Understanding the relationship between housing growth and exotic plant invasions

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OVERVIEW

The general objective of the project is to understand the relationship between housing growth and invasions of exotic plants in forested areas. I propose to work from broad regional patterns to detailed local scales to explore the importance of three housing characteristics for the distribution of exotic invasive plants: housing type, density of houses, and house locations.

Invasion of exotic species is a global problem, considered to be the second most important cause of species extinctions (Vitousek et al. 1997; Sax 2003). Invasive plants are exotic species that become established in natural areas, replacing native vegetation, altering ecosystems, becoming dominant or disruptive (Mehrhoff et al. 2003). Approximately 4,000 species of exotic plants have established free-living populations in the US and over 1,000 are a threat to native biodiversity (National Parks Service 2006).

Housing growth is also a global process with profound negative ecological effects (Theobald et al. 1997, Czech et al. 2000, Antrop 2000, 2004). In the US between 1950 and 2000, total proportion of urban land area increased from 1% to 2%, while low density housing growth located in rural areas increased from 5% to 25% (Brown et al 2005). Rural sprawl is spreading particularly rapidly in areas with natural vegetation, thus increasing the Wildland Urban Interface (WUI) (Radeloff et al. 2005a). The question is at which extent housing sprawl can be facilitating the dispersion of exotic invasive plants in natural areas.

Two processes relate exotic invasive plants to housing growth. First, humans purposefully import large numbers of exotic species to urban areas, and hence urban areas can be sources of propagules that invade adjacent areas (Mack & Erneberg 2002, Wania et al. 2006). Second, disturbances resulting from human activities near housing growth (e.g. creation of edges in native vegetation remnants, bare soil, trampling of native vegetation, etc) create a variety of microhabitats that can be colonized by invasive plants (Kowarick 1990, Wania et al. 2006).

In a scenario of rampant invasions and rapid housing growth it is a management priority to understand how future housing growth (particularly rural sprawl) can influence plants invasions at different scales in forested areas. I will develop four chapters which will range from broad and intermediate to fine scales of research. For each chapter I will consider two underlying questions: 1) How important is housing growth compared with other environmental and human-related factors for the dispersion of exotic invasive plants into forests? 2) Which types of invasive exotic plants or associated life history traits are favored by housing growth?

In the first chapter, I will study which housing pattern is the most important determinant of distribution of invasive exotic plants. Using a broad scale of analysis, I will relate the richness of exotic invasive plants to the area of four different patterns of housing growth (Intermix and Interface WUI, suburban and urban) in New England at the county level. This analysis will allow a direct comparison between the four most important patterns of housing growth in the US, including urban areas and rural housing.

After exploring the importance of housing pattern I will work at a finer scale in chapter 2 to determine how changes in rural housing densities affect distribution and invasion in different forest types. I will use FIA plots and census data in the Midwest and North East to relate the richness and cover of exotic invasive plants to variations in house densities for different forest types. In this analysis I will specifically compare the interaction between housing densities and forest condition and structure and its effects on plant invasions.

However, housing densities alone cannot reveal how spatial locations of houses influence the distributions of different invasive exotic plants at the landscape scale. Thus in chapter 3 I will use the actual location of houses in Baraboo hills, Wisconsin, to investigate the relationship between spatial pattern of housing and other landscape features and the distribution of invasive plants at the landscape scale.

Finally, in chapter four I will analyze the relationship between urban growth and a native invasive tree in central Argentina at the landscape scale. I will use satellite images to map all *Ligustrum lucidum* stands to analyze their spatial relationships with urban areas and landscape features. This chapter adds a different perspective by incorporating a reconstruction of the invasion history and urbanization in the area. It also allows a comparison of human-associated exotic invasive plant dispersion s in different biomes and socioeconomic contexts.

This project will make an impact in four areas: **ecology, management, technical** and **social**. In **ecology**, it will increase our understanding of the relationship between human and environmental factors of plant invasions, two processes with negative impacts in forests conditions. From a **management** perspective it will help to identify areas where housing growth could have larger impacts on plant invasions, thus selecting those areas for monitoring and control of invasive plants. The proposed study will provide fundamental information for science-based strategies of invasive plants management. For example, results of this project can be used in the four Elements of a National Strategy for invasive species management proposed by the Forest Service. From a **technical** point of view, I will test a methodology that has not been used previously for mapping the spread of invasive plants and can be applied to detect spread of *Ligustrum lucidum* at large scales and will also use novel GIS and statistical techniques. Finally, the project will have **social** implications. Results can be used to inform the public about the relationship between housing and plant invasions, and to raise awareness of and involvement in management programs.

BACKGROUND

Exotic species: a global problem

Invasion of exotic species is considered the second leading cause of species extinctions after habitat loss and one of the most detrimental consequences of global change (Vitousek et al. 1997; Sax 2003). Exotic species can cause the extinction of native species (due to predation or competition), and alter fire regimes, nutrient cycling, hydrology, and energy budgets of native species (Mooney 2005). Biological invasions in the US result in an estimated economic loss of 137 billion dollars per year, from which invasion of exotic plants account for 37 billion (Pimentel at al. 2000).

Invasive plants are exotic species that become established in natural areas, replacing native vegetation, altering ecosystems, becoming dominant or disruptive (Mehrhoff et al. 2003). Approximately 4,000 species of exotic plants have established free-living populations in the United States and over 1,000 have been identified as a threat to the native flora and fauna (National Parks Service 2006). While exotic plant species are distributed across the US, richness is especially high in the west, southwest, Gulf coast and New England areas (Stohlgren et al. 2006). Invasive species have accordingly been identified by the Chief of the Forest Service as one of the four significant threats to forest and rangeland ecosystems in the United States.

The magnitude of the problem has stimulated research to better understand the factors that promote invasions. Diverse factors have been found as key determinants of invasions (including ecological condition of the invaded community and propagule pressure), but the consensus is that biological invasions are highly related to human activities (Williamson & Fitter 1996, Lonsdale 1999). Humans facilitate invasions by carrying exotic species to new places and by making ecosystems more vulnerable to invasion through habitat disturbances and degradation (Forman 1995, Kowarik 1995, Mack et al. 2000).

Housing Growth, Rural Sprawl and the Wildland Urban Interface

Housing growth is also a global process occurring at an increasing rate and becoming one of the most important land use changes (Antrop 2000, 2004). In the US between 1950 and 2000, the total proportion of urban land area increased from 1% to 2%, while low density housing growth located in rural areas increased from 5% to 25% (Brown et al 2005). Housing growth in rural areas is mainly the result of an emigration process. Medium and high income people are moving away from large cities and are building houses in suburban and rural areas. The objective is to live "out of town", in closer proximity to natural amenities (Brown et al. 2005, Radeloff et al. 2005a).

Rural growth is spreading particularly in areas with natural vegetation, and as a consequence the Wildland Urban Interface (WUI) increased substantially across the U.S (Radeloff et al. 2005). The WUI is the area where houses meet (Interface WUI) or intermingle (Intermix WUI) with natural vegetation. Intermix WUI areas are defined as census blocks with more than 6.17 housing units/Km2 and more than 50% covered by natural vegetation. Interface WUI is characterized as developed areas in the vicinity of natural vegetation. Interface WUI was mapped as census blocks above 6.17 housing units/Km2 that contained less that 50% of natural vegetation but are in the proximity (2.4 Km) of a heavily vegetated areas (more than 75% of natural vegetation). The 2.4 km distance follows the recommendation of the California Fire Alliance (2001) and represents an estimate of the distance a firebrand can fly ahead a fire front.

In the conterminous USA, WUI covers 718,151 km2 (9% of total area) and contains 38% of all houses (44.1 million housing units). Intermix WUI account for the majority of WUI area nationally (81.8%), while interface WUI commonly limited to a ring separating non-WUI urban centers from outlying intermix areas. The WUI is widespread in the East, particularly in New England. For example, 72% of land area in Connecticut is considered WUI, while in New Hampshire 80% of houses are located in the WUI (Radeloff et al. 2005a). However, major WUI areas are also located along the West Coast.

WUI expansion is expected to continue in the future. Based on model forecasts, urban and suburban densities will expand to 2.2% of the US land area by 2020, whereas rural development will expand to 14.3% (Theobald et al. 2005). In the North Central U.S., areas with high potential for future residential density growth are spatially clustered on the periphery of metropolitan areas, in smaller urban centers, and in recreational areas thorough the region (Hammer et al. 2004). These trends indicate that in the future WUI areas will be a major factor of landscape processes at regional scales.

In the WUI, the combination of wildland ecosystems (such as areas of natural remnant vegetation and their respective ecosystems processes- e.g. disturbances) with human presence (population, infrastructure and human driven disturbances) can have important negative ecological consequences for both the ecosystems and human individuals and infrastructure. The WUI is thus a focal area for human-environment conflict such as the destruction of homes by wildfires, habitat fragmentation, introduction of exotic species and biodiversity decline (Haight et al. 2004, Radeloff et al. 2005a).

The extent and expected future expansion of the WUI highlight the need for ecological principles in land-use planning as well as sprawl-limiting policies to adequately address conservation problems (Radeloff et al. 2005b). As a consequence, urban and rural housing areas are becoming foci of ecological process and biodiversity change research (Johnson 2001).

What are the ecological consequences of housing growth?

Housing is probably the land use type with most profound and negative ecological consequences. In particular, the growth of urban or rural housing in natural areas is increasingly receiving more attention because the threats that it can impose on biodiversity and ecosystem functions (Theobald et al. 1997). In England, urbanization and roads development explain plant extinctions at the county level (Thompson and

Jones 1999). It has been estimated than more than 50% of all federally listed threatened species in the U.S. are in peril due to urbanization (Czech et al. 2000). Housing growth also affects landscape structure. In the US Midwest for example, housing growth since 1940 has caused a substantial increase of forest fragmentation (Radeloff et al. 2005 b). Several studies demonstrate a decrease in diversity when ecosystems become more developed, mainly because of the loss of natural vegetation but also because of factors like pollution, erosion and other human disturbances (McKinney 2002).

Rural housing results in habitat fragmentation and loss (Theobald et al. 1997) and changes in the forest composition around houses (Sabor 2005). It also results in more road development (Hawbaker & Radeloff 2004) that in turn can produce further habitat fragmentation and negative environmental impacts (Trombulak & Frissell 2000). The ecological consequences of rural housing are poorly known, however, particularly in relation to exotic species. In fact, rural housing is one of the most understudied land cover types (Hansen et al. 2003). This raises the question of how housing growth could be related to spread of invasive exotic plants in natural areas.

Housing growth as a determinant of exotic plant invasions

Although controversy exists about the factors that promote biological invasions, there is a general agreement that human activities cause dispersion of exotic species (Mack et al. 2000). Plant invasions are related to human population in reserves of the Czech Republic and the US (McKinney 2002, Pysek et al 2002), in US states (McKinney 2001, 2004), and California counties (Dark 2004).

However, from a management point of view we need to determine which aspects of human activities are the drivers of plants invasions (Pino et al. 2005). The most important human-related drivers appear to be socioeconomic and land-use factors. Richness of exotic plants is related to the level of development at a regional scale (Vila & Pujadas 2001) and the real estate gross product (GSP) (Taylor & Irwin 2004). Human-driven land use change is also a factor exotic species invasions (Hoobs & Mooney 2005). Urban growth and housing sprawl are related to the dispersion of exotic plants (Rapoport 1990, Deutschewitz et al. 2003). Roads associated with housing facilitate plant invasion act as corridors or agents of dispersal, providing suitable habitat and containing reservoirs of propagules (Forman 1995, Harrison et al. 2002).

In general terms, studies find a pattern of increased diversity in urban areas compared with more rural areas, determined at a large extent by the presence of exotic plants in urban areas. The amount of exotic plants increases with the number of houses and decreases with the distance to houses in south Argentina (Rapoport 1993). The same pattern was found in settlements of central Europe (Zerbe et al. 2003, Wania et al. 2006), Africa (Stadler et al. 2000), North America (Barton et al. 2004, Turner et al. 2005), and New Zealand (Sullivan et al. 2004).

What mechanisms explain the relationships found in these studies? Two processes may explain the relationship between urbanization and exotic invasive plants. First, humans purposefully import large numbers of exotic species to urban areas. A large proportion of the successful plant invaders in USA have been introduced for utilitarian reasons (aesthetic, food, medicine) (Mack & Erneberg 2002) and most of them as gardening plants (Reichard & White 2001, Mack & Lonsdale 2001). Thanks to active cultivation and protection, several gardening or cultivated plants survived until they reached a population large enough to become established (Mack & Erneberg 2002). Other non-cultivated plants can survive because of the warmer urban climate not found in colder areas outside cities (Kowarick 1990). These factors are critical in a scenario of global change, where due to environmental changes plants maintained in the city could later invade surrounding areas as global climate warms (Dukes & Mooney 1999). The exotic plants in houses and urban areas become then a source of propagules for invasion into adjacent sites (Wania et al. 2006). This is a dynamic process, since the growing number of human inhabitants (e.g. related to rural sprawl) increases the trade and traffic in and out of cities, which can continue to increase the proportion of non native species in the flora (Zerbe et al. 2003).

