Invasive species in Iowa's woodlands: using volunteers and remote sensing as tools for research

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Invasive species in Iowa’s woodlands:
Using volunteers and remote sensing as tools for research

by

Christopher Wilson Evans

A thesis submitted to the graduate faculty
In partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Forestry (Forest Biology)

Program of Study Committee:
Heidi Asbjornsen (Major Professor)
Janette Thompson
Kirk Moloney

Iowa State University
Ames, Iowa
2004
This is to certify that the master's thesis of

Christopher Wilson Evans

has met the thesis requirements of Iowa State University

Signatures have been redacted for privacy
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Abstract

This thesis consists of two papers that focus on woodland invasive species in Iowa. The first paper presents a new method for using volunteers to collect data concerning the distribution and abundance of invasive species. The benefits of this method, such as increased ability to efficiently survey large areas and private lands, are identified and addressed. Limitations of the method, including surveyor bias, misidentification, and the lack of an area-based measurement, are also dealt with. The volunteer-collected data is compared to expert-collected data (the experts being state foresters and university employees) and a bias in regard to site selection was found. Despite the potential limitations, the method proves to be a useful tool for managers and researchers, and volunteer-collected data appears to be a viable option when funding and time limitations prevents experts from collecting the necessary data.

The second paper explores the relationship between landscape characteristics, such as perimeter:area ratio and connectivity, and invasive species presence and abundance. Parcels of public woodlands throughout the state of Iowa were sampled for invasive species presence and abundance. Locations were mapped and, using GIS technologies, landscape characteristics were quantified. Based upon the results, no trends or relationships were evident. These results could indicate a lack of any relationship, but it is also possible that the absence of significant results could be due to a small sample size or a lack of sites representing the full spectrum of fragmentation (no or few relatively intact sites were sampled).

Both papers are attempts to use tools (volunteers in the first and remote sensing in the second) that allow managers and researchers to study invasive species on a large scale that
otherwise time or expense would otherwise prohibit. Further development of both
techniques could greatly advance the fields of invasion ecology and land management.
Chapter 1: General Introduction and Literature Review

Introduction:

Invasive species are among the most serious ecological threats today (Vitousek et al. 1996 and Wallner 1996). An invasive species is defined as an organism that is not native to the ecosystem and has the potential to cause economic and ecological damage (National Invasive Species Council 2001). Even though some studies have experimentally demonstrated negative impacts of invasive species (Gorchov 2003, Collier 2002, and Gould and Gorchov 2000), much of the suspected negative impacts are based on anecdotal, observational, or qualitative evidence (Blossey 1999). In addition, data documenting the distribution and abundance of invasive species are either absent or based largely on personal observations (Eiswerth and van Kooten 2002). The paucity of available knowledge limits the ability of land managers and researchers to develop and implement effective control measures (Blossey 1999). It also leads to difficulties in convincing funding agents and policymakers that a need exists to prioritize research on and control of the spread and persistence of invasive species. In addition, the public remains largely unaware of the ecological and economic impacts of invasive plants (Colton and Alpert 1998).

Many species have invaded Midwestern woodlands, at least in part due to intense disturbance and fragmentation of the native ecosystems since European settlement. Little is known about what ecosystem characteristics co-occur with the presence of invasive species. Spatial arrangement and size of woodland may contribute significantly to the invasibility of the wooded ecosystem. The thesis presented here is divided into two papers. The first paper is focused on the North Central Woodland Invasive Species Inventory, a volunteer-based...
project to survey woodland invasive species. The second paper aims at finding correlations between invasive species abundance and landscape characteristics.

The North Central Woodland Invasive Species Inventory aims to collect scientifically relevant data about the distribution and abundance of invasive species, while increasing public awareness and involvement. The goal of this project is to obtain baseline data about the distribution and abundance of four woodland invasive species throughout Iowa. The species involved are multiflora rose (*Rosa multiflora*), common buckthorn (*Rhamnus cathartica*), bush honeysuckle (*Lonicera tatarica* and *L. maackii*), and garlic mustard (*Alliaria petiolata*). An important secondary goal of the project is to increase public awareness about the problem of invasive species in Iowa. These two goals, combined with the need to survey a large area, led to the use of volunteers to collect the data. The use of volunteers may lead to an increase in misidentification and a bias in site selection. However, without the volunteers, researchers are limited in their ability to effectively sample woodlands across large areas due to funding, personnel, and time restrictions. To limit the amount of time and knowledge necessary to complete a survey, a survey methodology was developed that involved recording simply the presence or absence of each species along a transect. In 2002 a pilot study was initiated in Iowa to develop a methodology which both meets the goals of the project and involves volunteers. This paper presents the process and results of the pilot study, which was conducted throughout 2002 and 2003.

The correlation study, addressed in the second paper, was conducted during the summer of 2003 on randomly selected public lands throughout Iowa. Plots within these randomly selected public woodlands were sampled to determine the density of four invasive species, multiflora rose (*Rosa multiflora*), common buckthorn (*Rhamnus cathartica*), bush
honeysuckle (*Lonicera tatarica* and *L. maackii*), and garlic mustard (*Alliaria petiolata*).

Landscape scale ecosystem parameters, measuring spatial characteristics of the woodlands, were measured using GIS coverage themes and relationships were sought with the presence of each invasive species as well as abundance per woodland.

**Thesis Organization**

This thesis is divided into two separate journal articles (chapters 2 and 3) as well as an introductory literature review and a general conclusion. The general conclusion discusses both articles, their relevance to each other as well as their significance in the field of invasion ecology. Both papers have multiple authors. I have been listed as first author for both papers because the majority of the research, analysis, and writing were conducted by me. Dr. Heidi Asbjornsen, the other author, also contributed to the design and writing of the papers.

**Literature Review**

*Volunteer Survey Programs*

The use of volunteers in collecting data may have undesirable consequences due to an increase in misidentification of target species, potential bias in site selection, and greater error associated with data entry and transfer. Volunteers have been used in previous studies to collect ecological data, including data about plants (Brandon et al. 2003, Brown et al. 2001, and Stansbury and Scott 1999), amphibians (National Wildlife Federation 2004), birds (Ballard et al. 2003), marine organisms (Foster-Smith and Evans 2003, Darwall and Dulvy 1996, Mumby et al. 1995, and Halusky et al. 1994), and water quality (Fore et al. 2001, Evans et al. 2000, Obrecht et al. 1998, and Firehock and West 1995). Clear identification of potential biases and sources of error is vital when interpreting and analyzing data collected by volunteers. The strongest potential bias occurs when the data is highly subjective, such as
when the data is ranked by the volunteer. Examples of this type of data would be visual estimations of ground cover, canopy cover, dominant species, or disturbance. Sykes et al. (1983) found that visual estimates of percent cover varied significantly between 10 volunteer observers. Having the volunteers collect data that do not require any estimation can reduce the error associated with these types of biases. This type of data is usually collected by counting all targets (individuals, leaves, fruit, etc.) within a defined area or recording only presence or absence of targets.

Field identification of organisms is another significant source of error with volunteer-collected data. Sufficient training is vital to reduce the misidentification of organisms by volunteers. Darwall and Dulvy (1996) found increases in accuracy of volunteer-collected data as the volunteers gained additional experience. Brandon et al. (2003) asked volunteers to identify all tree and shrub vegetation within woodlands, which included 29 species. The authors found a significant amount of misidentification by the volunteers, potentially because of the large amount of information assimilation required of the volunteers. However, volunteers were able to correctly identify most organisms to the genus level, suggesting an ability to correctly identify a smaller subset of organisms.

Several recent studies have demonstrated the validity and applicability of volunteer-collected data (Foster-Smith and Evans 2003, Brandon et al. 2003, Fore et al. 2001, and Obrecht et al. 1998). Most recently Foster-Smith and Evans (2003) assessed the validity of volunteer-collected marine ecological data. During this study volunteers were trained to identify 24 species of marine organisms as well as recording the distribution and visually estimate the abundance. The study was limited to 13 volunteers during a 7 day period. The study found that the volunteers were capable of identifying the organisms and recording their
distribution, using presence/absence in pre-defined areas, adequately. However, the abundance estimates made by the volunteers were not consistent with each other. The authors attributed this to the volunteers interpreting abundances differently.

Brandon et al. (2003) tested data collected by a larger set of volunteers (150) assessing forest health parameters in Illinois. Volunteers collected data on the species composition and diameter at breast height (DBH) for trees, saplings and shrubs, including exotic invaders. The study tested three questions: “1. Were volunteers accurately identifying taxa? 2. Were volunteers accurately assigning tree class sizes and, therefore, accurately estimating forest age structure? 3. Since volunteers do not identify all plants to species level, how much information was lost when compared to complete identification by professionals?”

