Patterns of land use and land cover change and its consequences on wildlife: Land-Use Land-Cover Change and Brown Bear in Eastern Europe

A dissertation proposal submitted by
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Overview

The overarching goal of the research proposed is to contribute to a better understanding of the ***consequences of land use change on wildlife***. My dissertation will consist of three chapters based on coarse-resolution satellite images, remote sensing (RS), and geographic information systems (GIS). In my **first** chapter, *I will develop a novel LULCC classification method to map agricultural land abandonment using broad-scale imagery, exemplifying the method on a portion of Eastern Europe with MODIS imagery*. In my **second** chapter, I will *assess abandoned agricultural land and examine socioeconomic drivers across Eastern Europe*; *including European Russia*. In the **third** chapter I will *analyze the relationship between the documented land abandonment in the second chapter, and resulting changes in landscape fragmentation with brown bear populations in European Russia* (**Figure 1**).

More than half of the earth has been transformed by humans through Land-Use and Land-Cover Changes (LULCC) (Vitousek et al. 1997; Foley et al. 2005). LULCC has been analyzed under the Land Cover Transition theory (DeFries et al. 2004; Foley et al. 2005)and the Forest Transition theory (Rudel et al. 2005). LULCC in croplands, pastures, wetlands, and forest can degrade the ecosystem, producing pollution and changes in the carbon cycle, energy and water balances (Foley et al. 2005). The pace of LULCC has been particularly rapid in the last 30 years (Leff et al. 2004; Lepers et al. 2005; Lambin & Geist 2006), representing the main cause of habitat loss (Matson et al. 1997), and consequently loss of biodiversity (Dirzo & Raven 2003) through extinction and population decline (Kruess & Tscharntke 1994; Pimm & Raven 2000). *The challenge is to reduce the negative impacts on LULCC while maintaining economic and social benefits* (Kim & Weaver 1994; Foley et al. 2005).

Agriculture has been the most important human activity transforming the earth. More than 38% of the total land surface was either in agriculture or grazed by 2005 (FAO, (Food and Agriculture Organization of the United Nations) 2009). However, in the last 50 years several regions of the world have seen cropland areas stabilize or even decrease, specially in temperate regions (Lambin & Geist 2006), with concomitant reports of increases in forest regrowth in the same regions (Kauppi et al. 2006).

A prime example for declining agriculture is the area formerly under the sphere of the Soviet Union (Unwin 1997; Brooks & Bruce 2004; de Beurs & Henebry 2004; Gobulev & Dronin 2004; Dutch National Reference Centre for Agriculture et al. 2005). However LULCC studies are far from comprehensive for Eastern Europe (Lepers et al. 2005). *There is a need to assess the extent, rate and spatial pattern of LULCC in the former socialist countries and analyze them on the light of land cover transition and forest transition theories*.

Land use affects biodiversity (Harding et al. 1998; Zebisch et al. 2004; Reidsma et al. 2006). There is an urgent need to protect habitat given the threat of species extinctions. Based on current trends habitat loss will cause extinction rates to increase by more than two orders of magnitude higher than background rates within the next five decades (Dirzo & Raven 2003). *The challenge is to find tools to estimate habitat targets for conservation purposes* (Hoekstra et al. 2005; Brooks et al. 2006).

Identification of habitat needs of other species or even entire communities can be assisted by the use of surrogate species (Landres et al. 1988; Niemi & McDonald 2004), making possible to limit habitat loss through their protection. Focal species, which are a surrogate species concept (Niemi & McDonald 2004; Wiens et al. 2008), can be used as a proxy for biodiversity (Groves et al. 2002). Assessing focal species distribution with broad-area requirements that are affected by LULCC can provide information to a large number of naturally co-occurring species. *Understanding the relationship between LULCC and focal species will allow us to assess the changes on biodiversity*.

Large predators are key elements in many ecosystems (Morrison et al. 2007). They play a critical role on trophic cascades as top-down force to regulate terrestrial ecosystems (Terborgh et al. 2001). Large predators usually have wide home ranges, often requiring large areas (Maehr et al. 2001). They are also particularly vulnerable, at species and population levels. As a matter of fact, less than 21 % of the earth's terrestrial surface still contain all of the large mammals once held (>20 kg) (Morrison et al. 2007). Given the ecological importance of large mammals and in particular of top predators**,** *it is critical to analyze the relationship between land abandonment and top predators***.** ***Brown bears in European Russia may serve as focal species to assess the implications of LULCC on biodiversity*** (Simberloff 1999; Carroll et al. 2001; Niemi & McDonald 2004).

My dissertation will make contributions to science in several areas. Eastern Europe offers a unique natural experiment to analyze the consequences of land use change on wildlife through the assessment of LULCC and focal species distribution on similar territories that were under the same conditions in the past and differ in the present. My first chapter will contribute to the field of Remote Sensing by developing a novel method to assess land abandonment. Analyzing Land abandonment in Eastern Europe in my second chapter will add understanding on the broad-scale socioeconomic factors that drive LULCC and the potential to modify land cover transition and forest transition theories. Analysis of the relationship between habitat loss and fragmentation patterns with focal species are incipient topics being developed in science. Studying top predators in those large areas can serve as a proxy for ecosystem function as well as biodiversity.

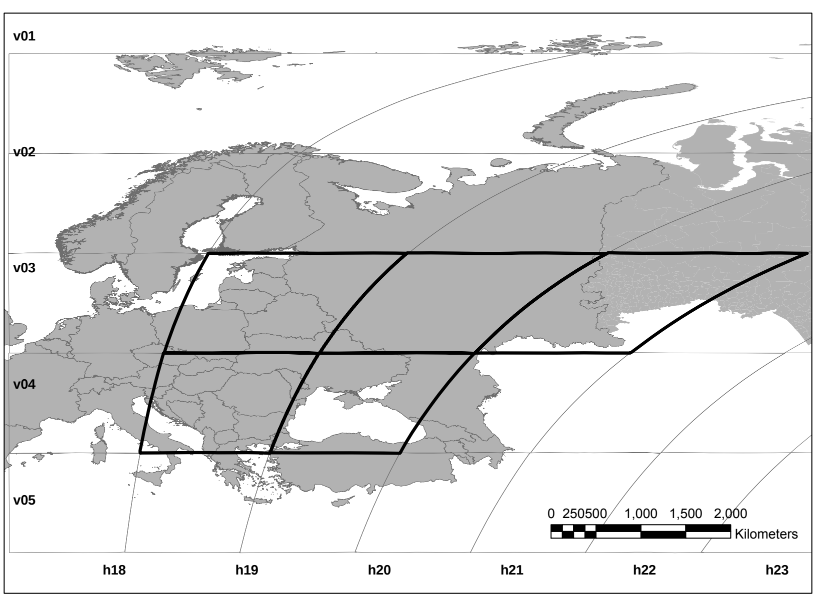

Figure 1. Study area: Eastern Europe. In black are the MODIS tiles with horizontal (h) and vertical (v) tile coordinate system (Sinusoidal grid).My study area includes tiles h18-v03, h19-v03, h20-v03, h21-v03, and h19-v04

Background

LULCC-Transition and Forest-Transition theory

Rapid land cover change is a major scientific concern given the increasing extent and magnitude of change over the last 30 years (Leff et al. 2004; Lepers et al. 2005; Lambin & Geist 2006). LULCC is a complex process, ranging from modifications in land cover to conversions (Lambin & Geist 2006). In order to understand drivers of LULCC one must consider population growth, poverty, and infrastructure as well as individual and social responses to changing economic conditions, mediated by institutional factors (Lambin et al. 2001; Parker et al. 2003). The proximate reasons for land abandonment are out of the scope of my research, although some of the proximate reasons can include land degradation, set-aside policies, and land-use shifting (e.g. from agriculture to forest), migration, market loss and low profitability

Agriculture and grazing, along with industrialization and migration of rural population to urban areas, are among the main human activities that have transformed the planet (Tilman et al. 2001; Goldewijk & Ramankutty 2004; Leff et al. 2004; Foley et al. 2005). Both agriculture and grazing land uses are estimated to have affected over 38% of the land surface on earth by 2005 (FAO, (Food and Agriculture Organization of the United Nations) 2009). Agricultural land alone has increased at an exponential rate during the last centuries, occupying from 3 to 4 million km^2 in 1700 to 15 to18 million km^2 in 1990, about 12% of the globe (Leff et al. 2004; Lambin & Geist 2006). Agriculture and grazing have increased more than 50% in area during the 20 century, mostly at the expense of forest (Goldewijk & Ramankutty 2004).

Agricultural changes can be explained by land use transition theory which predicts that land use potentially follows a series of transitions (**Figure 2**). Land use transitions parallel economic development changes over time, being largely the result of population growth and new technological capabilities (DeFries et al. 2004). The initial transition stages are from natural vegetation to frontier clearings used for subsistence and small-scale farms. Small-scale farms in turn transition to intensive agriculture, and ultimately, a portion of those agricultural lands are set-aside as parks and natural protected areas (DeFries et al. 2004; Foley et al. 2005).

