Remote Sensing of Environment 122 (2012) 134–145

Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

Monitoring the invasion of an exotic tree (*Ligustrum lucidum*) from 1983 to 2006 with Landsat TM/ETM+ satellite data and Support Vector Machines in Córdoba, Argentina

Gregorio I. Gavier-Pizarro [a,*], Tobias Kuemmerle [b,g], Laura E. Hoyos [c], Susan I. Stewart [d], Cynthia D. Huebner [e], Nicholas S. Keuler [f], Volker C. Radeloff [a]

[a] *Department of Forest and Wildlife Ecology, University of Wisconsin, Madison, 1630 Linden Drive, Madison, WI 53706, United States*
[b] *Earth System Analysis, Potsdam Institute for Climate Impact Research (PIK), P.O. Box 60 12 03, Telegraphenberg A62, D-14412 Potsdam, Germany*
[c] *Instituto Multidisciplinario de Biología Vegetal (IMBIV-CONICET), and Facultad de Ciencias Exactas, Físicas y Naturales, Universidad Nacional de Córdoba, Av. Vélez Sarsfield 299, C.C. 495, 5000 Córdoba, Argentina*
[d] *USDA-Forest Service Northern Research Station, 1033 University Place, Suite 360, Evanston, IL 60201, United States*
[e] *USDA-Forest Service Northern Research Station, 180 Canfield St, Morgantown, WV 26505, United States*
[f] *Department of Statistics, University of Wisconsin, Madison, 1300 University Avenue, Madison, WI 53706, United States*
[g] *Geography Department, Humboldt-Universität zu Berlin, Unter den Linden 6, 10099 Berlin, Germany*

ARTICLE INFO

Article history:
Received 21 February 2011
Received in revised form 22 August 2011
Accepted 10 September 2011
Available online 16 February 2012

Keywords:
Exotic tree invasions
Non-native invasive species
Ligustrum lucidum
Change detection
Support Vector Machines classification
Urban expansion
Landsat Thematic Mapper
Argentina
Sierras Chicas
Córdoba

ABSTRACT

In central Argentina, the Chinese tree glossy privet (*Ligustrum lucidum*) is an aggressive invasive species replacing native forests, forming dense stands, and is thus a major conservation concern. Mapping the spread of biological invasions is a necessary first step toward understanding the factors determining invasion patterns. Urban areas may function as propagule sources for glossy privet because it has been used as a landscaping tree for over a century. The objectives of this paper were to 1) map the patterns of glossy privet expansion from 1983 to 2006 using a time series of Landsat TM/ETM+ images, and 2) analyze the spatial pattern of glossy privet stands with regard to urban extent. Using six summer Landsat TM images (1983, 1987, 1992, 1997, 2001, and 2006) the expansion of glossy privet was analyzed using Support Vector Machines (SVM), a non-parametric classifier which we applied to a stack of all images simultaneously, a novel approach in its application to monitor non-native tree invasions. We then measured the area of glossy privet in a series of 200-m buffers at increasing distances around urban areas in 1983 and 2006, and compared it with the amount of privet expected in proportion to buffer area. Glossy privet in the study area has spread very rapidly during the 23 years that we studied and the SVM resulted in highly accurate classifications (Kappa Index 0.88, commission error 0.07, omission error 0.16). Between 1983 and 2006 glossy privet area increased 50 times (from 50 to 2500 ha), and 20% of all forest in the study area is now dominated by glossy privet. Most of the glossy privet dominated stands were located within 600 m of urban areas. However, the rate of glossy privet expansion accelerated substantially after 1992 and new glossy privet dominated stands tend to be located away from urban areas. This suggests that glossy privet is now self-sustaining, but expected urban growth in the area could further foster glossy privet invasion. Management and development plans should include mitigation efforts to contain this species and prevent invasion into native forests, and citizens should be informed about the risk of invasion associated with the use of glossy privet for landscaping.

1. Introduction

Biological invasions are one of the main components of global change, negatively affecting ecosystem functioning and biodiversity (Theoharides & Dukes, 2007; Vitousek et al., 1996). Invasions of non-native plants in particular can have strong effects on natural ecosystems, changing the dominant vegetation type (e.g., shrubland to grassland conversions), soil properties, biogeochemical cycles, patterns of herbivory, and disturbance regimes (Brooks et al., 2004; Mack et al., 2000). Invading non-native trees may result in the most substantial negative ecosystem impacts (Richardson et al., 1994). For example, pine invasion in the southern hemisphere has reduced the structural diversity, changed vegetation patterns, and altered nutrient cycling of grasslands and shrublands (Richardson, 1998; Zalba & Villamil, 2002).