To test the validity of this data set, volunteers and botanists sampled the same transects on 14 different sites. The authors found that volunteers correctly identified the easily identifiable species, but the volunteers differed significantly from the botanists in identifying the more difficult species. However, the volunteers correctly identified the difficult species to the genus level. Volunteers were able to correctly assign tree size classes, allowing for estimations of forest age structure. In answer to the third research question (“Since volunteers do not identify all plants to species level, how much information was lost when compared to complete identification by professionals?”), the authors stated that volunteers significantly underestimated species richness, resulting in the loss of information pertaining to the forest.

During the study by Brandon et al. (2003), volunteers were asked to identify and survey all woody vegetation >1m tall. This resulted in a total of 29 species at the 14 study sites, many of which were in the same genus (7 Quercus species and 3 Ulmus species).
Perhaps asking the volunteers to learn to identify so many species, some of which are hard to distinguish, led to the observed discrepancies between the volunteer data and the data collected by botanists. The high level of agreement between volunteers and botanists for the shrubs lends support for volunteers' abilities to correctly identify common invasive species, many of which are shrubs. The ability of the volunteers to correctly assign tree classes (by measuring DBH) further demonstrates volunteer ability to accurately collect objective, quantitative data.

In a study of stream macroinvertebrates, Fore et al. (2001) found no significant differences between data collected by volunteers and data collected by professionals. The study analyzed the data collected from six streams across the state of Washington. Species richness for all species and percent dominance of the three most abundant species, *Ephemoptera, Plecoptera,* and *Trichoptera,* was recorded by both the volunteers and the professionals. The only difference found between the two sets of data was in the level of taxonomic identification. The volunteers were able to identify the macroinvertebrates to the family level, whereas the professionals were able to make identifications to the genus or species level. In an additional aquatic study, Obrecht et al. (1998) tested the validity of volunteer-collected samples of lake surface water. Volunteers collected samples from various lakes in Missouri and submitted the samples for analysis. No difference in quality was found between the volunteer-collected samples and samples collected by professionals. This study did not require the volunteers to conduct any analysis on the samples. However, the study does demonstrate the ability of volunteers to follow specific scientific survey procedures.
Darwall and Dulvy (1996) tested the validity of Tanzanian coral reef fish data collected by volunteer divers. Due to the large area of the reef and the expense of surveying via diving, volunteer surveyors were necessary to adequately assess the success of the constructed reef. 12-25 amateur divers volunteered for 10-week periods three times each year. The volunteers underwent an extensive 3-week training period before collecting any data. Data on species composition and richness and a visual estimation of total length of Serrainds, a commercially important and vulnerable fish, were collected throughout the reefs. The authors found no significant differences between the data collected by professional divers and by the volunteers. Multiple trials were conducted and volunteer performance improved with every trial. This indicates that volunteer accuracy improves with additional training and/or experience.

**Volunteer monitoring projects for invasive species**

Brown et al. (2001) used volunteers to monitor 13 different invasive species along roads in the Adirondack Park, New York. Nineteen skilled volunteers were selected and underwent an intensive one-day training session. Volunteers worked as teams in small groups, each surveying a subset of the park. Locations along the road were recorded and abundance estimated for each species. Volunteers were instructed to drive the roads, searching for populations of the invasive species and record the location along the road as well as an estimate of abundance and nearness to a stream, wetland, or heritage site.

The Inland Seas Education Program (2002) uses volunteers to help monitor aquatic invasive species throughout the Great Lakes region. Many volunteers with varying levels of knowledge participated in this survey. Validity of volunteer-collected data was not in question during this study since volunteers were accompanied by a professional. Additional
projects that used volunteers to survey invasive species include “Weed Watch” aquatic invasive species monitoring by the New Hampshire Department of Environmental Services (2002), aquatic invasive species monitoring by the Maine Volunteer Lake Monitoring Program (Williams 2004), zebra mussel monitoring in the upper Midwest (Jensen et al. 1995), invasive plant monitoring in New England (Merhoff 2003), and monitoring for zebra mussel and Chinese mitten crab in Washington State (Washington Department of Fish and Wildlife 2001).

**Ecosystem characteristics and invasive species**

The structure of a landscape has the potential to affect invasive species at different stages of invasion (see With 2002 for detailed discussion). Fragmented landscapes present invasive species with potential trade-offs. Woodland habitat edges have been found to be more suitable environments for some invaders (Brothers and Spingam 1992). Fragmented landscapes have large amounts of edge, providing invasive species with more suitable habitat than less fragmented landscapes. In addition, species that are dispersed primarily by birds may have an enhanced dispersal ability in fragmented landscapes, because of the directed dispersal created by the preferential use of edge habitats by many birds (With 2002). However, fragmented landscapes demonstrate less connectivity than less fragmented landscapes (With and King 1999), potentially restricting invasive species’ ability to successfully colonize new areas. Several models have predicted that a fragmentation threshold occurs in landscapes, above which the landscape becomes rapidly disconnected (Gardner et al. 1987, With 1997, and With and King 1997). Hutchinson and Vankat (1998) found that the distribution of *Lonicera maackii* was correlated with changes in percentage of forested land and degree of forest connectivity. In large-scale transects, *L. maackii* reached
its distribution limit when forest cover dropped to <5% and forest connectivity was 0%, providing evidence that landscape structure strongly influences invasive species abundances and distribution. Road, forest, and field edges have all been found to harbor more invasive species than interior habitats (Cadenasso and Pickett 2001, Gelbard and Belnap 2003, Goldblum and Beatty 1999, and Watkins et al. 2003).

The quality and type of edge can influence the presence of invasive species. Cadenasso and Pickett (2001) found that upland deciduous forests with intact edges can function as a physical barrier to seed dispersal into the interior of the forests. Seed traveled farther into the interior of forests with thinned edges. The type of adjacent habitat may also influence the presence and abundance of invasive species. Gelbard and Belnap (2003) surveyed roads throughout semiarid Utah for invasive species. They found that richness and abundance of invasive species was greater on improved, paved roads than unimproved roads. While surveying unpaved roads in Wisconsin, Watkins et al. (2003) found significant decreases in invasive species prevalence with increasing distances from the road edge.

Based on the above studies, a hypothesis could be formulated that areas with greater fragmentation (higher amounts of edge) are most likely to have high amounts of invasive species. However, Ross et al. (2002) found disturbance or quality of habitat to be as important a factor as degree of fragmentation in eucalypt forests, leading to a hypothesis that fragmentation alone may not be an adequate parameter to explain invasive species distribution. Other factors, such as time since fragmentation, disturbance type, and time since invasion, may also play an important role.
**Target Species**

Although a large number of invasive species exist within woodlands in the Midwest, this thesis focused on only four species: garlic mustard (*Alliaria petiolata*), bush honeysuckle (*Lonicera tartarica* and *L. maackii*), common buckthorn (*Rhamnus cathartica*), and multiflora rose (*Rosa multiflora*). These four species were originally identified by the Iowa Department of Natural Resources as posing the greatest threat to woodland ecosystems in Iowa. The list of target species was limited to four in the hope of reducing the amount of information the volunteers were required to learn, thus reducing misidentification of the species by the volunteers.

*Garlic Mustard*

Garlic mustard is a biennial herbaceous plant that is naturally found throughout Europe. Garlic mustard is a member of the *Brassicaceae* family. First year plants are a basal rosette of chordate leaves with serrated margins. Second year plants produce a flowering stalk (10-40 cm). The leaves on the flowering stalk are deltoid with serrated edges. Garlic mustard is normally found in moist to dry woodlands and has a wide range of light tolerance, often being found in relatively undisturbed, high quality, shaded woodlands (Miller 2003). It was first introduced into America circa 1868 into Long Island, New York (Swearingen et al. 2002). Historically, garlic mustard was used as salad greens and as a meat spice. Garlic mustard quickly escaped cultivation and invaded neighboring woods. Since then, it has been increasing its range, spreading southward and westward. Currently, garlic mustard can be found throughout the eastern United States, south to the sandy coastal plains and west into South Dakota. Washington and Oregon have recently located small but expanding populations (USDA-NRCS 2002).
Bush Honeysuckle

Although several species of exotic honeysuckle occur in Iowa, field identification to the species level is often difficult. For this reason, the project does not distinguish between species, instead combining all species under the category “bush honeysuckle.” Bush honeysuckle, a member of the Caprifoliaceae family, is an erect multi-stemmed shrub, normally reaching heights of 2-3 meters. Leaf arrangement is opposite. Leaves are simple, ovate, and entire. Flowering occurs in the spring and fruits ripen in late summer through fall. The seeds are readily eaten and dispersed by many different species including birds (Bartuszeige 2002 and Ingold and Craycraft 1983), mice (Williams et al. 1992), and white-tailed deer (Velland 2002). Bush honeysuckle is native to Europe and Asia and was first imported to North America in the 1700s and 1800s for ornamental purposes (Miller 2003). Bush honeysuckle was later promoted heavily as wildlife food and cover and planted extensively throughout the eastern United States. It is currently widespread throughout the eastern United States (USDA-NRCS 2002).