Neighborhood characteristics also affect the likelihood of invasions. Generally the largest numbers of exotic plants are found in the wealthiest neighborhoods, probably due to the resources devoted to gardening (Rapoport 1990, Sullivan et al. 2004). Because the particular exotic plant species popular for landscaping and gardening change with time, each time period adds a different set of plants into the pool of species (Zerbe et al. 2003). In some areas, a time lag exists between population growth and plant invasions. For example, in New Zealand, current invasive plant richness is more strongly correlated with the population densities of suburbs in 1945 than in the present day (Sullivan et al. 2004).

The second process via which housing fosters plant invasions is the creation of many different microhabitats and high spatial heterogeneity at fine scales, due to disturbances resulting from human activities (e.g. creation of edges in native vegetation remnants, bare soil, trampling of native vegetation, etc) (Kowarick 1990, Wania et al. 2006). Disturbances are important partially because many invader plants possess the ability to colonize bare soil (Hobbs & Huenneke 1992). For example, in urban parks the increase in exotic species is related to the use of herbicides, mowing, sport field creation, and bicycle paths (De Candido 2004), and research in an urban park in Boston showed that areas along trails were more frequently invaded (Drayton & Primack 1994). At broader scales, the growth of urban areas can also result in more fragmented and thus vulnerable landscapes. For example, in developed areas of Seoul, exotic plants are concentrated in forest edges near roads and human settlements, and within patches of small size and complex shape (Song et al. 2005).

Which invasive exotic plants are more related to housing growth?

A large amount of research has been done to identify the life history traits that make an exotic plant a successful invader. Detecting potential invaders has important management consequences, such the prevention of new introductions like preventing importation of invasive plants. After much controversy on the issue, there is a general consensus about several attributes that can be associated with invasive plants in most circumstances. Traits associated with invasiveness include continuous small seed production with high overall output, lack of special requirements for germination, short juvenile period, small genome size, having multiple reproductive strategies (vegetative reproduction being particularly important), taller height, and good dispersal capabilities (wind, water or animal dispersed, particularly birds) (Baker 1974, Williamson 1996, Rejmanek & Richardson 2004, Rejmanek 2000, Kolar & Lodge 2001, Sakai et al. 2001). The set of life history traits used to define invasive plants has many exceptions, and there is a failure to recognize a particular set of traits that most invasive plants share. One reason for this is that some traits can be adaptive for specific environmental conditions and ecosystems, but not others (Kolar and Lodge 2001).

A new perspective in the search for potential invaders includes developing a Disturbed Resource-Flux Matrix (Sher & Hyatt 1999). With the matrix, the compatibility between the species life history traits and the ecological conditions of sites to be invaded is analyzed. Habitats are classified by alterations to the disturbance regime that have changed physical and chemical resource flux, such that traits of successful invaders can be determined. In the case of housing growth, however, it is difficult to generalize about the possible consequences for habitat conditions and resources fluxes, considering the large number of human disturbances associated with different types of housing growth (Kowarick 1990, De Candido 2004, Wania et al. 2006).

Most disturbances that determine spread of invasive exotic plants in urban habitats increase the availability of bare soil (e.g. human trampling, trails) and open areas such as clearings and forest borders (Drayton & Primack 1994, De Candido 2004). Human-related disturbances also decrease along the urban-rural gradient (Theobald et al. 1997, McDonnell and Pickett in 1990, Moffat et al 2004). As a consequence, we can assume that the type of invasive plants and their associated life traits will change along an urban-rural gradient and with different housing growth types.

In and around more suburban areas, the larger availability of bare soil will facilitate the invasion of more r strategist plants, i.e. species with rapid growth, smaller and numerous seeds and more shade intolerance. In the other extreme, in less disturbed areas (e.g. forest patches undergoing rural sprawl) invasive plants will exhibit more k-selected strategies, i.e. shade tolerance, stronger competitive abilities, larger and animal dispersed seeds (particularly by birds). For example *Rhamnus cathartica*, a forest invader, seems to have a competitive advantage over native shrubs by leafing early in the season and keeping functional leaves later in fall (Tom Givnish, pers. com).

The general trend of associations between disturbances types and plant life history traits can be affected by other factors. For example, past land-use legacies could be more important than housing for certain species, and the invasive plants pool could also be biased toward the types of life history traits found in landscaping plants.

OBJECTIVES AND APPROACH FOR MY RESEARCH

Considering the velocity, expansion and possible ecological consequences of exotic plants invasions and housing growth, understanding the relationship between these two processes is a priority for ecological studies that can contribute basic information for successful management plans. Specifically, we need to understand how future housing growth (particularly rural sprawl) can influence plant invasions at different scales in forested areas.

The main objective of my research is to understand the relationship between housing growth and invasions of exotic plants in forests of the Midwest and Northeast. Temperate forests are particularly affected by invasions of exotic species, and there is concern of how the forests ecological conditions (e.g. forest regeneration) could be affected in the future. The upper Midwest and Northeast forests are undergoing rampant exotic plant invasions. Plants with strong ecological impacts includes norway maple (*Acer platanoides*) and tree of heaven (*Ailanthus altissima*) (trees), honeysuckle (*Loniicera spp*.), Eurasian buckthorn (*Rhamnus cathartica*), Japanese barberry (*Berberis thumbergii*), multiflora rose (*Rosa multiflora*) (shrubs), and garlic mustard (*Alliaria petiolata*) (herb). All of these species except garlic mustard have been introduced as landscaping plants, are originally from Eurasia and are commonly found in streets and yards of houses in towns and rural areas (Cox 1999, Czarapata 2005). Housing growth, particularly exurban growth and consequently the wildland urban interface have increased dramatically in the last several decades and this trend is expected to continue in the future (Brown et al. 2005, Radeloff et al. 2005 a). The co-occurrence of extensive plants invasions and housing growth make Middle East forest a very appropriate research area to investigate the effects of housing growth on spread of invasive exotic plants in forested areas.

Specifically, I will explore how housing can determine exotic plant invasions in forests from regional housing distributions to specific house locations in the landscape using different scales of analysis. I will develop four chapters ranging from broad and intermediate to fine scales of research. For each chapter I will consider two underlying questions: 1) How important is housing growth compared with other environmental and human related factors for the dispersion of exotic invasive plants into forests? 2) Which type of invasive exotic plants or associated life history traits are favored by housing growth?

1) The relationship of housing and invasive plants in New England
In this chapter I will use a broad scale analysis to determine which pattern of housing growth (Urban, suburban, Interface WUI and Intermix WUI) is more related to richness of invasive exotic plants, and which life history traits are more associated with housing growth.

2) The interaction between housing density and forest type for exotic plants invasion.
After comparing the importance of housing growth types I will use FIA plots to determine the effects of varying housing density on the richness and abundance of invasive plants in different forest types of the Midwest and North East. This chapter will examine the effect of housing variations within the wildland urban interface on plants invasions at finer detail than chapter 1.

3) The effect of rural sprawl facilitating dispersion of invasive plants in forested areas of Baraboo Hills, Wisconsin.
After studying the effects of variations in housing densities, I will use the actual location of houses in Baraboo hills to investigate the relationship between spatial pattern of housing and the distribution of invasive plants at the landscape scale.

4) Urbanization patterns and invasion of an exotic tree (*ligustrum lucidum*) in central Argentina
The chapter is focused on one species that can create homogeneous stands at canopy level. I will use satellite images to map all *L. lucidum* stands in a study area located in Cordoba, central Argentina, to analyze the spatial relationship with urban areas and landscape features. This chapter adds the perspective of reconstructing the invasion history of the invasive specie.

CHAPTER 1
The relationship of housing and invasive plants in New England
Understanding the factors related to the distribution of exotic species at coarse scales is a management priority, because biological invasions are one of the most harmful processes of global change (Vitousek et al. 1997, Dukes & Mooney 1999). The necessity of understanding the global patterns of plant invasions coupled with the availability of large scale databases and GIS software to integrate them has changed the focus of studies from small to large scales (Vila & Pujadas 2001, Pino et al 2005).

What are the determinants of exotic plant distributions at large scales? Both environmental and human factors are good predictors. Environmental variables can be more important that human factors in some cases. Biological and physical variables, particularly, native plant richness, are more important than human-related factors in the US at the county level, (Stohlgren et al. 2005). Native species richness is also a strong predictor of the number of exotic plants at a global scale (Londsdale 1999). Native species richness may be a surrogate for several factors that determine the diversity of species in a site, like productivity, low environmental stress and habitats heterogeneity (Stohlgren et al. 2005).

Population density tracks a number of human processes like deliberate introduction of gardening plants, disturbances at different scales, roads and urbanization that can facilitate spread of exotic plants (Sullivan et al. 2004, McKinney 2001 and 2002, Dark 2004). Amount of imports and level of development are strongly related to exotic plant richness in most European and North African countries, highlighting the importance of socio economical factors (Vila & Pujadas 2001). Housing growth is an important factor for the distribution of exotic plants in certain regions. In Catalonia (Spain), Germany, and Africa urbanized area is strongly related with the number of exotic plants (Stadler et al. 2000, Deutschewitz et al.

2003, Pino et al. 2005). In West Virginia (USA) two species (*Lonicera tatarica* and *Ailanthus altissima*) were correlated with large urban land use at the county level (Huebner et al. 2003).

In sum, housing growth seems to be an important factor for dispersion of exotic invasive plants. However, housing growth has been rarely included in analysis at large scales, so researchers have no general conclusion about its importance for invasive exotic plant distributions. Specifically, it is necessary to analyze which housing patterns are more related to plant invasions and how important housing is compared to other environmental and human-related factors.

New England is the region with the longest story of plants invasions in the US, that started with plants brought for utilitarian reasons by the first Europeans settlers and the accidental introduction of several agricultural pests (Mack & Erneberg 2002). The current New England flora is composed of between 24 to 45 percent non indigenous species (approximately 1000 species), depending on the state. Some species have become invasive and are causing ecological and economical problems (Mehrhoff 2000, 2003). The invasive species are a threat particularly for rare native plants in New England. Invasive plants are also related to human made disturbances, like roads, mowing, erosion, trampling dumping, and to natural disturbances (herbivory, droughts) (Farnsworth 2004). The combination of a large history of invasion in a mainly forested region makes New England a good case to study the relationship between housing growth and dispersion of invasive exotic plants in forested areas at broad scales.

The objective of this chapter is to determine whether distribution of exotic invasive plants in New England is associated with housing growth. Specifically, I will test whether invasive plants are responding to certain patterns of housing growth, and will then compare whether there is a particular group of plants or ecological traits that are associated with housing.

I hypothesize that: 1) invasive plant distributions will be related to housing, because urban areas are sources of invasive plant propagules and the disturbances associated with development favor the colonization and spread of invasive plants, 2) Invasive plant distributions will be more strongly related to rural housing, because houses in rural areas will favor the dispersion of propagules into natural ecosystems, 3) The distribution of herbs and grasses (representing plants more adapted to open areas) will be more related to suburban housing while shade-tolerant shrubs and trees will be more related to intermix WUI, representing housing growth located in more forested area, 4) History of introduction will have an important role. Invasive exotic plants introduced for gardening and landscaping will be more related to housing growth than invasive plants that were introduced accidentally.

Technical plan

Study Area

The analysis will include New England (Vermont, Connecticut, New Hampshire, Rhode Island, Maine and Massachusetts) and will be performed at the county level (n= 67). I chose this grain of analysis (county) both because data on the distribution of invasive exotic plants at a finer scale (like townships) is very fragmented and variable and because the focus of the chapter is on broad patterns rather than variable local conditions. New England is large enough for a regional study and exhibits a fair degree of homogeneity in its environmental and socio-economical characteristics.

General approach

I will use multivariate regressions to analyze the relationships of richness of invasive plants species with a series of explanatory variables, including urbanization, other type of human disturbances and environmental variables.

