emphasizes the need to develop a process that will allow for better protection of both TES and commodity production. In Oceana County, Michigan, this opportunity was highlighted when tart cherry growers sought use of the "reduced risk" insecticide Avaunt™ (E. I. de DuPont de Nemours, Co., Newark, Delaware), through a pesticide EUP, which would have helped growers protect their tart cherry crops from plum curculio (pers. comm., M. Whalon, pers. comm., P. Korson, Project GREEEN 2005). The US Environmental Protection Agency (USEPA) denied the pesticide EUP as the endangered KBB exists within Oceana County (pers. comm., M. Whalon, pers. comm., P. Korson, Project GREEEN 2005). Although the species was present in the county, KBBs or KBB habitat may be located far enough from the TCOs to not be affected by pesticides thus not all tart cherry growers in Oceana County should have been denied use of the pesticide EUP without a more detailed spatial evaluation. "The failure to obtain the pesticide EUP jeopardized approximately 17% of the US's tart cherry production because growers in the County were not able to participate in University assisted research and transition to what were deemed by USEPA as "reduced risk" and theoretically environmentally safer insecticide tools" (pers. comm., M. Whalon).

For this project, I used a GIS to examine the spatial locations of Michigan's tart cherry commodity with regards to pesticides drifting from tart cherry blocks (TCB) and its potential interaction with three TES: KBB, Pitcher's thistle (PT; *Cirsium pitcheri*) and IB. These three TES were chosen because 1) they represent a wide range of organisms including insects, plants, and mammals, 2) they have confirmed presence locations in the same counties as those with TCBs or those counties immediately surrounding the TCB counties, and 3) they represent a variety of ways that organisms may be affected by pesticide use (e.g., KBB larvae have died from pesticide exposure (Herms et al. 1997), IB have contained high amounts of pesticides in their brain (O'Shea and Clark 2002), and PT was selected because it is a plant and may be susceptible to herbicides).

The goal of this project was to demonstrate a process for improved integration of commodity production and TES conservation. This was accomplished by producing TES habitat-suitability (HS) and TCB maps and developing an integration process for these entities to locate potential areas of overlap. The process outlined by this research can aid agencies, commodity producers, and landowners in decision-making (including policy) especially as it relates to pesticide use. This project serves as the pilot for establishing relationships among commodity producers and groups involved with TES protection to set a national example in proactive management techniques. This project also allowed for the generation of next step recommendations to refine the process.

OBJECTIVES

Specific objectives of this project were to:

1. Develop a process that unites TES conservation activities and TCB locations to identify potential areas of overlap,
2. Develop a process that can provide assistance in making decisions and policy regarding protection of TES and pesticide use,
3. Set a national example for the protection of quality commodity production and TES, and
4. Make recommendations for next steps in the process.

STUDY AREA DESCRIPTION

The study area was the state of Michigan, with the main emphasis located on 15 counties in the western portion of Michigan's Lower Peninsula due to the location of TCBs (Table 1, Figure 1). Major cities in or near the study area include Benton Harbor, Kalamazoo, Grand Rapids, Muskegon, and Traverse City. This area produces tart cherries, sweet cherries, apples, peaches, plums, blueberries, strawberries, pears, brambles, and grapes (Michigan Fruit Districts No Date). This region is suitable for fruit production primarily due to its proximity to Lake Michigan which helps to buffer temperature extremes (Olmstead 1956; Tart Cherry Pest Management Strategic Plan 2000, 2006). Similarly, the landscape is composed of moraines and elevated till plains, which, if orchards are located near the tops of these features, allow heavier, colder air to flow away from elevated areas protecting crops from frost damage (Olmstead 1956). Soils in the area are well-drained and sandy loamy which are well-suited for crops (Olmstead 1956; Tart Cherry Pest Management Strategic Plan 2000, 2006).

Table 1. Michigan counties (and abbreviations) containing tart cherry blocks (TCBs) examined for this project.

County	Abbreviation
Allegan	ALL
Antrim	ANT
Benzie	BEN
Berrien	BER
Cass	CAS
Grand Traverse	GRTR
Ionia	ION
Kalamazoo	KAL
Kent	KEN
Leelanau	LEE
Manistee	MAN
Mason	MAS
Muskegon	MUS
Oceana	OCE
Van Buren	VABU

Fig. 1. Project study area is the state of Michigan. The main focus lies within the counties highlighted in black as these contain the tart cherry blocks (TCB) under study. County abbreviations are listed in Table 1.

METHODS

Identifying and Convening a Working Group

The Endangered Species and Commodity Working Group (ESC WG) was formed to provide research guidance on developing the process for integrating TES information and TCB data. The ESC WG participants were limited to people who had interests, jobs, or involvement with commodity production and TES issues and included representatives from government agencies, universities, and commodity groups (Table 2). This group was used to resolve data needs and provide insights into the utility of the process being developed, including whether it would be accepted by different commodity and government groups, and whether it could be used by these groups in the future. Finally, this group established lines of communication among all parties involved who otherwise might not have the chance to meet.

Creation of the ESC WG began with development of an organization list from Michigan and the Chicago USEPA Region 5 whose personnel would be interested in contributing time and information pertaining to commodity production, GIS, modeling, laws and regulations, and TES. The commodity groups chosen were CMI, Michigan Potato Industry Commission, and Michigan Apple Committee. CMI was selected because it is the coordinating entity for the tart cherry producers throughout Michigan and the tart cherry commodity was selected as the example because of the fore mentioned pesticide EUP denial. The Michigan Potato Industry Commission and Michigan Apple Committee were asked to join because this project has the potential to expand to other commodity organizations in the future and their early involvement allowed for more holistic planning throughout the project. The US Fish and Wildlife Service (USFWS),

Table 2. Names and types of organizations participating in the Endangered Species and Commodity Working Group (ESC WG) meetings.

Organizations	Type
Cherry Marketing Institute (CMI)	Commodity
Michigan Apple Committee	Commodity
Michigan Department of Natural Resources (MDNR)	Government
Michigan Department of Agriculture (MDA)	Government
Michigan Natural Features Inventory (MNFI)	University
Michigan Potato Industry Commission	Commodity
Michigan State University (MSU) - Department of Entomology	University
MSU - Department of Fisheries and Wildlife	University
MSU - State Extension Agriculture Program Leader	University
US Environmental Protection Agency (USEPA)	Government
US Fish and Wildlife Service (USFWS)	Government

USEPA, Michigan Department of Natural Resources (MDNR; Wildlife Division), and Michigan Department of Agriculture (MDA) were selected to be members because of their understanding of laws and regulations pertaining to TES and pesticides at both the state and federal level. The MDNR and USFWS were also selected as they are responsible for TES protection. Michigan Natural Features Inventory (MNFI) contributed TES spatial data and GIS support to the project. The project was coordinated by researchers from MSU's Department of Fisheries and Wildlife, Department of Entomology, and the State Extension Agriculture Program Leader.

Michigan Tart Cherry Spatial Data

Collecting Data

Currently, Michigan tart cherry growers are not required to record the spatial coordinates for their TCOs in a GIS format (pers. comm., P. Hedin, Cherry Industry Administrative Board (CIAB)); therefore no GIS spatial data existed for TCO locations. A request was made to the Federal Marketing Order (FMO) to encourage the FMO to require tart cherry growers to use a GPS to record locations for their TCOs. While the FMO did not require that GPS coordinates be recorded for all TCOs, they did approve of GPS locations being recorded as a part of the 2006 TCO diversion process and used in this project. The orchard diversion process occurs yearly and allows tart cherry growers the option to leave their fruit in the fields when the fruit supply is greater than the demand for the fruit (pers. comm., P. Korson). For this process to be carried out, National Agricultural Statistics Service (NASS) employees enter each TCO and record which TCBs the grower is diverting.

Researchers worked alongside the CIAB to train NASS employees in the collection of TCB GPS coordinates throughout the orchard diversion process using Magellan GPS units. NASS employees were given GPS data collection and GPS data recording training while attending one of three regional orchard diversion process meetings (i.e., southwest, west central, and northwest). Before GPS units were sent to NASS employees, each was programmed with the WGS 84 datum to ensure consistency.

Corner coordinates (i.e., Lat/Long, deg.ddddd) for each TCB were collected and hand recorded by NASS employees throughout the 2006 TCB spatial data collection season. Corner coordinates for TCBs were collected in place of TCO coordinates as NASS employees were visiting TCOs to divert blocks and not the entire orchard. TCBs exist within TCOs and TCOs can contain multiple blocks of tart cherries (Figure 2). The data recorded for every TCB corner coordinate consisted of grower name, grower number, block number, GPS unit number, elevation, accuracy, latitude, and longitude. The NASS employees sent the completed data sheets to CIAB where the grower names were removed. The names of the growers are held with the CIAB to protect private landowner information.

Some TCB spatial data were collected by the researcher in 2005 using a Garmin GPS unit (i.e., spatial data representing 25 TCBs), but the majority of TCB spatial data were collected by NASS employees in 2006. The TCB spatial data collected in 2005 might consist of multiple TCBs combined into one as they were collected by the researcher who did not have access to paper maps representing each individual TCB. While spatial data collected in 2005 were collected using different methods, they were used in this project to increase the number of TCB locations. The error term for polygons

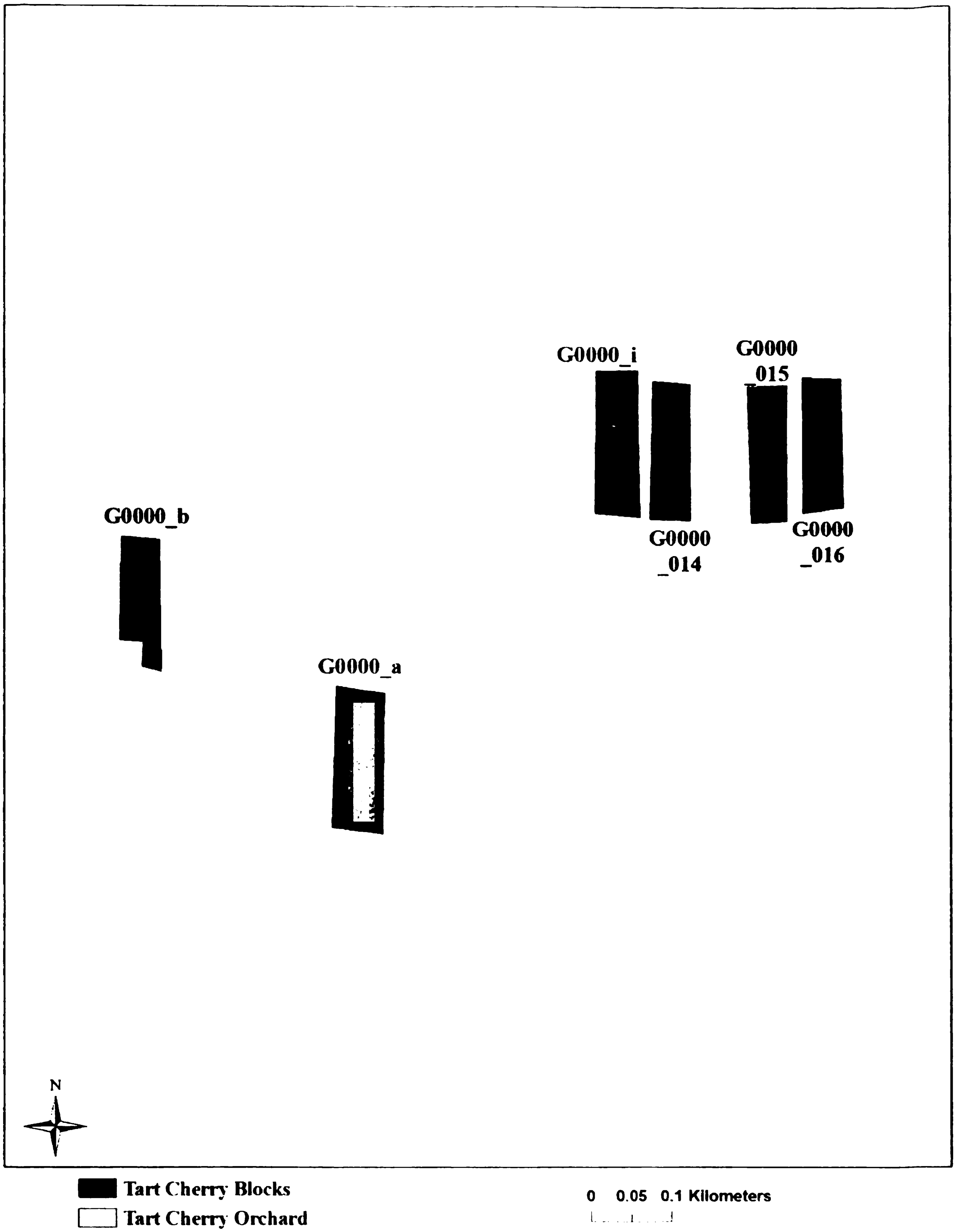


Fig. 2. Example layout of tart cherry orchard (TCO). The outside black line indicates the boundary of the TCO, which contains 6 tart cherry blocks (TCB). Each block is labeled with the same grower number (e.g., G0000) and a different block number (e.g., _a, _b, _014).

is unknown.

Loading TCB Spatial Data into a GIS

Corner coordinates, grower number, and block number for each TCB were entered into a Microsoft Excel spreadsheet along with the TCB spatial data collected in 2005. Spatial identification of TCBs was represented by the tart cherry grower number and TCB number (e.g., G0000_001). The Microsoft Excel file was saved as a .dbf file and uploaded into ArcView (Environmental Systems Research Institute (ESRI), Inc. Redlands, CA) where it was converted to a spatial point file. Using ArcView, the TCB corner coordinates were projected to the Michigan Georef projection and the corner coordinate locations for each TCB were converted into individual TCB polygons using the point to polygon function. The TCB polygons were examined for errors (i.e., overlapping boundaries, incorrect corner coordinate positions), and if an error was found that could not be fixed, that TCB was removed from the sample.

Federal TES Spatial Data

This project focused on three federally listed TES occurring in Michigan. Locations of all federally listed species were initially assembled from existing data obtained from MNFI in digital form. Other groups were contacted for TES spatial data (e.g., USFWS, researchers) to ensure that all TES spatial data available were used for this project.

TES and HS Layers

The TES data collected by MNFI represents only areas surveyed for TES as they are a positive sighting group (pers. comm., E. Schools, MNFI). As such, MNFI only has data for locations where the TES is known to occur as not every location in Michigan has been surveyed for TES, thus Michigan lacks a statewide survey for TES. Care must be taken when interpreting this data because areas not currently surveyed could be treated as lacking TES. For certain locations this is incorrect and misinterpretations could occur if only the current TES survey data were used as other places where the organisms exist would not be included. This obstacle was overcome by modeling TES habitat based on known locational data (i.e., presence or known locations) in Biomapper 3.1 software (Hirzel et al. 2002, Hirzel et al. 2004), which uses the Ecological Niche Factor Analysis (ENFA) (Hirzel et al. 2002). The ENFA identifies potential locations that may provide suitable habitat for the species by overlaying known species locational data and ecogeographical variables (EGV). EGVs are quantitative ecological, topographical, or anthropogenic variables that are spatially defined and found throughout a study area (Hirzel et al. 2002, Hirzel 2004). The ENFA takes the known species distribution on EGVs and compares it with the EGVs throughout the study area (Hirzel et al. 2002) ultimately allowing for the creation of HS maps.

Generation of TES Layers

The KBB, PT, and IB were the focal species for the project. A shapefile (i.e., data set for ArcView (ESRI 1997)) was obtained from MNFI containing presence data collected for all state and federally listed species in Michigan from 1831 to 2005. This shapefile was queried three times (i.e., once for each selected species) in ArcView to create the respective species layer whose last species observation occurred on or after 1990. Records older than 1990 were not considered because of the potential for organisms to move or for their habitat to have been altered since that time. The KBB and PT presence data were captured as polygons, while the IB presence data was captured as both polygon and point data. Both the point and polygon data were used for the IB analysis. The majority of the three TES presence data were not site specific, but were represented as polygons where every location within a presence polygon was equally likely to have the species in it (pers. comm., E. Schools).