Common Buckthorn

Common buckthorn is a large shrub or small tree in the Rhamnaceae family. This native of Europe was first introduced into America for ornamental purposes and has been widely planted as a yard tree. Common buckthorn is a dioecious tree, having both male and female trees. Leaves are subopposite, simple, slightly serrate, and ovate. Leaf veins are noticeably arcuate. Flowering occurs in early summer; flowers are small inconspicuous axillary flowers, green to dull white. Fruits, which ripen in late fall, are a cluster of large black-purple berries, often fed upon and dispersed by birds. Common buckthorn is found throughout the northern United States (USDA-NRCS 2002).
**Multiflora Rose**

Multiflora rose is a shrubby member of the *Rosaceae* family. It is native to eastern Asia, and was first introduced into America in 1866 as root stock for cultivated roses (Swearingen et al. 2002). In the mid-20th century, multiflora rose was widely planted both as a “living fence” for controlling livestock and as cover and food for wildlife (Miller 2003). Multiflora rose is a large shrub, often reaching canopy heights and diameters of 3 meters. Large curved thorns are found on the thick rounded canes. Leaves are pinnately compound with 3-9 leaflets. Five-part flowers occur in small clusters, producing small rose hips which ripen in the fall and often persist throughout winter. Multiflora rose occurs throughout the eastern United States and in parts of Washington and Oregon (USDA-NRCS 2002).
Chapter 2: Results and validation of a volunteer-based survey of woodland invasive species in Iowa, USA
C.W. Evans and H.A. Asbjornsen
Iowa State University
Department of Natural Resource Ecology and Management
A paper to be submitted to the Journal of Biological Invasions

Introduction

Invasive species are among the most serious ecological threats today (Vitousek et al. 1996 and Wallner 1996). An invasive species is defined as an organism that is not native to the ecosystem, and has the potential to cause economic and ecological damage (National Invasive Species Council 2001). Even though some studies have experimentally demonstrated negative impacts of invasive species (Gorchov 2003, Collier 2002, and Gould and Gorchov 2000), much of the suspected negative impacts are based on anecdotal, observational, or qualitative evidence (Blossey 1999). In addition, data documenting the distribution and abundance of invasive species are either absent or based largely on personal observations (Eiswerth and van Kooten 2002). The paucity of available knowledge limits the ability of land managers and researchers to develop and implement effective control measures (Blossey 1999). This also leads to difficulties in convincing funding agents and policymakers that a need exists to prioritize research on and control of the spread and persistence of invasive species. In addition, the public remains largely unaware of the ecological and economic impacts of invasive plants (Colton and Alpert 1998).

Midwestern woodlands are among the most severely invaded ecosystems in the United States. Little is known about the long-term impacts of these woodland invaders on the ecological functioning and economic systems within the region. This paper focuses on the North Central Woodland Invasive Species Inventory, which aims to collect scientifically
relevant data about invasive species while increasing public awareness and involvement. A pilot study for the project was initiated in 2002, the results of which are the primary substance of this paper. The goal of the study was to obtain baseline data about the distribution and abundance of four woodland invasive species throughout Iowa. The four species chosen for the study were multiflora rose (*Rosa multiflora*), common buckthorn (*Rhamnus cathartica*), bush honeysuckle (*Lonicera tatarica* and *L. maackii*), and garlic mustard (*Alliaria petiolata*). An important secondary goal was to increase public awareness about the problem of invasive species in Iowa. These two goals, combined with the need to survey a large area, led to the development of a volunteer-based approach to collecting data. Volunteers were solicited throughout the state of Iowa, and they collected data on both private and public lands from May 2002 until November 2003. Volunteers recorded the presence or absence of each invasive species along a transect in their self-selected woodland(s), allowing an estimate of invasive species frequency to be calculated.

The use of volunteers in collecting data may have undesirable consequences due to an increase in misidentification of target species, potential bias in site selection, and greater error associated with data entry and transfer. However, without the volunteers, researchers are limited in their ability to effectively sample woodlands across large areas due to funding, personnel, and time restrictions. Volunteers have been used in previous studies to collect ecological data, including data about plants (Brandon et al. 2003, Brown et al. 2001, and Stansbury and Scott 1999), amphibians (National Wildlife Federation 2004), birds (Ballard et al. 2003), marine organisms (Foster-Smith and Evans 2003, Darwall and Dulvy 1996, Mumby et al. 1995, and Halusky et al. 1994), and water quality (Fore et al. 2001, Evans et al. 2000, Obrecht et al. 1998, and Firehock and West 1995). Several recent studies have
demonstrated the validity and applicability of volunteer-collected data (Foster-Smith and Evans 2003, Brandon et al. 2003, Fore et al. 2001, and Obrecht et al. 1998). Clear identification of potential biases and sources of error is vital when interpreting and analyzing data collected by volunteers. The strongest potential bias occurs when the data is highly subjective, such as when the data is ranked by the volunteer. Examples of this type of data are visual estimations of ground cover, canopy cover, dominant species, or disturbance. Sykes et al. (1983) found that visual estimates of percent cover varied significantly between 10 volunteer observers. Having the volunteers collect data that do not require any estimation can reduce the error associated with these types of biases. This type of data is usually collected by counting all targets (individuals, leaves, fruit, etc.) within a defined area, or by recording only presence or absence of targets.

Field identification of organisms is another significant source of error with volunteer-collected data. Sufficient training is vital to reduce the misidentification of organisms by volunteers. Darwall and Dulvy (1996) found increases in the accuracy of volunteer-collected data as the volunteers gained additional experience. Brandon et al. (2003) asked volunteers to identify all tree and shrub vegetation within woodlands, which included 29 species. The authors found a significant amount of misidentification by the volunteers, potentially because of the large amount of information assimilation required of the volunteers. However, volunteers were able to correctly identify most organisms to the genus level, suggesting an ability to correctly identify a smaller subset of organisms.

Another potential bias with volunteer-collected data relates to the site selection. Volunteer selection of sites is non-random and therefore the results may be biased with regard to invasive species presence and abundance. For example, volunteers may choose to
survey a site because they know invasive species are present or choose not to survey a site because no invasive species are present, believing that the resulting survey would be of no use.

Several projects have used volunteers to survey invasive species. Brown et al. (2001) used volunteers to monitor 13 different invasive species along roads in the Adirondack Park, New York. The Inland Seas Education Program (2002) uses volunteers to help monitor aquatic invasive species throughout the Great Lakes region. Additional projects that used volunteers to survey invasive species include “Weed Watch” aquatic invasive species monitoring by the New Hampshire Department of Environmental Services (2002), aquatic invasive species monitoring by the Maine Volunteer Lake Monitoring Program (Williams 2004), zebra mussel monitoring in the upper Midwest (Jensen et al. 1995), invasive plant monitoring in New England (Merhoff 2003), and monitoring for zebra mussel and Chinese mitten crab in Washington State (Washington Department of Fish and Wildlife 2001).

This study uses a combination of volunteer-based and expert-based data collection approaches to address the following questions: 1) What is the distribution and abundance of multiflora rose, common buckthorn, bush honeysuckle, and garlic mustard in Iowa woodlands? 2) Are data collected from volunteer-selected sites biased in comparison with data collected from randomly selected lands? 3) Does frequency of invasive species, calculated using the volunteer method, correlate with density of invasive species found using an area-based survey method? In other words, the study seeks to determine whether or not data on frequency, which is easily collected using volunteers, can be used to predict density, which requires intensive (and expensive) surveying to directly measure.
The results of this study will provide a basis for making recommendations for implementing and improving a volunteer-based approach to invasive species surveying, as well as methods for interpreting data collected by volunteers and the limitations of such data.

Methodology

Study areas

The survey was conducted in woodlands throughout Iowa during 2002-2003 on both public and private lands. For the purpose of the study, "woodland" was defined as any parcel of land having at least some tree component. This definition allowed us to include habitats such as pastures and parklands that support trees.