Variables included and Data sources

Response variables

Response variables will include total number of invasive plants and then the number of invasive species by plant type (shrubs, herbs, grasses, vines, trees and aquatic) in each county. The original number of invasive plant species will be corrected by county size (number of species/county area) (Stohlgren 2005). Then I will analyze how the relationship to housing growth changes for plant types that represent different life history traits. The main data source is The Invasive Plant Atlas of New England (IPANE). This database is composed of herbarium records, field records taken from scientific studies in the area and field records of observations from a team of 500 volunteers specially trained by the IPANE program in the six New England states. The database includes 111 species of invasive plants, defined as exotic species of plants that become established in natural areas, replacing native vegetation, altering ecosystems, becoming dominant or disruptive (Mehrhoff et al. 2003). The distribution of these plants is based on more than 11,000 records, which I consider acceptable for an accurate presence/absence database at the county level.

Explanatory variables

I will use a set of 18 explanatory variables to account for invasive plants distributions organized into three groups: housing growth, other human influence, and environmental (Table 1). I chose variables that other studies have found to be related to exotic plant distributions.

I will include five variables related to **Housing growth:** The first four represent different degrees in a continuum of urbanization intensity, ranging from downtowns of high intensity urbanization to the suburban and rural areas dominated by the intermix WUI. This set of variables is a good representation of the most important housing growth process in New England (Fig. 1). A fifth variable represents the housing growth between 1940 and 2000. Variables accounting for **other factors related to human presence or disturbances** (other than urbanization) were focused infrastructure, land alteration and socio economical aspects. This last variable is included since some recent work indicates that residential areas in wealthy neighborhoods are associated with much more intense gardening, with larger plant diversity (Hope et al. 2003).

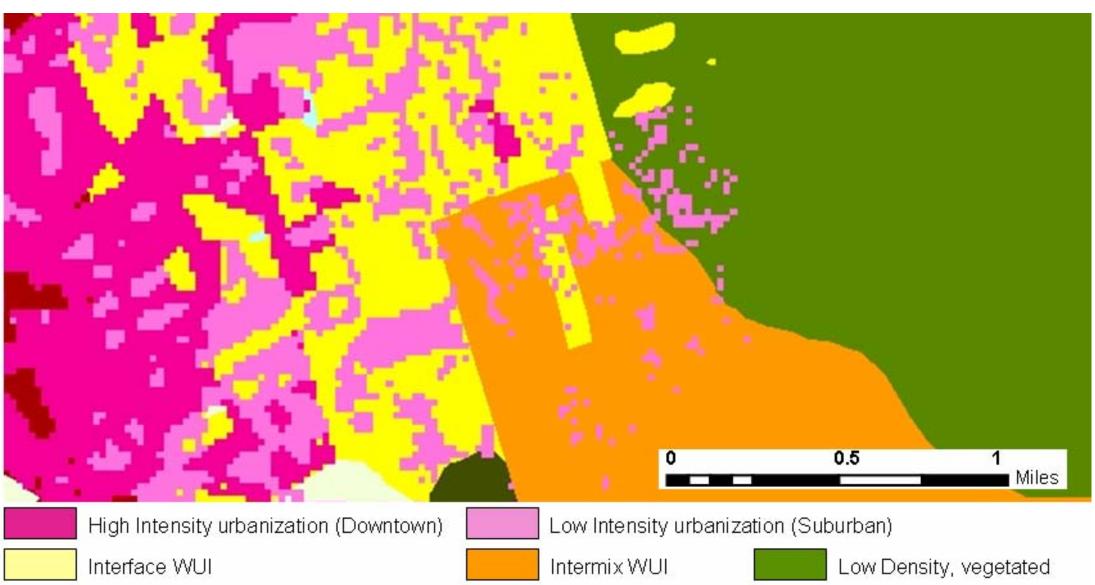


Fig 1. Example of the urbanization intensity gradient from downtowns to intermix WUI, for Rutland town, Vermont.

Environmental variables will include eight variables to account for ecosystem characteristics, climate and topography. Length of rivers has not been used as an exploratory in previous work at large scales, but riverine areas are more prone to invasion and act as sources of invaders to adjacent areas (Stolhgreen et al. 2005) (Table 1).

Table 1. List of explanatory variables organized in three groups: housing growth, other human influence, and environmental.

Variable	Comments	Source
Housing Growth		
Proportion of High and Low intensity residential areas	Surface of urbanized area (ha). From landsat images 30x30 m resolution years 1991 to 1993. Considers Low intensity and High intensity residential area divided county area	USGS National Land Cover Data, (NationalAtlas.gov)
Housing growth between 1940 and 2000	Change in the number of housing units at the end of the decade between 1940 and 2000.	GIS analysis of US Census Bureau data
Proportion of Interface WUI	Area of interface WUI /county area	WUI project. SILVIS Lab home page. http://silvis.forest.wisc.edu/silvis.asp
Proportion of Intermixed WUI	Area of Intermix WUI /county area	WUI project. SILVIS Lab home page. http://silvis.forest.wisc.edu/silvis.asp
Other Human Influence		
Population density	Number of inhabitants per county in 2000 divided county area	US Census Bureau
Cropland area	Area of cropland divided area of county	USGS National Land cover data, taken from the NationalAtlas.gov
Index of habitat disturbance	Sum of cropland, mining land and urban areas divided county area	GIS analysis of USGS National Land cover data (Vogelmann et al. 2001)
Amount of roads	Length of main roads in a county divided county area	The Major Roads of the United States map layer at a map scale of 1:2,000,000 compiled by the USGS
Per capita annual income	Per capita mean annual income per county	U.S Census Bureau

Table 1. *Continuation.*

Environmental		
NDVI	Normalized Difference Vegetation Index (NDVI), Average value per county, a surrogate for vegetation productivity	Derived from NOAA images taken each 2 weeks, and averaged for the year. In this analysis the average of 1990,1995,2000 and 2005 was used
Proportion of forested areas	Amount of forested area divided by county area	USGS National Land Cover Data, (NationalAtlas.gov)
Forest connectivity	Moving window analysis of forest connectivity, 9x9 window where the amount of forest to forest boundary is divided by the amount all forest boundaries. Final map resolution 270m window size, and averaged for the whole county	NationalAtlas.gov
Precipitation	Mean annual rainfall (mm)	Oregon Climate Service, PRISM climate digital data, taken from NationalAtlas.gov
Land cover diversity	Diversity of landcover classes (Shannon index)	GIS analysis on USGS National Land Cover Data (NationalAtlas.gov)
Density of main Rivers	Total length of main rivers in a county divided by county area	The main rivers of the United States map layer at a map scale of 1:2,000,000 compiled by the USGS (may be too coarse)
Temperature	Mean annual temperature	The Spatial Climate Analysis Service at Oregon State University, taken from NationaAtlas.gov
Mean elevation and elevation range	Mean elevation of each county (m), and elevation range	USGS GTOPO30 global digital elevation model (DEM), 30 meters resolution

Statistical analysis

General approach: I will fit multivariate regressions for each response variable adding urbanization variables one at a time in the models. That is, for each response variable five multivariate regression analyses will be performed to separate and compare the effects of the different urbanization variables.

Regression analysis: To avoid problems related to collinearity and to reduce the number of variables in the models, I will calculate a Pearson's correlation matrix for explanatory variables with a tolerance of r=0.7 and correlated variables with less ecological meaning will be dropped at that level. Using univariate regressions I will test that explanatory variables have a linear relationship with the response, and variables will be log transformed in case of non linearity. Then I will fit the models using the Best Subsets approach. This approach is based on a stepwise selection procedure that uses the AIC criterion but gives a number of better models (best subset) ranked by their AIC (Burnham & Anderson 2002) with a minimum number of variables. The number of models to obtain and the number of variables included are specified a priori (Miller 1990). The advantage of this approach is that it allows specifying the number of variables included in the obtained models, avoiding overfitting. It is also useful to know if the explanatory variables of interest (urbanization variables in this case) are always included among the best models and if it has a consistent effect on the response variable (it enters the better models with the same sign) (Jun Zhu, pers.com).

The residuals will be used to test assumptions of the models (Chatterjee et al 2000). If spatial autocorrelation is detected in the residuals of the models with a Moran's I test, I will fit autoregressive (SAR) models (Fortin & Dale 2005). Finally, with a Hierarchical Partitioning Analysis I will calculate the influence of each explanatory variable on the response variables when all variables are included in the model, to assess the importance of housing growth compared with other explanatory variables (Mc Nally 2002).

Expected outcomes and contributions

Exploring the relationship between invasive exotic plants and housing growth at broad scales will contribute to assess which housing growth patterns are more related to exotic plants invasions in New England, and the plant type or life history traits more related to conditions associated with housing growth. To my knowledge this is the first use of different patterns of housing growth to explain the distribution of invasive plants and the first comparison of housing pattern effects with other environmental and human-related variables Results of this chapter will also help to understand the pattern of invasive plants distribution in New England. The results could help to identify areas with a large amount of invasions depending on the amount of a particular housing growth type important for invasive exotic plants distribution, thus helping to anticipate part of the ecological impact of future housing growth development at regional scales.

Preliminary Results

The distribution of invasive plants in New England has a clear pattern of higher richness in southern and coastal counties, decreasing towards the north and center of the study area (Fig. 2). I present the results of my statistical analysis on the whole set of invasive plant species to assess the importance of the amount of Interface and Intermix WUI. After exploratory analysis the response variable and a few explanatory variables were log transformed to linear relationships. I eliminated a few outliers after exploratory analysis. I chose a set of 10 variables after collinearity analysis to start fitting my models resulting in a subset of four better models including a maximum number of 5 variables (Table 2). Interface WUI was always included in the models, as well as NDVI, density of roads and density of rivers. Intermix WUI was included just in one model. Interface WUI entered the models with a positive slope, indicating a positive relationship with the dispersion of invasive plants in New England. The best model of the set explained a 72% of the variability in the distribution of invasive plants (Table 3). The other models (B,C,D) presented spatial autocorrelation in the residuals so I fitted SAR versions of those models. The results are generally the same, but interestingly the SAR version of model D eliminated Intermix WUI.

The hierarchical partitioning analysis performed for the variables included in the best model shows

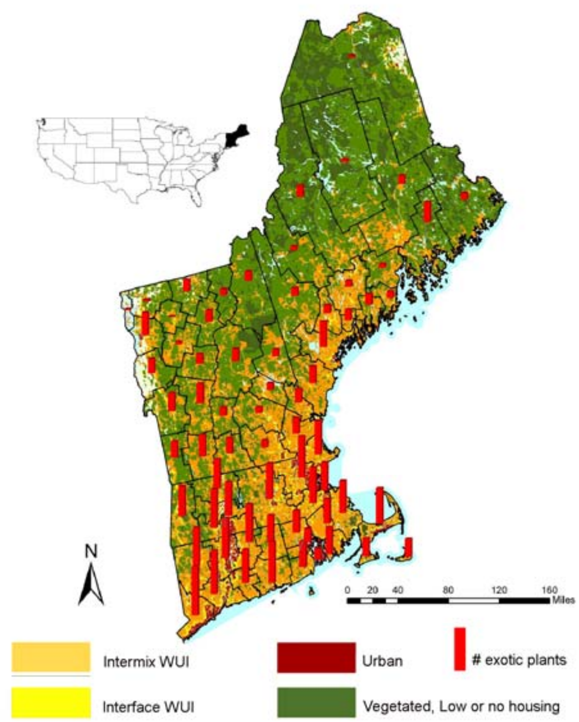


Fig 2. Distribution of the number of invasive exotic plants per county in New England and amount of WUI. Largest bar represents 44 species

clearly that Interface WUI is the second most important variable associated with distribution of invasive plants after density of roads. Interface WUI and roads are substantially more important than the other variables included, showing the importance of certain aspects of housing and human development and infrastructure in the distribution of invasive plants (Fig. 3).

Table 2. Best subset of models (4) using five variables. Models ranked according to the Bayes criterion (BIC). An **x** indicates variables included in each model.

Model	Intermix WUI	Interface WUI	Income	Altitude range	NDVI	Diversity of land cover	Proportion of forest	Proportion of agriculture	Density of roads	Density of rivers	r2	BIC
Best	-	x	-	-	x	x	-	-	x	x	0.72	-64.8
C	-	x	-	-	x	-	x	-	x	x	0.71	-63.9
B	-	x	x	-	x	-	-	-	x	x	0.71	-63.8
D	x	x	-	-	x	-	-	-	x	x	0.71	-62.9

Table 3. Best model fitted with the variables selected with Best. Subsets. Procedure. No spatial autocorrelation detected.