In ArcView, each species layer was converted to a 30 m raster. A 30 m raster was selected as it represented the finest resolution for EGV layers used in this project. The IB polygon species raster and IB point species raster were merged into one raster creating the IB species raster. In ArcMap, the KBB and PT species rasters were projected to Michigan Georef (Appendix A).

Although each species raster did not occupy the spatial extent of the entire state, it was necessary to expand each raster to this extent for use in Biomapper software as the entire state of Michigan was the study area for this project. To overcome this issue, a raster analysis mask was used to make each species raster statewide. Each species raster analysis mask was set to a blank Michigan county raster (i.e., all values 0), while the extent was set to each species' corresponding species raster (i.e., for KBB the analysis mask was the blank Michigan county raster and the extent was the KBB species raster). A blank Michigan county raster was used to ensure no values from the species raster changed during the process. The masking process was carried out as each species raster was reclassified such that all presence locations were represented by a 1 and locations with no data for the species were represented by a 0. KBB, PT, and IB species boolean layers (i.e., 1 representing species presence locations and 0 representing locations with no data for species) were created because it is the data format required for use in Biomapper software.

TES Habitat

Karner Blue Butterfly Habitat

KBB habitat is associated with remnant oak - pine savanna barrens, openings in forests, airports, military camps, old fields, forest roads and trails, and power line or highway right-of-ways (Rabe 2001, USFWS 2003). Important land cover types for the KBB include aspen, herbaceous openland, low density tree, oak, pine, and upland mixed forest (pers. comm., J. Kleitch, MDNR; pers. comm., J. Skillen, Community College of Southern Nevada; pers. comm., E. Schools). KBB larvae feed primarily on wild lupine (*Lupinus perennis*) while adults feed on nectar from flowers (Rabe 2001, USFWS 2003). Soil characteristics important to KBB habitat include well-drained and sandy soils (Rabe 2001, USFWS 2003) and the species has been shown to prefer areas with less tree canopy cover but can be found in areas with up to 80% cover (USFWS 2003). Consequently, EGV selections for KBB included important land cover types (i.e., aspen, herbaceous openland, low density tree, oak, pine, and upland mixed forest), soil texture and drainage (i.e., well-and moderately-drained soils), percent sand in soil, total precipitation, tree canopy cover, and elevation (Table 3). A layer representing statewide lupine occurrences could not be found.

Pitcher's Thistle Habitat

PT is a plant that grows on non-forested sand dunes around Lake Michigan, Lake Huron, and Lake Superior (Higman and Penskar 1999, USFWS 2002). Other variables important to plant species that were used in other predictive models include slope, precipitation, and temperature (Zaniewski et al. 2002, Engler et al. 2004) and these were also used in this study. Accordingly, EGV selections for PT included elevation, land

Table 3. Spatial data

Table 3. Spatial data sources used to create ecogeographical variables (EGV) representing habitat features for the Karner blue butterfly (KBB). The derived EGVs were used in the Ecological Niche Factor Analysis (ENFA). The table includes title of the spatial data, originator of spatial data, location the spatial data were obtained from, the appendix describing GIS processes for each spatial data layer, and EGVs derived from each.

Titles	Data Source Originator; Location Obtained From	Initial GIS Processes	Derived EGVs
2001 IFMAP/GAP Lower and Upper Peninsula Land Cover	MDNR, Forest, Mineral and Fire Management Division (2003); Michigan Center for Geographic Information	Appendix B	Frequency of herbaceous openlands, low density trees, oak, aspen, pine, upland mixed forest
Texture and Drainage	D. Lusch, Michigan State University (MSU); R.Schaetzl, MSU	Appendix F	Frequency of well-and moderately-drained soils
CONUS-Soil - Sand, Silt, Clay Fraction	Miller and White (1998); Soil Information for Environmental Modeling and Ecosystem Management	Appendix D	Percent sand in soils
Precipitation (Normals): (Total Precip., 30-yr average, Annual 1971-2000)	PRISM Group (2006a), Oregon State University; PRISM Group	Appendix C	Total precipitation
National Land Cover Database 2001 Tree Canopy	US Geological Survey (USGS) (2003); J. Dewitz, USGS Earth Resources Observation and Science (EROS)	Appendix E	Tree canopy cover
National Elevation Dataset	USGS, EROS Data Center (1999); H. Enander, Michigan Natural Features Inventory (MNFI)	Appendix G	Elevation

cover type (i.e., sand - soil), tree canopy cover, total precipitation, average daily maximum temperature, average daily minimum temperature, proximity to the Great Lakes, and slope (Table 4).

Indiana Bat Habitat

This study focused on the summer foraging and roosting habitat of the IB. Winter habitat was not considered as most IB hibernate in more southern states, although a few have been recorded hibernating at Tippy Dam in Michigan (Kurta et al. 1997, Kurta and Rice 2002). Many of the roosting sites for the IB consist of dead or dying trees with exfoliating bark (Humphrey et al. 1977, Callahan et al. 1997, USFWS 1999, Farmer et al. 2002, Kurta et al. 2002). Land types associated with foraging and roosting behaviors of the IB include wetlands, upland forests, riparian, agricultural, areas with water, flood plains, and coniferous forest (Humphrey et al. 1977, Clark et al. 1987, Kurta et al. 1996, USFWS 1999, Farmer et al. 2002, Kurta et al. 2002). As a result the EGV selection for IB included important land cover types (i.e., croplands, hydrologic features, wetlands, and uplands), tree canopy cover, total precipitation, average daily maximum temperature, average daily minimum temperature, elevation, and proximity to hydrologic features (Table 5). Layers representing dead or dying trees or exfoliating bark were not available.

Sources for and Initial GIS Development of EGV Layers

The spatial data sources obtained to create the EGV layers were developed by different organizations (Tables 3, 4, 5). See Appendices B-M for initial GIS processes used to manipulate each layer. All resulting rasters had a cell size of 30 x 30 m^2.

Table 4. Spatial data sources used to create ecogeographical variables (EGV) representing habitat features for Pitcher's thistle (PT). The derived EGVs were used in the Ecological Niche Factor Analysis (ENFA). The table includes title of the spatial data, originator of spatial data, location the spatial data were obtained from, the appendix describing GIS processes for each spatial data layer, and EGVs derived from each.

Titles	Data Source Originator; Location Obtained From	Initial GIS Processes	Derived EGVs
2001 IFMAP/GAP Lower and Upper Peninsula Land Cover	MDNR, Forest, Mineral and Fire Management Division (2003); Michigan Center for Geographic Information	Appendix B	Frequency of sand - soil
Maximum Temperature (Normals): (Average Daily Max. Temp., 30-yr average)	PRISM Group (2006b), Oregon State University; PRISM Group	Appendix I	Average daily maximum temperature
Minimum Temperature (Normals): (Average Daily Min. Temp., 30-yr average)	PRISM Group (2006c), Oregon State University; PRISM Group	Appendix I	Average daily minimum temperature
Great Lakes	Unknown; E. Schools, Michigan Natural Features Inventory (MNFI)	Appendix J	Proximity to Great Lakes
National Elevation Dataset	US Geological Survey (USGS), Earth Resources Observation and Science (EROS) Data Center (1999); H. Enander, MNFI	Appendices G, H	Elevation, Slope
National Land Cover Database 2001 Tree Canopy	USGS (2003); J. Dewitz (USGS EROS)	Appendix E	Tree canopy cover
Precipitation (Normals): (Total Precip., 30-yr average, Annual 1971-2000)	PRISM Group (2006a), Oregon State University; PRISM Group	Appendix C	Total precipitation

Table 5. Spatial data sources used to create ecogeographical variables (EGV) representing habitat features for Indiana bat (IB). The derived EGVs were used in the Ecological Niche Factor Analysis (ENFA). The table includes title of the spatial data, originator of spatial data, location the spatial data were obtained from, the appendix describing GIS processes for each spatial data layer, and EGVs derived from each.

Titles	Data Source Originator; Location Obtained From	Initial GIS Processes	Derived EGVs
2001 IFMAP/GAP Lower and Upper Peninsula Land Cover	MDNR, Forest, Mineral and Fire Management Division (2003); Michigan Center for Geographic Information	Appendix B	Frequency of croplands, uplands
Maximum Temperature (Normals): (Average Daily Max. Temp., 30-yr ave.)	PRISM Group (2006b), Oregon State University; PRISM Group	Appendix I	Average daily max. temperature
Minimum Temperature (Normals): (Average Daily Min. Temp. 30-yr average)	PRISM Group (2006c), Oregon State University; PRISM Group	Appendix I	Average daily minimum temperature
Michigan Geographic Framework: Hydrology	Michigan Center for Geographic Information (2006); Michigan Center for Geographic Information	Appendices L, M	Frequency of and proximity to hydrologic features
National Elevation Dataset	US Geological Survey (USGS), Earth Resources Observation and Science (EROS) Data Center (1999); H. Enander, Michigan Natural Features Inventory (MNFI)	Appendix G	Elevation
National Land Cover Database 2001 Tree Canopy	USGS (2003); J. Dewitz (USGS EROS)	Appendix E	Tree Canopy Cover
National Wetlands Inventory	US Fish and Wildlife Service (USFWS), National Wetland Inventory (1979-1994); H. Enander, MNFI	Appendix K	Frequency of wetlands
Precipitation (Normals): (Total Precip., 30-yr average, Annual 1971-2000)	PRISM Group (2006a), Oregon State University; PRISM Group	Appendix C	Total precipitation

Further Raster/EGV Layers Developmental Processes

Creating Analysis Mask and Analysis Extent

Each species' boolean layer (i.e., value of 1 representing species presence locations and value of 0 representing locations with no data for species) was used to create an analysis mask (define spatial area examined) and analysis extent for its species' boolean layer and rasters representing its EGVs. This process ensured all rasters would cover the same area, have matching spatial extents, and align for processing in Biomapper software. KBB rasters included KBB boolean layer, elevation, texture and drainage, percent sand in soils, IFMAP, tree canopy cover, and total precipitation. The rasters for PT included PT boolean layer, proximity to Great Lakes shoreline, total precipitation, IFMAP, slope, tree canopy cover, average daily maximum temperature, average daily minimum temperature, and elevation. IB rasters included IB boolean layer, elevation, IFMAP, total precipitation, hydrologic features, proximity to hydrologic features, wetlands, tree canopy cover, average daily maximum temperature, and average daily minimum temperature.

Converting ESRI Rasters to Idrisi Rasters

Biomapper software requires that all files be in Idrisi file format. This file format is the same as Idrisi GIS software (Clark Lab, Worcester, MA) file format and consists of a metadata file and data file (Hirzel 2004). All rasters for this project were ESRI rasters and were converted to Idrisi file format using the GridConverter (Biomapper 3.1, Hirzel et al. 2004). GridConverter is part of the Biomapper software package and allows for conversion from ESRI rasters to Idrisi rasters and vice versa.

Converting Qualitative Layers into Quantitative Layers

Before Idrisi rasters could be used in the ENFA, each qualitative layer had to be converted into quantitative layer (Hirzel 2006). An example of a qualitative layer would be IFMAP, where land cover types are coded as integers (e.g., 1 represents low intensity urban and 2 represents high intensity urban). IFMAP is considered a qualitative layer because the data are not portrayed as ratio or continuous values, but instead are represented by categorical or nominal values. The total precipitation layer is considered quantitative because data are portrayed as continuous values. Qualitative data cause problems during computations because average values are meaningless (Hirzel 2006). Two steps were used to create quantitative layers from the qualitative layers and are discussed below.

Boolean Layers

From the qualitative layers, boolean layers showing important TES habitat features were created using Booleanisator (Biomapper 3.1, Hirzel et al. 2004). These boolean layers were created to highlight important habitat features for the TES which could subsequently be further processed in Circular Analysis (CircAn; Biomapper 3.1, Hirzel et al. 2004), which created quantitative values from the boolean values (Hirzel 2004) described later. Booleanisator and CircAn both come in the Biomapper software package.

Qualitative layers for the KBB included soil texture and drainage and IFMAP (i.e., land cover type). Boolean layers representing well-and moderately-drained soils, herbaceous openlands, low density trees, oak, aspen, pine, and upland mixed forest were created for the KBB. The qualitative layer for PT included IFMAP, and from it, a boolean layer representing sand - soil was created. Qualitative layers for the IB included IFMAP, hydrologic features, uplands, and wetlands. One boolean layer from IFMAP representing croplands (i.e., non-vegetated farmland, row crops, and forage crops) was created. Booleanisator was not used to create boolean layers for hydrologic features, uplands, and wetlands as they were already available as boolean layers (refer to Appendix L for hydrologic features, below for uplands, Appendix K for wetlands).

In ArcView, a boolean layer representing uplands was created from IFMAP, as the IFMAP land cover types selected to represent uplands (i.e., northern hardwoods, oak, mixed upland deciduous, and upland mixed forests) were not numbered consecutively and thus could not be processed by Booleanisator. To create the uplands boolean layer, the IFMAP raster was reclassified such that 1 represented northern hardwoods, oak, mixed upland deciduous, and upland mixed forests, and 0 represented all other land cover types.

CircAn and Frequency of Occurrence Percent Statistical Method

The final step for creating quantitative EGV layers involved creating continuous values from the boolean layers (i.e., values 0 and 1). This was accomplished by processing each boolean layer through CircAn using the frequency of occurrence percent statistical method. Hirzel (2004, 2006) suggests using CircAn and the frequency of occurrence percent statistical method when EGV layers represent resources used by the species, thus the reason this method was selected to process these EGV layers. The frequency of occurrence percent statistical method computes the frequency of occurrence of number of pixels or area comprised by a particular habitat feature in a circle around the focal cell (Hirzel et al. 2002, Hirzel 2004). For CircAn to process the boolean layers, a circle radius had to be established. The radii for KBB and PT analysis were based on the average spatial extent of mapped MNFI data, while data from other studies was used to determine the radius for the IB.

The KBB and PT average spatial extents were calculated by determining the average area occupied by all presence records whose last observation date was after 1990 within the species original presence file. The average area mapped by MFNI for KBB presence locations occurring after 1990 was 112,890 m^2 (11.289 ha). The radius for a circle of this size was calculated and converted to a number of 30 m cells (n=6). The precision estimate at this level is unknown. The frequency of well-and moderately-drained soils, frequency of herbaceous openlands, frequency of low density trees, frequency of oak, frequency of aspen, frequency of pine, and frequency of upland mixed forests layers were calculated based on this area. The average area mapped by MFNI that corresponded to PT presence locations whose last observation date occurred after 1990 was 240,010 m^2, which corresponded to a radius cell count of 9. The frequency of sand - soil layer for PT was calculated based on this area.

The IB's average spatial extent was not determined based on MFNI mapped polygons. The radius for the IB CircAn process was determined to be 1 km according to Farmer et al. (2002). Dividing the radius by 30 resulted in a radius of 33 cells encompassing an area of 3,168,900 m^2. This process created the frequency of uplands, frequency of wetlands, frequency of hydrologic features, and frequency of croplands layers for the IB.

Biomapper Processes

TES and EGV Layers

The ENFA in Biomapper software was used to create statewide HS layers for each TES. Each TES was processed separately, but followed a similar process. Multiple EGV layers were used for each TES (Table 6).

Processes

As suggested in the Biomapper software manual (Hirzel 2004) and the Biomapper Frequently Asked Questions (Hirzel 2006) the EGV layers were normalized. For each TES, corresponding EGV layers were normalized by the box-cox bytes transformation method. Next, each TES's EGV layers were verified by examining EGV layers for errors that could cause problems and cell value discrepancies (Hirzel 2004). An example of a discrepancy is when one EGV layer has a cell value while another EGV layer for the same cell has a "no data" value (e.g., 255 represents the background value "no data" for a byte map) (Hirzel 2006). "No data" cells are not used in the ENFA and are removed from processing. After viewing each TES's discrepancy layer, I allowed the Biomapper software to remove discrepancies from the analysis as most occurred along the edges of Michigan, most likely caused by variations in shoreline interpretation.