Identification of private woodlands

Since most of Iowa is under private ownership (> 90%), the ability to conduct surveys on private lands becomes crucial to obtaining accurate statewide estimates of invasive species. In order to establish a pool of available private lands to survey and increase the number of potential volunteers, mailings were sent out to private landowners across the state explaining the project and soliciting their participation. Names and addresses of the private landowners were obtained from membership lists of Master Woodland Managers, Community Tree Stewards, and the Iowa Woodland Owners Association. Landowners were asked if they wanted to become volunteers or, if not, if they would give permission for a volunteer to survey their land. Business reply postcards were sent with this mailing with a standard format for easy completion by the volunteers and analysis by project staff. A list was created of woodlands that were available to be surveyed, which increased the number of lands available to the volunteers.
Random selection of public lands

For public woodlands it was possible to include all sites within the total population of public woodlands greater than 5 ha, and therefore to select a random sample from the population. Iowa was divided into 5 regions, each consisting of approximately 20 counties. Every public tract that was over 5 ha in size and had a woodland component was identified using Arcview 3.2 together with the Luse and IaGapPub themes (available at the Iowa State University Geographic Information System (GIS) laboratory website: www.gis.iastate.edu). For woodlands over 280 ha, the unit was sub-divided based upon natural or obvious breaks (rivers, constrictions, roads, etc.) into smaller units of approximately 120-200 ha. (These subdivisions were created prior to sample selection.) A total of 60 public lands were selected using a stratified random sample to be surveyed throughout the state. Within each tract of land selected for the survey, a start point for the survey was randomly selected. Only one survey was conducted within each selected woodland. The surveys conducted on randomly selected public lands were conducted by the Iowa Department of Natural Resources state foresters to help ensure data reliability and allow for comparisons with the surveys conducted by the volunteers.

Volunteers Recruitment

Private landowners were solicited as volunteers during the initial mailing (See Identification of private woodlands above). In addition, solicitation letters were sent to members of Iowa Nature Mapping, Iowa Prairie Network, and the Iowa chapter of the Nature Conservancy. Press releases to the general public were also used to solicit volunteers.
Survey Methodology

To limit the amount of time and knowledge necessary to complete a survey, a simple survey methodology was developed based upon the determination of presence or absence of each target species within a defined area. The assumption was made that if the methodology was too difficult to understand or too labor intensive to conduct, volunteers would be reluctant to assist and the data obtained would be less accurate.

The steps involved in assessing a sample unit were as follows: 1.) The volunteer select an edge of the woodland to begin the survey. 2.) The volunteer walks a transect through the site, stopping approximately every 30 meters (using a pre-determined number of steps to approximate 30 meters) to collect data. 3.) At each stop (i.e., 30m), presence or absence is recorded for each species within an approximate 2m radius circle (volunteers were instructed to use a meter stick, held at arm’s length, to approximate 2m). 4.) Every time the edge of the woodland is reached, the volunteer turns perpendicular to the direction traveled and conducts two more stops (60 meters total), and then establishes a new transect parallel to the first, walking in the opposite direction (Figure 1).

For woodlands of less than 40 ac, volunteers were requested to survey the entire unit. For woodlands greater than 40 ac, volunteers were instructed to conduct at least 70 stops, which are approximately equivalent to 40 ac of woodland and takes about 2 hours to complete. Volunteers were instructed to survey their own woodland or, if they did not own a woodland (or if they wanted to survey additional woodlands), to survey a neighbor’s woodland, a woodland from the list, or a parcel of public land.
Website development and electronic data entry

A website was created to keep volunteers informed about upcoming training sessions, provide additional information concerning invasive species, and serve as the avenue for electronic submission of data. The data sheet used by volunteers in the field resembles the electronic entry form, thereby facilitating the transfer of data to the website. Information Technology Development (ITD) from Des Moines created the online data entry format. The information database is stored at the Iowa State University Geographic Information Systems Facility.

Training session development

Training sessions were conducted throughout Iowa to equip volunteers with the knowledge and skills necessary to conduct the surveys. County conservation boards were often asked to assist with the training sessions by providing a location for the session and by assisting with publicity and solicitation. Each training session lasted about three hours and included modules on plant identification, survey methodology, mapping techniques, data entry, and selection of survey sites. Each volunteer received a series of handouts that complemented the training session content. These handouts included the plant identification material, data collection sheets, and instructions on methodology and mapping. In order to ensure data reliability, each volunteer received a password to allow him or her to submit data electronically.

During the winter of 2002, letters were sent to all volunteers thanking those who had submitted data and reminding others about the project, as it was observed that a relatively small percentage of the total number of volunteers trained had actually submitted data. In addition, an email survey was sent out to all volunteers asking them to provide their
assessment of the effectiveness of the training session and methodology and whether they had conducted and submitted a survey, and if not, some of the reasons why.

Severity analysis

Data collected using the volunteer-based survey methodology were used to calculate of invasive species frequency, defined as the percentage of stops along a transect with species X present. The advantage of this approach is that it does not require that specific data on percent cover per area or number of individuals per area be determined (which would require an advanced level of technical knowledge by the surveyor). This method was chosen because it is both quick to conduct and easy to learn, while at the same time providing a means to estimate severity and distribution of invasive species across large areas of land. A quantitative index of severity was developed according to the following severity classes: 0% = absent, 1-25% = light invasion, 26-50% = light medium invasion, 51-75% = heavy medium invasion, and 76-100% = heavy invasion.

Frequency and Density Correlations

A major disadvantage of the volunteer-based survey methodology is the inability to extrapolate from the data to predict the area that is covered in an invasive species because of the lack of a number-of-plants per area measurement (i.e., the methodology only allows for the determination of frequency, not density). However, the more accurate assessment of invasive species abundance is density, defined as the number of individuals within a given unit of land. To determine if any correlation exists between frequency of invasive species, found using the volunteer method, and an area-based measurement of density, a study was conducted by Iowa State University researchers within four counties in central Iowa (Boone, Dallas, Polk, and Story counties). Parcels of public woodlands were randomly selected and
surveyed using the volunteer method. In addition to presence or absence, number of individuals for each species was counted within the 2m-radius circle. This allowed for a calculation of density and frequency based on the same unit of land sampled. Woodland average density and frequency for each species was calculated and graphed on a scatterplot. Correlations were sought using linear regressions, and p-values calculated using a two-way t-test.

### Randomly Selected Woodlands Vs. Volunteer-selected Woodlands

To test for potential biases in the data collected from volunteer-selected sites, comparisons were made between the woodlands randomly selected (surveyed by DNR foresters or trained Iowa State University staff) and volunteer-selected (and volunteer-surveyed) woodlands. After the surveys were submitted, the data were divided into “random” and “volunteer” and the average frequencies for each species were calculated. Two-way t-tests were used to detect significant differences across all surveys conducted in Iowa for each species.

### Results

**Volunteer-based survey**

The pilot study was conducted throughout Iowa between May 2002 and October 2003. During that period 4750 letters of solicitation were sent to potential volunteers. Eight hundred and seventy-one replies were received that indicated a willingness to either be a volunteer or allow a volunteer to survey their land (representing a response rate of 18.34%). Seventeen training sessions were conducted throughout Iowa. Two hundred and eighty-seven volunteers attended training sessions (an average of 17 per training session). A total of 158 surveys were submitted, covering 55 counties (out of 99 total counties) by 56 volunteers.
The location of each survey was mapped on Arcview 3.2 using the Universal Transverse Mercator coordinate system (North American Datum 1983).

Figure 3 shows the distribution of each species throughout the 55 counties surveyed in the state, averaged by county. Multiflora rose was present in 61% of surveys. Multiflora rose was widely distributed throughout the central and eastern parts of the state, being found in 33 of the 45 counties surveyed and 69% of surveys conducted. However, it was absent in all surveys conducted in 11 counties of western Iowa. Common buckthorn was present in 22% of surveys. The distribution of common buckthorn in Iowa is variable (19 out of 55 counties surveyed), with buckthorn being widely distributed in northeastern Iowa and spotty with scattered clumps in northwest, central, and southeast Iowa. Bush honeysuckle was present in 46% of surveys. Bush honeysuckle is widely distributed throughout Iowa (32 out of 55 counties surveyed). Garlic mustard was present in 31% of surveys. Garlic mustard was found in 16 out of the 55 counties surveyed, 12 in eastern Iowa, 2 in central Iowa and 2 in western Iowa. The average frequencies, using only surveys with the species present, are 19% for multiflora rose, 25% for common buckthorn, 21% for bush honeysuckle, and 35% for garlic mustard (table 1).

Frequency and Density Correlations

A total of 18 woodlands were sampled in central Iowa as part of the parallel study to assess the relationship between frequency and density. No survey recorded the presence of garlic mustard. The average frequency and density for the remaining three target species were 17% frequency and .05 individuals/m² density for multiflora rose, 3% frequency and .01 individuals/m² for common buckthorn, and 40% frequency and .32 individuals/m² for bush honeysuckle. Significant correlations were found between density and frequency for
multiflora rose (n= 15, R² = 89 and p<.001; Figure 4a), bush honeysuckle (n= 9, R² = .93, and p = .002: Figure 4b) and common buckthorn (n= 4, R² = .94 and p=.0286), but with a very small sample size.

Random vs. Volunteer

A total of 111 volunteer-based surveys (volunteer sites) and 47 expert-based surveys (random sites) were used for these comparisons. Figure 5 summarizes the comparisons between volunteer and random sites for each species. The average frequency for multiflora rose was 16% for volunteer sites and 3% for random sites. The average frequency for common buckthorn was 6% for volunteer sites and 4% for random sites. The average frequency for bush honeysuckle was 12% for volunteer sites and 3% for random sites. The average frequency for garlic mustard was 16% for volunteer sites and 1% for random sites. The average frequency for the random sites was significantly lower than the volunteer sites for multiflora rose, bush honeysuckle, and garlic mustard (p=.0001, .008, and .0009 resp.). No difference between selection methods was found for common buckthorn (p = .572, Figure 5).