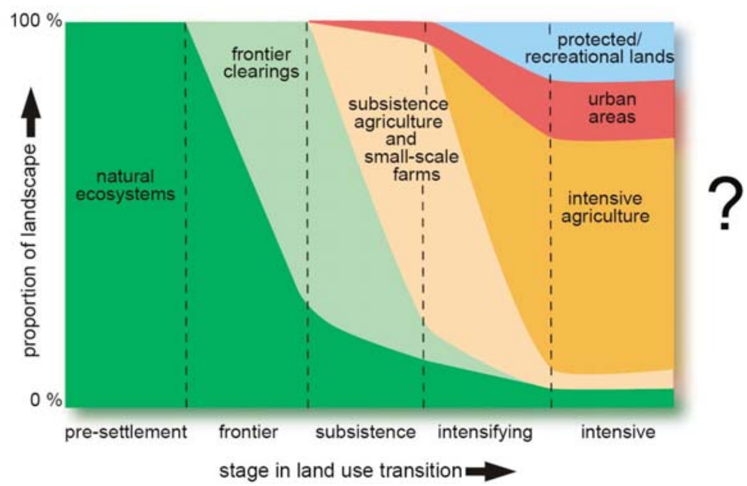

Figure 2. Land Use transition theory (Foley et al. 2005).

Actual land use transitions depend on a range of factors including history, socio-economical conditions and technological capabilities, as well as the ecological context (DeFries et al. 2004; Foley et al. 2005). There are some well documented examples of land-use transitions worldwide (Lambin & Geist 2006), but the role and extent of the factors that rule them remains largely unknown (Lambin & Geist 2006; Verburg et al. 2009). This raises the question how universal and unidirectional these land use transition trends are.

In recent decades some regions of the world have shown a reduction, even reversion, of the pace of agricultural expansion, while agricultural production has intensified (Rudel et al. 2005; Kauppi et al. 2006). Widespread land abandonment apparently contradicts the notion of unidirectional land use intensification. Many countries have experienced **land abandonment** and forest regrowth; a distinct turning point from large declines to slow increases in forest cover had become noticeable, an idea named 'the forest transition' by Alexander Mather (MacDonald et al. 2000; Rudel et al. 2005) (**Figure 3.**).

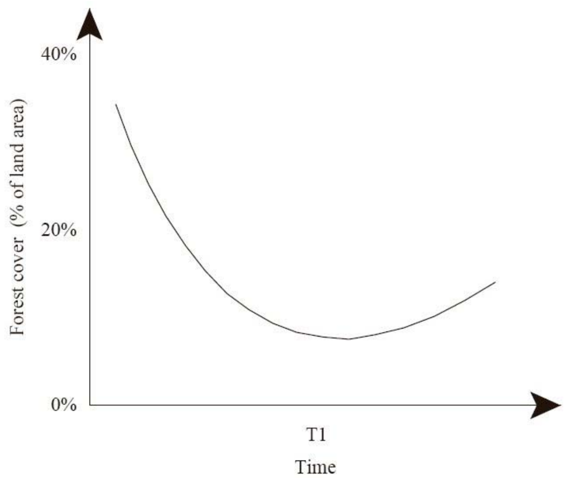

Figure 3. Forest transition theory (Rudel et al. 2005)

Both, land use transition theory and forest transition theory aim to explain change in land cover; the reasons of that change in land cover and the land use and forest transition theories themselves still under research. For instance, there can be many reasons why people plant trees and/or abandon land. At the same time forest plantation and land abandonment can be two completely different processes that seem to be cofounded in the theories; it does not necessarily parallel economic development in the country where transition occurs; and in some cases the increase in forest is not a smooth change (Perz 2007; Rudel 2008).

Three alternative explanations to this increase in forest cover have been proposed. First, expansion in the forest extent is attributed to shifts in market forces due to the urbanization of societies and the globalization of forest products markets (Market-based explanation) (Rudel et al. 2005) Second, political decisions based on the ecosystem services that the forest provides have lead to several countries to promote forest regrowth (Ecosystem service explanation) (Satake & Rudel 2007; Rudel 2008). A third explanation claims that arid conditions or forest cover declines cause forest product scarcity, leading to a response from the people to plant trees (Forest scarcity explanation) (Satake & Rudel 2007; Rudel 2008).

Eastern Europe provides a unique natural experiment to test forest transition and land use transition theories. The breakdown of the USSR is a consequence of a sudden political change which together with globalization leads to farmland abandonment. Forest regrowth on abandoned farm land is reportedly widespread but has not been accurately quantified. Cultural, economic and political decisions were different in each of the former Soviet Union countries after they became independent. These decisions affected the slope and pace of the forest transition. *Analyzing **land abandonment** on this region will thus allow us to understand better the LULCC process and to refine both land use transition theory and forest transition theory.*

Land abandonment

Land abandonment concept has been defined in two different ways. The first land abandonment definition regards the intensity of use, and defines abandonment as “change in land use from the traditional or recent pattern to another less intensive pattern” (Baudry 1991). The second definition of land abandonment is more restrictive, and states “land no longer used by agriculture” (Baudry 1991). Currently there is no reliable method to assess land abandonment according to the first definition for large areas. All broad-scale reports on land abandonment thus employ a version of the second definition, generally adding a time span (e.g. land no longer used by agriculture for two years (Dutch National Reference Centre for Agriculture et al. 2005). My research will look at land abandonment using the second definition “land no longer used by agriculture”.

Concerns have been raised in regards to the long-term about sustainability and environmental consequences of the intensification of agricultural systems (Stoate et al. 2001) but less attention has been paid to the consequences and assessment of land abandonment. Land abandonment is not a new phenomenon. Expansion or shrinking of agricultural land area has been common throughout history; but recent agricultural land abandonment is a worldwide phenomenon (Kauppi et al. 2006). Notable cases include areas in the United States (Hart 1968), Europe (Dutch National Reference Centre for Agriculture et al. 2005; MCPFE Liason Unit Warsaw et al. 2007) and South America (Aide et al. 1995; Farley 2007). Most land abandonment has occurred in developed countries and hence temperate ecosystems, though abandonment has also been reported in developing tropical countries such as Puerto Rico (Grau et al. 2003), Brazil (Alves D.S. et al. 2003), Mexico (Klooster 2003), Ecuador (Farley 2007), Honduras (Redo et al. 2009), Panama (Sloan 2008) and Vietnam (Meyfroydt & Lambin 2008).

Abandonment of agricultural land, especially due to the termination of traditional farming practices is common across mountain areas in Europe (MacDonald et al. 2000), especially in the Swiss Alps (Walther 1986; Gellrich et al. 2008) and the Carpathians (Kuemmerle et al. 2008). Land abandonment has also been reported in a number of countries across Europe, such as: Spain (Suárez-Seoane et al. 2002), Italy (Scozzafava & De Sanctis 2006; Falcucci et al. 2007), Denmark(Kristensen et al. 2004), and Austria (Walther 1986; Rutherford et al. 2008).

Although abandonment is apparently widespread in many countries, there are not exact data for entire countries. Some countries have reported land abandonment estimations based on reductions on production yields (Ioffe & Nefedova 2004; Ioffe 2005), which is an imperfect measure at best due to increases in yields per hectare on remaining farmlands. The European Union has thus expressed concerns about existing methods to monitor land abandonment, specifically in the context of former socialist countries that joined the European Union accession and the Common Agricultural Policy (CAP)(Dutch National Reference Centre for Agriculture et al. 2005; MCPFE Liason Unit Warsaw et al. 2007). However, the EU accession process did result in some abandonment estimates. The Rural Development Programs for 2002-2004 for Poland, Hungary and the Baltic countries report land abandonment estimates. Abandoned land in those reports was defined as “land not used for agriculture for more than two years”. Poland reported that 17.6% of agricultural land was abandoned from 1998 to 2002 (2.3 million hectares). The proximate causes cited were a decrease in livestock numbers and as a result a lower demand of grass and crops. The area of abandoned land, including agricultural land and other forms of abandonment, is estimated to be more than 30% from 1998 to 2004(Dutch National Reference Centre for Agriculture et al. 2005; MCPFE Liason Unit Warsaw et al. 2007). In Estonia 10.1 % of the agricultural land was categorized as abandoned in 2002 (172.421 ha (Unwin 1997).). Latvia reported a 21.1 % of agricultural land is abandonment (44,600 ha), especially in the Latgale region. Latvia reports poor soils, small scale of farms and unfavorable climatic conditions as the main causes of abandonment. Lithuania reported that 10.3% of the agricultural land is abandoned in 1999, mentioning poor soils and unfavorable economic conditions. Hungary reported 26.7 % of the agricultural land being no longer cultivated by 2002 (1.6 million ha) but this may be an overestimation since the Hungarian definition of uncultivated land included nature reserves and other areas which are not managed (Dutch National Reference Centre for Agriculture et al. 2005).

In the case of Russia, there was a sharp reduction in agricultural production (**Figure 4**) probably reflects land abandonment (Ioffe & Nefedova 2004; Ioffe 2005). However, those land abandonment claims in Russia are rough estimates, based on non-spatial official statistics, and have not been verified by independent data (Ioffe & Nefedova 2004; Ioffe et al. 2004). Furthermore, differences in agricultural statistics preclude making comparisons in time (socialism vs. post-socialism) and space (among countries) (Filer & Hanousek 2002). A reliable figure on land abandonment across the former socialist countries is lacking (Ioffe & Nefedova 2004). In the case of Russia there is a particularly urgent need to monitor land abandonment given the sudden loss in agricultural production after the breakdown of state-controlled socialism (Ioffe & Nefedova 2004).