The ENFA, similar to a Principal Component Analysis, creates uncorrelated factors from input variables where the first factor represents marginality of the species and the other factors represent species specialization (Hirzel et al. 2002; Hirzel and Arlettaz 2003a, b). Marginality looks at how much the mean for the species distribution differs from the mean for the entire study area (Hirzel et al. 2002, Hirzel 2006). Marginality is calculated by comparing the mean cell values corresponding to known

Table 6. Ecogeographical variable (EGV) layers used during the Ecological Niche Factor Analysis (ENFA) and corresponding species. Species include Karner blue butterfly (KBB), Pitcher's thistle (PT), and Indiana bat (IB).

EGV Layers	Species
Frequency of Aspen	KBB
Frequency of Croplands[a]	IB
Elevation[b]	KBB, IB
Frequency of Herbaceous Openlands	KBB
Frequency of Hydrologic Features[c]	IB
Frequency of Low Density Trees	KBB
Average Daily Maximum Temperature	PT, IB
Average Daily Minimum Temperature	IB
Frequency of Oak	KBB
Percent Sand in Soil	KBB
Frequency of Pine	KBB
Total Precipitation	KBB, PT, IB
Proximity to Great Lakes	PT
Proximity to Hydrologic Features[c]	IB
Frequency of Sand - Soil	PT
Slope	PT
Tree Canopy Cover	KBB, PT, IB
Frequency of Upland Mixed Forest	KBB
Frequency of Uplands[d]	IB
Frequency of Well and Moderately Drained Soils	KBB
Frequency of Wetlands[e]	IB

[a]non-vegetated farmland, row crop, and forage crop
[b]elevation was represented by 8 categories ranging from 10-80 where ArcView separated heights by natural breaks ranging between 141-602 m
[c]lakes, rivers, streams, creeks, ditches, drains, and ponds
[d]northern hardwood, oak, mixed upland deciduous, and upland mixed forest
[e]lacustrine, palustrine, and riverine wetlands

species locations to the mean cell values for the entire study area (Hirzel et al. 2002, Hirzel 2004). The larger the absolute value for the marginality coefficients the more the species differs from mean study area conditions for that EGV (Hirzel et al. 2002, Hirzel 2004). If the marginality coefficient is positive it indicates that the species prefers areas with higher cell values for that EGV than the average location in the study area and if the marginality coefficient is negative it indicates the species prefers areas with a lower cell value for that EGV than the average location in the study area (Hirzel et al. 2002, Hirzel 2004). The error term is unknown. Specialization is determined by comparing the variance of cell values associated with known species locations to the variance for the entire study area (Hirzel et al. 2002, Hirzel 2004). The larger the absolute value for specialization coefficients the more the species range is restricted by that EGV (Hirzel et al. 2002). Global marginality, tolerance (inverse of specialization), and specialization values were also calculated for each TES. For more details about how these calculations were completed refer to Hirzel et al. (2002) and Hirzel (2006).

After the ENFA was computed for PT, a large eigenvalue warning was encountered. All eigenvalues must be ≥ 0 in Biomapper and large eigenvalues could be caused when two EGV layers are correlated (Hirzel 2004, 2006). The correlated EGV layers were listed by Biomapper and in an attempt to eliminate this large eigenvalue warning, the elevation and average daily minimum temperature EGV layers were removed from the PT analysis, and the ENFA was recomputed. The elevation layer was correlated with proximity to Great Lakes layer and removed because the distance PT is located from the Great Lakes seemed more biologically important than elevation. The proximity to the Great Lakes seemed more important because most PT grow on the dunes along the shorelines of the Great Lakes (Higman and Penskar 1999, USFWS 2002). Average daily minimum temperature was removed because it was correlated with average daily maximum temperature. The average daily minimum and average daily maximum temperature layers shared a similar spatial pattern, thus average daily minimum temperature was selected to be removed.

Generating the HS Layers for the TES

The next Biomapper step involved computing HS layers for each TES. The medians algorithm was used to compute these layers because it can perform well and provide results in a timely manner (Hirzel and Arlettaz 2003a, b; Hirzel 2004). Details about the median algorithm can be found in Hirzel et al. (2002), Hirzel and Arlettaz (2003a, b), and Hirzel (2004). The number of factors (i.e., created by the ENFA) selected to become factor maps for each TES were determined based on suggestions provided by Biomapper, which uses Mac-Arthur's broken stick distribution (Hirzel et al. 2002, Hirzel and Arlettaz 2003a, Hirzel 2006). Factor maps (i.e., "...a map that summarize all ecogeographical variables according to the score matrix computed by the ENFA." (Hirzel 2004)) were evaluated with the median algorithm to create individual HS layers for each TES. The final HS layer values range from 0-100 where 0 represents less suitable habitat and 100 represents more suitable habitat.

Creation of Two Example HS Layers per Species

Two HS layers were created for each species. One layer represented a conservative reclassification scenario and the other layer represented a liberal reclassification scenario. Under the conservative reclassification scenario any potentially suitable habitat for the TES was identified, while under the liberal reclassification scenario only the most suitable habitat for the TES was identified.

The conservative and liberal HS layers for each species were created in ArcMap through the reclassification process. The conservative HS layers for each TES were reclassified such that HS values of 0 represented unsuitable habitat and HS values from 1-100 represented suitable habitats. The liberal HS layers for each TES were reclassified such that HS values from 0-99 represented unsuitable habitats and HS values of 100 represented suitable habitat. These reclassification scenarios were used during the integration process described later. Emphasis needs to be placed on the fact that these reclassification scenarios were created simply to show how the data could be used and further work is needed to determine the most suitable reclassification scenario for each species.

Biomapper Cross-validation

Cross-validation (CV) is important because it allows the user to determine the usefulness or the predictive power of the model output. The default k-fold CV procedure in Biomapper was used to evaluate the predictive power of the HS layers for each TES (Hirzel 2004). The CV procedure was conducted twice for each TES HS layer once to reflect the conservative scenario and once to reflect the liberal scenario. In the CV procedure KBB and PT species known location data were partitioned into 10 equal-sized subsets, where 9 subsets were used to calibrate an HS layer and the last was used for validation. The IB species known location data were partitioned into 5 equal-sized subsets, where 4 subsets were used to calibrate an HS layer and the last was used for validation. This process was repeated 10 times for KBB and PT and 5 times for IB, each time with a different subset being held out. Resultant CV HS layers were each partitioned into 2 bins, where each bin covered a proportion of the maps' area (A_i) and contained a proportion of the validation cells (N_i) (Hirzel 2004). Two bins were selected to reflect suitable and unsuitable habitat. The bin boundary was set at HS 1 for the CV processes reflecting the conservative reclassification scenario, while the bin boundary was set at HS 100 for the CV processes reflecting the liberal reclassification scenario. From this process, area-adjusted frequencies were calculated for each bin using the equation $F_i = N_i / A_i$, where if all bins have a F_i value of 1 it indicates a random HS map (Hirzel 2004). Models with good predictive power have F_i<1 for low HS and F_i>1 for high HS (Hirzel and Arlettaz 2003a, Hirzel 2004). More details on the CV procedure can be found in Boyce et al. (2002), Hirzel and Arlettaz (2003a), Reutter et al. (2003), and Hirzel (2004).

Before area-adjusted frequency calculations were used to evaluate the models, the predictive power of these models could be evaluated using the absolute validation index (AVI) and contrast validation index (CVI) found in Biomapper (Hirzel 2007) (also calculated during CV procedure). The AVI indicates how well the model performs by determining if TES presence locations are associated with high HS values, while the CVI indicates if the model is predicting better than chance (Hirzel 2007). The AVI score was calculated by computing the proportion of validation raster cells with HS values greater than 50 for each of the 10 partitions (Hirzel and Arlettaz 2003b; Hirzel 2006, 2007). The CVI scores were also computed for each partition, and the CVI values were obtained by subtracting from AVI the proportion of all raster cells with a HS score greater than 50 (Hirzel and Arlettaz 2003b; Hirzel 2006, 2007).

Making the HS Layers for each TES Useable in ArcView or ArcMap

For the HS layer for each TES to be useable for further analysis in GIS software, each layer was individually converted from Idrisi file format to an ESRI raster using DIVA-GIS 5.2 software (Hijmans et al. No Date). Each TES HS layer was imported as an Idrisi file into DIVA-GIS and exported as an ESRI ASCII raster. In ArcView, the ESRI ASCII rasters were imported as an ASCII file with integer cell values.

Integration of TES HS Layers and TCBs

Creation of Pesticide Drift Layer

A pesticide drift layer was created to demonstrate how tart cherry growers could be affecting potential TES suitable habitat near their orchards. Pesticide drift distance was based on pesticide drift studies conducted by the Spray Drift Task Force (1997), which measured pesticide drift up to 549 m (1800 ft) outside an orchard. The Spray Drift Task Force (1997) found that the majority of pesticide drift deposited within 183 m (600 ft). In ArcMap, a 210 m pesticide buffer (i.e., pesticide drift layer) was created around the perimeter of each TCB. A 210 m pesticide drift distance was used in place of 183 m to accommodate the 30 m resolution of TES HS layers. The pesticide drift layer created did not consider wind direction or pesticide application equipment used. Rather the intent was to provide a snapshot in time and a starting point for this process.

Data Integration Process

The data integration process was used to produce data layers (i.e., one each for KBB, PT, and IB) for identifying which tart cherry growers had TES potentially suitable habitat within 210 m of their TCB. In ArcMap each TES HS layer was projected to the Michigan Georef projection and analysis mask and analysis extent was set to the TCB pesticide drift layer. This step reduced the amount of data portrayed for each TES HS layer to only show potential habitat within the pesticide drift layer and ensured that the raster cells aligned. During data integration, each TES HS layer was reclassified. As stated previously for this project, the example HS layers for each TES were reclassified twice, once conservatively and once liberally (see section on Creation of Two Example HS Layers per Species above). Reclassified TES HS potential habitat areas were intersected with the TCB pesticide drift layer and boundaries were dissolved by TCB name. Again, these HS reclassification scenarios are just examples of the outputs that can be derived from the process. Selecting the correct HS reclassification scenario for each species is really important and should be refined in the future based on CV results. However, these HS layers do not represent a failed product rather that more work is needed to refine the proper HS reclassification scenario for each species.

This process resulted in three TES layers (i.e., one for each TES) for each reclassification scenario and a table identifying growers within 210 m of the TES potential habitat. Per reclassification scenario, the three TES layers were condensed into one table to simplify the output. In each condensed table, three new fields were added to represent KBB, PT, and IB potentially suitable habitat. The original TCB and each TES's attribute tables were joined by the TCB name field. All TCBs found to contain a value other than null were selected and given the value 1. A 1 indicates a particular TCB was identified to be within 210 m of TES suitable habitat. The remaining null values were set to equal 0, identifying no TES suitable habitat was within 210 m of the TCB. This process produced two final tables, one for each reclassification scenario, indicating which TCBs are within 210 m of TES potential habitat.

RESULTS

ESC WG

The ESC WG consisted of 17 members and met 4 times over the course of this study (March 2005, July 2005, February 2006, and September 2006). The first ESC WG meeting allowed participants to discuss the USEPA pesticide EUP denial previously described, voice their level of support for the project, and talk about concerns for obtaining spatial location data. At the second meeting, discussions occurred about the results that would be distributed to TCO growers (e.g., map, list of potentially affected TES) from this project and the lack of statewide surveys for TES. The working group also discussed how to obtain TCO spatial data and whether both federal and state listed species should be investigated. It was decided to focus on federally listed species. Topics discussed at the third meeting included initial modeling effort results for KBB, collection of additional TCB spatial location data, priority of TES investigated for the pilot study, and landowner's sensitivity toward the use of predictive models. The fourth meeting covered items related to modeling effort results for KBB and PT. In addition, it was decided to use a generic modeling approach to simulate pesticide drift rather than a site specific pesticide drift model. In place of the site specific pesticide drift model, the ESC WG decided that a layer representing the distance pesticide drifts beyond TCBs would be created as a first step to identify locations where potential interactions could occur. The members also agreed that as the project progresses, a site specific pesticide drift model (e.g., based on grower application equipment, methods, and weather conditions) could be developed to more accurately portray pesticides drifting off site.

Michigan Tart Cherry Spatial Data

Spatial data for 213 TCBs were collected representing 97 different tart cherry growers in Michigan (Table 7). The greatest number of TCB spatial data coordinates were collected from Berrien County (n = 56), while the smallest number was from Ionia, Manistee, and Muskegon Counties each having 1 (Figure 3). The TCB spatial data collected accounted for 5.91% of all tart cherry hectares occurring in Michigan based on 2003 tart cherry total hectares.

Michigan TES Spatial Data

I examined three federally listed TES, the endangered KBB and IB and the threatened PT. With the data available from MNFI, the KBB had the greatest number of documented presence locations throughout Michigan while the IB had the fewest (Table 8). The number of cells represented presence locations after each species layer was converted to raster. Some of the PT and IB polygon presence locations may have been point presence locations that were buffered by MNFI, thus not all locations within the buffer are a "true" presence location, but each cell within these polygons was used as a presence location after it was converted to raster. The PT had the greatest number of cells throughout Michigan, while the IB had the fewest (Table 8). The PT likely had more presence location cells than the KBB because the PT presence locations tended to encompass larger areas.

Biomapper Processes

EGV Layers

Twenty-one EGV layers were created. The KBB required 11 EGV layers, while PT and IB required 6 and 10, respectively (Table 6).

Table 7. Total number of tart cherry blocks (TCB) with total, mean, maximum, and minimum hectares (ha) for all TCBs included in this study.

Number of TCBs	Total TCB Hectares (ha)	% of all TCB ha in MI	Mean TCB Size (ha)	Maximum TCB Size (ha)	Minimum TCB Size (ha)
213	765.10	5.91	3.59	27.44	0.14

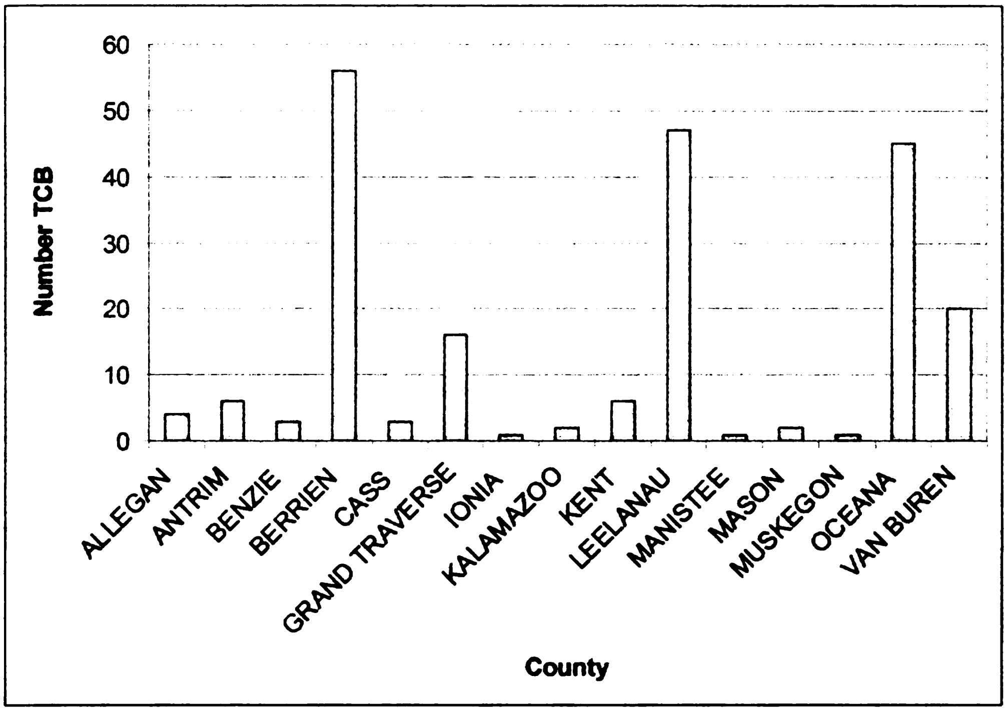


Fig. 3. Number of tart cherry blocks (TCB) by county considered in this study.