Variable	Estimate	Std. Error	t value	Pr(>|t|)
Intercept	-50.92	17.93	-2.83	**
Interface WUI	0.68	0.14	4.9	***
NDVI	9.55	3.63	2.62	*
Land cover Diversity	-1.45	0.71	-2.02	*
Density of Roads	4.77	0.70	6.76	***
Density of Rivers	1.49	0.25	5.96	***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
Adjusted R-squared: 0.7227 F= 34.89 on 5 and 60 DF, p-value: < 0.0001

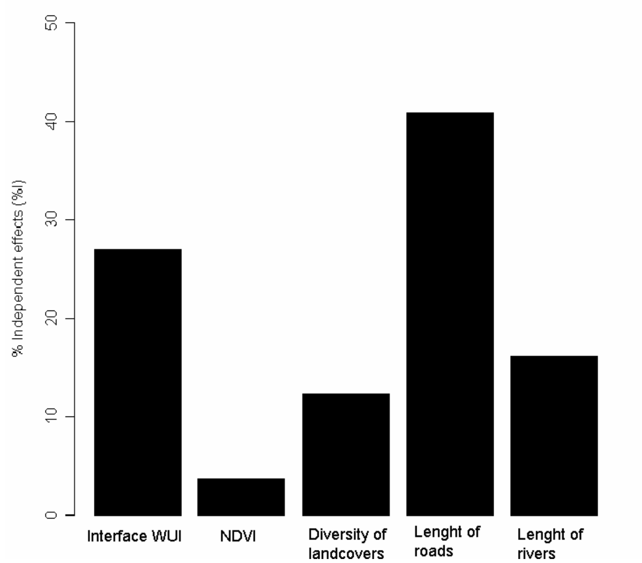


Fig 3. Percent of variation in the richness of invasive plants explained individually by each explanatory variable when all variables are included in the models.

CHAPTER 2
The interaction between house density and forest type for exotic plants invasion.

In my first chapter I will examine how different types of housing growth are associated to invasive plants richness at broad scales. The second chapter will be focused on understanding how the variation in densities of rural housing and forest type influence both richness and abundance of invasive plants. Considering rural housing in forested areas, this analysis will contribute to a better understanding of the possible consequences of WUI as a special combination of factors for the dispersion of invasive exotic plants.

Human activities and infrastructure related to housing in natural areas are direct or indirect determinants exotic invasive plants distribution in natural ecosystems. Gardening plants around houses are a source of propagules colonizing surrounding areas (Reichard & White 2001, Mack & Erneberg 2002). Small cities and towns are also sources of exotic plants colonizing adjacent forests (Barton et al. 2004, Wania et al. 2005). In general terms, disturbances related to houses (high nutrient inputs, warmer climate, higher light availability, changes in soil structure) produce spatial heterogeneity at a micro scale that creates habitat for exotic plants (Kowarick 1990, DeCandido at al. 2004, Zerbe et al. 2003). Other types of infrastructure (like roads or trails, parking lots, or mountain shelters) can be sources of exotic plants in areas of natural vegetation (Rapoport 1990, Forman & Deblinger 2000, Gelbard & Belnap 2003). Because of the increased activity and infrastructure in areas with several houses, it has been hypothesized that the relative abundance of weedy plants will increase with the density of houses in rural areas (Hansen et al. 2005). For example the richness and cover of alien plants was larger in areas developed with ranchettes than in ranches of large areas in Colorado (Hansen et al. 2005).

Invasibility of forests is also a function of stand ecological conditions and disturbance/use history. Exotic shrubs have greater densities in young and mid-successional than in mature stands in deciduous forests of Indiana (Flory & Clay 2005). Topography is another important factor. Invasive plants are more abundant in sites located on northeast-facing slopes, with more mesic conditions in West Virginia (Huebner & Tobin 2006) and in sites with steeper slopes in Yosemite National Park (Klinger et al. 2006). In southeastern New York soil conditions (soil nitrogen mineralization, nitrification rates, soil calcium levels, magnesium and phosphorus) were strongly related to the degree of site invasion (Howard et al. 2004). Management history has a strong impact on plant invasions. In Oregon forests, nonnative plants are more abundant in stands that have been recently clear cut or thinned than in stands that had not (Gray 2005). In Sierra conifer forest (California) plots under a group selection, single tree selection or reserve management regime had a greater proportion of introduced exotic species compared with plantations and shelterwoods (Battles et al. 2001).

We can then hypothesize that the distribution and abundance of invasive exotic plants in forests of the Midwest and North East will be a function of the interaction between houses densities and forest type. Due to the present extent and ecological characteristics of the WUI in the U.S. (Radeloff et al. 2005), testing whether the interaction of house densities and forests type influences distribution of invasive plants will help to understand large-scale patterns of plant invasions in forests. These patterns can in turn help to identify areas in the wildland urban interface at high risk for invasion and prioritize them for management and conservation.

The objective of this chapter is to assess whether richness and cover of invasive exotic plants increase with house density in the WUI, and if the relationship between plant invasions and house densities changes with forest type. Specifically, I will a) assess the relationship of house densities, forest condition and other environmental variables with richness and abundance of invasive plants in WUI areas for different forest types and assess which plant life history traits are more related to housing densities in forested areas and b) compare the richness and abundance of invasive plants in plots located in forested WUI areas and in forested non-WUI areas.

I hypothesize that invasive plant species will be more related to higher housing densities, because a larger number of houses will determine more human disturbances that can help invaders to colonize. Also, plants better adapted to colonize open areas (e.g. high dispersal capabilities, short generational times and more shade intolerant) will be associated with areas with larger housing densities, that could provide the open areas and bare soil spots they need. Finally, plants will be associated differentially to WUI types, because interface and intermix WUI represents different housing densities and also different spatial interaction with natural vegetation

TECHNICAL PLAN

Study area

The study region encompasses the Midwest and Northeast regions (North Dakota, South Dakota, Nebraska, Kansas, Missouri, Illinois, Indiana, Ohio, Michigan, Iowa, Wisconsin, Minnesota, Kentucky, Pennsylvania, New York, Vermont, Connecticut, Massachusetts, Rhode Island, New Hampshire and Maine).

Data

Exotic invasive plants and Forest type and condition

I will obtain data on exotic invasive plant richness and abundance, and variables of forest composition and condition from Phase 3 plots of the Forest Inventory and Analysis program. Phase 3 plots (forest health) are a subset of the FIA sample grid (one plot of every 16 standard FIA plots, which is equivalent to one Phase 3 plot per 96,000 acres of forest and an interplot distance between 10 and 20 miles) (Fig. 4). In each plot, core FIA and forest health measurements are taken. Each plot is composed of four circular subplots and an arrangement of small quadrats and transects to measure different sets of variables (Fig. 5). The vegetation indicator measures the type and abundance of trees, shrubs, herbs, grasses, vines and ferns on three permanently positioned 1m^2 quadrats on each subplot. Exotic invasive plants are also identified and measured, since a priority of the forest health program is to monitor spread of invasive plants in forests. In my analysis I will include biological and physical FIA plot variables to account for environmental effects. Biological variables are: richness and cover of invasive exotic and native plants, and stand structure and composition (mean dbh, basal area, number of trees and saplings, stand age, forest type). Physical variables are: soil type and condition (compacted degree, erosion, nutrient concentrations), topography (slope, aspect, altitude), and stand history (previous land use, tree removals, fire history).

House unit densities

I will use the number of house units per census block available through our lab's WUI database. The census block is the minimum mapping unit in the WUI definition and is therefore also the minimum grain of analysis. The census blocks are defined based on physical features like roads or rivers and have a median size of 0.01 km (Radeloff et al. 2005 a).

Data analysis

1- Separating the effects of housing density, environmental variables and forest type on the abundance and richness of invasive exotic plants.

I will use multiple regression analysis with richness and abundance of invasive plants as response variables. Explanatory variables will be housing density and environmental (biological and physical). Multiple regressions including the whole set of explanatory variables will allow me to assess the

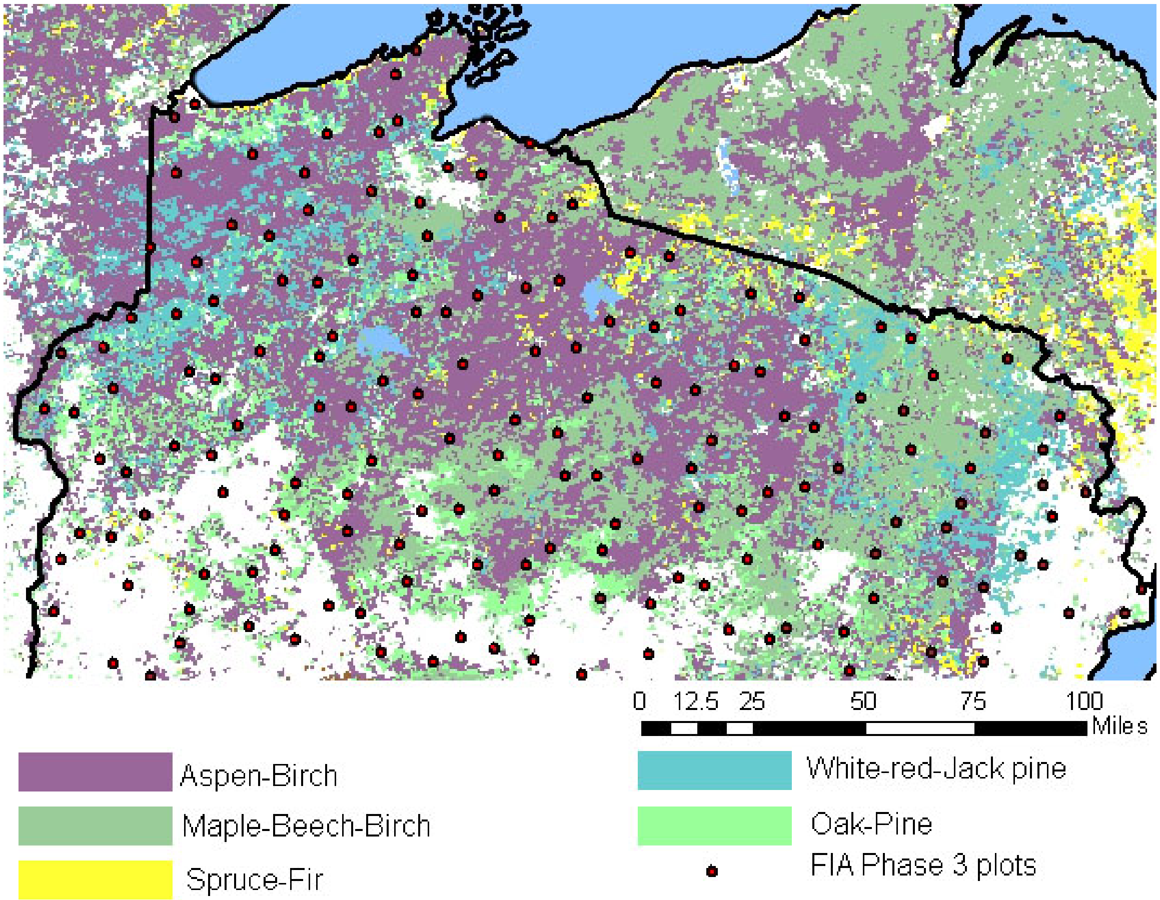


Fig 4. Example of distribution of Phase 3 by forest type in North Wisconsin.

importance of sprawl density compared to environmental variables for the whole region. I will then repeat the analysis but for each forest type separately. Forest types for the Midwest and North east include Oak-hickory, Maple-beech-birch, Aspen-birch, White-red-jack pine, Elm-ash-cottonwood and Spruce-fir. So for each forest type and the whole set of plots I will perform two regression analysis (for richness and cover of invasive exotic plants). I will also include analysis for the cover of individual invasive exotic plants. A set of the most abundant plants will be used to compare species with different life history traits and their relationship with housing growth.

The statistical treatment of these regressions will be the same that I used for the first chapter. Variables will be scrutinized for correlation with a threshold of 0.7, and best subset analysis will be used to get the best set of models. Spatial autoregressive models will be fitted if spatial autocorrelation is found in the models. Finally, with hierarchical partitioning analysis of the best model I will determine the importance of individual variables to explain richness and cover of invasive plants.

2-Comparing the number and cover of exotic invasive plants among WUI areas and non WUI forested areas.

As a secondary and coarser analysis, I will use two-way ANOVA to compare the effects of WUI and forest type on the number and cover of exotic plants. Factor 1 will be Intermix and Interface, and Non-WUI forest, and Factor 2 will be forest type. I will determine differences between groups with a Tukey's a posteriori test using an α= 0.05 in every test. If assumptions of the ANOVA are not met, I will apply a non-parametric Kruskal-Wallis test (Sokal & Rohlf 1994). This analysis will help to determine if there is a qualitative effect of WUI type (Interface of Intermix) different from house densities.

Expected outcomes and contributions

This analysis will address the effects of interaction between forest types and conditions and house densities, to identify forest types that are more sensitive to the effects of housing sprawl facilitating exotic plant invasions. In this way, this chapter will provide fundamental information to understand an important aspect of the potential human/nature conflicts in the WUI (human activities as facilitators of biological invasions). From a management point of view, identification of forest types or conditions particularly susceptible to housing effects will help to prioritize areas in the WUI for detection and management of invasive exotic plants.