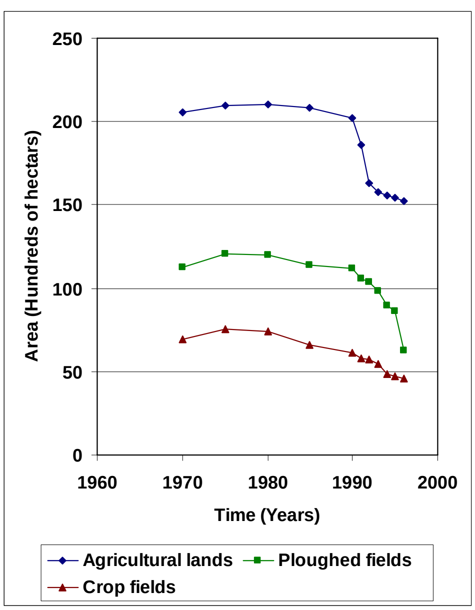

Figure 4.Reductions in Russian agricultural production after the breakdown of the Soviet Union (Source: State Committee for Statistics, Russian Federation, Center of Economic Research, Moscow).

An historic review of land ownership in Eastern Europe

The agricultural revolution of the Middle East spread into Europe by 4000 B.C. (Pongratz et al. 2008). The region registered continuous increases in agricultural area until a sudden halt between AD 1347–1353 due to the plague epidemics Black Death that killed a quarter to a third of the human population (Pongratz et al. 2008). An estimated $2.3 \cdot 10^5$ km^2 of farmland were abandoned and allowed for some regrowth of forest. Until the 15 century, fast rates of land cover transformation were registered, but agricultural expansion stopped in the early 17th century in Europe as a consequence of several regional processes (Pongratz et al. 2008). Extensive forest clearing in the area has been attributed to economic and political activities during the nineteen century by German, Russian and Austro-Hungarian Empires. Forest suffered large conversion to farmland; particularly in the valleys of the region (Ramankutty & Foley 1999).

Agricultural land was passed from being private to state owned in the Soviet Union on the first days of October 1917 (Alayev et al. 1990; Lerman 2001; Brooks & Bruce 2004). In western parts of Ukraine, Belarus, Moldova, and the Baltic States agricultural land passed from private to state when these regions were integrated into the Soviet Union, after World War II (Lerman 2001). The post World War II regimes imposed pretty similar socio-economical conditions on all these countries in general, and on their agriculture in particular. Yet, there are major cultural, social and economic differences between countries under the sphere of the Soviet Union (including the Baltic States) now called Central and Eastern European (CEE) countries, and the 12 successor republics of the former Soviet Union now known as the Commonwealth of Independent States (CIS) (**Table 1**).

Central and Eastern European countries (CEE)	
Baltic States	*Bulgaria*
- *Estonia*	*Albania*
- *Latvia*	***States of former Yugoslavia***
- *Lithuania*	- *Slovenia*
Poland	- *Croatia*
Czech Republic	- *Bosnia and Herzegovina*
Slovakia	- *Serbia*
Hungary	- *Montenegro*
Romania	- *Republic of Macedonia*
Members of the Commonwealth of Independent States (CIS)	
Armenia,	*Moldova,*
Azerbaijan,	*Russia,*
Belarus,	*Tajikistan,*
Georgia,	*Turkmenistan,*
Kazakhstan,	*Ukraine,*
Kyrgyzstan,	*Uzbekistan*

Table 1. Distribution of countries under the sphere of the former Soviet Union

The soviet model of agriculture, based on centralized control, dominated the region since 1953, when Khrushchev extended maize and wheat campaigns (Brooks & Bruce 2004). Poland and the former Yugoslavia partially deviated from this common pattern, their agriculture rely mainly on small individual farms but with strong central controls (Lerman

2001; Dijk 2003). In 1989-1990 most land in the Soviet Union and CIS, regardless of its ownership was cultivated collectively in large-scale farms that managed thousands of hectares and employed hundreds of member-workers (Lerman 2001; Lerman & Csaki 2004).

With the exception of the Baltic States, in CEE private ownership of land did not cease after World War II. Private ownership of land was allowed before 1990 and is allowed today. State land was created by confiscating the holdings of socially and politically non desirable elements. Property of most individual land owners remained untouched. Albania was the only country that nationalized agricultural land by the constitution in 1976 (Lerman 2001).

After the Breakdown of the Soviet Union there was a process of transformation from collective to individual agriculture as the ultimate goal (Brooks & Bruce 2004). This agenda partially succeed in the region. Depending on cultural and political decisions made on its implementation (Macours & Swinnen 2002); 15 former Soviet Republics became sovereign after 1991 and in Russia by more than 20 federation members. All of them had constitutional freedom of action on the issue of land ownership (Lerman 2001).

Land ownership after the breakdown of the Soviet Union

All CIS began changes on the land ownership in 1991, mostly succeeding on that year, with differences on their implementation. Russia legalized private land ownership back in 1990, and put it in the constitution in 1993. Ukraine did so in 1990 and changed the constitution in 1993. Moldova followed that example in 1991 but changed legislation several times until 1996. Belarus initially follow the Russian example but reversed in 1993, changing law code restricting private ownership to household plots of up to 1 ha. All other countries change their constitution legalizing private land ownership on 1991 (Lerman 2001).

Albania is the only country outside the former Soviet Union that had to switch from sole state ownership to private ownership of land, also on 1991. CEE countries had already private ownership allowance on their legislation (Lerman 2001; Macours & Swinnen 2002).

Nowadays the so-called Soviet model of agriculture is being to diverge along the path of market reforms from a common institutional and organizational heritage. Two most relevant elements can be considered from changing land ownership: *privatization of land in the law and disposition of the socialized land* (Lerman 2001; Dijk 2003).

Regarding the implementation of private ownership laws, we can recognize four groups, the first, characterized for legally allowing private ownership, include 16 countries: the CEE countries plus Moldova, Armenia, Georgia, Azerbaijan and recently Kyrgyzstan that legally allow private ownership. The second, that allows private ownership but with buying and selling being restricted in practice, include Russia and Ukraine. The third group retains exclusive state ownership of practically all land and yet the use of rights is freely transferable, this group include Kazakhstan and Tajikistan. The group four is those countries that retain exclusive state ownership of farmland, not allowing transferring the rights; this group includes Belarus, Uzbekistan and Turkmenistan (Lerman 2001; Macours & Swinnen 2002).

Once law changes were set on the region there were two main procedures to dispose the socialized land: *restitution to former owners* and *distribution to workers*. However there are countries that followed a mixed strategy: land is restituted to former owners and also distributed without payment to agricultural workers in the interest of social equity (Lerman 2001; Lerman & Csaki 2004). The distribution of countries following these procedures is summarized in **Table 3**.

Group	Countries	Distribution to workers	Restitution to former owners
1	CIS (12 states)	√	
	Albania	√	
2	Hungary, Romania	√	√
3	Bulgaria, Czech/Slovak Republics, Baltics (3 states)		√
4	Poland, Slovenia	Land ownership already allowed	

Table 3. Disposition of socialized land after the breakdown of the Soviet Union (1991) according the procedure followed. From the procedure of disposition of land it is possible to recognize four groups. Modified from (Lerman 2001)

Broad-scale land cover mapping

Knowing conditions, amount and dynamics of natural resources are crucial for human well being. Assessing rates and spatial patterns of LULCC has impacts on policies at all levels. In order to understand processes and consequences of policies regarding land, LULCC mapping and monitoring has been strongly supported by national and international agencies since 1972, with the use of earth observation satellites.

Some of the programs that have been created to map LULCC and provide better understanding of LULCC include efforts from the United Nations Food and Agriculture Organization with their Forest Resource Assessments (FAO 1995, 1996, 2001 and 2005) (FAO UN 2006), Humid Tropical Landsat pathfinder (NASA, US) (http://www.geog.umd.edu/tropical/), TREES (Joint Research Center, Europe) (Mayaux et al. 1998), IGBP 1 km land cover (IGBP) (Loveland et al. 2000), Global Forest Watch (Russia) (http://www.globalforestwatch.org/english/index.htm), North American Landscape Characterization (U.S Environmental Protection Agency) (http://edc2.usgs.gov/pathfinder/nalc_proj_camp.php), Global Rainforest Mapping (Japan and US) (Rosenqvist et al. 2000) and the MODIS Land products (NASA, US) (Justice et al. 1998). However, mapping and monitoring projects had been made with different criteria, with a different scope in extend and objectives. Gathering information across the world in a consistent manner is challenging due to economic and social changing situations as well as the natural and cultural diversity (Townshend & Brady 2006).

The first space photograph was taken in 1959, on board of the Explorer 6 satellite. However, more than a decade would pass until the first program developed for the collection of multispectral remote sensing data for the analysis and monitoring of the earth's natural resources appeared. The Earth Resources Technology Satellite (ERTS) program launched an unmanned satellite called ERTS-1 on 23 July 1972 with the instrument multispectral scanner (MSS). ERTS program was latter known as Landsat. Landsat is the longest running space-based remote-sensing program, used extensively to study land-cover change around the world (http://landsat.gsfc.nasa.gov/).

Landsat satellite data falls into the category of medium resolution data. According with the spatial resolution, sensors on board satellites can be classified into three main categories:

broad, medium and high (Wulder et al. 2008). For land cover mapping for very large areas typically uses broad scale imagery since the 1980´s simply due to image availability and size. The most common satellite sensors used to map LULCC at broad scale have been AVHRR, SPOT-VGT, and MODIS (Friedl et al. 2002), with MODIS becoming particularly important since 2001 (Fensholt & Sandholt 2005).