Table 8. Number of presence locations (i.e., polygons, points) used for Karner blue butterfly (KBB), Pitcher's thistle (PT), and Indiana bat (IB). The mean, maximum, and minimum areas for presence locations whose last observation date occurred after 1990 are also listed. Total number of cells represents presence locations after each species layer was converted to raster.

Spp.	Total Presence Locations (#polygons, # points)	Total Presence Location Size (ha)	Mean Presence Location Size (ha)	Max. Presence Location Size (ha)	Min. Presence Location Size (ha)	Total Presence Location Cells
KBB	175, 0	1,975.54	11.29	120.53	0.01	21,907
PT	115, 0	2,760.06	24.00	643.99	0.13	28,722
IB	6, 18	—*	—	—	—	14,180

* indicate lacking area measurements because also contained point data

Verification

Verification is done to identify EGV layers that could be problematic during analysis procedures. Aspects of verification included identifying problematic EGV layers and identifying discrepancies between EGV layers. Problematic layers included those that did not contain a wide range of values and, as a result, resembled a boolean map surface (i.e., 0 and 1 values) (Hirzel 2004, 2006). Problematic layers were not found for the KBB. The PT verification process identified the sand - soil layer as "not continuous enough," and the IB verification process identified the proximity to hydrologic features layer as "not continuous enough." While problematic, I continued to use these layers as per Hirzel's (2006) instructions where the first option is to continue to include them through the ENFA process.

The EGV layers for KBB produced 1,372,366 discrepancies (0.3%), while PT and IB had 17,201,514 (3.4%) and 30,745,825 (6.0%) discrepancies, respectively. The discrepancies for all three TES EGV layers occurred primarily along the edges of Michigan's state boundary. For the KBB EGV layers the percent sand in soil and well- and moderately-drained soils led to the majority of discrepancies along the interior boundary of the state. For PT and IB EGV layers, a large portion of the discrepancies were likely caused by the elevation layer that had a 3.2 km buffer around the perimeter of the state. This would cause a problem because the buffer exceeded the spatial extent of other EGV layers, making those overlapping areas incompatible. The elevation layer did not cause many discrepancies for the KBB EGV layers because the buffer, which came with the original layer, had been removed. The reason the buffer from the original layer was not removed from the elevation layer for the IB and PT is not known, but may have been due to a different GIS process being used. The frequency of wetlands layer may have also contributed to the large number of IB EGV layer discrepancies as it also exceeded the spatial extent of the other EGV layers. After examining discrepancy layers, I allowed the Biomapper software to disregard cells with discrepancies.

ENFA

The ENFA produced 11 factors for the KBB. The first factor explains marginality and a portion of specialization (i.e., 20%), while the remaining factors explain more of the specialization (Table 9). The marginality coefficients indicated that KBB locations were associated with higher cell values on frequency of oak, percent sand in soils, total precipitation, frequency of herbaceous openlands, frequency of low density trees, frequency of well-to moderately-drained soils, frequency of upland mixed forests, frequency of pine, and frequency of aspen than the average location in Michigan (Table 9). KBB locations were also associated with lower elevations than the average location in Michigan (Table 9). KBB locations displayed no difference from average locations in Michigan for tree canopy cover (Table 9). Frequency of well-and moderately-drained soils in Specialization 1 and total precipitation in Specialization 2 are important factors for specialization (Table 9).

A large eigenvalue was encountered after performing the ENFA for PT and can be caused by correlated EGV layers (Hirzel 2006). Two pairs of EGV layers were found to be correlated: elevation and proximity to Great Lakes, average daily minimum temperature and average daily maximum temperature. The elevation and average daily minimum temperature EGV layers were removed from the analysis, but the large eigenvalue persisted. Large eigenvalues are acceptable when combining multiple factors

Table 9. Ecological Niche Factor Analysis (ENFA) results for Karner blue butterfly (KBB). Column headings indicate the first 8 (out of 11) ecological factors (marginality, specialization 1 through 7), and the percent of specialization explained. Table values include coefficients on the marginality factor (sorted by decreasing absolute value) and specialization coefficients for the ecogeographical variables (EGVs).

Eco. Factors:	Marginality	Spec. 1	Spec. 2	Spec. 3	Spec. 4	Spec. 5	Spec. 6	Spec. 7
Specialization:	(20%)	(22%)	(18%)	(10%)	(8%)	(6%)	(5%)	(4%)
EGVs for the KBB								
Frequency of Oak	0.54	-0.04	0.15	-0.47	-0.55	-0.05	-0.17	0.02
Percent Sand in Soil	0.37	0.19	0.25	-0.18	0.35	0.83	0.20	-0.14
Total Precipitation	0.37	0.46	-0.69	-0.08	0.24	-0.15	-0.08	0.19
Frequency of Herbaceous Openlands	0.37	-0.27	0.37	0.13	0.35	-0.49	0.12	-0.01
Frequency of Low Density Trees	0.33	0.02	-0.07	0.04	0.10	-0.16	0.59	-0.15
Elevation	-0.26	-0.26	-0.25	-0.61	0.11	-0.04	0.26	-0.10
Frequency of Well and Mod. Drained Soils	0.22	-0.74	-0.45	0.57	-0.46	-0.01	0.04	0.07
Frequency of Upland Mixed Forests	0.19	-0.04	-0.11	0.11	0.23	-0.06	-0.51	-0.54
Frequency of Pine	0.13	-0.02	0.15	-0.06	-0.08	0.02	0.07	0.61
Frequency of Aspen	0.10	-0.20	0.04	-0.10	0.14	0.05	-0.46	0.05
Tree Canopy Cover	0.00	-0.13	-0.02	-0.01	0.30	-0.13	0.11	0.49

(Yu No Date), thus the analysis was continued with a large eigenvalue. Six factors were produced after the ENFA for PT. The marginality coefficients imply PT locations were associated with higher values on frequency of sand - soil and slope than the average location in Michigan (Table 10). PT locations were closer to the Great Lakes, had lower average daily maximum temperatures, received less total precipitation, and had less tree canopy cover than the average Michigan location (Table 10). The majority of the specialization (i.e., 99%) is explained by the marginality factor for PT (Table 10).

The ENFA produced 10 factors for the IB. Marginality coefficients showed that IB locations were associated with higher cell values of total precipitation, frequency of croplands, frequency of hydrologic features, average daily maximum and average daily minimum temperatures, and elevation than the average location in Michigan (Table 11). IB locations are also closer to hydrologic features and were associated with lower cell values for frequency of uplands and tree canopy cover than the average location in Michigan (Table 11). The IB displayed little difference from average locations in Michigan for frequency of wetlands. Proximity to hydrologic features in Specialization 1 and average daily minimum temperature in Specialization 2 were driving factors for specialization (Table 11).

The ENFA produced global marginality values greater than 1 for the KBB (1.441), PT (2.128), and IB (1.528) indicating that their habitats associated with known locations differed from the average conditions available in Michigan (Hirzel et al. 2002, Hirzel 2006). The ENFA also produced global tolerance and global specialization (inverse of global tolerance) values closer to 1 for the KBB (T=0.617, S=1.621) suggesting it is specialized and can live in a wide range of habitat conditions (Hirzel

Table 10. Ecological Niche Factor Analysis (ENFA) results for Pitcher's thistle (PT). Column headings indicate the first 4 (out of 6) ecological factors (marginality, specialization 1-3) and the percent of specialization explained. Table values include coefficients on the marginality factor (sorted by decreasing absolute value) and specialization coefficients for the ecogeographical variables (EGVs).

Eco. Factors: / Specialization: / EGVs for the PT	Marginality (99%)	Spec. 1 (0%)	Spec. 2 (0%)	Spec. 3 (0%)
Frequency of Sand – Soil	0.83	-0.07	0.05	0.24
Proximity to Great Lakes	-0.46	-0.43	0.39	0.66
Average Daily Maximum Temp.	-0.23	0.81	0.12	-0.28
Total Precipitation	-0.14	-0.38	-0.82	0.10
Slope	0.13	-0.09	0.40	-0.12
Tree Canopy Cover	-0.10	-0.06	0.06	-0.64

Table 11. Ecological Niche Factor Analysis (ENFA) results for the Indiana bat (IB). Column headings indicate the first 3 (out of 10) ecological factors (marginality, specialization 1-2) and the percent of specialization explained. Table values include coefficients on the marginality factor (sorted by decreasing absolute value) and specialization coefficients for the ecogeographical variables (EGVs).

Eco. Factors: / Specialization: / EGVs for the IB	Marginality (67%)	Spec. 1 (16%)	Spec. 2 (10%)
Total Precipitation	0.59	0.06	0.14
Average Daily Maximum Temperatures	0.41	0.01	-0.47
Average Daily Minimum Temperatures	0.39	-0.28	0.72
Frequency of Croplands	0.39	-0.10	-0.36
Frequency of Hydrologic Features	0.22	0.00	-0.01
Frequency of Uplands	-0.22	0.00	-0.05
Tree Canopy Cover	-0.22	0.00	0.00
Elevation	0.13	0.00	-0.32
Proximity to Hydrologic Features	-0.11	-0.95	-0.08
Frequency of Wetlands	0.04	0.00	-0.05

2006). Global tolerance values range from 0 to 1 (with 0 representing a more specialized species using a narrow range of habitat conditions and 1 representing a species that can live in a wider range of habitat conditions) and global specialization (inverse of global tolerance) values range from 1 to infinity (Hirzel 2006). Global tolerance values for PT (0.073) and IB (0.035) were near 0 and specialization values for PT (13.750) and IB (28.858) were greater than 1 suggesting they are more specialized and live in a more narrow range of habitat conditions (Hirzel et al. 2002, Hirzel 2006).

TES HS Layers

Based on Mac-Arthur's broken stick distribution (Hirzel et al. 2002; Hirzel and Arlettaz 2003a, b; Hirzel 2006) eight factor maps were created and used to compute the final HS layer for the KBB; four factor maps were created for PT and used to compute the final HS layer for PT; and three factor maps were created to compute the final HS layer for IB. Each derived HS map for the three TES ranged in values from 0-100, where 0 represents less suitable habitat and 100 signifies more suitable habitat.

A majority of the more suitable habitat for the KBB occurs in the west central part of Michigan's Lower Peninsula, while the Upper Peninsula and eastern Lower Peninsula tend to contain the less suitable habitat (Figure 4). The HS map for PT identifies the majority of more suitable habitat occurring along the coasts of Michigan, although a small amount of the more suitable habitat does occur within the interior of Michigan (Figure 5). The majority of less suitable habitat for the PT occurs in the interior (Figure 5). The HS map for the IB shows the bulk of more suitable habitat occurring in the southern part of the Lower Peninsula (Figure 6). The Upper Peninsula and northern Lower Peninsula contain the majority of the less suitable habitat for the IB (Figure 6).

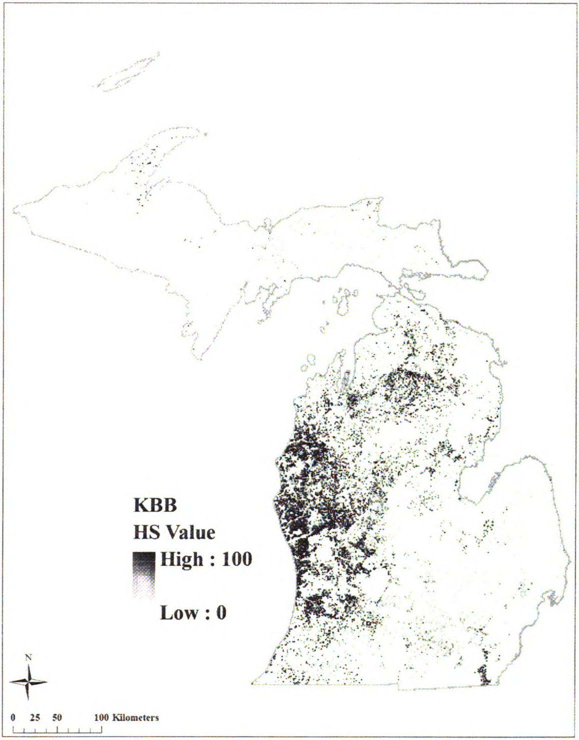


Fig. 4. Habitat-suitability (HS) map for Karner blue butterfly (KBB). HS values range from 0 (i.e., less suitable, lighter areas) to 100 (i.e., more suitable, darker areas). The gray outline represents the Michigan state boundary.

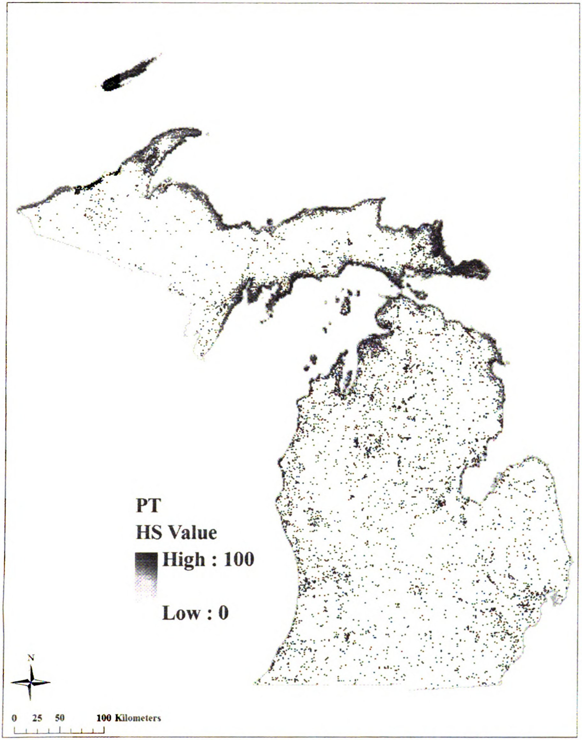


Fig. 5. Habitat-suitability (HS) map for Pitcher's thistle (PT). HS values range from 0 (i.e., less suitable, lighter areas) to 100 (i.e., more suitable, darker areas). The gray outline represents the Michigan state boundary.

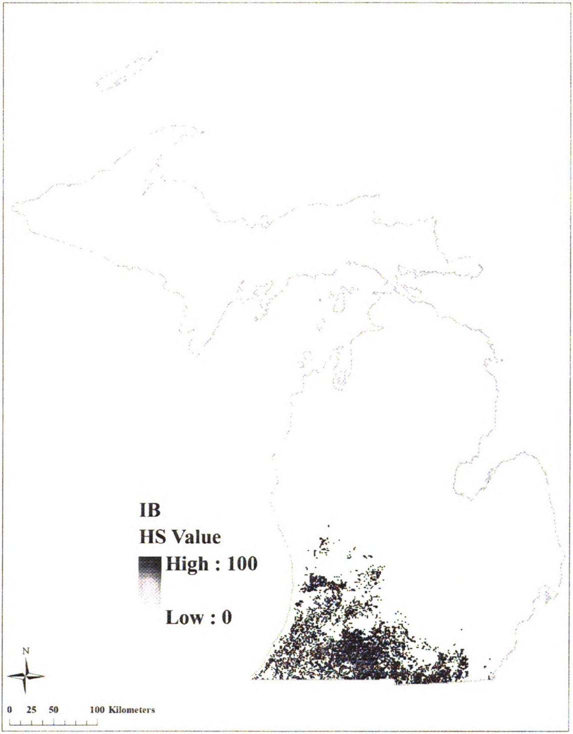


Fig. 6. Habitat-suitability (HS) map for Indiana bat (IB). HS values range from 0 (i.e., less suitable, lighter areas) to 100 (i.e., more suitable, darker areas). The gray outline represents the Michigan state boundary.

CV

The k-fold CV results for the KBB generated a mean AVI of 0.80454 (SD 0.00861) and a mean CVI of 0.75321 (SD 0.00856). Useful models should have an AVI score >0.75 while models not trustworthy have AVI scores <0.50 (Hirzel 2007). A useful model should also have a CVI score >0.30 (Hirzel 2007) while models with a contrast index of 0 indicates performance comparable to random (Hirzel and Arlettaz 2003b). The CV results for PT and IB indicated that the models performed acceptably as PT had a mean AVI of 0.658 (SD 0.012) and a mean CVI of 0.64004 (SD 0.01248) and the IB had a mean AVI of 0.64267 (SD 0.01562) and a mean CVI of 0.60837 (SD 0.01562).