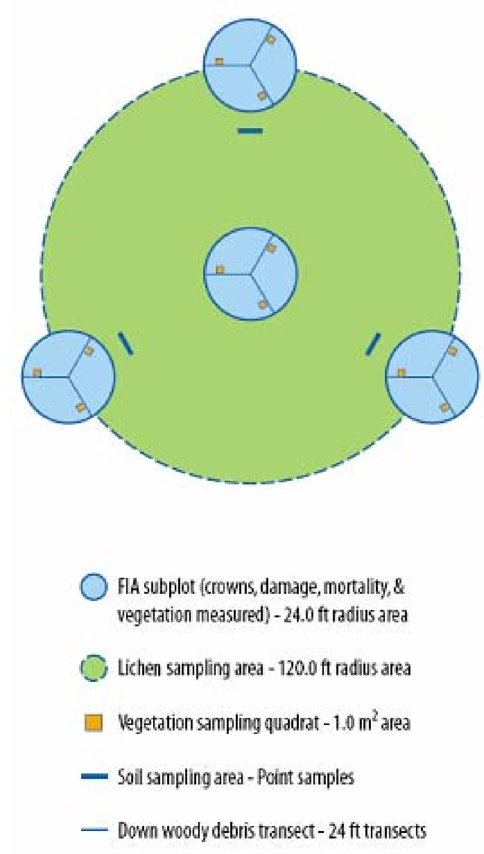


Fig 5. Phase 3 plot and forest health indicators measured

CHAPTER 3
Rural sprawl as determinant of plant invasions in forests of Baraboo Hills, Wisconsin

The previous chapter will enhance our understanding of how variations in housing densities influence the distribution of invasive plants in different forest types. However, that analysis lacks one piece of information that is necessary for complete understanding of invasive plant distributions: the influence of landscape configuration on the invasion process at local scales. In this chapter I will analyze how the pattern of invasive plant distributions is associated with the locations of houses compared with other landscape features (like forests edges and roads) and forest stand composition and structure.

Studies at small scales find spatial relationships between the locations of houses and the distributions of invasive exotic plants. In a property adjacent to a non-urbanized forest in the suburban area of Bariloche, Argentina, the largest number of exotic plant species is found around the houses and it decrease outwards. This set of exotic plants invading adjacent areas is composed mostly of escaped cultivar plants and weedy non-cultivated plants. The causes of this small-scale pattern include several human activities like trampling, soil removal, introduction of organic soil for gardening, soil covering by turf, planting of ornamentals, fertilizing, watering, etc (Rapoport 1990).

The Argentine case exemplifies the type of ecological mechanisms associated with rural sprawl that affects exotic species. Those mechanisms include habitat alteration (creation of yards and structures, habitat fragmentation), alteration of ecological processes (fire suppression and flood regime alteration), alteration of biotic interactions (invasive plants out-compete native ones, propagule pressure of invaders increase) and human disturbances (increased human trampling, invasive exotic seeds dispersion).

The negative effects of human-related factors on habitat decrease with distance from the source of origin, creating a *building effect* beyond which ecosystems are not affected (Theobald et al. 1997). Henceforth, each house affects a circular area with a radius defined by the *building effect*. The total area affected by sprawl in a region will depend on housing density but also on the spatial pattern of houses. A clustered distribution of houses has been suggested as a way to concentrate the individual effect of houses and decrease the overall area affected (Theobald et al. 1997).

The objective of this chapter is to analyze whether the spatial pattern of richness and abundance of invasive species is related to the location and level of ecological effect of houses in Baraboo Hills, Wisconsin. Specifically, I will a) analyze if the abundance and richness of invasive exotic plants is larger in areas with larger ecological influence of houses b) assess the importance of house spatial distribution and building effects on the distribution of invasive exotic plants compared with other landscape features and stand composition and structure c) determine whether time lags exist in the relationship between invasive exotic plants and rural sprawl and d) compare species specific responses to determine which species are strongly associated with rural sprawl in the Baraboo Hills.

I hypothesize that a) the highest cover and richness of exotic invasive plants will be found where the spatial pattern of houses creates a higher building effect b) there is an interaction of environmental factors and rural housing, where environmental factors can increase or decrease the importance of housing for invasive plant distributions, c) species with different ecological traits and introduction histories will have different association with sprawl. I hypothesize that there is a gradient of association to sprawl from gardening species with smaller dispersal capabilities and larger generational time (stronger association) to species not used for gardening with high dispersal capabilities and short generational times (weaker association). I also hypothesize that different dispersion capabilities of plants will determine different time lags in the association with sprawl.

Technical plan

General

My overall approach is to measure the presence and cover of a set of invasive forest plants in the Baraboo Hills area and relate their distribution to the pattern of rural sprawl and other human-related and environmental variables.

Study area

The study area is located in the Baraboo Hills in southern Wisconsin (89º 43’ 52”W, 43º 24’ 56.6”S) and encompasses 22 by 13.4 km (Fig. 6). It is a hilly area that represents the largest tract of continuous forest in southern Wisconsin. The area was originally covered by Precambrian sediments which eroded and left a quartzite remnant, the Baraboo Hills. Erosion created a number of stream gorges, for example Baxter’s Hollow. Later it was altered by Pleistocene glaciations, and the eastern portion of the area was covered by the Wisconsin glacier (Mossman & Lange 1979, Dott & Attig 2004).

The Baraboo Hills contains 27 distinct plant communities, 15 of which are rare in the state. There are 915 native vascular plants and 307 non vascular species (Department of Natural Resources-Wisconsin 1995). Most of the area is covered by mixed forest dominated by red and white oaks. Other common but less dominant trees are red and sugar maple, aspen, basswood, slippery elm, white and yellow birch and ironwood. Sugar maple-basswood forest is rare in the area and only some isolated stands remain (Curtis 1959, Lange 1998). The area also contains 171 aquatic invertebrate species, 135 breeding bird species, 50 fish species, 39 mammals and 29 amphibian and reptile species (Department of Natural Resources-Wisconsin).

There are several protected areas in the Baraboo Hills. Some are state owned (e.g. Devil's Lake Natural Area) while other are owned and administrated by NGO's, for example Baxter Hollow, which is administrated by The Nature Conservancy. The rest of the land is privately owned and lots are typically small.

European settlement has changed the vegetation considerably, through logging and land use conversion to agriculture. No major logging has occurred in the last thirty years in protected areas, but several private landowners still manage their forests. Most of the less protected areas are covered by secondary forest. Fire has not been a large disturbance for more than a century, but wind creates forest openings (Mossman & Lange 1979; G. Gavier, pers. obs.). The area is undergoing fast rural sprawl on private lands. Invasive plants are becoming a conservation concern particularly in protected areas. The most widespread invaders include garlic mustard, common buckthorn, honeysuckle, Japanese barberry and multiflora rose (pers. Obs).

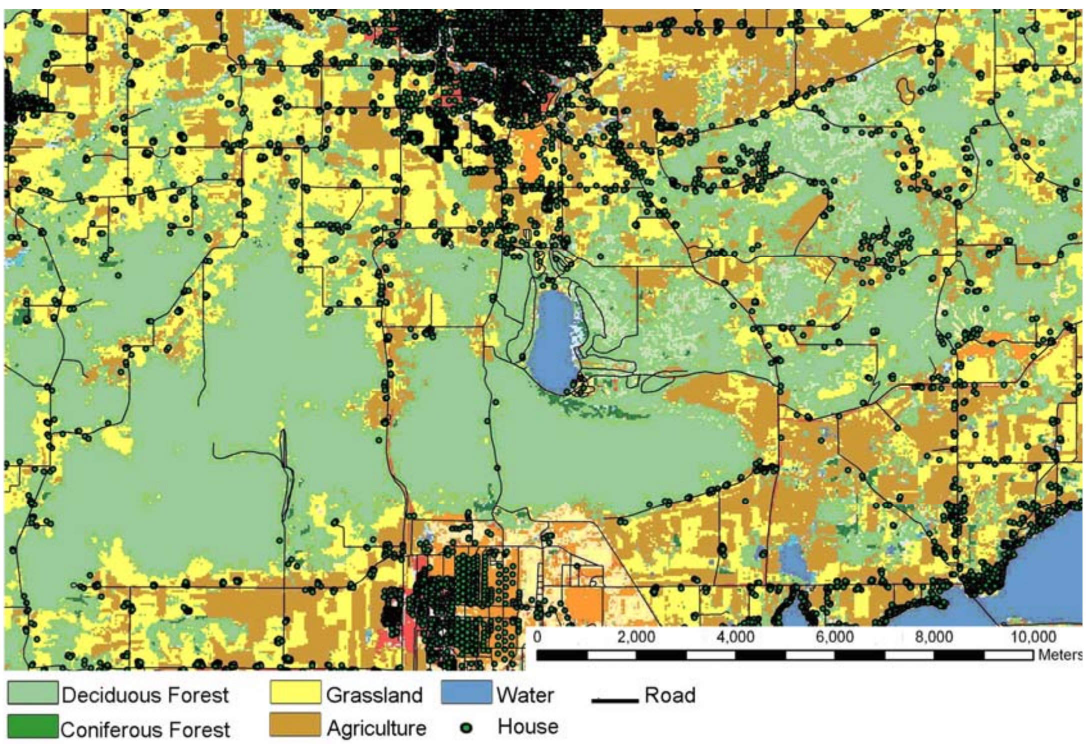


Fig. 6. Land cover and infrastructure in the study area in 2001.

Data

Invasive plants

I will work with a set of 9 species of common invasive plants of Southern Wisconsin Forests (Table 4). The species selection was based on several criteria, including: a) index of impact on the Working List of the Invasive Plants of Wisconsin (Invasive Plants Association of Wisconsin 2003), b) confirmed presence in the Baraboo Hills area according to the Wisconsin State herbarium, c) a ranking of invader plant abundance from field plots in Wisconsin and comments by Dave Rogers, Department of Botany of the

University of Wisconsin, Madison, d) other information from literature on invasive plants of Wisconsin and e) exploratory field trips to the study area.

The final list represents species that are common exotic invaders capable of colonizing forest interiors (not only edges), are easily recognizable in the field and are present during the whole growing season. Most of them have been introduced as landscaping plants (Table 4).

Table 4. List of invasive plants of forest in the Baraboo Hills

Latin name	Common name	Reason of introduction
Alliaria petiolata	garlic mustard	Early settlers for cooking
Berberis thunbergii	japanese barberry	Planted as sedge, ornamental
Elaeagnus umbellata	autumn olive	Landscaping, wildlife food, roads, revegetation
Leonurus cardiaca	lion's-tail	
Lonicera x bella	bell's honeysuckle	Horticultural planting
Morus alba	white mulberry	Planted for silkworms, ornamental
Rhamnus cathartica	common buckthorn	Ornamental, planted visual screening
Rosa multiflora	multiflora rose	Ornamental
Solanum dulcamara	bittersweet nightshade	

Sampling design

To capture the effects of rural housing I will use a stratified random design (Elzinga et al. 1998). The plots will be distributed in three strata. I will develop a variable called Ecological Influence of Houses (EIH) to stratify the area according to the building effect. According to Theobald et al. (1997) the negative ecological effects of a single house decrease from a central point outwards. This effect can have different maximum distance depending on the processes observed. Values range from 100 meters to 1 km. I used a conservative approach with three distances determining concentric areas around each house. A value of ecological impact will be assigned to each distance, 3 for 0 to 200 m, 2 for 200 to 400 m and 1 for 400 to 600 meters.

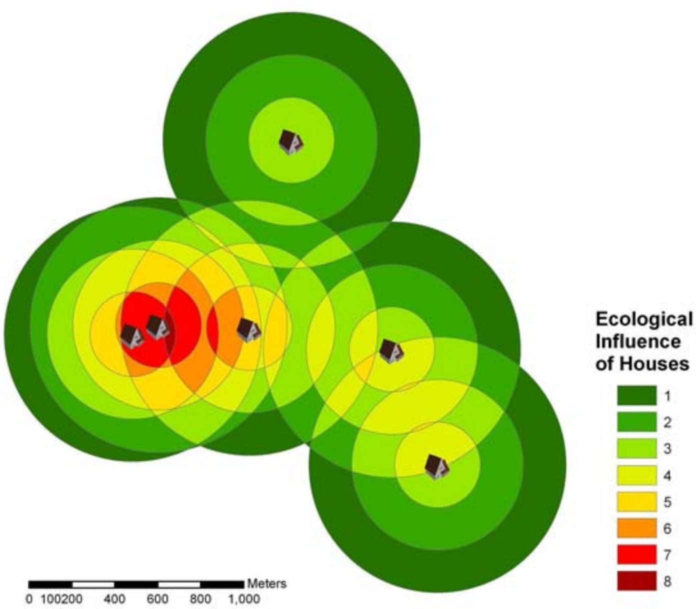


Fig. 7. Example of Ecological influence of houses defined after the overlays of three buffers (0-200m, 200-400m and 400-600m) around six houses in the Baraboo Hills area.