*The Advanced Very High Resolution Radiometer (*AVHRR) imagery was launched on board NOAA satellites. NOAAA satellites were designed to observe the Earth's weather, looking at of cloud patterns. However, they have been used for more than monitoring weather phenomena. Today the NOAA/ AVHRR satellites are used in many applications. Since the 1980's AVHRR at 1 km and 8 km resolution had been used to classify continental to global land cover (Justice et al. 1985; Tucker et al. 1985; DeFries & Townshend 1994; Hansen et al. 2000; Loveland et al. 2000). High temporal resolution and the ability to use phenological information allowed to map LULC (Malingreau 1986; Lobell & Asner 2004). Most AVHRR mapping efforts have classified general vegetation types and or/aggregated land cover classes, including a mixed crop/natural vegetation class.

Satellite Pour l'Observation de la Terre (SPOT) is the earth observation satellite system developed in Europe, operating since 1986. From this family of satellites the one that provides broad-scale resolution imagery for analyzing land cover is SPOT-VEGETATION (SPOT-VGT) on board of SPOT-4 platform, launched in March 1998. SPOT-4 is not anymore operational, but second payload VEGETATION 2 imagery is on board SPOT 5 and still on production. SPOT-VGT provides imagery in four spectral bands (Saint 1996). Since then it has been used to map different aspects of Land Cover, from mapping phenology in boreal regions (Delbart et al. 2006) to mapping burned areas in Russia (Zhang et al. 2003).

MODIS

The MODerate-resolution Imaging Spectroradiometer (MODIS) is a coarse-spatial resolution sensor instrument on board of two Satellites, part of the Earth Observing System (EOS), Terra and Aqua. MODIS inherits the AVHRR (Spatial/temporal) and Landsat TM (spectral) features with improvements in spatial and spectral resolution. MODIS/AVHRR MODIS provides the potential to identify land cover changes such as land abandonment over large and sometimes inaccessible or sensitive areas. Terra was launched on December 1999 while Aqua was launched on May 2002. MODIS covers the entire surface of the Earth every one to two days. MODIS was specially designated to capture atmospheric, ocean and land data on 36 spectral bands with different resolutions: 1000 m. (Bands 8-36), 500 m. (Bands 3-7), and 250 m. (Bands 1-2). MODIS data are transferred from the satellite to ground stations and preprocessed by the EOS Data and Operations System (EDOS). MODIS team derives 63 different Land Products at six different temporal resolutions (daily, 8 days, 16 days, monthly, quarterly and yearly) and four nominal spatial resolutions (250 m, 500 m, 1000 m, and 5600 m). Most standard MODIS Land Products use the Sinusoidal grid tilling system. Tiles are 10 degrees by 10 degrees at the equator. MODIS Land Products are distributed freely to the science applications community through the Land Processes Distributed Archive Center (LP-DAAC) (Justice et al. 2002).

Reflectance product MCD43 Nadir BRDF-Adjusted Reflectance (MODIS NBAR) provides 500 and 1000 m reflectance data adjusted using a bidirectional reflectance distribution function (BRDF) to model the values as if they were taken from nadir view, produced every

8 days with 16 days of acquisition. These MODIS NBAR data are 16-day composites provided since February 24 2000 as a level-3 gridded product in the Sinusoidal projection. MODIS/Terra+Aqua are products that come from both satellites, Terra and Aqua. MODIS 16-Day use data from 8 days before and 8 days after the nominal date, but they are released on a weekly basis. MODIS NBAR products are validated at Stage 1, meaning that accuracy has been estimated using a small number of independent measurements obtained from selected locations and time periods and ground-truth/field program efforts(Schaaf et al. 2002). Atmospheric correction, geometric and locational accuracy permit the use of multitemporal analysis with relatively high sub-pixel accuracy (near 50 m) (Wolfe et al. 2002) Data sets include seven spectral channels, ordered by wavelength are at 0.46-0.48, 0.55-0.57, 0.62-0.67, 0.84-0.88, 1.23-1.25, 1.63-1.65 and 2.11-2.16 μm. NBAR Product also provides four bands with extensive quality information (Schaaf et al. 2002). *On my research I am using MODIS NBAR imagery to detect land abandonment.*

The MODIS team release an annual and biannual global Land Cover Type product with five different classification schemes, which describe land cover properties derived from observations spanning a year's input of Terra and Aqua data. The MODIS Land Cover product is released at 500-m resolution. MODIS team has released the Land Cover products from 2001 to 2005; but the resulting maps still under evaluation. MODIS team is planning to release a MODIS global land cover dynamics product (Friedl et al. 2002). *In any event though, the MODIS land cover products are global in scope and not detailed enough to provide accurate information on land abandonment in Eastern Europe*.

Landsat images to validate MODIS

The use of Landsat imagery to get sampling points and validate MODIS classifications is an extension of the classical remote sensing methods. These methods use airborne and higher resolution satellite data coupled with field data for getting ground truth data and validation of coarser resolution products. In fact, MODIS team suggested the use of Landsat images as well as other finer resolution remote sensing images to validate MODIS Land products (Morisette et al. 2002). Some of the MODIS products that use Landsat images for validation include Land Cover (Friedl et al. 2002), Vegetation Indices (Huete et al. 2002), Snow (Hall et al. 2002), and Leaf Area Index (LAI) (Tian et al. 2002b; Cohen et al. 2003). MODIS classification assessments using Landsat are commonly done based on visual interpretation of point measurements on the higher resolution imagery. The aggregation of point data over large areas for getting ground truth data and validation is currently under research (Cohen & Justice 1999). Regularly the aggregation methods include the use of a classified image made with a higher resolution source (e.g. airborne photographs, IKONOS, Landsat) and the selection of center points within the class of interest (Jin & Sader 2005), but it can be done with the use of convolution algorithms (Tian et al. 2002a) or aggregation to the coarser resolution with the use of majority or square-wave filters (Ozdogan & Gutman 2008). Another approach is the use of pixel footprints from the coarser resolution image and the retrieval of composition in percentage of each class in the finer resolution map within each footprint. This method was used successfully by Wardlow and Egbert to validate croplands (Wardlow & Egbert 2008). They used MODIS footprints over a Kansas Gap Analysis Program LULC classification at 30 m with a threshold of 50% to split between crop class and non-crop class. *On my research I am using pixel footprints from MODIS within land abandonment mapping at 30 m but I am looking at different thresholds in class composition in order to investigate its effects on the accuracy of my classification.*

LULCC classification methods

LULCC mapping has been made possible by the development of a multitude of classification methods (Singh 1989; Mas 1999; Tso & Mather 2003; Lu et al. 2004; Radke 2005). Advanced methods include learning machines that proved to improve classification capabilities (Pal & Mather 2003; Tso & Mather 2003; Mas & Flores 2008). Particularly successful are non-parametric methods that can classify a multispectral space; making them able to discriminate multi-modal distributions. Some of those non-parametric methods include neural networks, decision trees and support vector machines (SVM). Neural networks and decision trees have been the selected techniques to map LULCC at global scales by different MODIS team groups (Justice et al. 2002) and have produced high classification accuracies for LULC(Friedl & Brodley 1997). The remote sensing community has used SVM with Landsat imagery with great success to map LULC since 1999 (Hermes et al. 1999). Lately the use of SVM has become more common to map LULCC (Kuemmerle et al. 2009) and specifically land abandonment (Kuemmerle et al. 2008). For broad scale mapping SVM has been used successfully to predict Gross Primary Production (GPP) over the conterminous U.S. comparing a calculation of GPP using MODIS land cover product (MOD12Q1) with MODIS GPP (MOD17A2) (Yang et al. 2007). There is only one report of land cover classification with Support Vector Machines applied to MODIS MOD09A1 500 m. from February 2000 to January 2001 over Portugal (Goncalves et al. 2006). To date there is not a single work that uses SVM with coarse resolution data focused on mapping land abandonment for large areas. *I will use support vector machines to classify MODIS satellite imagery across Eastern Europe in order to assess land abandonment.*

Chapter I. Mapping abandoned agricultural land using MODIS in Eastern Europe

Introduction

In recent decades remote sensing data have been widely used to understand interactions between humans and nature (Cohen & Goward 2004; Fassnacht et al. 2006). Remote sensing data can provide independent and uniform source to detect different aspects of land-use and land-cover change (LULCC) (Lu et al. 2004). Derived land cover data can help to monitor and improve management and decision making (Nepstad et al. 1999; Laurance et al. 2001; Cohen & Goward 2004; Boyd & Danson 2005). The main advantages on the use of remote sensing data are that they allow a) to assess LULCC on sites that otherwise are inaccessible, b) to perform repeated measurements and c) to make complete spatial comparisons over large areas (Fassnacht et al. 2006). Satelllite remote sensing techniques have been applied at least for 30 years to assess LULCC across three types of information: land cover pattern, cover composition, and biophysical properties of land cover (Boyd & Danson 2005). However, land cover estimates commonly focus on deforestation estimates, frequently ignoring the fate of cleared land. What has been less considered, for instance, are the separate processes of gross forest clearing and the rates of land abandonment and subsequent forest regrowth (Ramankutty et al. 2007). This is unfortunate because land abandonment has strong implications of on soil stability, carbon sequestration, nutrient cycles and biodiversity (MacDonald et al. 2000; Stoate et al. 2001; Ramankutty et al. 2007).