The area-adjusted frequency graph for the conservatively reclassified KBB layer included data for only one bin, even though 2 bins had been specified (Figure 7). The summary of CV results for conservatively reclassified KBB displayed data for 2 bins where the mean area-adjusted frequency was listed as 0 (SD 0) for bin 1, and for bin 2, the mean area-adjusted frequency value was 1 (SD 0). Based on the area-adjusted frequency graph all of the partitioned area and species validation points are likely included in potentially suitable habitat based on this reclassification scenario. When the HS bin boundary was placed at HS 2, the area-adjusted frequency graph displayed two bins with bin 1 having area-adjusted frequency values of 0 and bin 2 having area-adjusted frequency values of 1. These outputs matched the area-adjusted frequencies listed in the summary of CV results. When the bin boundary was placed at HS 20 the area-adjusted frequencies for bin 1 were below 1 and for bin 2 above 1. This suggests a bin boundary at HS 20 could be a better model because bin 1 had an area-adjusted frequency less than1 and bin 2 had an area-adjusted frequency greater than 1. These results suggest that an

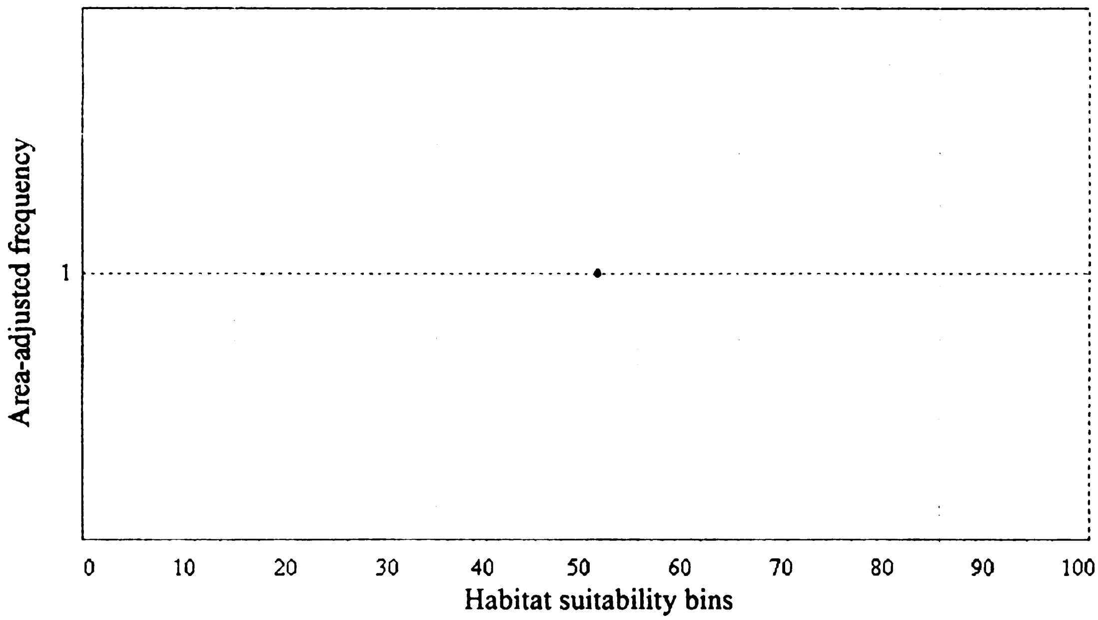


Fig. 7. Area-adjusted frequency graph for the conservatively reclassified KBB. The horizontal dashed line at 1 on the y-axis represents the random frequency line. The area-adjusted frequency values are along the y-axis. The dot indicates partition values where the first set of dots represents the results for bin 1 and the second set of dots represents the results for bin 2. This graph only shows dots representing results for 1 bin's partitions.

acceptable model could be achieved by using a different reclassification scenario.

Based on the mean area-adjusted frequencies for bins 1 and 2 of the liberally reclassified KBB layer (Table 12), the values suggested this was not a useful model. Upon examination of the summary of CV results and area-adjusted frequency graph (Figure 8), the values in bin 1 were close to 1 and the majority of values in bin 2 were closer to 0 (i.e., only one number was above 1), and bin 2 also had a very high standard deviation, all of which suggest it was not a useful model. The area-adjusted frequency values listed in the summary of CV results did not match the values on the area-adjusted frequency graph. The reason for this is unknown, but is thought to be a Biomapper error. With such an extreme HS bin boundary, the line continues off the graph and may cause problems when the data is being recorded. When all lines end on the graph the values match those recorded in the summary of CV results. It is unknown how this error may have affected other CV results, but the AVI and CVI values were the same for both the conservative and liberal scenarios.

Based on the mean area-adjusted frequencies for bins 1 and 2 of the conservatively reclassified PT layer (Table 12), this was a useful model. This is also true for the liberally reclassified PT layer, conservatively reclassified IB layer, and liberally reclassified IB layer (Table 12). For the conservatively and liberally reclassified PT and IB area-adjusted frequency graphs refer to Figures 9 and 10, respectively. Again, like with the liberally reclassified KBB layer, the liberally reclassified PT and IB layers each had area-adjusted frequency values listed in the summary of CV results that did not match the values on their area-adjusted frequency graphs. The reason for this is thought to be an error in the Biomapper software when the values were recorded in the summary

Table 12. Mean area-adjusted frequency values resulting from the cross-validation (CV) process. Table values represent the mean area-adjusted frequencies for bins 1 and 2 for each species reclassification scenario, while the values in parenthesis represent the standard deviation.

Species and Reclass. Scenario	Bin 1	Bin 2
Conservative KBB	*	1.00 (0.00)
Liberal KBB	0.99982 (0.00058)	66.59 (210.59)
Conservative PT	0.00019 (0.00024)	4.62 (0.0009)
Liberal PT	0.57626 (0.01417)	85.98 (2.8418)
Conservative IB	0.00000 (0.00)	2.20 (0.005)
Liberal IB	0.36617 (0.015504)	51.54 (1.24)

*No bin was shown on the area-adjusted frequency graph

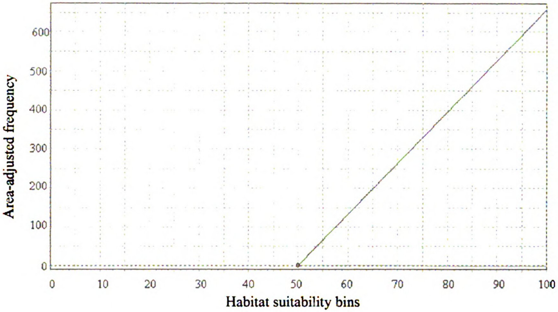


Fig. 8. Area-adjusted frequency graph for the liberally reclassified KBB. The 1 on the y-axis represents the random frequency line. Area-adjusted frequency values are indicated on the y-axis. The dots indicate partition values where the first set of dots represents the results for bin 1 and the second set of dots (not shown, but close to where the solid lines run off the graph at <1 and 650) represents the results for bin 2.

(a)

(b)

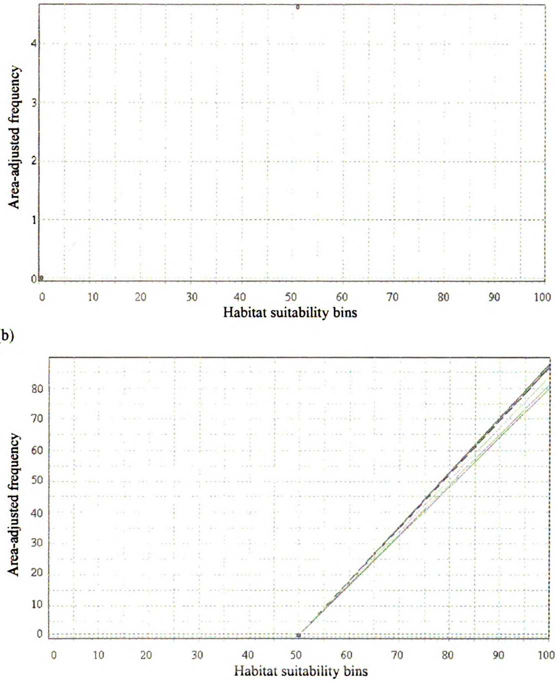
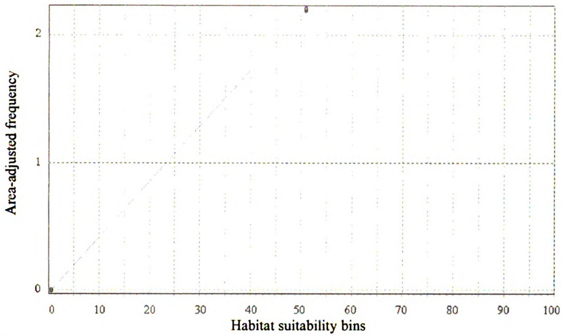


Fig. 9. Area-adjusted frequency graphs for PT where a) represents the conservative reclassification scenario and b) represents the liberal reclassification scenario. The 1 on the y-axis represents the random frequency line. Area-adjusted frequency values are indicated on the y-axis. The dots indicate partition values where the first set of dots represents the results for bin 1 and the second set of dots represents the results for bin 2.

(a)



(b)

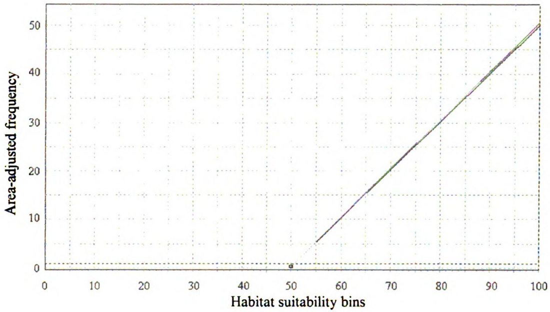


Fig. 10. Area-adjusted frequency graphs for IB where a) represents the conservative reclassification scenario and b) represents the liberal reclassification scenario. The 1 on the y-axis represents the random frequency line. Area-adjusted frequency values are indicated on the y-axis. The dots indicate partition values where the first set of dots represents the results for bin 1 and the second set of dots represents the results for bin 2.

of CV results they were placed in the wrong location.

At the time the reclassification scenarios were selected the CV process had not been performed on any of the TES models, therefore, it was unknown that the KBB models were not useful models. The best set of resulting maps for the KBB were not determined for this portion of the project, but can be completed in the future. Again, the focus of this portion of the pilot project was on creating the process. In the future the CV process should be completed after the species HS layer has been created to determine if the model is useful and to select the best reclassification scenario.

Integration of TES HS Layers, TCBs, and Pesticide Drift Layer

The conservatively reclassified KBB HS map (i.e., HS values of 0 represent unsuitable habitat and HS values from 1-100 represent suitable habitat) shows the majority of the state as suitable habitat (Figure 11a). The liberally reclassified KBB HS map (i.e., HS values from 0-99 represent unsuitable habitat and HS values of 100 represent suitable habitat) shows suitable habitat occurring in the west central Lower Peninsula (Figure 11b). The conservatively reclassified PT HS map (i.e., HS values of 0 represent unsuitable habitat and HS values from 1-100 represent suitable habitat) shows high concentrations of suitable habitat occurring along the shorelines in Michigan (Figure 12a). There is some suitable habitat in the interior portions of the state also (Figure 12a). The liberally reclassified PT HS map (i.e., HS values from 0-99 represent unsuitable habitat and HS values of 100 represent suitable habitat) shows the majority of the state as being unsuitable with suitable habitat occurring along the coastlines (Figure 12b). The conservatively reclassified IB HS map (i.e., HS values of 0 represent unsuitable habitat and HS values from 1-100 represent suitable habitat) shows most of the suitable habitat

(a) (b)

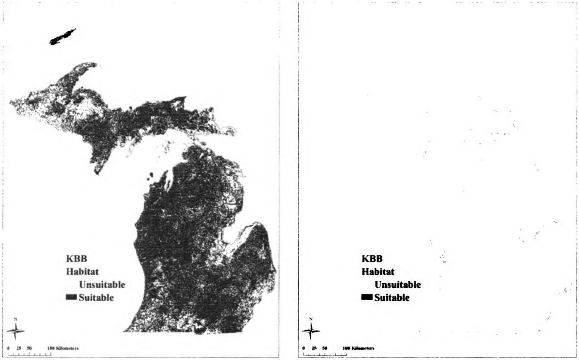


Fig. 11. Reclassified habitat-suitability (HS) maps for Karner blue butterfly (KBB), where (a) represents the conservative reclassification scenario and (b) represents the liberal reclassification scenario. In both maps unsuitable habitat is white and suitable habitat is black. In the conservative HS map (a) unsuitable habitat represents HS values of 0 and suitable habitat represents HS values from 1-100. In the liberal HS map (b) unsuitable habitat represents HS values from 0-99 and suitable habitat represents HS values of 100. The gray outline represents the Michigan state boundary.

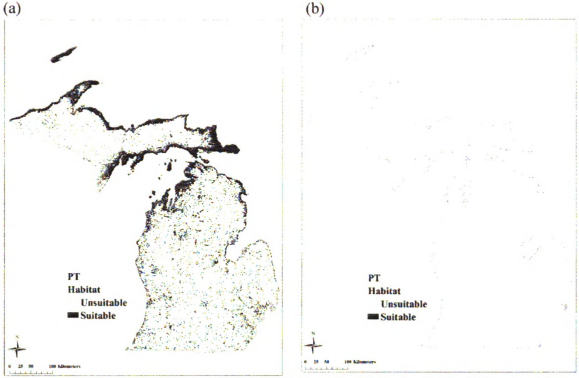


Fig. 12. Reclassified habitat-suitability (HS) maps for Pitcher's thistle (PT), where (a) represents the conservative reclassification scenario and (b) represents the liberal reclassification scenario. In both maps unsuitable habitat is white and suitable habitat is black. In the conservative HS map (a) unsuitable habitat represents HS values of 0 and suitable habitat represents HS values from 1-100. In the liberal HS map (b) unsuitable habitat represents HS values from 0-99 and suitable habitat represents HS values of 100. The gray outline represents the Michigan state boundary.

occurring in the southern Lower Peninsula (Figure 13a). The liberally reclassified IB HS map (i.e., HS values from 0-99 represent unsuitable habitat and HS values of 100 represent suitable habitat) shows suitable habitat occurring in the south central Lower Peninsula (Figure 13b).

When the conservatively reclassified TES HS layers were intersected with the TCBs and the pesticide drift layer, all TCBs were found to be within 210 m (i.e., pesticide drift distance) of potential habitat for at least one TES. One-hundred and twenty seven TCBs (60%) were within 210 m of PT, 201 TCBs (94%) were within 210 m of KBB, and 97 TCBs (46%) were within 210 m of IB. Of the 213 TCBs, 21 TCBs (9.9%) intersected only one TES potential habitat, 172 TCBs (80.8%) intersected 2 TES potential habitats, and 20 TCBs (9.4%) intersected all 3 TES potential habitats.

When the liberally reclassified TES HS layers were intersected with the TCBs and the pesticide drift layer, 5 TCBs representing 4 tart cherry growers, were found to be within 210 m (i.e., pesticide drift distance) of at least one TES. The KBB suitable habitat was the only TES intersected. The results pertaining to the KBB under both reclassification scenarios should be taken with caution as these were considered to be not useful models by the CV results.

The main focus for this project was developing the process. The process developed does work and portrays a simple interaction occurring. In the future work can be completed (site specific pesticide drift model, useful TES HS models) to enhance the realism for this process.

(a) (b)

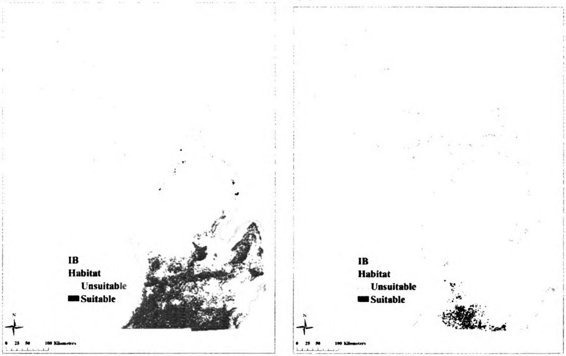


Fig. 13. Reclassified habitat-suitability (HS) maps for Indiana bat (IB), where (a) represents the conservative reclassification scenario and (b) represents the liberal reclassification scenario. In both maps unsuitable habitat is white and suitable habitat is black. In the conservative HS map (a) unsuitable habitat represents HS values of 0 and suitable habitat represents HS values from 1-100. In the liberal HS map (b) unsuitable habitat represents HS values from 0-99 and suitable habitat represents HS values of 100. The gray outline represents the Michigan state boundary.