Houses in the area will be digitized from 1978 and 2001 aerial photographs using ArcGIS 9.1. For each house the three buffers will be calculated with its associated value of ecological influence. Then the values of the overlaying areas of ecological influence for different houses will be summed to get the map of this variable for the study area (Fig. 7). This method is effective in considering both variation of ecological influence with distance to house and the accumulative effect of several houses in areas with high densities.

I will divide the study area in three different levels of Ecological influence of houses: no influence (value=0), low influence (values=1-15) and high influence (value>15). Then overlapping these three classes with a map of the forest patches (NLCD project, cite) will provide the forested areas to be sampled. Any forest patch smaller than 10 hectares will not be included in the analysis.

I will distribute 150 sampling plots among the three strata in proportion to their areas. In each stratum the points will be located randomly but with an inhibition radius of 300 m to avoid spatial autocorrelation and to cover the area sampled more uniformly (Fig. 8). The sampling effort will be eventually adjusted after a power analysis to determine an adequate number of plots in each stratum (Southerland et al. 1996).

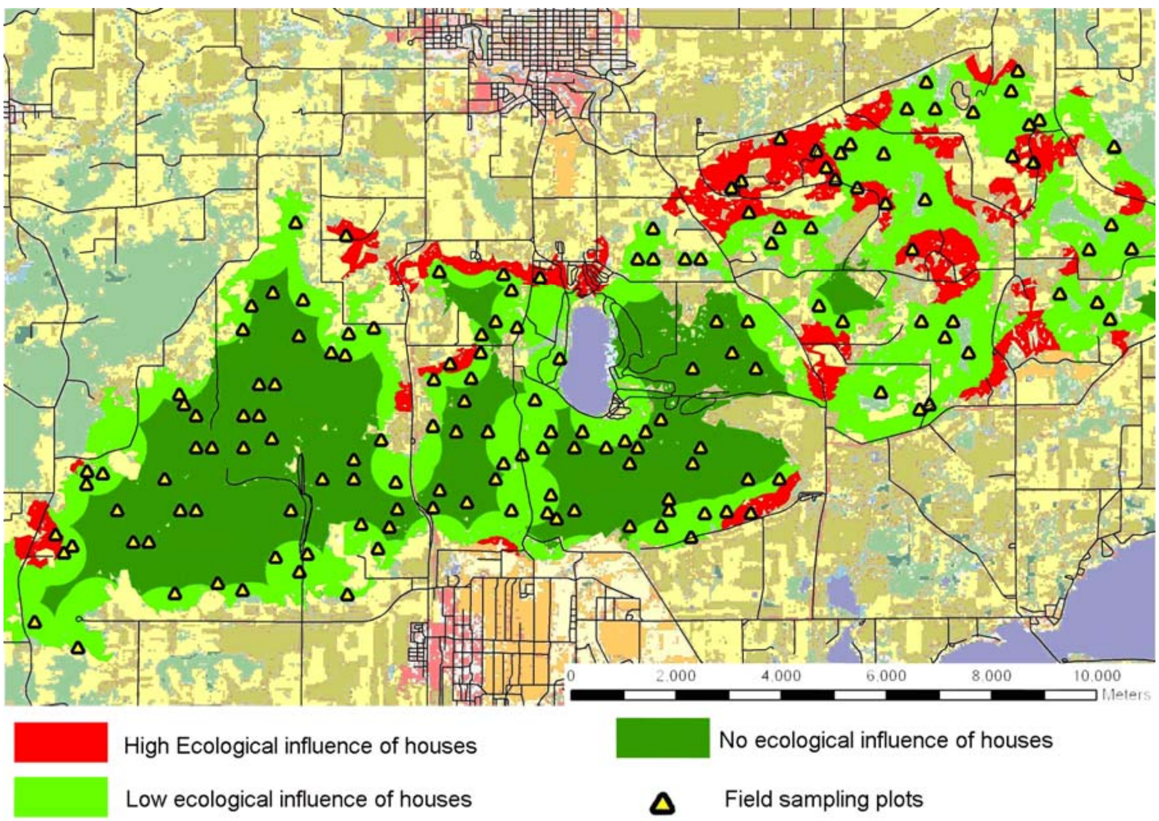


Fig. 8. Distribution of sampling plots on forested areas separated in three strata of high, low and no ecological influence of houses. The forests area sampled has a surface of 11,235 ha.

Plot design and data recorded

I will use 20m radius circular plots. Plot size was chosen after sampling presence/absence of the set of invasive plants in 30 plots using three nested circles of 10, 15 and 20m diameter. Using 20m plots added a substantial number of recorded species of invasive plants to those recorded in the 10 and 15 m plots. In each plot, three transects to measure cover will be located from the center of the plot outwards at 120 degrees between them and starting two meters from the center, to avoid overlap of measures (Fig. 9).

Circular plots have been used widely for vegetation sampling, for example in the Forest monitory and Analysis inventory program, since they can decrease border effects in the sample (Elzinga et al. 1998). My plots are essentially a modification of the plot design proposed for the North American Weed Management Association (NAWMA) by Stohlgren et al (2005) where I replaced a quadrat plot with an intercept line transect for the measure of vegetation cover. My circular plots cover an area slightly larger (1,256 m^2) than the 20 x 50 m standard rectangular plots used for estimation of vegetation richness (1,000 m^2) (Whittaker 1977, Stohlgren et al. 2005). Comparative work shows that both visual estimation in quadrat plots and line intercepts produce good results of plant cover measurement (Hanley 1978). However, line intercept is better because it provides a direct measurement instead of a visual estimation, resulting a more precise measure of cover, the mean values stabilize with less number of samples and are effective with different vegetation types (visual estimation do not perform at the same level with grasses and forbs) (Hanley 1978, Floyd and Anderson 1987, Etchberger & Krausman 1997). I will use this transect arrangement because a) generally, there is an agreement that transects longer than 30 m do not increase precision to the cover estimation, and previous work suggest that is better to increase the transect number than meters in the transect (Floyd and Anderson 1987, Etchberger & Krausman 1997), b) a radial set of transects perform better (less variability) than just setting them in a straight line, because it covers local conditions and is not sampling a larger scale of spatial heterogeneity (Etchberger & Krausman 1997).

Invasive Plants

Richness of species will be calculated as presence/absence of invasive species in the 20 meter circle.
Cover will be measured as the length of the intersection of each species crown projection on a measuring tape to the closest inch.

Large individuals: To have a complementary measure of individual sizes and cover I will measure the number and area dominated by invasive plant individuals when they occupied an area equal or larger than a square meter (crown projection on the floor). This measure will be used only with shrub species with a compact shape including *Berberis thunbergii*, *Lonicera x bella*, *Rosa multiflora* and the vine *Solanum dulcamara*. I consider this measure a good proxy indicator of individual age and time since invasion of the site.

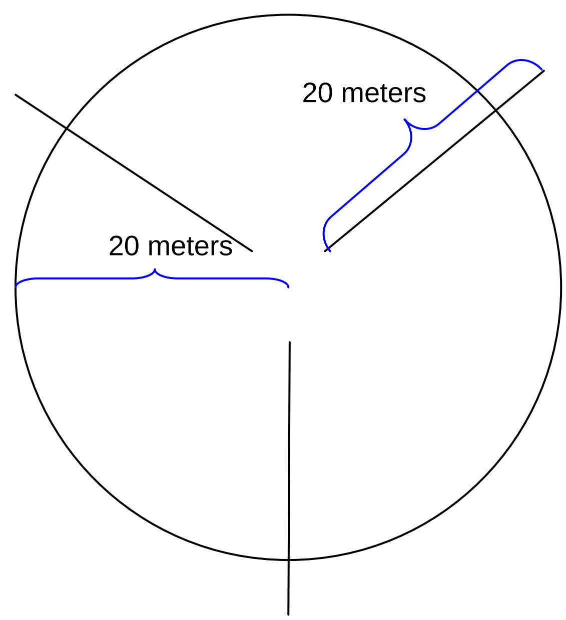


Fig 9. Plot design with subsampling transects. Transects were kept in fixed positions.

Buckthorn size: to have an idea of the colonization history of buckthorn (*Rhamnus cathartica*), in each plot I will measure the diameter at 5 centimeters above ground of the largest individual. In plots where just small buckthorn individuals are present (less than 1.5 cm diameter), I will assign a value of 0.5 cm based on field observations.

Forest structure

Stand characteristics: in a nested 15 m diameter circle I will record species at least at genus level and DBH for all

trees larger than 5 inches in diameter. Heights will be measured for three individuals representative of the stand canopy.
Cover: vertical structure of the forest will be divided in three strata, stratum A from 0 to 1 meter (small shrubs and herbs), stratum B from 1 to 4 meters (large shrubs, saplings and small threes) and stratum C represents forest canopy (above 4 meters). Cover will be measured for each stratum as the vertical projection of vegetation crowns in the 20m cover transects. Native vegetation will be categorized by vegetation type, but will not be identified to species. For stratum A cover will be categorized as shrub, herb, litter, rock, log (fallen logs larger than 6 inches in diameter) and bare soil. In stratum B no vegetation types will be used. Cover in Stratum C will be recorded using a categorical system: 0 to 25% (1), 25 to 50% (2), 50 to 75% (3) and 75 to 100% (4).
Disturbance: I will record three variables representing forest disturbances as present/absent: signs of fire, past forest logging (presence of stumps) and deer browsing. When possible, distance to closest trail will be calculated in the field.

Environmental variables

Topography: for each plot, altitude, slope and aspect were calculated from a 10 meter resolution DEM using ArcGIS.
Soil Type: I assigned soil type for each plot using data from the USDA Natural Conservation Resources Center.
Fragmentation: for each plot, distance to closest forest edge was measured using ArcGIS.

Rural Sprawl

I calculated for each plot distance to nearest house in 2001 and 1978, number of houses in a 1000 m buffer area around the plot, value of the Ecological influence of houses and distance to the nearest road using ArcGIS 9.1.

Statistical analysis

I will use two main approaches:

1) In a more general analysis I will use 1- and 2- way ANOVA to compare richness and cover of invasive exotic plants among strata of different Ecological influence of Houses. I will use three categories of forest stand composition selected a priori in the field (maple dominated, oak dominated, mixed) as a second factor in the analysis.

2) I will perform a more detailed analysis to determine which variables are related to the distribution and cover of invasive exotic species. I will use multiple linear regressions with richness and cover of all exotic invasive plants and individual species as response variables. Explanatory variables will include three groups: **human infrastructure** (Distance to nearest house present in 2001 and 1978, number of houses in a buffer area around each plot, value of the Ecological influence of houses and distance to the closest road), **environment** (altitude, slope, aspect, distance to closest forest edge) and **forest structure** (cover of native vegetation for strata A, B and C, mean DBH, basal area, and dummy variables including forest type, presence of logging, fire or browsing).

To avoid collinearity a Pearson's correlation matrix will be calculated for the explanatory variables. A threshold of $r>0.7$ will be applied, and correlated variables with less ecological meaning will be eliminated. Several multiple linear regression models will be constructed, using total cover and richness of invasive exotic plants and then fitting models for cover of individual species. Stepwise selection will be applied to remove insignificants predictors with a $p=0.05$ (Chatterjee et al 2000). Logistic regressions will be used with presence absence of single species. If spatial autocorrelation is detected with semivariograms for the model residuals, I will use Generalized Linear Models (GLM) that allows incorporating a semivariogram to model the spatial autocorrelation in the regression model (Isaaks & Srivastava 1989). The Akaike Information Criterion (AIC) and Information-Theoretical model selection (Burnham & Anderson 2002) will be used to evaluate the regression models.

Expected outcomes and contributions

Ecologically, this chapter will contribute to our understanding of how the most invasive plants of forests in the region differ in their association with housing development in rural areas. Results at this local scale can help to explain the effects of house density found in chapter 2. From a management perspective, this chapter will help to forecast the possible plant invasions related to new housing growth in forested areas of the Midwest. The maps of exotic invasive plants will provide a good understanding of the spatial patterns of plant invasions in the Baraboo Hills area, thus helping managers to create more effective management plans for reserves in the area.