Land abandonment as land-cover class comprises several land-uses that include land not in use, land abandonment, forest regrowth and forest plantations. With the sole use of remote sensing and relatively short time series analysis those land-use classes are not possible to be discriminated. In order to discriminate land-uses we need to include field work and a longer time-span. On my dissertation I am looking at abandoned agricultural land. There have been several studies to assess land abandonment using remote sensing but none have mapped land abandonment using broad-resolution imagery. In the United States of America remote sensing has been used to map land abandonment in the context of the Conservation Reserve Program (CRP). CRP mapping used post-classification change detection (Egbert et al. 1998; Egbert et al. 2002; Park & Egbert 2008); but the automatic use of Support Vector Machines coupled with Decision Trees, two non-parametric classification techniques applied to multitemporal imagery, has been suggested (Song et al. 2005). In Europe, successful land abandonment mapping with remote sensing techniques was conducted in the Carpathians (Kuemmerle et al. 2008; Kuemmerle et al. 2009), Italy (Falcucci et al. 2007), Denmark(Kristensen et al. 2004), Estonia (Peterson & Aunap 1998) and the Siberian part of Russia (Bergen et al. 2008). All these studies used Landsat imagery from multiple dates, separated at least three years. *None of the current efforts to map abandoned land allow for direct comparisons over large areas because they are based on a sample of Landsat images, frequently from different dates.*

Goal/Objectives

To develop a novel LULCC classification method to map abandoned agricultural land using broad-scale imagery in Eastern Europe using MODIS imagery.

The specific objectives for this chapter are:

- To develop a digital change detection approach based on a multitemporal MODIS image classification to assess abandoned agricultural land.
- To exemplify the method to detect abandoned agricultural land in the Baltic countries, Belarus, and Kaliningrad (Russia) between 2001 and 2008.

Methods

The study area for this chapter comprises Lithuania, Latvia, Estonia, Belarus, Kaliningrad, a section of the Russian Federation, a small portion of Ukraine and more than 50% of Poland (**Figures 1,3**). This area was selected because there are reports that land abandonment is widespread in this region (**Figures 2,3**) (Peterson & Aunap 1998; Dutch National Reference Centre for Agriculture et al. 2005; Nikodemus et al. 2005). The area of study is 1,236,434 km^2, the extent of one MODIS scene (tile h19-v03).

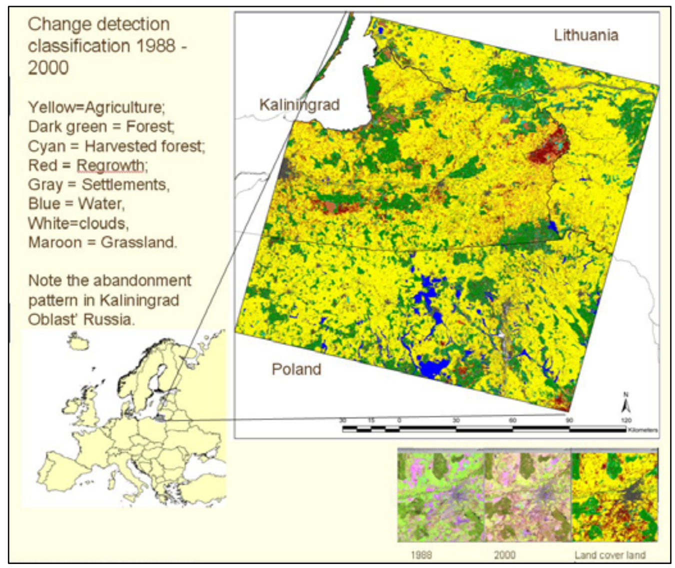

Figure 2. Land cover and land use change detection in Kaliningrad, Russia with Landsat TM/ETM+ time series data (Alcantara et al. 2006)

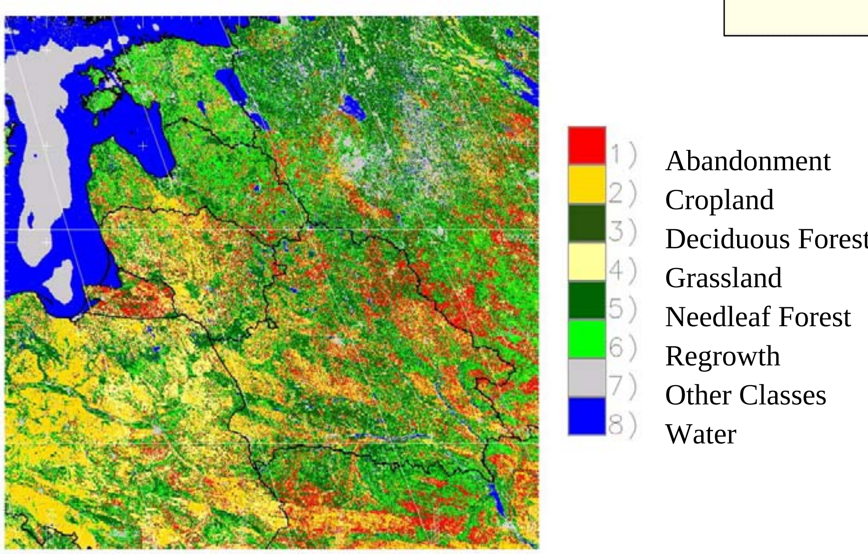

Figure 3. Abandoned agricultural land over Eastern Europe including Lithuania, Latvia, Estonia,, Kaliningrad and Belarus. MODIS scene (tile h19-v03). The classification was conducted with bi-weekly data for the year 2005 and using maximum likelihood (own elaboration)

There is a lack of automated methods to assess abandoned agricultural land, mainly because most change detection methods use only one image in a given year and stable signatures over time (Coppin et al. 2004) which is not the case in time series. In the case of abandonment, phenology and different crop types make it difficult to detect change. I will use a weekly MODIS multitemporal dataset, calculate vegetation indices (NDVI) and identify phenology to overcome those limitations of change detection methods. My first chapter will analyze one MODIS tile (h19-v03) combined MODIS/Terra+Aqua Nadir BRDF-Adjusted Reflectance 16-Day L3 Global 500 m**.** SIN Grid V005 MCD43A2 (MODIS NBAR) (Schaaf et al. 2002) weekly data from 2001 to 2008. MODIS NBAR data will allow to analyze variations in reflectance throughout one growing season, identify abandoned land in a given year and then to look at the patterns of abandoned land through time.

The operative definition of abandoned land to be used on my research will be: land no longer used by agriculture for three or more years. The assumption is that, if agricultural fields not in use in a single year can be mapped; then, the amount of land that is abandoned through the analysis for each year can be estimated by tracking agricultural land use over time. Once maps of land not in use for the whole sequence (eight maps, one per year) are calculated, then *areas that have not been in use for more than three years in a row without being taken again for production* will be identified as abandoned land.

Farmland not in use in 2005 will be mapped first. The year 2005 was chosen because it provides the best data in the MODIS record (52 images, **Figure 3**). Classifications of MODIS data with 500 m resolution result essentially the same results of land cover composition than the ETM+ data from a Landsat Satellite, but mapping broad areas using coarse resolution images results in mixed classes in many pixels (Price 2003).

Ground truth and validation data will be provided by land cover maps for three Landsat scenes. Two of the Landsat scenes have been analyzed by Alexander Prischepov to map land abandonment from 1989 to 1999 around the Baltic countries. The third Landsat scene was classified by Patrick Hostert (Humboldt University, Berlin) to map abandonment from 1980 to 2000 scheme on a single Landsat around Chernobyl, Ukraine. The classification scheme includes 8 classes (Abandonment, Cropland, Deciduous Forest, Grassland, Needleaf Forest, Regrowth, Water, and Other Classes). The percentage of each Landsat classification contained within each 500 m MODIS pixel footprint will be calculated.

A library containing two hundred and fifty areas with more than 90% of the same class will be generated randomly for each class in the Landsat classification. Areas that have 90% or more for the same class will contain 22.5 ha or more of the same class within 25 ha. Those pixels will be labeled as “pure” pixels. Additionally 50 areas with mixed categories but a majority of the same class will be calculated (80%, 70%, 60%, and 50% thresholds). Areas with pixels not dominated by any class (less than 50% of any class) will be summarized. Mixed classes will be included on five separated validation assessment schemes (one for each % threshold).

I expect that some classes will exhibit multi-modal or non-normal distributions, caused, for instance, by different crop types prior to abandonment reverting to one land cover type. The most appropriate classifiers for non-normality distributed data are non-parametric classifiers. Support Vector Machines (Huang C. et al. 2002), a machine learning algorithm, will thus be applied to classify the 2005 MODIS data.

Abandoned land is expected to be detectable better through changes in the weekly spectral signature throughout the year. On a first round, classifications with the reflectance data will be conducted. On a second round classifications with the Normalized Difference Vegetation Index (NDVI) will be tested. NDVI will be calculated for weekly MODIS data. Additionally, phenological analysis will be conducted and the maps generated will be added to the layer stack with reflectance and NDVI as ancillary data to test whether or not the addition of phenology improves the land cover classification.

The NDVI time series from 2001 to 2008 will be analyzed through the use of TIMESAT (Jonsson & Eklundh 2004). TIMESAT will calculate phenological information to be added to the classification as ancillary data. In TIMESAT, the Savitsky-Golay algorithm calculates five phenological indices for each year: Start of the season, End of the season, Length of the season, Base level, Middle of the season. I will test whether or not the phonological indices improve the detection of abandoned land. A statistical accuracy assessment will be conducted using the random sample design described above, using Landsat classifications as a ground truth.