DISCUSSION

Developing the Process to Unite Groups and Identify Potential Areas of Overlap

ESC WG

The first step in developing a process for uniting TES conservation and commodity production is to involve individuals and groups having concerns or knowledge pertaining to the system under study. This step is important as it brings together groups having an investment in the product and allows them the opportunity to express ideas, fears, hopes, and other comments as the project develops. For this project, this was accomplished by the ESC WG.

A variety of groups (Table 2) were involved with development of this process and helped address issues as they arose throughout the project. One important topic addressed by the ESC WG members included fears about maintaining the privacy of tart cherry grower's information (e.g., names, addresses). As a result of this discussion, steps were taken to protect the tart cherry grower's identities. This was accomplished by employing NASS employees (through CIAB) to collect and record TCB spatial data. CIAB subsequently removed grower names and addresses from the spatial data sheets before sending them to MSU.

Another theme discussed by ESC WG members was the potential reaction of tart cherry growers to the use of predictive HS maps to represent potential habitat that might support a TES location. Some ESC WG members were concerned about how tart cherry growers would respond because predictive maps do not necessarily represent the actual presence location of a TES, but instead specify potentially suitable habitat for a species in particular locations. While this is a valid concern, using current TES spatial data was not possible because a statewide survey for TES does not exist. If the TES presence spatial data had been used, less the modeling effort, results from the project would have misrepresented potential and highly probable areas of overlap between TES and commodities. Potential and highly probable areas of overlap may not have been represented or shown in the resulting maps because the current data does not represent a complete survey for all TES occurrences. An important part of this process was to help commodity producers identify those areas of potential TES concern and as such, the HS maps offer a first approximation that should be verified with field surveys. Aerial photos could also be used to determine if the landscape surrounding a TCO is suitable for the TES.

Another topic discussed by the ESC WG members was design of the pesticide drift model. At the onset of the project, it was proposed that a highly specialized (i.e., parameterized for weather, topography, spray apparatus) pesticide drift model be built in a GIS to represent pesticides moving beyond TCO/TCB boundaries. ESC WG members decided as part of this pilot project a site specific drift model would be premature, because the overall integration process was still being developed. In place of a specialized pesticide drift model a 210 m buffer (pesticide drift layer) was created around every TCB as a first attempt to represent pesticide drift distances and its potential influence on TES potential habitat. The ESC WG members also agreed that in future stages of this project, a site specific pesticide drift model (e.g., variable parameters to represent weather conditions during pesticide application, pesticide application equipment efficiency, and pesticide types applied) would become important as it would allow a more accurate representation of pesticide drift.

The previous examples demonstrate how ESC WG members and researchers worked collaboratively to develop the project. As this project evolves, the hope is that the ESC WG will continue to convene meetings and play a role in refinements, including expansion to other commodities.

Tart Cherry Spatial Data

Tart cherries were chosen as the commodity for this pilot project for many reasons. First, the majority of TCOs occur in the western counties of Michigan's Lower Peninsula, creating a more concentrated spatial extent. Second, TCO owners have shown dedication and interest in protecting the environment by employing IPM practices (Tart Cherry Pest Management Strategic Plan 2000, 2006). Finally, the tart cherry commodity was selected because it had recently been affected by denial of a pesticide EUP due to the presence of TES (pers. comm., M. Whalon, pers. comm., P. Korson, Project GREEEN 2005).

The process for collecting spatial data on TCB locations worked effectively. It is important to recognize that these spatial data represent TCBs that occur within TCOs. This is relevant because TCBs were overlaid with the TES potential habitat and not the TCO boundaries. Actual TCO perimeters are not known and thus individual TCBs could actually occur in the middle of an orchard. In the future, when perimeters of most TCBs have been mapped it would be interesting to combine each grower's TCBs into one and create the actual TCO boundary polygons to observe how they overlay with TES potential habitat.

While only a small percentage of tart cherry acreage was sampled it was sufficient to demonstrate how this process would work. In the future as NASS workers become familiar with GPS units it would be more efficient if TCB spatial coordinates were saved on the GPS units' memory cards, which could be sent in for direct download onto the computer. This would reduce the risk for errors in data collection and data entry and reduce the amount of time spent entering data.

The majority of TCB locations were used throughout this project, but a few had to be discarded as they appeared abnormal (i.e., overlapping boundaries, one corner extended abnormally from others) when portrayed in GIS. Abnormal TCBs were sent back to CIAB and a few were fixed by NASS employees returning to the TCB and re-recording the corner coordinates; most abnormalities could not be corrected and these TCBs were eventually discarded. In the future, continual collection of TCB locations is important to increase the total number of TCBs and tart cherry growers in the sample. This will provide more growers the opportunity to know if they could potentially be impacting TES or TES habitat. Another potential option to increase the TCO/TCB sample size would be the generation of a NASS cropland dataset for Michigan. This dataset would likely allow for identification of TCOs/TCBs in Michigan and is currently under construction at MSU's Land Policy Institute.

Biomapper Challenges and Solutions

Biomapper software was selected for this project for multiple reasons. First, Biomapper software functions using only presence locational data for a species, which is the type of data Michigan has for its TES. Second, Biomapper is a free software that is readily accessible for download over the internet, thus if this process is to expand to other states or commodities they will be able to obtain this modeling software.

While Biomapper is a useful modeling software program, challenges were encountered while preparing spatial layers for or using layers in this software. One of the first challenges was in converting ESRI rasters to Idrisi file format. Different methods were explored, including GridConverter and ESRI extensions (Hirzel 2006). The ESRI extensions did not work, likely because ESRI rasters were too large for the program. The GridConverter worked and was the method employed here.

Challenges were also encountered when importing EGV layers into the Biomapper software. After the first EGV layer was added and the second EGV layer was in the process of being added, an error occurred stating they could not be overlaid. To bring all EGV layers into Biomapper software without this error, the EGV layers had their analysis extent and analysis mask set to its corresponding species boolean layer in ArcMap. This ensured that the EGV layers covered the same spatial extent and the raster cells lined up. This should not be viewed as a "problem", but rather a good error check to make sure the data layers are aligned.

During the verification process discrepancies between EGV layers and potential problematic EGV layers were identified (Hirzel 2004, 2006). Discrepancies must be corrected because they can cause raster cells in the EGV layers to be eliminated from the analysis (Hirzel 2006). Several EGV layers contained discrepancies and were reclassified. For example, reclassifying the temperature layer to different units (e.g., Celsius to Fahrenheit) allowed for cell values to range between 0 and 250, which were byte layers with a background value of 255 (Hirzel 2006). The elevation layer presented a different scenario and was reclassified with values between 10-80, where 10 represented low elevations (i.e., 141-201 m) and 80 represented high elevations (i.e., 458-602 m). Converting the elevation layer to different units (e.g., meters to miles) did not work because it led to values of 255 which led to discrepancies. In the future, a different method could be attempted to eliminate discrepancies between EGV layers that would not require reclassifying the EGV layer values or converting the EGV layer values to different units. Instead of getting all EGV layers into the byte data type, maybe EGV layers could be integer or real data types or the background values could be changed for EGV maps. For other concerns, challenges, and solutions refer to Appendix N.

TES, EGVs, and GIS Spatial Data Matters

Spatial locations for TES were obtained from MNFI, which is a positive sighting organization that surveys for rare organisms where they have received funding to search for them (pers. comm., E. Schools). This project required a statewide perspective of TES to help identify potential interactions with TCBs. The statewide perspective was needed because there were no guarantees that MNFI sampled TES in areas near TCBs. To overcome this shortcoming, a predictive model was used to create statewide HS maps.

Creation of the HS maps involved using species presence data, and EGVs reflecting each species' habitat requirements and needs. The EGV layers were created by and obtained from different entities (Table 3, 4, 5) often with different spatial resolutions. For example, the total precipitation layer had a spatial resolution of 800 m while the tree canopy cover layer had a spatial resolution of 30 m. Because 30 m was chosen as the analysis resolution, the 800 m raster had to be resampled to a 30 m cell size. The resampling process did not cause a loss of information, but also did not improve the quality of the total precipitation layer. Thus any map that used the total precipitation layer only has a useful accuracy of 800 m.

The majority of EGV layers required to model TES habitat were identified and obtained directly for the project. However, several unavailable data layers would have greatly enhanced the quality of final HS maps. For example, lupine is the food source for KBB larvae (Rabe 2001, USFWS 2003) thus a layer representing the statewide distribution of lupine would have been valuable. A layer representing lupine was available, but it was not completed at a statewide level (pers. comm., E. Schools). In the future a statewide lupine survey could be completed and this layer could be incorporated into the KBB habitat model. A more practical alternative would be to use lupine presence locations to build a predictive model in support of the KBB assessment.

Along with locating spatial data layers, at the heart of GIS technology lies the concern for spatial data accuracy. The outputs produced by GIS are a product of the data input, therefore if data input to a GIS are not accurate the output will reflect that quality. In many cases extremely accurate spatial data are not available thus the spatial data currently available had to be used. In the future when new or more accurate spatial data layers are created these spatial data layers can be substituted and replace the older less accurate spatial data layers used in this modeling process. For example, if new layers are produced that have a higher accuracy or a finer resolution (i.e., 10 m instead of 30 m) than the older layers, these new layers can be replaced within the models and the model outputs updated.

The National Land Cover Dataset 2001 Tree Canopy layer had an attribute accuracy value of 93% (these values were obtained from the original layers metadata).

The IFMAP layer had an overall accuracy value of 88% for major land cover classes, while it had an accuracy of 81% for non-forested classes and 68% for forested classes (Space Imaging 2004). Attribute accuracy values were not able to be determined or located for the remaining original GIS layers.

TES Outputs and HS Layers

The KBB model indicated that their habitat differs from average habitat conditions available in Michigan. Model results suggest that within these habitats KBB can live in a wide range of conditions (based on the global tolerance and specialization values). The model outputs are not biological intuitive as KBB is an endangered species and has specific habitat needs (USFWS 2003). The lack of a lupine layer may have resulted in a more generalized model output, but this is not known for fact. Lupine is a major determinate for KBB presence, and its inclusion could alter the models global tolerance and specialization values. Incorporating a lupine layer into the KBB model might also refine its HS layer to better identify suitable areas.

The final PT HS layer showed highly suitable habitat for PT occurring primarily along the coasts in Michigan, which would be expected as it grows on dunes (USFWS 2002). There were some areas modeled as suitable habitat towards the interior of the state which might not be likely places to encounter PT. These areas may have been identified by the IFMAP frequency of sand - soil layer as this variable tended to occur in these interior areas. Eliminating these suitable areas in the interior part of the state is possible if the PT HS layer is reclassified such that suitable habitat is ≥ 40. Although it is less likely for PT to be occurring in the interior portions of Michigan it would be worth surveying these areas to see if the species occurs there.

The final IB HS layer predicted lower HS values for IB presence locations (i.e., points) found further northeast than the other IB presence locations (i.e., points and polygons). This might be caused by one large IB presence location (i.e., polygon) being located in the south central part of Michigan. This large IB polygon presence location might have been created by MNFI buffering an IB point location, thus not all areas within the polygon are "true" IB presence locations. When the large IB polygon presence location was converted to raster, every 30 m location within the polygon was recorded as a presence location. It would be informative to examine model performance if only point presence locations were used to see how the results would change. The polygon presence locations would not have to be discarded, but a random point could be assigned within each presence polygon to represent it rather than the full polygon.

The CV results for the conservatively reclassified HS layer for KBB suggested that all the area and species validation points were within suitable habitat based on this reclassification scenario as only 1 bin was shown (i.e., random map). As the HS boundary is increased (i.e., HS 20, HS 50) the area-adjusted frequencies for bin 1 remain under 1 and for bin 2 the area-adjusted frequencies increase to values greater than 1 suggesting they could be useful models. This suggests that the conservative reclassification scenario for KBB HS layer is not the best, but the reclassification scenario could be changed (i.e., HS values from 0-20 represent unsuitable habitat and HS values from 21-100 represent suitable habitat) to create a better model. The conservative reclassification scenario for KBB was still used for this project as demonstration of the process.

The CV results for the liberally reclassified HS layer for KBB suggest that it was not a useful model. When the HS bin boundary was placed at HS 99, bin 1 had area-adjusted frequency values slightly less than one while bin 2 had values greater than 1 (i.e., ranging between 20 and 90), suggesting this could be a better model, although variation was still high. Again, the reclassification scenario can be changed in the future.

The area-adjusted frequencies listed in the summary of CV results for the liberally reclassified HS maps for KBB, PT, and IB did not match the values shown on the area-adjusted frequency graphs. This problem did not occur with the conservatively reclassified PT or IB HS maps as the area-adjusted frequencies shown on the graph matched the list in the summary of CV results. A possible explanation might be that when the Biomapper software was recording the area-adjusted frequency values shown in the area-adjusted frequency graph it was not functioning properly and the values were not recorded in the correct locations in the summary of CV results. With the extreme HS bin boundary (i.e., HS value 100) the lines extended past the boundary of the graph and the area-adjusted frequencies were recorded in incorrect locations in the summary of CV results. When the HS bin boundary was placed at HS 99 for the IB, the lines on the graph moved, but were not yet completely contained on the graph, and in the summary of CV results, the area-adjusted frequencies still were not in the correct positions, but they did move. When the HS bin boundary was placed at HS 98 for the IB, all lines ended on the graph, and the area-adjusted frequencies were located in the correct place in the summary of CV results. This suggests that it was just an issue with the recording process. The newest version of the Biomapper software has developed a new CV result which is less sensitive to the number of bins selected and where the bin boundaries are placed (Hirzel et al. 2006). This new method could be used to gain a better understanding and refine the current CV results and TES reclassification scenarios (Hirzel et al. 2006).

To better represent locations of more suitable habitat for the TES, changing the reclassification classes should be attempted (e.g., unsuitable habitat represented by HS values from 0-9 and suitable habitat represented by HS values from 10-100). The two extreme scenarios used in this project were a first attempt to include as much and as little potentially suitable habitat as possible. Hirzel et al. (2006) lists a variety of methods on how to reclassify HS layers in a meaningful way based on examining the curves produced in the CV process.

The species models created for this portion of the pilot project should not be viewed as definitive or the final models that should be used to base decisions on. My goal was to show a process not develop the "best" habitat models. If this process is deemed a good one, then the investment in creating really good habitat models should be made.

Identification of Potentially Overlapping TES Habitat and TCBs

Again, I want to stress that this is a crude first approximation for identifying potential areas of overlap between TES habitat and TCBs. Based on results produced in GIS all TCBs examined were found to be within at least 210 m of one TES under the most conservative habitat identification scenario. Most TCBs were found intersecting KBB suitable habitat as its modeled habitats were most widespread. It is important to also remember that the KBB model is flawed and not useful when reclassified under this scenario, thus these numbers are likely incorrect. PT had the second greatest number of TCBs intersecting suitable habitat, although this number was likely artificially high because some TCBs identified occurred away from the coasts and more towards the interior of the state where PT is not likely to occur. This artifact is probably caused by the areas identified as suitable habitat towards the interior part of state because of the frequency of sand – soil layer. The IB had the fewest TCBs intersecting its suitable habitat. This result is logical as the majority of IB modeled suitable habitat occurs in the southern portion of the state and does not continue into northwestern Michigan where some TCB locations tend to occur. Four TCBs were identified in the northern Lower Peninsula as intersecting IB suitable habitat.

Based on results produced in GIS under the most liberal habitat reclassification scenario, only 4 tart cherry growers and 5 TCBs were within 210 m of suitable TES habitat. The KBB was the only TES found to intersect with TCBs when this reclassification scenario was used. These interactions occurred in the northwest and west central parts of Oceana County, but again should be interpreted with caution because the KBB models were found not useful under the extreme reclassification scenarios used. This variability in results stresses the importance of habitat model reclassification on implementing this process. Accurate habitat models are critical to implementation of the commodity-TES process.