Preliminary results

Richness of invasive exotic plants was inversely related to the distance to the closest house in 1978 ($R2= 0.2539$, $p< 0.0001$) and in 2001 ($R2=0.2068$, $p<0.001$). Interestingly the richness was more strongly related with distances to houses in 1978. Richness of invasive exotic plants was also inversely related to the distance to closest forest edge ($R2=0.253$, $p<0.0001$) and road ($R2= 0.1063$, $p= 0.003157$). Cover of invasive exotic species was not related to distances to houses, forest edges or roads. Using a multiple linear regression analysis with stepwise variable selection, the best model included the distance to nearest house in 2001, and cover of litter, shrubs, herbs and exposed rocks in the plot (all variables were inversely related to invasive exotic plants richness) ($R2= 0.3525$, $p<0.0001$).

CHAPTER 4
Urbanization patterns and invasion of an exotic tree (*Ligustrum lucidum*) in central Argentina

In my fourth chapter I will examine glossy privet (*Ligustrum lucidum*), an invasive tree in central Argentina. The species analyzed and the geographical location will add two new components to my study. First, glossy privet in the study area forms dense and almost mono-specific stands that can be mapped using satellite imagery (Gavier & Bucher 2004). Mapping these stands, I will be able to reconstruct the invasion history in the area and relate the spatial distribution of the stands to other landscape features, particularly urban growth. Second, in central Argentina there is a strong process of urban growth in rural areas and rural towns. This chapter will allow me to analyze whether exurban growth is related to the dispersion of an invasive exotic plant in a different ecological and social context.

In Argentina, invasive exotic plants also constitute a huge ecological and economic problem (Bertonatti & Corcuera 2000). One of the most affected ecosystems is the Sierras de Cordoba in central Argentina (Marco & Páez 2000), where the most widespread and invasive exotic plant is the glossy privet. The glossy privet is originally from China, was imported to Argentina as an ornamental, and has become invasive in several regions (Montaldo 1993, Montaldo 2000). Glossy privet has been recognized as a successful invader in several countries like Australia and New Zealand (Panetta 2000, Cronk & Fuller 1995, Swarbrick et al. 1999). It grows fast, reaching 15 m in height, which exceeds the height of native trees in Cordoba, central Argentina. Shaded conditions prevent native trees from growing under the privet canopy and consequently native trees are eliminated in the invaded areas. The glossy privet grows successfully under conditions ranging from shade to full sunlight, and bird dispersed seeds and vegetative propagation ensures rapid spread (Aragón & Morales 2003, Aragón & Groom 2003).

Particularly in the Sierras Chicas, privet is expanding rapidly on forested slopes, constituting an additional threat to native forests already experiencing rapid deforestation. In severely invaded areas it forms large and almost mono-specific stands where native vegetation is eliminated, seriously threatening native biodiversity (Gavier & Bucher 2004, Hoyos 2007). The distribution of invaded areas appears to be spatially related to urban areas, which may act as seed sources and also facilitate invasion when native forest is cleared for human development.

Detection and mapping is a fundamental part of exotic species management (Rejmanek & Pitcairn 2002). Satellite images have been extensively used to map vegetation at large scales (Cabido & Zak 1999, Shugart et al. 2001, Gavier & Bucher 2004). However, even though remote sensing products have been available for more than 30 years, just a few studies have used satellite images to map distributions of exotic plants (Hunt et al 2003). A possible reason is the limitations of satellite images to differentiate between invasive and native plants when they are intermixed (particularly if the satellite images have pixels size larger than 30 x 30 m in the field like Landsat TM) (Hunt et al. 2003, Lass et al. 2005). The development of new finer resolutions or hyperspectral sensors (like IKONOS and AVIRIS) is beginning to overcome these resolution limitations and providing good tools to map exotic plants (Ramsey et al. 2005, Lawrence et al. 2006, Bradley & Mustard 2006).

However, Landsat TM images have been successfully used to map invasive exotic plants that form mono-specific invasive patches larger than 0.5 ha (Peterson 2005, Bradley & Mustard 2006). One of the most widely used classification algorithms in Landsat images, Maximum Likelihood Classifier, assumes homogeneous cover in the pixels used as reference cites (Campbell 2002). In Cordoba, the glossy privet creates large homogeneous patches and preliminary analysis shows that Landsat TM Images are adequate to differentiate glossy privet stands from native forest (Gavier & Bucher 2004, Hoyos 2007).

No studies to my knowledge, however, have used satellite images to map the expansion of an invasive exotic plant. Several techniques using satellite images have been developed to detect temporal change at broad spatial scales, to address for example land use change, vegetation changes, deforestation, urban growth, etc. (Singh 1989, Lu et al. 2004). In this chapter I propose to apply a combination of change detection techniques used with Landsat TM images to detect changes in vegetation (Sader & Winne 1992, Sader et al. 2001, Lu et al. 2004) to map the spread of *Ligustrum Lucidum* between 1983 and 2001.

The objective of this chapter is to analyze whether the spread and location of *Ligustrum lucidum* dominated stands are related to the urbanization pattern in the study area between 1983 and 2001. Specifically, I will a) map the spread of *Ligustrum lucidum*- dominated stands using Landsat TM images and change detection techniques between 1983 and 2001, and b) analyze the importance of urban sprawl as a factor influencing the spread of *Ligustrum lucidum* compared with other environmental and human factors.

I hypothesize that *Ligustrum lucidum*- dominated stands will be spatially related to the distribution of urban areas, because urban areas act as a source of propagules and have associated disturbances (like clearing of properties) that facilitates the invasion of *L. Lucidum*.

Technical plan

Study area

The area is located 25 Km north of Cordoba city, Central Argentina (31S-64W, 50,000 ha). The altitude ranges from 450 m in an agricultural plain in the east to 1350 m on a grassland plateau (Sierra Chica) in the west. The slopes of this plateau (700 to 1000 m) are covered by native *Lithraea molleoides* and *Fagara coco* forests (Fig. 10).

The area represents an extreme case of glossy privet invasion, with large stands (more than 150 ha) totally dominated by this species (Gavier & Bucher 2004). The area has a long history of land use: cattle grazing, wood extraction and the expansion of agriculture. Recent practices include human-induced fires. The annual deforestation rate is 2.8 %. Urban and exurban growth and population increase have been rampant in the last 30 years (Cabido & Zak 1999, Gavier & Bucher 2004).

Fig 10. Study area location and detail of landscape features

Satellite Images and Change Analysis

I will use 3 Landsat TM images from 1983, 1997 and 2001 obtained from NASA, CONAE (Argentine Commission for spatial activities) and University of Maryland respectively. The canopy of glossy privet-dominated stands has different characteristics from the native forest canopy, being more dense and closed (Fig.11).

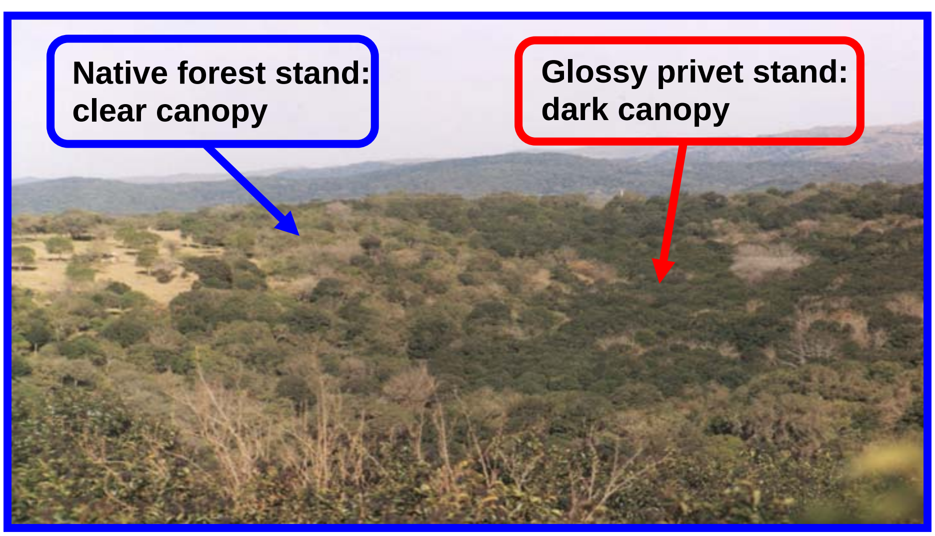


Fig 11. Example of the differences in canopy characteristics of native forests and glossy privet stands

The difference of canopy characteristics between native and glossy privet stands results in differences of reflectance in the light spectrum, particularly in band 4, that makes them differentiable using Landsat TM images (Fig. 12).

I will use the Normalized Difference Vegetation Index (NDVI) to differentiate areas dominated by glossy privet from areas dominated by native forest in 2001. NDVI is an index that quantifies the amount of photosynthetic biomass and is based on a quotient between Landsat TM bands 3 and 4. Based in privet areas detected by the NDVI index, I will classify the Landsat TM image of 2001 using a maximum likelihood classifier (Jensen 1996) to map the distribution of invaded areas in the most recent time analyzed. This preliminary map will help to focus the change analysis in the invaded areas, making the analysis more efficient.

I will compare the performance of three methods of change analysis applied to the case of glossy privet: post-classification comparison, change vector analysis and RGB-NDVI with multivariate analysis classification. In post-classification comparison, each image (1983, 1997 and 2001) is classified individually into thematic maps. Then, a pixel-by-pixel comparison of the images is performed. Post classification comparison has been used successfully to map different types of changes, for example of forest cover in New England (Miller et al. 1998).

Change vector analysis calculates a vector that represents the movement of a pixel in a multidimensional space from time 0 to time 1. The multidimensional space is determined by a set of n indicators measured for the pixel, which can be measured every year (or for a certain period of time). In this case, the vector is composed of the value of the pixel in each of the seven bands of a Landsat image in date 1. With two Landsat dates, we can compare the position of the focal pixel in the multidimensional space for time 1 and 2. Then a vector is used to calculate the direction of the movement (angle of the vector) and the magnitude of the change (length of the vector) (Lambin & Strahler 1994, Lu et al. 2004).

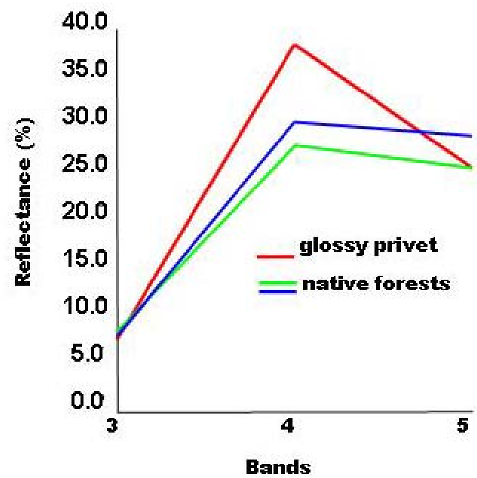


Fig 12. Spectral signature for glossy privet stands and native forest. Note the difference in band 4.

The RGB-NDVI methodology is based on the NDVI index. A NDVI index is calculated for each date (1983, 1997 and 2001). Then, a false color composite image is created using each NDVI image as a color channel (1983 represents red, 1997 represents green and 2001 represents blue). This methodology allows detection of areas where changes occurred in a visual analysis. Areas representing change can be differentiated from areas where no change occurred based in their associated colors determined as different color combinations (red, green and blue) representing NDVI values in 1983, 1997 and 2001 (Sader & Winne 1992, Sader et al. 2001). In a second step, a multivariate analysis is used to reduce the original number of bands in 1983, 1997 and 2001 images to a smaller set of orthogonal bands, and bands representing noise or not related to privet are eliminated (Lu et al. 2004). Finally, the change areas detected visually in the RGB-NDVI image are used as training sites to classify an image that includes the new bands selected with PCA analysis with a maximum likelihood classifier (MaxLike). In the MaxLike technique, the reflectance curve in the different satellite bands (spectral signature) of each pixel is compared with the spectral signature of training sites (different types of changes detected in the RGB-NDVI image) and then each pixel is assigned to the statistically most similar type of change.

Field data and trees cores

To validate the maps of glossy privet spread I will collect field data on privet tree's distribution and age. Field data is essential to validate the classification results and quantify the accuracy of maps created from satellite images (Lillesand et al. 2003). With this 'ground truth' information I can quantify the accuracy of the maps created with satellite images and verify that the privet stand age (and invasion history) obtained through digital image processing is correct. I will use a stratified sampling design (Elzinga et al. 1998) to cover areas with different histories of invasion. In 10 x 10 m plots I will measure DBH of all glossy privet trees larger than 5 inches in diameter and core the three largest trees in the plot. Relating size to age I will develop a function to calculate age for all sampled trees. With information of tree ages I can determine whether the oldest privet stands according to my image analyses correspond to the oldest and larger trees.