Once the best classification method has been established for 2005, I will apply the method to MODIS data for each year from 2001 to 2008. The resulting maps of land not in use will be combined using a single scheme to discriminate areas with more than three years in a row that are not in use, those pixels will be labeled as abandoned land (**Table 4.**). A table with abandoned areas for the period 2001-2008 will be summarized as well as separated tables for the different threshold of mixed pixels.

Outcomes

The outcomes of my first chapter will be a) a classification method to map abandoned land (to ~500 m. resolution) and b) one abandoned land map for the years 2001 to 2008 for one MODIS tile. This chapter is going to be submitted for publication to the journal Remote Sensing for Environment, as a first choice, or the International Journal of Remote Sensing.

	Year							
Land status	2001	2002	2003	2004	2005	2006	2007	2008
NA								
NA	x							
NA		x						
NA			x					
NA				x				
NA					x			
NA						x		
NA							x	
NA								x
NA	x	x						
NA		x	x					
NA			x	x				
NA				x	x			
NA					x	x		
NA						x	x	
NA							x	x
NA	x	x	x					
NA		x	x	x				
NA			x	x	x			
NA				x	x	x		
NA					x	x	x	
NA						x	x	x
A	x	x	x	x				
A		x	x	x	x			
A			x	x	x	x		
A				x	x	x	x	
A					x	x	x	x
A	x	x	x	x	x			
A		x	x	x	x	x		
A			x	x	x	x	x	
A				x	x	x	x	x
A	x	x	x	x	x	x		
A		x	x	x	x	x	x	
A			x	x	x	x	x	x
A	x	x	x	x	x	x	x	
A		x	x	x	x	x	x	x
NA	x	x	x		x			
NA		x	x	x		x		
NA			x	x	x		x	
NA				x	x	x		x
NA	x		x	x	x			
NA		x		x	x	x		
NA			x		x	x	x	
NA				x		x	x	x
NA	x	x	x		x	x		
NA		x	x	x		x	x	
NA			x	x	x		x	x
NA	x	x		x	x	x		
NA		x	x		x	x	x	
NA			x	x		x	x	x
NA	x	x	x		x	x	x	
NA		x	x	x		x	x	x
A	x	x	x		x	x	x	x
A	x	x	x	x		x	x	x
A	x	x	x	x		x		
A		x	x	x	x		x	
A			x	x	x	x		x
A			x		x	x	x	x
A		x		x	x	x	x	
A	x		x	x	x	x		
A	x	x	x	x		x	x	
A		x	x	x	x		x	x
A		x	x		x	x	x	x
A	x	x		x	x	x	x	
A	x	x	x	x		x	x	x
A	x	x	x		x	x	x	x
A	x	x	x	x	x		x	
A		x	x	x	x	x		x
A		x		x	x	x	x	x
A	x		x	x	x	x	x	
A	x	x	x	x	x		x	x
A	x	x		x	x	x	x	x
A	x		x	x	x	x	x	x
A	x	x	x	x	x	x		x
A	x	x	x	x	x	x	x	x

Table 4. Land abandonment classification scheme, "x" represents years with the land not in use. A = Abandoned; NA= Not abandoned

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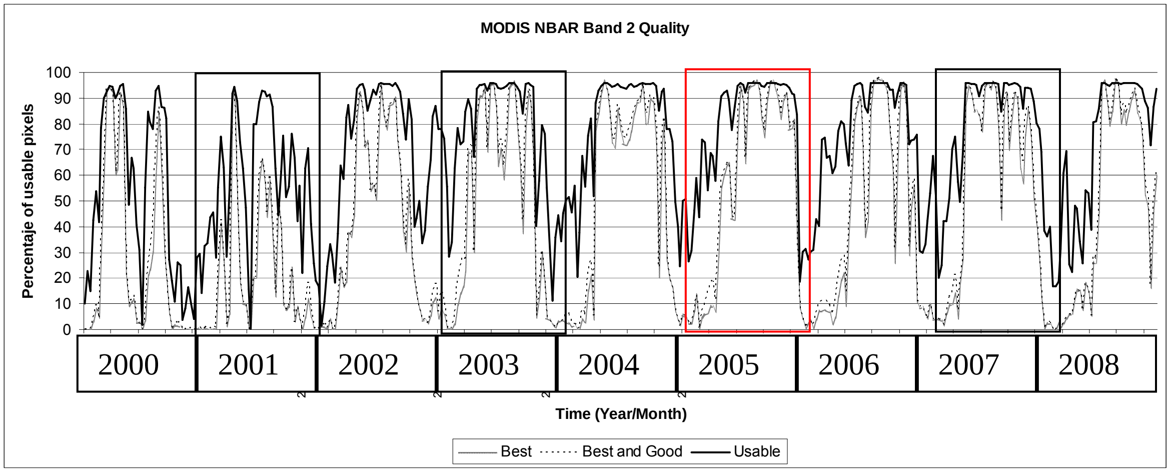

Figure 4. MODIS NBAR percentages of usable data from 2000 to 2008 tile h19-v03. The year with the largest amount of available data is 2005 (in red)

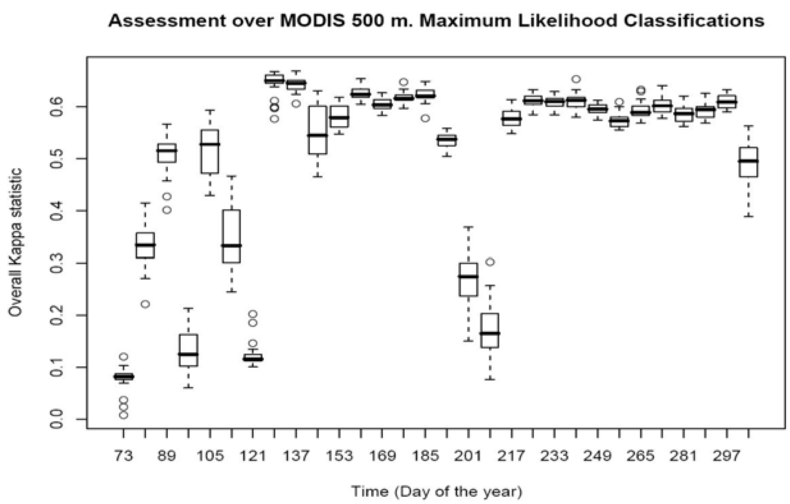

Figure 5. Weekly MODIS classification performance, each box represents 30 separated runs using independent random training sets. A maximum likelihood classification to detect land abandonment was conducted for the year 2005, the best classification (may 17) is shown on Figure 3. (own elaboration).

Relevance

There has been little previous work to date on the development of methods that would allow mapping land abandonment at broad scales. This chapter will contribute to the Remote Sensing discipline with the development of a new method to map land abandonment over large areas. Mapping land abandonment over Eastern Europe with a common time span and level of detail will allow direct comparisons across countries. My research will also test a new MODIS product, the MODIS NBAR imagery at 500 m resolution (MCD43A4); a product that was just released on October 2008.

This chapter will also make a new contribution to the integration of satellite data with different resolution (30 m to 500 m pixel size) and the analysis of mixed pixels accuracy. And last but not least, this chapter will be one of the first to use Support Vector Machines for MODIS time series data.

Ultimately my research for this chapter will provide a basis for approaching the following questions:

- Mapping land abandonment globally;
- Mapping the fate of abandoned land and eventually to discriminate among the different land-uses confounded in the land abandonment cover class;
- Land abandonment dynamics relationship with changes in political and socio-economical decisions;
- Land abandonment effects on wildlife.

Having a reliable method to assess land abandonment will allow studying more accurately the implications of land abandonment on ecosystem services, soil stability, carbon sequestration, nutrient cycles and biodiversity.

Chapter II. Assessing LULCC at coarse spatial resolution. Agricultural land abandonment across Eastern Europe.

Introduction

Land use intensification transforms the planet at unprecedented rates (DeFries et al. 2004; Foley et al. 2005). Hundreds of studies have examined the causes and trajectories of LULCC. However, there is not an integrative framework that provides insights in the causes of LULCC. Forest transition theory claims to be one starting point to set up an integrative framework for LULCC, and a second one is land use transition theory (see background). LLULC dynamics are driven by multiple underlying driving forces, ranging from demography, economics, technology policies and culture. Most LULCC studies have a good grasp on the proximate and underlying causes of LULCC though, only a handful of them have attempted to analyze the underlying driving factors that rule LULCC looking at the national level, mainly due to the impossibility to set up an experiment to test them (Lambin & Geist 2006). Underlying driving forces operate at different scales, but there is a lack of knowledge of the effects of broad-scale factors (e.g. National policies) that rule LULCC. *I propose that broad-scale factors can be quantified due to differences among countries.*

In my second chapter I will analyze the national policies that determined LULCC transition and forest transition over a prime and ongoing example, the European part of Russia and the countries under the sphere of influence of the former Soviet Union (**Figure 1**). This region shares the same ecological conditions and a common recent history from 1946 to 1991. In the early 1990s, the dissolution of the Soviet Union allowed new countries to (re)emerge and transformed centralized state-economies into market economies; accompanied by de-collectivization of land (Lerman 2001; Dekker 2006). The outcome was a substantial drop in *agricultural production* (Liefert & Swinnen 2002) (**Figure 4**), resulted in large amounts of *abandoned land* (Dutch National Reference Centre for Agriculture et al. 2005).