The pesticide drift layer used in this pilot project allowed for creation of a zone of interaction (i.e., area of overlap) that portrayed pesticides leaving the TCBs. While this layer served its purpose there are concerns regarding its use that could be addressed in the future if site specific pesticide drift models are created. Currently the pesticide drift layer surrounds each TCB uniformly. To better reflect pesticide drift it would be important to include dominant wind direction as a factor influencing how pesticides may be deposited.

The pesticide drift layer also does not allow for differences in pesticide application equipment and this could potentially influence how much pesticide drifts from the site. Growers use pesticide application equipment that varies in its accuracy and thus pesticides could drift varying distances depending on equipment. This factor was not portrayed when using the fixed width buffer for each TCB.

While the results for the conservative scenario most likely over predicts the actual number of TES-TCB interactions, results for the liberal interpretation most likely under predicts the actual number of interactions. These results, however, are an important place to start. The conservative scenario portrays the largest amount of potential habitat and it is likely that fewer positive TES occurrences would be found in the areas with very low HS values. In contrast, the liberal scenario portrays only the best habitats, but positive TES occurrences would most likely occur in more marginal habitat. Biomapper software does offer a process and the associated statistics for measuring model performance under different reclassification scenarios. In the future as the process continues to be refined, Hirzel et al. (2006) suggests ways to reclassify HS maps based on CV curve outputs. For example, reclassifying the HS values (e.g., HS values from 0-10 represent unsuitable habitat and HS values from 11-100 represent suitable habitat) could be a better model and reduce the amount of habitat put into the suitable category possibly lowering the number of tart cherry growers found within 210 m of TES suitable habitat.

Develop Process to Aid in Decisions

The processes outlined by this pilot research project can be useful for other commodities and states that want to take proactive measures to protect commodity production, private landowners, and TES. These types of proactive processes could become increasingly important as the human population continues to increase and consume more land that was once used by these species, thus increasing the potential for TES interactions.

This project has the potential to help commodity producers and government agencies make more informed decisions with regards to TES and pesticide use. The process could aid commodity producers by informing them of potential TES locations based on modeled habitat and help evaluate pesticide application options. For example, if a grower is identified as overlapping with potential TES habitat they could change their pesticide application methods or timing or put in a hedgerow or buffer area to reduce the potential for interaction between the pesticide and TES. Government agencies might also benefit from the process described herein because it would allow them to base their pesticide use or TES protection decisions or survey requirements on more resolute spatial relationships between TES potential habitat and TCBs. Under this process decisions are based on a more biologically meaningful rather than political (i.e., county) scale.

Future work to improve the process is still needed. Current TES models should be updated (e.g., using newest version of Biomapper software for CV processes, changing the reclassification scenarios to better represent areas of suitable habitat for each TES, incorporating new TES presence locations, adding new and refining currently used EGV layers). Alternative habitat modeling approaches could be examined to determine which habitat model is best suited for this process (e.g., MaxEnt). HS maps should be created for other TES and the process expanded to include state listed species. The amount of TCB (and other commodity) spatial data should increase allowing for more comprehensive evaluations of potential TES interactions. The TCBs identified as potentially affecting TES should be overlaid with aerial photos to help verify if TES habitat actually occurs. Results from the habitat models should be used to identify priority areas to search for TES search areas. A more site specific pesticide drift model should be parameterized to reflect weather conditions and each TCB grower's pesticide application methods (e.g., equipment, pesticide type). Refinement of the pesticide drift model would provide a more accurate representation of pesticide drift behavior thereby improving identification of TES-commodity production interactions. The TES phenologies could also be examined to determine if TES are likely to be present when pesticides are applied.

Once these steps have occurred narrowing where potential interactions may be occurring, then meetings with the individual grower's identified to potential be affecting TES/TES habitat can be scheduled and mitigation procedures (i.e., prevent TES and pesticide interactions) discussed. Finally, this process could expand to other commodities in the state and throughout the nation. For this project to expand to other commodities it would require TES spatial data and commodity spatial data for those of interest to be known along with EGVs for the entire study area. Again, I want to re-stress that my work was simply to develop the process and not to ensure that the "best" models were developed. As such my work needs refinement before this is implemented at operational scales. The utility of my project was to show some of the capabilities that can be brought to bare on the issue of TES conservation and commodity production.

APPENDICES

APPENDIX A:

Michigan Georef

In ArcMap, the KBB and PT species rasters were projected to Michigan Georef with the nearest sampling method. The projection file for each species raster was edited such that the Azimuth at center of projection was 337.25556 instead of 337 15 20.016. This is an error that occurs when working with rasters in ArcMap and if not fixed can cause a 25 km shift between rasters (pers. comm., E. Schools). The project file was checked for this error for all rasters created in ArcMap throughout this project.

APPENDIX B:

Initial GIS Processes for IFMAP

Important land cover types were extracted from the 2001 30 m Integrated Forest Monitoring Assessment and Prescription (IFMAP/GAP) Lower and Upper Peninsula land cover images. The Upper and Lower Peninsula IFMAP images were each converted into rasters in ArcView at a 30 m cell size. A 30 m cell size was selected for all rasters because it was the smallest resolution of the EGV rasters. In ArcMap, each IFMAP raster was projected into Michigan Georef with the nearest sampling method at a 30 m cell size. When working with rasters in ArcMap, the projection file has to be checked after each process and the azimuth corrected or the rasters would not line up correctly (pers. comm., E. Schools) and this was completed for all rasters created.

Each IFMAP raster was processed to show only data in the state of Michigan boundary. In ArcMap, the Upper and Lower Peninsula IFMAP rasters were each masked with county rasters. For both the Upper and Lower Peninsulas, IFMAP raster's analysis mask was set to its corresponding county raster while the extent was snapped to its corresponding IFMAP raster. This process was carried out as IFMAP rasters were evaluated.

Once the above steps were completed, the Upper and Lower Peninsula IFMAP rasters were merged in ArcMap with the extent snapped to the Lower Peninsula IFMAP raster because the TCBs are located in the Lower Peninsula and this area was more important for the raster cells to remain in their current location. The merging process caused the Upper Peninsula IFMAP raster to shift in location, but ESRI examined the data and determined that the Upper and Lower Peninsula IFMAP rasters had different starting extents and thus one of the rasters would have to shift slightly. This did not affect the modeling process.

APPENDIX C:

Initial GIS Processes for Total Precipitation

Data pertaining to total precipitation amounts in Michigan was portrayed by the 800 m total precipitation (normals; total precipitation, 30-year (1971-2000 average)) raster. The total precipitation layer was in mm. This layer was imported into ArcView as an ASCII raster where its values were set to integer to convert cell values to whole numbers and not decimals (i.e., not floating point). In ArcMap the total precipitation ASCII projection was defined as WGS72 as this was the datum specified in the metadata (PRISM Group 2006a). It was projected as a raster to WGS72 and bilinearly resampled with a cell size of 0.008333, which is the resolution in decimal degree units for the total precipitation layer (PRISM Group 2006a). Next, the total precipitation raster was projected to Michigan Georef and bilinearly resampled with a cell size of 2,088. The 2,088 cell size was automatically used by ArcMap and kept to ensure the process worked. In ArcInfo a value attribute table (VAT) was built for the total precipitation raster to be able to examine raster cell values. In ArcView the total precipitation raster was clipped by a complete Michigan county shapefile to eliminate data for the rest of the US. The total precipitation raster was converted to a shapefile for further clipping and converted back to a raster at a 30 m cell size. The total precipitation raster values were converted from mm to inches. This was done to avoid discrepancies in Biomapper software as many of the EGV rasters created for this project when converted to Idrisi file format were byte maps. Byte maps values range between 0-255 (i.e., 255 is background value), and with total precipitation amounts in mm the values exceeded this range and led to discrepancies.

APPENDIX D:

Initial GIS Processes for Percent Sand in Soil

The percent of sand in soil was portrayed by the 1 km Conus - Soil, Sand, Silt, Clay fraction layer. The percent sand in soil layer included data for the entire US and was converted to show only data from Michigan. This layer consisted of soil samples taken at 11 different ground depths where the percent of sand, silt, and clay were recorded (Miller and White 1998). The soils attribute table was edited and a total sand field was added to create a new value scheme for this layer that would show the amount of sand found in each soil type. The total sand field was populated by taking the sum of the first 9 of the 11 sand values measurements taken at different levels below ground to determine the amount of sand in each soil. The last two sand value measurements underground were not used as the majority of them were 0. A new percent sand field was added to the attribute table and was filled by values when the total sand field values were divided by 900 and multiplied by 100 to get the percent of sand in each layer. The value in the total sand field was divided by 900 as 9 sand values were summed for each layer and the sand value could reach 100 at each of the 9 distances where it was sampled. This was completed to obtain values between 0-255 and not lead to discrepancies in Biomapper software. In ArcMap the percent sand in soils raster was projected to Michigan Georef and resampled in a bilinear method.

APPENDIX E:

Initial GIS Processes for Tree Canopy Cover

The amount of tree canopy cover was portrayed by the 30 m National Land Cover Database 2001 forest canopy image. In ArcMap, the tree canopy cover layer was projected as a raster with a bilinear sampling method and converted from an image to a raster with a 30 m cell size. The tree canopy cover raster was masked to a blank Michigan county raster (i.e., all values 0) to show only data occurring within Michigan.

APPENDIX F:

Initial GIS Processes for Texture and Drainage

Well and moderately drained soils were extracted from the texture and drainage shapefile. This shapefile consisted of three drainage categories including well and moderately drained, somewhat poorly drained, and very poorly drained soils. As the shapefile contained qualitative names it had to be reclassified such that the names were changed to numbers (e.g., 3 = well and moderately drained, 2 = somewhat poorly drained, 1 = poorly drained). This step had to be completed to create values that could be selected to produce a boolean map. Next, the well and moderately drained soils shapefile was converted to raster and in ArcMap projected to Michigan Georef using the nearest sampling method. The nearest sampling method was chosen as it performs well for categorical data as it does not change the cell value (ArcMap help file).

APPENDIX G:

Initial GIS Processes for National Elevation Dataset

Elevation was portrayed by the 30 m national elevation dataset layer. The values for this raster were in m multiplied by 1000. A 3.2 km buffer occurred around the perimeter of the state. To obtain raster values ranging from 0-255, the raster was classified into 8 natural break groups and reclassified to get low elevation values represented by 10 and high elevations represented by 80 with the other elevations ranging between them (i.e., 10 represents 141-201 m).

APPENDIX H:

Initial GIS Processes for Slope

The slope was also derived from the national elevation dataset. In ArcMap's spatial analyst surface analysis a raster representing slope was created for the entire state of Michigan. The output was represented in degrees. The z-factor was set to 0.001 as the original national elevation dataset raster was in m multiplied by 1000. The cell size was set to 30 m. This process created a floating point raster, which was converted in ArcView to an integer raster.

APPENDIX I:

Initial GIS Processes for Average Daily Maximum and Average Daily Minimum Temperatures

Average daily maximum temperatures were portrayed by the 800 m average daily maximum temperature (normals; average daily maximum temperature, 30-year (1971-2000) average) layer and average daily minimum temperatures were portrayed by the 800 m average daily minimum temperature (normals; average daily minimum temperature, 30-year (1971 - 2000) average) layer. Both layers had temperature values recorded in degrees Celsius. This layer was manipulated in a similar fashion to the total precipitation layer (Appendix C) as it was obtained from the same source. Each layer was imported into ArcView as an ASCII raster and the values were set to integer. In ArcMap, the ASCII projection was defined to WGS72 and then projected as a raster to WGS72 where it was bilinearly resampled with a cell size of 0.008333. Next, each raster was projected to Michigan Georef and bilinearly resampled with a cell size of 2,088. In ArcView, each raster was clipped by a complete Michigan county shapefile to eliminate extraneous data while further clipping occurred after they were converted to a shapefile. Each shapefile was then converted back to a raster with a 30 m cell size. The attribute table was edited to get values between 0-255 and this was accomplished by converting the current degrees Celsius values into degrees Fahrenheit.

APPENDIX J:

Initial GIS Processes for Proximity to Great Lakes

A Great Lakes shapefile was used to create a layer portraying proximity to Great Lakes. The five Great Lakes were selected and converted to a 30 m raster where all the Great Lakes had a common value of 1. In ArcMap the Euclidean distance from the Great Lakes to inner areas of Michigan was determined, thus creating the proximity to Great Lakes raster. This raster was converted from a floating point raster to an integer raster and masked to a blank Michigan county raster to display only values occurring in Michigan. In ArcInfo a VAT was built to view the distance values associated with this raster. To obtain the distance values of this raster between 0-255 (byte values) in Arc the values were converted from m to mi.

APPENDIX K:

Initial GIS Processes for Wetlands

Wetlands were portrayed by the National Wetlands Inventory raster (created at 1:24,000 resolution). The wetlands layer consisted of 5 types of systems including lacustrine wetlands, palustrine wetlands, riverine wetlands, uplands, and unknown. The attribute table was edited such that each type of system had a numeric code associated with it. The raster was reclassified such that all wetlands' (i.e., lacustrine, palustrine, riverine) new values were set to 1 and the unknown and uplands were 0 creating a boolean raster.

APPENDIX L:

Initial GIS Processes for Hydrologic Features

Hydrologic features were portrayed by the Michigan geographic framework hydrology shapefile (created at 1:24,000 resolution). The hydrologic features layer consisted of rivers, lakes, ponds, creeks, ditches, drains, and streams. The attribute table of the hydrologic features shapefile was edited such that each hydrologic feature had a common value of 1. In ArcView the hydrologic features shapefile was converted to a 30 m raster and reclassified in ArcMap to get all hydrologic features represented by 1 and all other values represented by 0, creating a boolean raster. It was masked to a blank Michigan county raster to show only data within Michigan.

APPENDIX M:

Initial GIS Processes for Proximity to Hydrologic Features

A proximity to hydrologic features layer was created. In ArcMap the hydrologic features boolean raster (created in Appendix L) was reclassified such that all hydrologic features were a 1 and all other were no data instead of 0. The other values had to be no data for the Euclidean distant analysis to function. Next, the raster was processed through the Euclidean distance analysis at a 30 m raster cell size. In ArcView it was clipped by a Michigan county shapefile to show only data for Michigan and in ArcInfo the values were converted from m to km to get values between 0-255.

APPENDIX N:

Biomapper Challenges and Solutions

Computing times and computer space and memory became factors when using Biomapper software. Depending on the algorithm selected, the amount of time to compute the HS map and CV results can vary (Hirzel and Arlettaz 2003a, b). For example, I attempted to use the distance geometric mean algorithm to create an HS map, but after 24 hours the process had barely progressed. In place of the distance geometric mean algorithm I chose the medians algorithm which for the KBB took 4.5 hours to produce the HS map and 8.5 hours for the CV procedure. These times exclude time spent gathering data, preparing data for use, verifying EGV layers, and normalizing EGV layers.

The median and distance geometric mean algorithms were both tried as the HS algorithm. The medians algorithm makes an assumption about the species distribution (i.e., "...that the best habitat is at the median of the species distribution on each factor, and that these distributions are symmetrical." (Hirzel 2004)), but was computed for all 3 TES as it can provide results in a timely manner (Hirzel and Arlettaz 2003a, b; Hirzel 2004). The distance geometric means algorithm was tried because the assumption about species distribution is not made (Hirzel 2004), but was not selected because it performed too slowly. Studies by Hirzel and Arlettaz (2003a, b) also noted the distance geometric mean, distance harmonic mean, and minimum distance algorithms had slower computing times than the medians. Hirzel and Arlettaz (2003b) suggested that since the median algorithm can be computed faster it could be used first and then the data can be examined to determine if the distance geometric mean needs to be used. In the future it might be useful to attempt the distance geometric mean algorithm again to observe differences between output HS maps.

The output files created were also large and for one complete TES project the files could consume 20 to 30 GB of hard drive space on the computer. The use of external hard drives becomes important in this case for storage and backup copies.