Email Survey

Respondents (11 out of 36) of the email survey stated that they enjoyed participating in the training sessions, but suggested that more time be allocated to identifying and surveying the invasive species. Most respondents had not conducted a survey, stating that they were either too busy or waiting until nicer weather. In response to the survey, additional reminder letters were sent to the volunteers in the spring, pointing out the nice conditions for conducting a survey. Also, training session content was altered to allow for additional training in identification and surveying.
Discussion

Distribution trends

The lack of multiflora rose in western Iowa may be a result of a small sample size (n=22), or it may indicate an inability of multiflora rose to successfully invade woodlands in western Iowa. Multiflora rose has been widely planted throughout the region and has had ample time to establish itself. If indeed multiflora rose has a reduced ability to invade western Iowa woodlands, several explanations are possible. Western Iowa is both drier (Spatial Climate Analysis Service 2000) and colder (Smith 2004) on average than the rest of Iowa. Either of these characteristics could be a limiting factor that would prevent multiflora rose from growing in a light-stressed environment such as a woodland. Secondly, western Iowa does not have the amount of woodland grazing that occurs in other portions of Iowa, southern and northeastern Iowa in particular. Multiflora rose was often planted as living fences for livestock control, potentially leading to more invasions in areas with pastures.

With the exception of northeastern Iowa, the observed scattered distribution of common buckthorn could possibly be the result of buckthorn being found within close proximity of more densely populated areas (Sioux City in northwest Iowa, Iowa City in the southeast, and Ames and Des Moines in central Iowa). Buckthorn was used extensively as an ornamental shrub and hedgerow component during the last half of the twentieth century (Converse 1984), potentially producing higher propagule pressure and increased escapes to woodlands surrounding population centers.

No statewide distribution trends are evident for bush honeysuckle; it is found throughout every region of Iowa. Every county that did not show honeysuckle present had relatively few surveys conducted (3 or fewer) compared with most other counties. This
supports the assumption that the lack of honeysuckle presence in some counties may be primarily related to low sample size.

Garlic mustard is more widely distributed throughout eastern Iowa, but also occurs in several counties in the central and western parts of the state. The observed pattern is likely due to garlic mustard being a relatively new invader of Iowa, and is still in the process of expanding its range. Dubuque County (far eastern Iowa) appeared to have the highest invasion of garlic mustard, with 11 of the 13 surveys conducted finding garlic mustard. In addition, the 13 surveys averaged a frequency of 53% for garlic mustard with 4 surveys having a frequency greater than 80%.

**Frequency and Density Correlations**

Significant correlations between density and frequency were found for three of the species, multiflora rose, bush honeysuckle, and common buckthorn. This suggests that the differences in frequencies calculated from the data obtained from the volunteer-based methodology are likely indicative of similar differences in density for these species. No garlic mustard and only small amounts of common buckthorn were found during this section of the study. Since garlic mustard is an herbaceous plant, while multiflora rose, bush honeysuckle, and common buckthorn are woody, the assumption that garlic mustard would behave similarly cannot be made without additional supportive data.

**Random vs. Volunteer Surveys**

Surveys conducted by experts on randomly-selected woodlands found significantly lower severities of invasive species cover than surveys on volunteer-selected lands. Therefore, the volunteer data have the potential of leading to an over-estimation of state-wide invasive species severity. Two potential explanations exist for the observed differences
between the volunteer and random surveys. The first explanation is that the data demonstrates a volunteer bias with regard to woodland selection. Volunteers may select woodlands to survey based upon previously gained knowledge of invasive species presence, selecting woodlands only if they know an invasive species is present. The second explanation is based upon the difference in regional dispersion of the woodlands surveyed. The random woodlands were selected from public lands throughout Iowa, giving an evenly dispersed set of woodlands. Volunteers were not evenly dispersed throughout Iowa, with more volunteers attending training sessions in eastern Iowa, leading to more surveys being conducted in eastern Iowa. To test whether the dispersion of survey affected the results, the data only from eastern Iowa was analyzed in the same manner (Figure 6). Significant differences were found for multiflora rose and garlic mustard \((p=.015\text{ and } p=.008\text{ resp.})\). No differences were found for common buckthorn or bush honeysuckle \((p=.337\text{ and } p=.720\text{ resp.})\). The average frequency for the randomly-selected sites was higher than the volunteer-selected sites for common buckthorn \((5.9\%\text{ vs. } 2.9\%)\). The results from the regional comparison give mixed results. The differences between volunteer and randomly-selected sites remain for multiflora rose and garlic mustard. However, common buckthorn and bush honeysuckle do not display the same trends with the regional comparison. Based upon the results, we cannot verify or rule out the possibility of differences in dispersion affecting the differences between the frequency calculated from the surveys on the randomly-selected and volunteer-selected sites. The volunteer-bias in site selection remains a valid possibility.

If indeed the results indicate a volunteer bias when selecting woodlands, this does not necessarily hinder the applicability of the survey. One of the goals of the project was to gather data about the distribution of invasive species throughout Iowa. Volunteer-collected
data, even if a bias occurs, give us specific information about where invasive species occur and estimates of their abundance. Conducting regional comparisons and targeting control measures does not necessarily require statistically valid, unbiased data. In fact, if the volunteers are biasing their woodland selection to over-represent invaded woodlands, it may actually help regional comparisons and targeting control efforts because it preferentially identifies those woodlands where invasive species are known to exist. The potential bias with regard to woodland selection does, however, become a problem when the data are used for either extrapolation mapping or correlations with other parameters, such as habitat type, slope, etc. The data collected by the volunteer violates the assumption of random selection and equal probability that is inherent in both of the above analyses.

**Recommended changes to project methodology**

The North Central Woodland Invasive Species Inventory project will, hopefully, continue using volunteers to collect data about invasive species, in the process informing the public about the problems of invasive species. This pilot study has highlighted needed changes to several of the aspects of the project that may have the potential to increase the number of volunteers and their level of involvement. First, many of the project volunteers were elderly members of rural communities and were self-described computer illiterates; and several volunteers reported having problems entering data electronically. The electronic data entry possibly was too complicated, thus providing a strong disincentive for completing the survey. An optional mail-in data form along with a postage-paid envelope included in the training session handout material could help address this problem by providing an alternative avenue for data submission.
Another important goal for the project is to increase the total number of volunteers. By providing more training sessions in more places, an increase in the total number of volunteers could be achieved. Holding a “Train the Trainers” session, in which governmental agency employees on how to conduct training sessions, could potentially increase volunteer numbers greatly without substantially increasing costs. Several of the “Train the Trainers” sessions could be conducted across the state and the new trainers would then solicit and train volunteers. This method has several advantages: 1.) It requires little input from the project coordinator. 2.) Potential volunteers would have more training session locations and times to choose from, making it more likely that a training session would be scheduled for a time that they could attend. 3.) Local agencies often already have a close working relationship with potential volunteers thereby potentially facilitating recruitment success and increasing overall training session attendance.

Data analysis techniques

Accurate location information for the surveys makes it possible to map the data at multiple scales. The easiest method of predictive mapping is to simply delineate the boundaries of desired mapping units, state counties for example, then use the average of surveys conducted within that unit as the unit value. However, averaging surveys across a unit of area may lead to broad or inaccurate conclusions, especially if the survey results are highly variable. For reasons such as these it is crucial that the appropriate resolution for the data be determined before any conclusions are drawn from the data. Determining the appropriate resolution for the data depends upon what the data are going to be used for. If the data are going to be included within a multi-state analysis of distribution trends of invasive species, then the appropriate resolution for the data would either be a regional
(similar landforms, spanning multiple counties) or county level. However, if the data are to be used to identify hotspots of invasion across a region of the state, then the township or woodland level may be more appropriate.

When using survey techniques to look for the presence and abundance of any type of organism, it is crucial to recognize the boundaries and limitations inherent in this type of research. No one can definitively say that a plant does not occur within a certain area, unless the area is small enough to exhaustively survey every individual or the effort put forth is large enough to do likewise. The former of these two cases does not provide data on a scale that is useful, while the latter is impractical and unachievable at large scales no matter how large the effort put forth. This said, the results from this survey cannot lead to the conclusion that an invasive species is absent in an area, be it a region, county, or woodland. What we can say is that, based upon our study, the invasive species was not found in the area and the assumption can be made, at least for individual woodlands, that the invasive species is either absent or that it occurs at low densities. Even this assumption may be false and the accuracy with which this can be stated is inversely proportional to the size of the area surveyed. However, this survey technique does allow it to be definitively stating that a species is present in an area, and to give some estimate of severity.