Economic transformation was accompanied by a near elimination of agricultural subsidies in the former Soviet Union, price liberalization, sudden competition on the global markets in the newly independent countries, change of the socialist governments, and institutions (Liefert & Swinnen 2002). After the breakdown of the Soviet Union, several countries (e.g Poland, Lithuania, Latvia, and Estonia) were integrated to the European Union with the subsequent subsides (Dutch National Reference Centre for Agriculture et al. 2005). In terms of LULCC there was a de-collectivization process; generally involving the fragmentation of large collective and/or state farms and the privatization of land (Lerman & Csaki 2004; Dekker 2006).

Market disruption and limited access to capital resulted from a lack of governance on the first years after the breakdown of the Soviet Union (Estrin & Wright 1999). Competing on global markets required the use of new technologies to improve yields but the scarcity of equipment and technical support made yield increases challenging (Liefert & Swinnen 2002), especially for small farmers without formal education (Dutch National Reference Centre for Agriculture et al. 2005). Mechanization and economic failure on small farms resulted on unemployment (Liefert & Swinnen 2002). Ownership fragmentation in some countries (e.g Poland) means that farmers have to rent the land from large numbers of different owners to create a viable holding. Especially young farmers often left the farmlands for better paid jobs in cities. The transition time weakened the link between ownership and land use has been. Once land was restituted, new owners were often urban dwellers not interested or with few experience in farming; confronting uncertainty on land tenure (Dutch National Reference Centre for Agriculture et al. 2005).

Central and Eastern Europe experienced more adverse economic changes than the EU; reducing the viability of established forms of production (Mathijs & Swinnen 1998). There was a sharp decline in output, particularly in the livestock sector, in most countries in the early 1990s (**Figure 4**) (Liefert & Swinnen 2002).Reduced production was accompanied by both a trend towards less intensive farming systems and *land abandonment*, either temporarily or permanently; the affected areas have included especially marginal lands (Dutch National Reference Centre for Agriculture et al. 2005).

Declines in agricultural production after the breakdown of the USSR were not uniform across Eastern Europe though. Different policies, cultures and land use tradition in each country all affected the temporal and spatial patterns of land abandonment (Baltowski & Mickiewicz 2000; Childress 2002; King 2002; Kuemmerle et al. 2007; Kuemmerle et al. 2008). However, reliable and independent data on the extent and patterns of post-socialist agricultural abandonment is lacking (Filer & Hanousek 2002; Kuemmerle et al. 2008). To date there is not any wall-to-wall assessment on land abandonment. *The breakdown of the Soviet Union provides a natural experiment with the potential to analyze both land-use transition and forest transition theories*.

When farmland is abandonment there is an opportunity to restore historical vegetation states (Bellemare et al. 2002). However, all prior cultivation leaves legacy, because modification of the environment for agriculture causes degradation, and changes ecosystems processes affecting soils, vegetation composition and structure (Bellemare et al. 2002; Foster et al. 2003). The longer and more intensely a land was modified, the longer legacies are likely to last (Cramer et al. 2008). Understanding the long-term consequences of past land use thus provides a better understanding of current plant and wildlife communities, and to predict future disturbance and environmental change (Flinn & Vellend 2005). Patterns of deforestation and land abandonment affects species distribution and those raise questions about controls on species distribution, regarding dispersal and succession trajectories (Wallin et al. 1994; Hermy & Verheyen 2007; Cramer et al. 2008).*Landscapes with a history of agriculture provide the opportunity to quantify the influence of past disturbance versus conditions on current vegetation* (Wallin et al. 1994; Foster et al. 2003).

Some researchers have pointed out that geographical patterns of land use and environmental variation are often correlated. Differences between old-growth and second-growth forests may therefore be due to environmental differences rather than disturbance legacies. The best way to control for pre-existing environmental conditions is to focus on regions were the past land use varies across areas with homogeneous soils and topography or to select adjacent pairs of sites with similar topography and soils (Flinn & Vellend 2005). Eastern Europe has a fairly uniform environment, but the historic borders of Germany, Russia and Austro-Hungarian Empire may have had effects on agricultural patterns. The question is if these historic borders are still having legacy in current landscape patterns or if intensification and new technologies overruled those cultural legacies. *Knowing patterns and distribution of land abandonment at broad scale can serve as a proxy for agricultural patterns in the past.*

Goal/Objectives

Assess differences in land abandonment rates in Eastern Europe and relate those differences with land use policies and historical legacies

My objectives on this chapter are

- To quantify the extent and rates of farmland abandonment across Eastern Europe
- To relate differences in abandonment to differences in land reforms between countries
- To explore historic legacies on land abandonment

Methods

The study area comprises nineteen countries from the east of the Baltic's to the Ural Mountains, including: Estonia, Latvia, Lithuania, Poland, Belarus, Ukraine, Czech Republic, Slovakia, Hungary, Austria, Slovenia, Croatia, Bosnia and Herzegovina, Montenegro, Bulgaria, Serbia, Moldova, Albania, and a portion of Germany and Russia including the Kaliningrad enclave and the upper Volga basin. The part of Russia that is being analyzed encompasses eleven out of the twenty largest cities of Russia, including its capital, Moscow; and Saint Petersburg (**Figure 1**).

I will use the land abandonment detection method developed in Chapter I to map abandoned lands across Eastern Europe and countries that used to be under the sphere of the USSR (Five tiles, comprising rows h19, h20, h21 and paths v03, v04) (**Figure 1**). I will analyze MODIS data from 2001 to 2008 (**Figure 3**).

Ground-truth points for training and validation will be collected from Landsat land cover change classifications (30 m spatial resolution, I will analyze three Landsat footprints in each MODIS tile); and from high-resolution satellite images (Quickbird images available in Google Earth).

The overall assessment of the amount of land abandoned in Eastern Europe will quantify Land abandonment (km^2)/agricultural areas (km^2) and Land abandonment (km^2)/total area (km^2) for all of Eastern Europe. Country-level comparisons will be conducted via the summary over land abandonment in each, measuring again both Land abandonment (km2)/agricultural areas (km2) and Land abandonment (km^2)/total area (km^2).

In order to explore the effect of political decisions on land abandonment I will group countries according to land ownership policies (collective vs. private) and compare their respective amount of land abandonment. Another grouping of countries will examine the privatization of land in the law (4 groups) and the disposition socialized land (4 groups) as described in the background section and I will analyze whether or not land abandonment differed among the groups.

To explore the effect of historic legacies I will digitize former boundaries for German, Russian and Austro-Hungarian empires and explore if there are differences in land abandonment along these borders.

Land abandonment patterns

To assess land abandonment patterns I will calculate landscape indices, such as mean patch size, area-weighted mean patch size, patch density and morphological features (perforated, edge, patch and core areas) according to Vogt (2007). Patch density is going to be calculated as number of patches per 10,000 km2. The landscape indices will be summarized and compared for each country and among former German, Russian and Austro-Hungarian territories.

Mathematical morphology (MM) is a theory and technique for the analysis and processing of geometrical structures, based on set theory, lattice theory, topology, and random functions. MM is most commonly applied to digital images, but it can be employed as well on graphs, surface meshes, solids, and many other spatial structures. Mathematical Morphology was invented in 1964 from the collaborative work of Georges Matheron and Jean Serra, at the École des Mines de Paris, France. Matheron and Serra collaboration resulted in a novel practical approach, as well as theoretical advancements in integral geometry and topology (Matheron and Serra 2002).

The application of mathematical morphology to landscape characterization was first proposed by Vogt in collaboration with Riitters (Vogt et al. 2007). Riitters prior work characterized fragmentation using convolution matrices (Riitters et al. 2002) that were not as accurate in characterizing spatial features mathematical morphology is(Riitters et al. 2007; Vogt et al. 2007). A morphological characterization of the class of interest calculates, for instance, the amount of patches, edge and core areas for a given landscape (Vogt et al. 2007). Using this approach I will calculate *Core, Patch, Perforated* and *Edge* classes for forest + scrubland and scrubland within 1.5, 2.5, 5, 10 and 15 Km from the *border*. *Border* is defined as the intersection between a pixel labeled with the class of interest and a pixel with a different class. *Core* is defined as areas of the class of interest that are beyond a given linear distance from the *border*. *Edges* are areas of the class of interest that are within a given linear distance from the *border*. *Patch* are regions of the class of interest that are too small to contain *core*, they are pure border regions. *Perforated* areas are those surfaces within a given linear distance surrounding a small area of the non interest class. A small area of non-interest class is defined as a gap in a matrix of the region of interest that is smaller or equal in size than a *patch*.

Outcomes

The outcomes of this chapter will be a) a land abandonment map for the years 2001-2008 for five MODIS tile (~500 m. resolution), b) One overall assessment on the amount of land abandoned in Eastern Europe, c) Among country comparison of the amount of land abandoned in Eastern Europe, d) A comparison of land abandonment between countries with collective land ownership versus countries with private land ownership after the breakdown of the Soviet Union, e) A comparison of land abandonment countries between countries with different status on the privatization on the land, f) A comparison of land abandonment regarding the disposition of the socialized land, g) An analysis on land abandonment on areas that were under different regimes in the past to assess the effect of historic legacies on land abandonment, f) An analysis on the abandonment patterns on the region, per country.