I also experienced "out of memory" errors during the CV process and this was an inconvenience as many times it takes 30 minutes per partition and each time the error occurs the process starts over from the beginning. In many situations to get the CV process to successfully finish I would have to reduce the number of partitions (e.g., 5 partitions instead of 10 partitions). This made the goal of achieving CV results with 10 partitions, the number recommended by Hirzel (2006), hard to achieve and in some cases it could not be reached. The other option provided by Hirzel (2006) to decide on the number of partitions was Hubert's rule, which bases its result on the number of EGV layers used (Hirzel 2006). The KBB and PT were cross-validated using 10 partitions, but the IB was cross-validated with only 5 partitions. The five partitions were between the 10 partitions recommended by Hirzel (2006) and the 4 partitions recommended by Hubert's rule. I have found no way to get around the "out of memory" error that occurs. Recently a newer version of the Biomapper software was made available and the CV methods are one of the main differences between these two versions and should be looked at in the future.

LITERATURE CITED

LITERATURE CITED

Boyce, M. S., P. R. Vernier, S. E. Nielson, and F. K. A. Schmiegelow. 2002. Evaluating resource selection functions. Ecological Modelling 157: 281-300.

Callahan, E. V., R. D. Drobney, and R. L. Clawson. 1997. Selection of summer roosting sites by Indiana bats (Myotis sodalis) in Missouri. Journal of Mammalogy 78: 818-825.

Carroll, M. S., C. W. McKetta, K. A. Blatner, and C. Schallau. 1999. A response to "Forty years of spotted owls? A longitudinal analysis of logging industry job losses." Sociological Perspectives 42: 325-333.

Clark, B. K., J. B. Bowles, and B. S. Clark. 1987. Summer status of the endangered Indiana bat in Iowa. American Midland Naturalist 118: 32-39.

Clark D. R., Jr., C. M. Bunck, E. Cromatrie, and R. K. LaVal. 1983. Year and age effects on residues of dieldrin and heptachlor in dead gray bats, Franklin County, Missouri-1976, 1977, and 1978. Environmental Toxicology and Chemistry 2: 387-393.

Clark, D. R., Jr., R. K. LaVal, and D. M. Swineford. 1978. Dieldrin-induced mortality in an endangered species, the gray bat (Myotis grisescens). Science 199: 1357-1359.

Clawson, R. L., and D. R. Clark, Jr. 1989. Pesticide contamination of endangered gray bats and their food base in Boone County, Missouri, 1982. Bulletin of Environmental Contamination and Toxicology 42: 431-437.

Engler, R., A. Guisan, and L. Rechsteiner. 2004. An improved approach for predicting the distribution of rare and endangered species from occurrence and pseudo-absence data. Journal of Applied Ecology 41: 263-274.

Environmental Systems Research Institute, Inc. [ESRI]. 1997. ESRI shapefile technical description: an ESRI white paper—July 1998. <www.esri.com/library/whitepapers/pdfs/shapefile.pdf>. Accessed 11 May 2007.

Farmer, A. H., B. S. Cade, and D. F. Stauffer. 2002. Evaluation of a habitat suitability index model for the Indiana bat. Pages 172-179 *in* Proceedings of the Indiana bat: biology and management of an endangered species. Bat Conservation International, Austin, Texas, USA.

Freudenburg, W. R., L. J. Wilson, and D. J. O'Leary. 1998. Forty years of spotted owls? A longitudinal analysis of logging industry job losses. Sociological Perspectives 41: 1-26.

Guisan A., and N. E. Zimmermann. 2000. Predictive habitat distribution models in ecology. Ecological Modelling 135: 147-186.

Hardy-Short, D. C., and C. B. Short. 2000. Science, economics, and rhetoric: environmental advocacy and the wolf reintroduction debate, 1987-1999. Pages 65-72 *in* USDA Forest Serve Proceedings RMRS-P-15-VOL-2.

Herms, C. P., D. G. McCullough, L.S. Baue, R. A. Haack, D. L. Miller, and N. R. Dubois. 1997. Susceptibility of the endangered Karner blue butterfly (Lepidoptera: lycaenidae) to *bacillus thuringiensis* var. *kurstaki* used for gypsy moth suppression in Michigan. The Great Lakes Entomologist 30: 125-141.

Higman, P. J., and M. R. Penskar. 1999. Special plant abstract for *Cirsium pitcheri*. Michigan Natural Features Inventory, Lansing, Michigan, USA. < http://web4.msue.msu.edu/mnfi/pub/abstracts.cfm#Plants>. Accessed 1 March 2006.

Hijmans, R. J., L. Guarino, A. Jarvis, R. O'Brien, and P. Mathur. No Date. DIVA-GIS 5.2. International Potato Center and International Plant Genetic Resources Institute, Lima, Peru. <http://www.diva-gis.org/>.

Hirzel A. H. 2004. BioMapper 3 user's manual. Lab. of Conservation Biology, Department of Ecology and Evolution, University of Lausanne, Switzerland. < http://www.unil.ch/biomapper>.

Hirzel, A. H. 2006. BioMapper - frequently asked questions version 22.02.2006. < http://www2.unil.ch/biomapper/faq.html>. Accessed 3 April 2006.

Hirzel, A. H. 2007. Evaluation. <http://biomapper.wikispaces.com/Evaluation>. Accessed 28 February 2007.

Hirzel, A. H., G. LeLay, V. Helfer, C. Randin, and A. Guisan. 2006. Evaluating the ability of habitat suitability models to predict species presences. Ecological Modelling 199: 142-152.

Hirzel, A. H., J. Hausser, D. Chessel, and N. Perrin. 2002. Ecological-niche factor analysis: how to compute habitat-suitability maps without absence data? Ecology 83: 2027-2036.

Hirzel, A. H., J. Hausser, and N. Perrin. 2004. Biomapper 3.1. Lab. of Conservation Biology, Department of Ecology and Evolution, University of Lausanne, Switzerland. < http://www.unil.ch/biomapper>.

Hirzel, A .H., and R. Arlettaz. 2003a. Environmental-envelope based habitat-suitability models. Pages 67-76 *in* 1st Conference on Resource Selection by Animals (B.F.J. Manly, ed.). Omnipress, Laramie, Wyoming, USA.

Hirzel, A. H., and R. Arlettaz. 2003b. Modeling habitat suitability for complex species distributions by environmental-distance geometric mean. Environmental Management 32: 614-623.

Hirzel, A. H., V. Helfer, and F. Metral. 2001. Assessing habitat-suitability models with a virtual species. Ecological Modelling 145: 111-121.

Humphrey, S. R., A. R. Richter, and J. B. Cope. 1977. Summer habitat and ecology of the endangered Indiana bat, Myotis sodalis. Journal of Mammalogy 58: 334-346.

Kurta, A., K. J. Williams, and R. Mies. 1996. Ecological, behavioral, and thermal observations of a peripheral population of Indiana bats (*Myotis sodalis*). Pages 102-117 *in* Bats and Forests (R. M. R. Barclay and R. M. Brigham, eds.). Research Branch, Ministry of Forests, Province of British Columbia, Victoria, British Columbia.

Kurta, A., J. Caryl, and T. Lipps. 1997. Bats and Tippy Dam: species composition, seasonal use, and environmental parameters. Michigan Academician XXIX: 473-490.

Kurta, A., and H. Rice. 2002. Ecology and management of the Indiana bat in Michigan. Michigan Academician XXXIV: 175-190.

Kurta, A., S. W. Murray, and D. H. Miller. 2002. Roost selection and movements across the summer landscape. Pages 118-129 *in* the Indiana bat: biology and management of an endangered species (A. Kurta and J. Kennedy, eds.). Bat Conservation International, Austin, Texas, USA.

Michigan Center for Geographic Information. 2006. Michigan geographic framework: state of Michigan: Hydro, version 6b. Michigan Center for Geographic Information. < http://www.mcgi.state.mi.us/mgdl/?action=thm>.

Michigan Department of Natural Resources, Forest, Mineral and Fire Management Division [MDNR, Forest, Mineral and Fire Management Division]. 2003. IFMAP/GAP lower and upper peninsula land cover. Michigan Center for Geographic Information. < http://www.mcgi.state.mi.us/mgdl/?action=thm>.

Michigan Fruit Districts, Michigan fruit inventory 2003-2004: all fruits [Michigan Fruit Districts]. No Date. < www.nass.usda.gov/mi/mi_fruit04/allfruit.PDF>. Accessed 15 December 2006.

Miller, D. A., and R. A. White. 1998. A conterminous United States multi-layer soil characteristics data set for regional climate and hydrology modeling: sand, silt, clay fraction. Earth Interactions. <http://EarthInteractions.org>.

Olmstead, C. W. 1956. American orchard and vineyard regions. Economic Geography 32: 189-236.

O'Shea T. J., and D.R. Clark, Jr. 2002. An overview of contaminant in bats with special reference to insecticides and the Indiana bat. Pages 237-253 *in* the Indiana bat: biology and management of an endangered species, (A. Kurta and J. Kennedy, eds). Bat Conservation International, Austin, Texas, USA.

Pollack, S., and A. Perez. 2006. Fruit and tree nut outlook FTS-323. US Department of Agriculture, Electronic Outlook Report from the Economic Research Service. < www.ers.usda.gov/Publications/FTS/2006/07Jul/FTS323.pdf>. Accessed 27 September 2006.

Pope, R., S. Brown, and J. Ellerhoff. 1998. Why do farmers use pesticides? Iowa State University: University Extension, Ames, Iowa, USA.

PRISM Group. 2006a. Precipitation (normals): total precipitation (30-year average, annual 1971-2000; created 16 June 2006). Oregon State University. <http://www.prismclimate.org>.

PRISM Group. 2006b. Maximum temperature (normals): average daily maximum temperature (30-year average, annual 1971-2000; created 28 June 2006). Oregon State University. <http://www.prismclimate.org>.

PRISM Group. 2006c. Minimum temperature (normals): average daily minimum temperature (30-year average, annual 1971-2000; created 28 June 2006). Oregon State University. <http://www.prismclimate.org>.

Project GREEEN. 2005. Partnering with growers, industry to protect endangered species. Challenges...innovations...advancements...growth. Michigan State University, East Lansing, Michigan, USA. < http://www.greeen.msu.edu/2005_Annual_REPORT.pdf>. Accessed 26 February 2007.

Rabe, M. L. 2001. Special animal abstract for *Lycaeides melissa samuelis* (Karner blue). Michigan Natural Features Inventory, Lansing, Michigan, USA. < http://web4.msue.msu.edu/mnfi/pub/abstracts.cfm >. Accessed 9 March 2006.

Ragsdale, N. N. 1999. The role of pesticides in agricultural crop protection. Annals of the New York Academy of Sciences 894: 199-205.

Reichel, W. L., S. K. Schmeling, E. Cromartie, T. E. Kaiser, A. J. Krynitsky, T. G. Lamont, B. M. Mulhern, R. M. Mulhern, R. M. Prouty, C. J. Stafford, and D. M. Swineford. 1984. Pesticide, PCB, and lead residues and necropsy data for bald eagles from 32 states - 1978-81. Environmental Monitoring and Assessment 4: 395-403.

Reutter, B. A., V. Helfer, A. H. Hirzel, and P. Vogel. 2003. Modeling habitat-suitability using museum collections: an example with three sympatric *Apodemus* species from the Alps. Journal of Biogeography 30: 581-590.

Scharpf, C. 2001. Farmers vs. fish: the battle of the Rio Grande silvery minnow. American Currents 27: 8-12.

Space Imaging. 2004. Review of remote sensing technologies used in the IFMAP project: final report. Ann Arbor, Michigan, USA.

Spray Drift Task Force. 1997. A summary of airblast application studies. < http://www.agdrift.com/Text%20pages/Pub_PDF.htm>. Accessed 8 November 2005.

Tart Cherry Integrated Orchard Management. 2006. About the project. < http://www.ipm.msu.edu/tcabout.htm>. Accessed 20 October 2006.

Tart Cherry Pest Management Strategic Plan. 2000. Tart cherry pest management in the future: development of a strategic plan. <http://pestdata.ncsu.edu/pmsp/pdf/mitartcherry.pdf>. Accessed 23 June 2005.

Tart Cherry Pest Management Strategic Plan. 2006. Tart cherry pest management in the future: development of a strategic plan. <www.ipmcenters.org/pmsp/pdf/MITartCherry2.pdf>. Accessed 8 May 2007.

US Environmental Protection Agency [USEPA]. 1972. DDT ban takes effect; EPA press release. US Environmental Protection Agency. < http://www.epa.gov/history/topics/ddt/01.htm>. Accessed 30 April 2007.

US Environmental Protection Agency [USEPA]. 2001. Tart cherry initial benefits assessment for azinphos-methyl and phosmet. Office of Prevention, Pesticides and Toxic Substances. < www.epa.gov/pesticides/op/phosmet/bead_Cherry_Tart1.pdf>. Accessed 20 October 2006.

US Environmental Protection Agency [USEPA]. 2006. What is a pesticide? US Environmental Protection Agency. <www.epa.gov/pesticides/about/index.htm>. Accessed 8 November 2006.

US Environmental Protection Agency [USEPA]. 2007. Aldrin/Dieldrin. US Environmental Protection Agency. < http://earth1.epa.gov/oppt/pbt/pubs/aldrin.htm>. Accessed 30 April 2007.

US Fish and Wildlife Service, National Wetlands Inventory [USFWS]. 1979-1994. National wetlands inventory. US Fish and Wildlife Service, National Wetlands Inventory.

US Fish and Wildlife Service [USFWS]. 1983. Northern states bald eagle recovery plan. US Fish and Wildlife Service, Fort Snelling, Minnesota, USA.

US Fish and Wildlife Service [USFWS]. 1996. The endangered species act: history and evolution of the endangered species act of 1973, including its relationship to CITES. US Fish and Wildlife Service. <http://www.fws.gov/endangered/esasum.html>. Accessed 27 July 2005.

US Fish and Wildlife Service [USFWS]. 1999. Agency draft Indiana bat (*Myotis sodalis*) revised recovery plan. US Fish and Wildlife Service, Fort Snelling, Minnesota, USA.

US Fish and Wildlife Service [USFWS]. 2002. Pitcher's thistle (*Cirsium pitcheri*) recovery plan. US Fish and Wildlife Service, Fort Snelling, Minnesota, USA.

US Fish and Wildlife Service [USFWS]. 2003. Final recovery plan for the Karner blue butterfly (*Lycaeides melissa samuelis)*. US Fish and Wildlife Service, Fort Snelling, Minnesota, USA.

US Fish and Wildlife Service [USFWS]. 2006. Bald Eagle: recovery, biologue, bald eagle (*Haliaeetus leucocephalus*). US Fish and Wildlife Service. < http://www.fws.gov/midwest/eagle/recovery/biologue.html>. Accessed 16 March 2007.

US Geological Survey, EROS Data Center [USGS]. 1999. National elevation dataset. US Geological Survey.

US Geological Survey [USGS]. 2003. National land cover database zone 60 tree canopy layer, edition 1.0. US Geological Survey. <http://www.mrlc.gov/mrlc2k_nlcd.asp>.

Whalon, M. E., B. J. Jacobson, S. D. Rawlins, D. Ricks, and S. M. Swinton. 1999. Agriculture impact of the sudden elimination of key pesticides under the food quality protection act. Council for Agricultural Science and Technology: Issue Paper 11: 1-14.

Wiemeyer, S. N., T. G. Lamont, C. M. Bunck, C. R. Sindelar, F. J. Gramlich, J. D. Fraser, and M. A. Byrd. 1984. Organochlorine pesticide, polychlorobiphenyl, and mercury residues in bald eagle eggs—1969-79—and their relationship to shell thinning and reproduction. Archives of Environmental Contamination and Toxicology 13: 529-549.

Yu, C. H. No date. Gabriel biplot for principle component analysis/factor analysis. <http://www.amstat.org/publications/jse/v10n1/yu/biplot.html>. Accessed 28 February 2007.

Zaniewski, A. E., A. Lehmann, and J. McC. Overton. 2002. Predicting species spatial distribution using presence-only data: a case study of native New Zealand ferns. Ecological Modelling 157: 261-280.