Applications of the data

The data received from this survey on distribution and severity patterns of a particular invasive species on the landscape could be used to target areas or regions to focus control efforts. This survey can potentially help to identify the leading edge of an active invasion or, through correlation with habitat characteristics, such as topography or vegetation cover, can identify types of areas in which to focus control efforts. Futher, since the project surveys
multiple invasive species, the various species can be ranked according to the level of threat or risk that each one poses within a given area or region.

By having volunteers resurvey an area every 3-5 years, this survey can readily be used as a continuous index, with the ability to monitor shifts in the distribution and abundance of invasive species over time. This is particularly helpful in determining direction and rate of spread of an invasive species that is actively expanding its range. Additionally, the index could detect whether a large-scale control effort, such as biological control, has been effective in reducing the range or slowing the spread of an invasive species.

*Applicability of methodology to different habitats and invasive species*

This type of survey does not have to be limited to known invaders throughout the region. A potential use of this survey is to search for species that are known or suspected invaders in other areas but have not been documented within the target region. Good examples of such potential invasive species are kudzu (*Pueraria montana*), a species known to be invasive in states south of Iowa but which has not yet been documented as being invasive in Iowa; and giant hogweed (*Heracleum mantegazzianum*), a species that is beginning to show invasive properties in some areas of the United States but has not been documented in Iowa. By training volunteers to identify these potential invaders, early detection of a new invasive species is more likely, allowing a rapid response and easier, more cost-efficient control. The standard surveying technique used in the pilot study need not be used when searching for new invaders since detection of the species is paramount, and estimates of abundance secondary. Any new invasive species found is of interest and the survey technique could be changed to allow for a broader area of detection.
An advantage of this survey technique is its applicability to different types of habitats or different species. The survey methodology will work in almost any type of terrestrial ecosystem with little adjustment of techniques. Using the same survey methodology for different habitats or species would enable: 1.) Comparisons among species using the same type of data. 2.) Enabling estimation of invasion rates of different habitats. 3.) Rapid transfer of the survey to new areas or habitats, and 4.) Reduction in the amount of information a trainer or volunteer needs to assimilate in order to conduct surveys in different habitats. Application of the survey in multiple states would allow for easy comparisons across states as well as information and training strategy sharing.

Conclusions

Volunteers provide managers and researchers with the ability to conduct many samples over a large geographic area. Although volunteer-collected data is constrained statistically, it provides adequate baseline information about the distribution and abundance of invasive species. This information can aid in developing management plans and research proposals. Comparisons with data collected from randomly selected woodlands suggests that volunteers tend to select woodlands based on previous knowledge of invasive species presence. Even though this further constrains the statistical power of the survey, this bias potentially provides many more known spots of invasive species presence. Frequency, calculated from volunteer-collected data, appears to be strongly correlated to density, at least for woody invasive species. Region-wide adoption of this or similar methods would allow for easier comparisons across states and reduce the cost and time of developing survey protocols.
Acknowledgements

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Literature Cited


**Figure 1:** Schematic diagram of the methodology used by volunteers to survey the distribution and severity of woodland invasive species, based on walking a transect line and stopping at 30m intervals to collect presence/absence data on the target invasive species within a 2m radius circle.

![Schematic diagram](image)

- 30 meters (distance between stops)
- 2m radius circle (plot for each stop)

**Figure 2:** Locations of the surveys conducted for the pilot study on invasive woodland species distribution and severity. Randomly-selected sites surveyed by experts are shown in red. Volunteer-selected and surveyed sites are shown in blue.

![Map of surveys](image)
Figure 3: Results from the 2-year pilot study on woodland invasive species distribution and severity. Severity ratings are based on averages calculated by county for each species.

Table 1: Proportion of the total number of surveys that recorded each species as being present and the average frequency of each species. Frequency values are calculated using only those surveys which found the species present.

<table>
<thead>
<tr>
<th>Species</th>
<th>% of Surveys present</th>
<th>Average Frequency (surveys with species present)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiflora Rose</td>
<td>61%</td>
<td>19%</td>
</tr>
<tr>
<td>Common Buckthorn</td>
<td>22%</td>
<td>25%</td>
</tr>
<tr>
<td>Bush Honeysuckle</td>
<td>46%</td>
<td>21%</td>
</tr>
<tr>
<td>Garlic Mustard</td>
<td>31%</td>
<td>35%</td>
</tr>
</tbody>
</table>
Figure 4: Scatterplots showing the relationship between density (individuals/m²) and frequency (% sample points with species “present”) for both multiflora rose (a) and bush honeysuckle (b).

a)

**Multiflora Rose**

\[ R^2 = 0.816 \]

b)

**Bush Honeysuckle**

\[ R^2 = 0.9309 \]
**Figure 5:** Graph showing differences in the average frequency (% of stops present) calculated for volunteer and random sites.

**Figure 6:** Graph showing differences in the average frequency (% of stops present) calculated for volunteer and random sites in eastern Iowa.
Chapter 3: Influence of spatial arrangement of woodlands on invasive species presence and abundance
C.W. Evans and H.A. Asbjorsen.
Iowa State University
Department of Natural Resource Ecology and Management
A paper to be submitted to the American Midland Naturalist

Introduction

Invasive species are among the most serious ecological threats today (Vitousek et al. 1996 and Wallner 1996). An invasive species is defined as an organism that is not native to the ecosystem and has the potential to cause economic and ecological damage (National Invasive Species Council 2001). Many species have invaded Midwestern woodlands, at least in part due to intense disturbance and fragmentation of the landscape since European settlement. Little is known about what ecosystem characteristics co-occur with the presence of invasive species. Spatial arrangement and size of woodland may contribute significantly to the invasibility of the wooded ecosystem. Little research has been done, and data concerning the distribution and abundance of invasive species are either absent or based largely on anecdotal evidence (Eiswerth and van Kooten 2002).

The structure of a landscape has the potential to affect invasive species at different stages of invasion (see With 2002 for detailed discussion). Fragmented landscapes present invasive species with potential trade-offs. Woodland habitat edges have been found to be more suitable environments for some invaders (Brothers and Spingam 1992). Fragmented landscapes have high amounts of edge, providing invasive species with more suitable habitat than less fragmented landscapes. In addition, species that are dispersed primarily by birds may have an enhanced dispersal ability in fragmented landscapes, because of the directed
dispersal created by the preferential use of edge habitats by many birds (With 2002). However, fragmented landscapes demonstrate less connectivity than less fragmented landscapes (With and King 1999), potentially restricting an invasive species' ability to successfully colonize new areas. Several models have predicted that a fragmentation threshold occurs in landscapes, above which the landscape becomes rapidly disconnected (Gardner et al. 1987, With 1997, and With and King 1997). This leads to the formulation of the hypothesis that landscapes which have an intermediate amount of fragmentation, resulting in a high amount of edge while still being below the threshold of connectivity, will display the highest abundance of invasive species.

Hutchinson and Vankat (1998) found that *Lonicera maackii* distribution was correlated with changes in percentage of forested land and degree of forest connectivity. In large-scale transects, *L. maackii* reached its distribution limit when forest cover dropped to <5% and forest connectivity was 0%, providing evidence that landscape structure strongly influences invasive species abundance and distribution. Road, forest, and field edges have all been found to harbor more invasive species than interior habitats (Cadenasso and Pickett 2001, Gelbard and Belnap 2003, Goldblum and Beatty 1999, and Watkins et al. 2003). However, Ross et al. (2002) found disturbance or quality of habitat to be as important a factor as degree of fragmentation in eucalypt forest, leading to a hypothesis that fragmentation alone may not be an adequate parameter to explain invasive species distribution. Other factors, including time since fragmentation, disturbance type, and time since invasion may also play an important role.

To test whether the spatial structure of woodlands (particularly edge and connectivity) influence the distribution and abundance of invasive species, data on invasive
species and landscapes was collected from public woodland sites across Iowa and analyzed for relationships, both independently and within a principal components analysis. The four target species for this study were multiflora rose (*Rosa multiflora*), common buckthorn (*Rhamnus cathartica*), bush honeysuckle (*Lonicera tatarica* and *L. maackii*), and garlic mustard (*Alliaria petiolata*). All four of these species are problematic invaders in woodlands and occur in Iowa. The following hypotheses were formulated:

1. Landscapes with smaller amounts of woodlands are more likely to have higher rates of invasion by exotic species.
2. Woodland landscapes with higher amounts of edge are more likely to have higher amounts of invasion by exotic species.
3. Woodland landscapes with a higher perimeter:area ratio are more likely to have higher rates of invasion by exotic species.
4. Woodland landscapes with a high degree of connectivity are more likely to have higher rates of invasion by exotic species.