Many factors determine invasion success and patterns, but most biological invasions are connected to human activities (Lonsdale, 1999; Williamson & Fitter, 1996). One of the potential factors related to the distribution of invasive non-native plants is the expansion of urban areas which is occurring rapidly in many parts of the world (Antrop,

* Corresponding author at: Instituto Nacional de Tecnología Agropecuaria (INTA), Centro de Investigación en Recursos Naturales (CIRN-IRB), De los Reseros y Las Cabañas S/N, HB1712WAA Hurlingham, Buenos Aires, Argentina. Tel./fax: +54 11 4481 2360 int. 125.
E-mail address: ggavier@cnia.inta.gov.ar (G.I. Gavier-Pizarro).

0034-4257/$ – see front matter © 2012 Elsevier Inc. All rights reserved.
doi:10.1016/j.rse.2011.09.023

2000, 2004). Non-native plants in residential areas can invade adjacent natural areas (Sullivan et al., 2005; Wania et al., 2006) and housing development creates habitat that can easily be invaded (due to the creation of forest edges, soil exposure, etc.; De Candido, 2004; Hobbs & Huenneke, 1992; Wania et al., 2006). As a result, rural housing and urbanization in suburban areas often cause the invasion of adjacent forests by non-native plants originally planted for landscaping (Duguay et al., 2007; Gavier-Pizarro et al., 2010a,b; Moffatt et al., 2004).

In an increasingly globalized world, the frequency and spatial scale of biological invasions are growing rapidly, and thus, there is a growing need for monitoring the spread, and forecasting future distributions of non-native plants invasions (Meyerson & Mooney, 2007; Vitousek et al., 1996). Detailed maps of invasive species' spread provide the baseline data needed for defining the factors associated with their successful invasion and are a necessary first step for successful management action (Elton, 1958; Mack et al., 2000). However, detailed and up-to-date maps of invasive species are often lacking.

Remote sensing is a very promising tool to map invasive non-native plants across broad geographic extents. The availability of satellite image archives permits mapping non-native invasive plants spread retrospectively (Cohen & Goward, 2004; Rejmanek & Pitcairn, 2002; Wulder et al., 2008). However, most existing studies have used high-resolution or hyperspectral imagery covering a relatively small area and analyzed only a single point in time or a short time (Akasheh et al., 2008; Hestir et al., 2008). The limitation of such approaches in a management context is their high cost, limiting their use for long-term assessments of invasive plants spread particularly in developing countries (Asner et al., 2008; Hunt et al., 2003; Lass et al., 2005; Noujdina & Ustin, 2008) and the general lack of historic data, thus limiting the use of change detection techniques to monitor the invasion process over time.

The Landsat program has been extensively used for ecosystem monitoring (Cohen & Goward, 2004; Goward & Masek, 2001) and the almost 40 year long record of Landsat imagery provides a rich dataset to map the invasion of trees at the landscape scale. Landsat images are now available at no cost (Woodcock et al., 2008) and that makes it feasible to analyze both larger areas, and denser time series. Landsat TM/ETM+ (Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper Plus) images with their 30-m resolution do not permit mapping of individual trees and it can be difficult to distinguish tree species (Foody et al., 2005). However, Landsat TM/ETM+ images have been successfully used to map invasions for single points in time for invading plants that form homogeneous patches larger than 0.5 ha and have a different phenology from the surrounding native vegetation (Peterson, 2005). Although Landsat TM images have been successfully used to map non-native plant invasions between two points in time (Bradley & Mustard, 2006), we are not aware of research that takes full advantage of multi-temporal Landsat images availability to develop detailed time series analysis of non-native plants invasion, particularly for trees.

Digital change detection can map changes in vegetation composition, and is thus a powerful tool for mapping the spread of invasive trees. Composite analysis is a type of change detection where all images are combined into one multi-temporal dataset and change classes are directly classified (Coppin & Bauer, 1994). Composite analysis allows inclusion of more than two points at a time, while accounting for inaccuracies associated with comparing two images classified independently (Coppin et al., 2004; Pu et al., 2008).