Spatial and statistical analysis

After comparing thee results of the change detection methods I will perform a series of spatial analyses on the image obtained with the most effective method, to assess the spatial relationship between housing growth and spread of glossy privet. I will measure the expansion and the current extent of glossy privet stands with the GIS Erdas Imagine. To analyze the spatial association between forests and urban areas I will quantify the amount of glossy privet in a series of 200m-wide buffers around urban areas. Then I will determine if the amount of forest in each buffer is larger or smaller than expected under randomness (Neu et al. 1974, Byers & Steihorst 1984). With QRule (Gardner 2006) I will test the hypothesis that glossy privet stands is associated with urban areas. QRule can perform a large number of simulated landscapes with the same landscape characteristics of the real one. From this set of simulations the distribution of an index of association between the glossy privet stands and urban areas is obtained to perform a statistical test. I will also use the buffer analysis with other landscape features (roads and rivers), and I will analyze whether glossy privet expansion is associated with some topographic characteristics using a preference test (Neu et al. 1974, Byers & Steihorst 1984). I will perform the analyses for the glossy privet stands in 1983, in 1997 and the expansion between dates.

Expected outcomes and contributions

This chapter will contribute to four areas: regarding technical aspects, it will prove the applicability of change detection techniques to the case of glossy privet, providing a useful tool to map its distribution and expansion at regional scales in Argentina and other countries. Ecologically, it will determine the expansion rate of the glossy privet invasion and examine they key factors for its distribution at landscape scales. From a management perspective, the maps produced will help to determine priority areas for glossy privet control in management plans. Results can be used to reduce ecological impacts of future urban growth. It will also help us to anticipate the future patterns of invasion and its consequences in different areas or regions. For example, glossy privet is becoming an important invader in the southeastern U.S. From a social point of view, the results and maps can be powerful tools to raise awareness in the general public and particularly the local communities about the importance of the problem and its consequences. Awareness and involvement of local communities are critical for the success of any management plan to address exotic species problems.

Preliminary results

The NDVI index successfully differentiated glossy privet from native forests stands (Fig. 13), thus indicating the utility of NDVI composite images for detecting areas with different invasion histories.

The RGB-NDVI method allowed me to determine three different areas regarding their invasion history: 1) areas already dominated by glossy privet in 1983 and still glossy privet stands in 2001, 2) areas where privet was present but not dominant in 1983 (mixed with native forest) that became glossy privet stands in 2001 and 3) areas where glossy privet were not present or rare in 1983, but that become glossy privet stands in 2001, corresponding to the more recently invaded areas. With the PCA analysis and final classification, I obtained a first map of the invasion history in the area (Fig. 14). No substantial invasion between 1997 and 2001 was detected with this technique.

Between 1983 and 2001 the glossy privet stands increased from less than 200 hectares to almost 1800, indicating a rapid expansion. In 2001, Glossy privet was much more abundant around urban areas than expected by chance (Fig. 15).

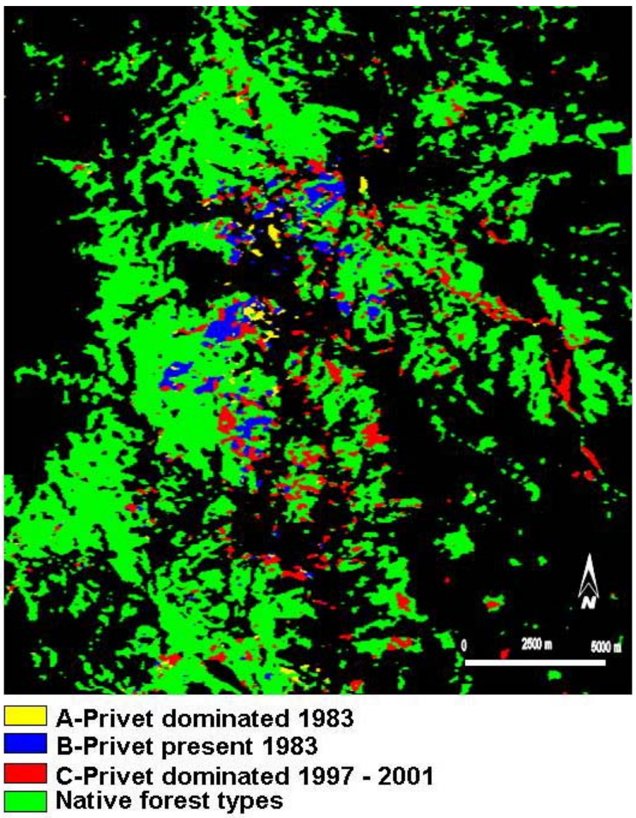


Fig 14. Expansion and present distribution of glossy privet stands in the study area. The addition of the three types of invasion history glossy privet stands represents the present invasion distribution (2001).

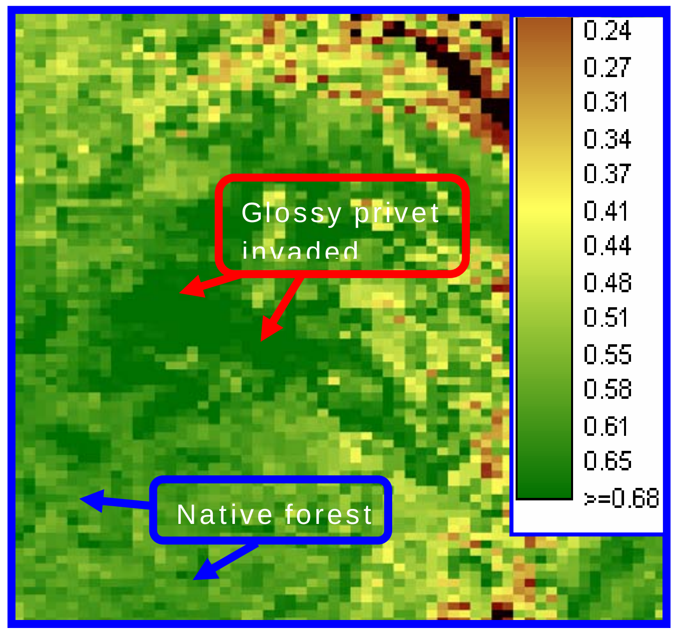


Fig 13. Example of the different NDVI values for native forest and glossy privet invaded areas in a sample of the study area already explored in a field trip

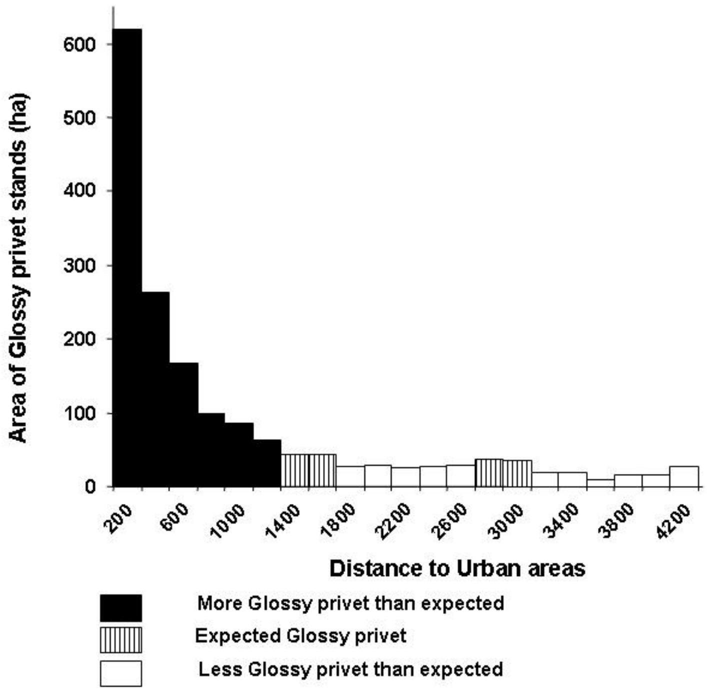


Fig. 15. Area of glossy privet in a series of buffers around urban areas. Bonferroni confidence intervals test if the proportion of privet in each buffer deviates from expected by chance considering the area of each buffer.

SIGNIFICANCE

My research will offer new perspectives to understand the relationship between two of the most important factors of forest loss and degradation, housing growth and invasive exotic plant invasions in forests of the North east. **Ecologically**, my work will address a more general problem of main interest for the science of invasion biology: the effects of human activities as a cause of biological invasions. At a large-scale, results will help to determine which housing growth pattern is most related to plant invasions. At intermediate scales my results will assess the importance of the wildland urban interface as a focal area of invasive plant dispersion, and at a small scale the effect of landscape distribution of houses and small urban areas on spatial patterns of invasions. An innovation in my approach is the comparison of the importance of housing growth with other environmental and human factors for invasive exotic plant distributions and determining the plant type or life history traits most favored by housing growth.

The results will have a direct **management** implication. The proposed study will provide fundamental information to inform science-based strategies of invasive plant management, since invasion of exotic species is a research and management priority in the US. For example, results of this project can be used in the four Elements of a National Strategy for invasive species management proposed by the US Forest Service. Using different scales of analysis will increase the potential applicability of results compared to other single scale projects because it can help focus management at a particular scale where urbanization is a more important driver of exotic plants distributions. Of particular importance is the fact that contrary to other factors of invasive plants distributions, housing can be managed via planning to minimize its effects on invasive plant dispersion. Finally, results will indicate which areas should receive special attention regarding urbanization types and ornamental plants that should be avoided in urbanization projects.

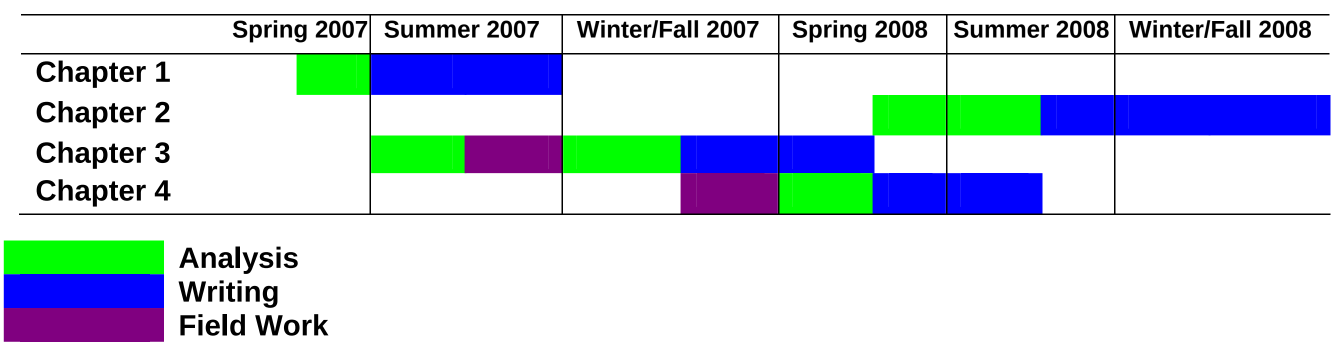
The management implications of this project become more valuable when we consider not only the present extent of natural areas under urban and exurban influence, but the projected trend of exurban growth intensification in the future. Understanding the relationship between housing growth and ecological processes is the only way to anticipate negative impacts of the expected housing growth and implement effective management plans.

My work will also contribute in **technical** aspects. Change analysis using satellite images can provide a powerful tool to monitor the spread of an invasive tree (*Ligustrum lucidum*) at large scale in central Argentina. A comparison of change detection methods will provide information to select effective techniques for other situations or regions. Also, providing technical alternatives that are less expensive and easier to use can contribute substantially to management of invasive plants in developing countries, where hyper spectral and high resolution imagery is too expensive or unavailable. The development of the Ecological Influence of houses constitutes a novel approach in studies of ecological effect of housing in that for the first time distance to a house and the cumulative effects of several houses are combined into a single metric. My project will also contribute to develop the research possibilities of the FIA Phase 3 plots, created among other objectives to better understand the degree of invasions in different forest types. Finally, regressions that account for spatial autocorrelation are a novel technique not widely used in ecology yet. My project will contribute to a better selection of appropriate methods for model spatial autocorrelation in different situations

From a **social** perspective, the results of the project can help managers to inform the public about the consequences of rural sprawl regarding plant invasions, to gain public support necessary for management plans that successfully monitor and control invasive plants. On the other hand, it can also help managers to educate and convince politicians and decision makers about the necessity of better tools (e.g. specific legislation) to deal with housing growth related ecological problems and invasive species in particular.

In summary, because urbanization is one of the main driving forces of global change, elucidation of the relationship between urban growth and exotic plants should be a priority. I believe that this project has great potential to substantially contribute to our understanding of how urbanization influences plant invasions in forests and will have clear implications for ameliorative management actions.

TIMELINE



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