**Methods**

**Study area**

For this study, the state of Iowa was divided into 5 regions, each consisting of approximately 20 counties. Every public tract that was over 5 ha in size and had a woodland component was identified using Arcview 3.2 together with the Luse and IaGapPub themes (available at the Iowa State University GIS laboratory website: www.gis.iastate.edu). For woodlands over 700 acres, the unit was sub-divided based upon natural or obvious breaks (rivers, constrictions, roads, etc.) into smaller units of approximately 300-500 acres in size prior to selection. A total of 60 public lands were selected to be surveyed throughout the
Within each tract of land selected for the survey, a start point for the survey was randomly selected. Only one survey was conducted within each selected woodland. The surveys of randomly selected public lands were conducted by the Iowa DNR state foresters to help ensure data reliability and allow for comparisons with the surveys on volunteer-selected lands. In addition, 22 public woodlands were selected at random and sampled within a five county (Boone, Dallas, Warren, Polk, and Story) area in central Iowa and sampled by trained Iowa State University staff.

**Field sampling methods**

Circular plots with a diameter of 4 meters were sampled approximately every 30m (approximations were made by walking 40 steps) along a transect. The transect was run in a cardinal direction which bisected the woodland. Once a plot along the transect was reached where the next plot would be placed outside the woodland, the transect direction was shifted 90 degrees and continued for 2 plots (approximately 60m) in that direction before shifting 90 degrees again, making the next transect in the opposite direction as the first one and parallel to it. At each plot, every individual plant was counted for the four invasive species. The transect continued until either the entire woodland was surveyed, a section of woodland with natural boundaries (stream, bluff, etc.) was completed, or 70 plots were completed. Locations were recorded using a hand-held global positioning system (GPS) unit.

**Landscape analysis**

All data was mapped in ARCView 3.2. Woodland size and shape was determined using the Gap Analysis Program (GAP) vegetation coverage, based upon 1992 Landsat imagery (30m X 30m grid cell size). The vegetation was reclassified into forest and non-forest classes and a 1 kilometer buffer was created around the center point for each survey
The values were calculated by analyzing the forested area contained within the buffer around each point. For cohesion calculations, the nearest 4-neighbor definition was used. All landscape parameters were calculated using Fragstats 3 (McGarigal et al. 2002).

Four landscape parameters were calculated:

1. Total area of forest type (ha), equals the area (m$^2$) of woodland, divided by 10,000 (to convert to hectares).
2. Total edge (m), calculated as number of grid cell sides (30m) that do not border another forest cell or the buffer boundary.
3. Perimeter:Area ratio, total edge (m) over total area (ha).
4. Cohesion (a measure of connectivity), equals 1 minus the sum of patch perimeter (in terms of number of cell surfaces) divided by the sum of patch perimeter times the square root of patch area (in terms of number of cells) for patches of the corresponding patch type, divided by 1 minus 1 over the square root of the total number of cells in the landscape, multiplied by 100 to convert to a percentage (McGarigal et al. 2002).

Statistical analysis

The 4 landscape variables were independently analyzed using a simple linear regression for each species. In addition, to compensate for any covariance, data was analyzed using a principal components analysis. Data was analyzed both by invasive species frequency (# of stops with species present / # of stops total) and presence/absence (0=present, 1=absent) using a principal components analysis.
Principal components analysis:

\[ P_{hj} = \lambda_{hA}A_j + \lambda_{hC}C_j + \lambda_{hE}E_j + \lambda_{hP}P_j = \lambda_{h}R_j \]

Where \( \lambda_{h} = (\lambda_A, \lambda_C, \lambda_E, \lambda_P) \) and \( R_j = (A, C, E, P) \) (R stands for "regressors").

\( A_j, C_j, E_j, P_j \) are respectively, the values of Area Cohesion, Edge, and Perimeter:Area ratio for location \( j \).

For the frequency analysis we modeled the following:

\[ \log (E(W_p)) = \gamma_1P_{1,j} + \gamma_2P_{2,j} = \beta_1(\lambda'_{1}R_j) + \beta_2(\lambda'_{2}R_j) = \gamma_A A_j + \gamma_C C_j + \gamma_E E_j + \gamma_P P_j \]

Where \( W_{pj} \) is the count of plant \( p \) at location \( j \) and \( \gamma_I = \beta_1 \lambda_{1,I} + \beta_2 \lambda_{2,I} \) with \( I = A, C, E, \) or \( P \).

For the Presence/Absence analysis we modeled the following:

\[ \logit (Pr(X_j = 1)) = \beta_1P_{1,j} + \beta_2P_{2,j} = \beta_1(\lambda'_{1}R_j) + \beta_2(\lambda'_{2}R_j) = \gamma_A A_j + \gamma_C C_j + \gamma_E E_j + \gamma_P P_j \]

Where \( \gamma_I = \beta_1 \lambda_{1,I} + \beta_2 \lambda_{2,I} \) with \( I = A, C, E, \) or \( P \).

Results

Independent regression found only one slightly significant result, common buckthorn and edge. All other tests yielded non-significant results (Table 1). The landscape variables demonstrated a high level of covariance. Table 2 shows the correlation matrix between four landscape variables. A strong positive correlation exists between area and cohesion and strong negative correlations exists between area and perimeter:area ratio as well as cohesion and perimeter:area ratio (Figure 2). Each landscape variable measured displayed considerable amounts of variation between sites (Table 3).
The principal components analysis for the 4 variables produced four principal components with the first explaining .6872 of the variability and the first two explaining .9114 of the variability (Table 4). Eigenvectors for the principal component 1 display a contrast between (Area, Edge, Cohesion) and Perimeter:Area ratio (Table 5). Principal component 2 is an Edge and Perimeter:Area ratio effect (Table 5). Based upon the Eigenvalues and Eigenvectors, the first two principal components were used for analysis.

Neither the frequency method nor the presence/absence method of analysis produced many significant results (Table 6). No clear trends are evident.

Discussion

Neither the independent regression nor the principal components analysis found many significant results. Additionally, no trends were evident in the results. Two separate principal component analyses were conducted. The first tested the differences in frequency, a measure of abundance, for each species. This analysis was testing habitat suitability, assuming that the species can disperse to the area and the differences in frequency found would be due to differences in habitat, most particularly edge habitat. However, no significant results or trends support that hypothesis. The second analysis tested the differences in presence/absence for each species. This analysis was not testing habitat suitability, since any frequency found was ranked as 1 (present) or no individuals being found ranked as 0 (absent). This test was focused more on the ability of an invasive species to successfully disperse into the habitat. The hypothesis that cohesion, a measure of connectivity, would have the greatest influence of dispersal ability was not supported by the results.
Two possible explanations exist for the lack of significant results. The simplest explanation would be that no relationships exist and thus any study would not find significant results. This explanation would lead to the conclusion that the spatial arrangement, in particular area, edge, perimeter:area ratio and connectivity, do not influence the presence and abundance of invasive species in woodlands in Iowa. Other factors, such as local woodland characteristics, may have greater influences over invasive species presence and distribution. The lack of significant results can also be explained by a small sample size. Sixty-five sites may not be a large enough sample size to produce results, especially if the variation due to other factors is great. Additionally, Iowa is a severely fragmented state, with almost all of the land having been cleared at some point in time. The range of sites sampled may not have been adequate to sample the full spectrum of fragmentation, with all of the sites being severely fragmented and no relatively intact sites sampled. Similar research with a large sample size is needed to fully answer the question of landscape parameters' influence on invasive species presence and abundance.

Acknowledgements

We thank Reid Landes for statistical advice and Greg Curler and Iowa DNR Foresters for survey assistance. This project was supported in part by a grant through the Iowa Department of Natural Resources and from the Northeastern Area State & Private Forestry, USDA Forest Service.

Literature Cited


Ross, K.A., B.J. Fox, and M.D. Fox. (2002) Changes to plant species richness in forest fragments: fragment age, disturbance and fire history may be as important as area. Journal of Biogeography. 29:749-765.


Figure 1: Example of a grid used to calculate landscape metrics. Radius = 1km. All landscape parameters were calculated using the forested grid cells (30mX30m cell). One measurement of each parameter (4 total) was calculated for each grid.

![Example of a grid used to calculate landscape metrics](image)

Table 1: Results from simple linear regression of four landscape parameters and four target species. Significant results shown in bold.

<table>
<thead>
<tr>
<th></th>
<th>MR</th>
<th>BT</th>
<th>HS</th>
<th>GM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>R²</td>
<td>p</td>
<td>R²</td>
<td>p</td>
</tr>
<tr>
<td>Area</td>
<td>0.014</td>
<td>0.3519</td>
<td>0.002</td>
<td>0.9177</td>
</tr>
<tr>
<td>Edge</td>
<td>0.005</td>
<td>0.5588</td>
<td>0.065</td>
<td><strong>0.0407</strong></td>
</tr>
<tr>
<td>Cohesion</td>
<td>0.032</td>
<td>0.1508</td>
<td>0.009</td>
<td>0.457</td>
</tr>
<tr>
<td>P:A Ratio</td>
<td>0.027</td>
<td>0.1942</td>
<td>0.014</td>
<td>0.3494</td>
</tr>
</tbody>
</table>

Table 2: Correlation Matrix between 4 landscape variables. Possible values range from -1 (perfect negative relationship) to 1 (perfect positive relationship). Values near or at 0 denote are interpreted as no relationship.