Landcover change classes obtained from multi-temporal datasets are often characterized by complex class distributions (multi-modal, non-normal). Non-parametric classifiers such as decision trees, neural networks, or Support Vector Machines (SVM) are therefore better suited for change classifications than parametric classification algorithms (e.g. maximum likelihood) (Foody & Mathur, 2004). Moreover, SVM have successfully been applied to analyze landcover changes using Landsat TM/ETM+ images (Baumann et al., 2011; Kuemmerle et al., 2008, 2009; Nemmour & Chibani, 2006). However, the suitability of SVM to map biological invasions combined with change detection techniques has not been tested yet.

We were particularly interested in invasions by non-native trees in Argentina because these invasions entail high ecological and economic costs (Chaneton et al., 2004; Grau & Aragón, 2000; Zalba & Villamil, 2002). One of the most widespread invasive trees in central Argentina is the glossy privet (*Ligustrum lucidum* W. T. Aiton), native to China and imported for use as an ornamental plant (Montaldo, 1993, 2000; Ribichich & Protomastro, 1998). Glossy privet is particularly widespread in the Sierras Chicas of Córdoba (central Argentina), where it was introduced around 1900 as an ornamental plant (Río & Achával, 1904) and has become a very successful invader of forested sites resulting in dense stands that eliminate most native vegetation (Gavier & Bucher, 2004; Grau & Aragón, 2000; Hoyos et al., 2010). Glossy privet is an aggressive invader in many other countries as well, including Australia and New Zealand (Cronk & Fuller, 1995).

Glossy privet invasion results in profound negative ecological impacts. Glossy privet grows fast under both shaded and full-sun conditions, reaching heights of up to 15 m. Dispersal occurs through abundant, bird-dispersed seeds and via vegetative propagation (Aragón & Morales, 2003; Aragón & Groom, 2003). Once it reaches the canopy, glossy privet can outcompete most native plant species by creating conditions of low luminosity that hinder the regeneration of other species, ultimately resulting in glossy privet dominance (Grau & Aragón, 2000). The regeneration of native tree species in the glossy privet invaded areas is very rare (Hoyos et al., 2010). Optimal conditions for the dominant native tree *Lithraea molleoides* seed germination (i.e., complete sun exposure and moderate humidity, Bianco, 1989; Marco & Páez, 2000) are not found under the dense evergreen canopy of glossy privet stands, which cast strong shade all year long

Glossy privet-dominated stands are very different in terms of their vertical structure and composition from native forests, with a substantial loss of native tree species and much less cover in both the herbaceous and the shrubby strata. As a consequence, there is a substantial biodiversity and habitat loss in glossy privet stands compared with native forest stands (Hoyos et al., 2010). Many animal species could be negatively affected by the habitat lost, while others, such as birds that feed heavily on glossy privet seed, will potentially be favored. Other potential consequences may include changes in nutrient cycling, soil properties, and disturbance regimes (Hoyos et al., 2010).

The Sierras Chicas of Córdoba have also experienced widespread landscape change since 1970, especially forest loss, forest fragmentation, and urban growth (Gavier & Bucher, 2004). Glossy privet has been widely used as a landscaping tree, and privet expansion may thus be connected to the region's urban growth. Nevertheless, the relationship between privet expansion and urban growth remains to date largely hypothetical. While earlier work has shown the potential for mapping glossy privet from Landsat TM/ETM+ images (Gavier & Bucher, 2004; Hoyos et al., 2010), no previous research has assessed privet expansion. Hence, the glossy privet invasion provides an excellent case to test the use of SVM as a change detection technique for the detailed monitoring of biological invasions using a time series of Landsat TM/ETM+ images.

The objectives of this paper were to 1) map the spread of glossy privet stands in the Sierras Chicas between de Córdoba (Argentina) between 1983 and 2006, 2) analyze the rates and spatial patterns of privet invasions, and 3) assess the relationship between privet expansion and urban development. We hypothesized that glossy privet dominated stands are spatially related to the distribution of urban areas, because urban areas act as a source of propagules and have associated disturbances (e.g. clearing of properties) that facilitate the invasion of glossy privet.

2. Study area

The study area encompasses 380 km^2 on the eastern slope of the Sierras Chicas of Córdoba, Argentina (−31° 17.4′S; 64° 30′W).