<table>
<thead>
<tr>
<th></th>
<th>AREA</th>
<th>EDGE</th>
<th>COHESION</th>
<th>P:A RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA</td>
<td>1.0000</td>
<td>0.4533</td>
<td>0.6902</td>
<td>-0.7956</td>
</tr>
<tr>
<td>EDGE</td>
<td>0.4533</td>
<td>1.0000</td>
<td>0.4182</td>
<td>-0.1313</td>
</tr>
<tr>
<td>COHESION</td>
<td>0.6902</td>
<td>0.4182</td>
<td>1.0000</td>
<td>-0.8500</td>
</tr>
<tr>
<td>P:A RATIO</td>
<td>-0.7956</td>
<td>-0.1313</td>
<td>-0.8500</td>
<td>1.0000</td>
</tr>
</tbody>
</table>
Figure 2: Scatterplots of the relationships between the landscape variables. a) Total area and Cohesion, b) Total area and Perimeter:area ratio, and c) Perimeter:area ratio and Cohesion.
Table 3: Descriptive statistics of the four landscape variables measured

<table>
<thead>
<tr>
<th></th>
<th>Area (ha)</th>
<th>Edge (m)</th>
<th>Cohesion</th>
<th>P:A Ratio (m/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>111.327</td>
<td>87.366</td>
<td>94.636</td>
<td>295.527</td>
</tr>
<tr>
<td>StD</td>
<td>52.670</td>
<td>28.017</td>
<td>5.890</td>
<td>141.394</td>
</tr>
</tbody>
</table>

Table 4: Eigenvalues of the correlation matrix. Proportion column denotes what percentage of variation is explained by each principal component (1-4). Cumulative column denotes percentage of variation explained by each principal component and the preceding principal components.

<table>
<thead>
<tr>
<th></th>
<th>Eigenvalue</th>
<th>Difference</th>
<th>Proportion</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.74899226</td>
<td>1.85220436</td>
<td>0.6872</td>
<td>0.6872</td>
</tr>
<tr>
<td>2</td>
<td>0.89678791</td>
<td>0.58806356</td>
<td>0.2242</td>
<td>0.9114</td>
</tr>
<tr>
<td>3</td>
<td>0.30872435</td>
<td>0.26322887</td>
<td>0.0772</td>
<td>0.9886</td>
</tr>
<tr>
<td>4</td>
<td>0.04549548</td>
<td></td>
<td>0.0114</td>
<td>1.0000</td>
</tr>
</tbody>
</table>

Table 5: Eigenvectors of the four principal components. Eigenvectors describe relationship between landscape parameters. Positive values (0-1) denotes a positive relationship. Negative values (-1) denotes a negative relationship.

<table>
<thead>
<tr>
<th></th>
<th>Prin1</th>
<th>Prin2</th>
<th>Prin3</th>
<th>Prin4</th>
</tr>
</thead>
<tbody>
<tr>
<td>AREA</td>
<td>0.547084</td>
<td>0.004149</td>
<td>0.743043</td>
<td>0.385447</td>
</tr>
<tr>
<td>EDGE</td>
<td>0.315076</td>
<td>0.896625</td>
<td>-0.081196</td>
<td>-0.300330</td>
</tr>
<tr>
<td>COHESION</td>
<td>0.554631</td>
<td>-0.089700</td>
<td>-0.663886</td>
<td>0.493552</td>
</tr>
<tr>
<td>PARATIO</td>
<td>-0.542043</td>
<td>0.433590</td>
<td>0.023452</td>
<td>0.719471</td>
</tr>
</tbody>
</table>

Table 6: Estimate and P-values calculated from regression on first two principal components. Significant P-values in bold.

<table>
<thead>
<tr>
<th></th>
<th>MR Estimate</th>
<th>P Value</th>
<th>BT Estimate</th>
<th>P Value</th>
<th>HS Estimate</th>
<th>P Value</th>
<th>GM Estimate</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Presence/Absence</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>-0.4481</td>
<td>0.0985</td>
<td>-1.6082</td>
<td>&lt;.0001</td>
<td>-0.285</td>
<td>0.2607</td>
<td>-3.7865</td>
<td>0.0002</td>
</tr>
<tr>
<td>Prin1</td>
<td>0.4045</td>
<td>0.0515</td>
<td>-0.0458</td>
<td>0.8146</td>
<td>0.0727</td>
<td>0.642</td>
<td>0.9938</td>
<td>0.1253</td>
</tr>
<tr>
<td>Prin2</td>
<td>0.0777</td>
<td>0.7742</td>
<td>-0.2304</td>
<td>0.5081</td>
<td>0.2949</td>
<td>0.2914</td>
<td>0.0517</td>
<td>0.9354</td>
</tr>
<tr>
<td>Frequency</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>2.1221</td>
<td>&lt;.0001</td>
<td>1.2615</td>
<td>0.0089</td>
<td>3.2308</td>
<td>&lt;.0001</td>
<td>0.4308</td>
<td>0.2062</td>
</tr>
<tr>
<td>Prin1</td>
<td>0.5715</td>
<td>0.0314</td>
<td>0.027</td>
<td>0.9267</td>
<td>-0.1021</td>
<td>0.8065</td>
<td>0.1178</td>
<td>0.5694</td>
</tr>
<tr>
<td>Prin2</td>
<td>-0.1155</td>
<td>0.8014</td>
<td>-1.2724</td>
<td>0.0131</td>
<td>0.6822</td>
<td>0.35</td>
<td>-0.1898</td>
<td>0.6006</td>
</tr>
</tbody>
</table>
Chapter 4: General Conclusion

Invasive species are widely regarded as one of the most serious threats to natural systems. Accurate information concerning the distribution and abundance of invasive species, as well as the types of habitats invaded, is vital to any comprehensive invasive species management plan, either for a single parcel of land, a state, or nationwide. The study developed and tested a method of gathering some of this necessary information in both a cost efficient and timely manner. The use of volunteers to collect data presents several potential avenues for error within the data. These avenues were identified and taken into account when designing the survey methodology. By designing the methodology to be as objective as possible and restricting the amount of information to be collected, most of the concerns over using volunteers to collect data were either reduced or eliminated. The most serious and unavoidable concern in using volunteers is the potential for misidentification of the target species. By limiting the number of target species to four and providing detailed instructions and handouts about species identification, this error was, hopefully, kept to a minimum. Comparisons of the volunteer-collected data with expert-collected data revealed a bias in the volunteer-collected data. Volunteers tend to select sites that they know have invasive species present. This restricts the ability of researchers and managers to extrapolate the data to areas that have not been surveyed. However, this bias in the survey also allows for more infested sites to be identified than would a random survey.

The methodology described here can be used in a variety of habitats as well as for many different invasive species. Wide adoption of the methodology would allow for easy comparisons and interpretation of the data. The survey would best be used either as an
ongoing index to monitor changes over time or in conjunction with a more systematic and random methodology. As with any project, ongoing quality assurance and improvements are necessary to keep the collected data relevant and useful.

Satellite imagery coupled with advancements in geographic information systems has allowed for explorations into aspects of ecology that scientists were previously unable to research. The second research project in this thesis was one of the first projects that used GIS technologies to examine the relationship between spatial arrangement, fragmentation, and invasive species abundance. Based upon the data collected, no relationship was found between any aspect of spatial arrangement and invasive species abundance. As stated earlier, this is possibly due to the fact that most of the sites selected were highly fragmented and disturbed. Any relationship that was present might have remained hidden due to the lack of sites covering the full spectrum of fragmentation (no or few sites were relatively intact and unfragmented). With a more robust data set, covering the full range of fragmentation, a relationship may be more likely to be found. This aspect of invasion ecology is one that needs further research. Identification of any relationships between the spatial arrangement of ecosystems and invasive species abundance would allow managers and planners to take invasive species into account when designing and managing natural areas.

As the threat of invasive species continues, invasion ecology also continues to grow as a field. Surveying and research projects that use volunteers and/or remote sensing have the ability to cover large areas efficiently. Inclusion of such techniques into the field of invasion ecology provides managers and researchers with data that otherwise would not be available. Currently these techniques are underutilized in invasion ecology. This thesis was
an attempt to include large-scale research methods into invasive species management and ecology.

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Literature Cited


Ross, K.A., B.J. Fox, and M.D. Fox. (2002) Changes to plant species richness in forest fragments: fragment age, disturbance and fire history may be as important as area. Journal of Biogeography. 29:749-765.