This chapter is going to be submitted for publication to the journal BioScience, Global Environmental Change-Human Policy Dimensions or Agriculture, Ecosystems and Environment. The datasets that result will include a set of land cover classifications from 2001 to 2008, and a land abandonment classification for the period per country and for the region.

Relevance

Underlying driving forces operate at different scales, but there is a lack of knowledge of the effects of broad-scale factors (e.g. National policies) that rule LULCC. Broad-scale factors can be quantified by looking at differences in LULCC among countries. To understand the ultimate factors that rule land-use transitions, my dissertation will document land cover transitions and have empirical information about their extent over present and past land-uses. Knowing the differences in land reforms and their relationship with land abandonment will provide a basis for testing the relationship between land reforms with the intensification and land abandonment processes. This chapter attempts to contribute to research in Land Use Science, Landscape Ecology, and Agricultural Economics.

Land abandonment pattern and distribution assessment will allow studying questions related to:
- Ecosystem services
- Soil stability
- Carbon sequestration
- Nutrient cycles
- Biodiversity

Mapping land abandonment coupled with field date will allow answering more general ecological questions such as species distribution (both occurrence and abundance), studies on succession, dispersal and seed banks. My research will state that the use of a focal species can serve as a proxy to define habitat targets and delineate large areas for conservation purposes, but it is limited. There is the need to analyze LULCC effects over a group of species in order to have a more accurate picture of the effects of LULCC over biodiversity.

Chapter III Analyzing habitat changes in size and fragmentation through the measurement of the relationship between LULCC with brown bear populations in Russia

Introduction

Large animals are particularly important to ecological dynamics. They are also particularly vulnerable, at species and population levels. Less than 21 % of the earth‘s terrestrial surface still contains all of the large (>20 kg) mammals once held (Morrison et al. 2007). Large Carnivores are key species in terms of conservation and tourism. For instance, carnivorous species returning to the Yellowstone Park restored ecological interactions that otherwise would be impossible to recover (Wolf et al. 2007). Carnivores returning is not only happening on the natural protected areas, but in the northern areas of the United States, with promising results (Mladenoff et al. 1995). Abandoned agricultural fields in Eastern Europe are new areas were large carnivores are likely to use as part of their habitat. *Given the ecological importance of large mammals and in particular of top predators, is critical to analyze the relationship between land abandonment and a top predator population returning to what remains from their historical ranges.*

Brown Bears are a charismatic species whose presence in a given area implies both love and rejection from humans. Bears can attract tourism and improve the people’s awareness of conservation. At the same time bear may be rejected because they can predate livestock and cause problems on rural areas. When dealing with wild brown bear populations there are also issues related with poaching and wildlife trade that must be addressed. *Using brown bear as a focal species I will assess changes in bear its habitat and bear distribution* which will to better understanding the ecological role of LULCC and its consequences on wildlife. Brown bears may serve as focal species to assist ecosystem management (Simberloff 1999; Carroll et al. 2001). Ecologically though, brown bear is considered a species that plays an important role on the food chain providing ecosystem services. *The attractiveness of brown bears to people for tourism and hunting, their ecological role as top predators; their large home ranges, and the fact that they have relatively low dispersal abilities raises the importance of studying bear populations and their response to the sudden socio-economical changes in Eastern Europe.*

Worldwide, brown bear populations have undergone dramatic declines during the 19th and early 20th centuries (Breitenmoser 1998; Servheen et al. 1999). Habitat loss, hunting, poaching, management removal, and defense for life and property by citizens account for as much as 90% of adult bears mortality (Schwartz et al. 2003).

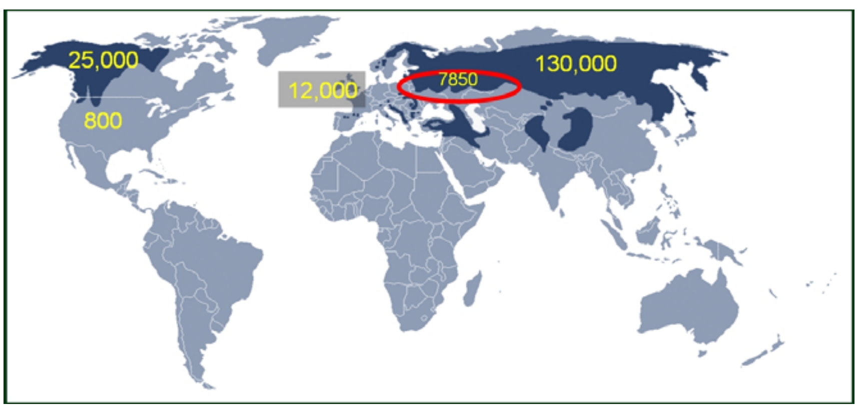

Figure 6. Study area (red) with the bear population of interest on top of the current distribution of brown bears in the world (in dark blue). The numbers in yellow are estimated population sizes from left to right in Canada, US, Western Europe, and Russia, respectively. Adapted from (Servheen et al. 1999).

Brown bear populations are small in the European Union. Although a Conservation Action Plan for the brown bear was prepared by IUCN (Swenson et al. 1998; Servheen et al. 1999), there are few population viability analyses for European Brown Bear compared to the North American Grizzly Bear. Brown bear population trends in Europe differ among countries. Some areas exhibit substantial population increases (e.g. Scandinavia 13% and Romania 7%). On the other hand there are Brown bear populations that have pretty small numbers or with high poaching rates. Such small populations are being expected to go to extinct as the Pyrenean's and Cantabrican Cordillera's population and potentially for the Austrian bear population who has remained stagnant for some years.

However, the main bear population changes are probably occurring in Eastern Europe. Currently the European Commission advises its member states to develop plans for lager carnivores, for instance in the Habitat's Directives (92/43/EEC) Annexes III and IV. It is claimed that the there is a great expansion of the brown bear range west and southwards originating from the European part of Russia (Chestin 1999). The increase in the numbers of brown bears are accompanied by increases in the populations of other large carnivore's populations as well (Enserink & Vogel 2006).

The Russian population of Brown Bears is the largest of the world (**Figure 6**). Historically bear populations have being hunted. For instance, approximately 3,500 bears were hunted annually during the Soviet Union regime. For 2008 the Russian Federation allowed to hunt almost 10,000 bears (9377, total for 52 regions of Russia) (Russian Ministry of Agriculture 2009). Despite the legal hunting and poaching, bear populations increase in numbers between 1960 and 1990 in the European part of Russia (Chestin 1999). Even more, since 1990 wildlife data show a further southward expansion of the brown bear range (**Figure 8**).

Land abandonment in Russia occurred at the same time span than the increase in large carnivore populations (Bergen et al. 2008). *Using brown bear as a focal species* I will assess changes in bear habitat and bear distribution which will allow us to understand better the ecological role of LULCC and its consequences on biodiversity.

Habitat Selection

Habitat selection is considered to happen at four spatial scales, defined as orders (Johnson 1980). First: Physical-geographic range of a species; Second: Home range scale within a geographic range; Third: Feeding sites within a geographic range; Fourth: Specific foraging decisions. Most studies of brown bear habitat use focus on second and third – order selection.

Brown bears are omnivorous, generalist, highly adaptable makes them able to occupy a variety of primary habitats; Only 5 to 7 months of the year are active; forests provide important habitat for them; they present natal philopatry, biased towards females; male sub-adult bears are the most common dispersers; cub survival is independent of mother age; in highly hunted populations infanticide by sub-adult is detrimental to population survival.

Land abandonment occurred at the same time span than the increase in large carnivore populations. Using brown bear as umbrella species I will assess changes in its habitat and their distribution which will allow us to understand better his ecological role of LULCC and its consequences over the European wildlife.

Goal/Objectives

In this chapter I will analyze Brown bear habitat selection and habitat changes in size and fragmentation through the measurement of the relationship between the documented land abandonment in the second chapter with Brown bear populations in Russia.

Methods

In 1979 The Governmental Service of Game Animals' Calculation (Gosokhotuchet RSFSR) was organized (Chestin et al. 1992). This gathers information from the Oblast Game Boards over all the republic of Russia. After the breakdown of the Soviet Union, Gosokhotuchet RSFSR became part of the Ministry of Agriculture. The material of Gosokhotuchet RSFSR was the source of recent data on bear numbers in the USSR. The first geographical analysis of these data was made by Sitsko (1983, reported by Chestin 1992, 1999) the second analysis of those data was conducted by Chestin (1999).

In spite of the systematic gathering of data, even in the RSFSR with its special services, their precision varies widely. As mentioned above, regular counts are organized in only a few oblasts (Chestin et al. 1992). In others the main method of evaluation is based on reliance upon the expertise of local game servicemen. In certain cases the data for some oblasts are subjectively corrected by the opinion of a bear specialist working in that region, in the form of a publication or personal communication, when available. According to the official forms, data exist only for regions as a whole.

So, modern population estimates of brown bears represent either (smaller part) data of Y.P. Gubar, obtained by communication with local specialists, or data from Gosokhotuchet RSFSR. Compare data from one to two years of difference is incorrect, as specialists and local hunting management authorities report numbers averaged in time. Furthermore, data for less than 10 bears in single districts are not always reported, because such small populations are not hunted and this data is not included in quotas requests (Y.P. Gubar, personal communication)

I will analyze brown bear densities at the rayon level (similar to counties in the U.S.) in European Russia (n = 529) for the years 1985, 1990 and 2005 (**Figure 7**). I will include rayons with less than 10 bears by adding a random number to rayons reporting zeros.

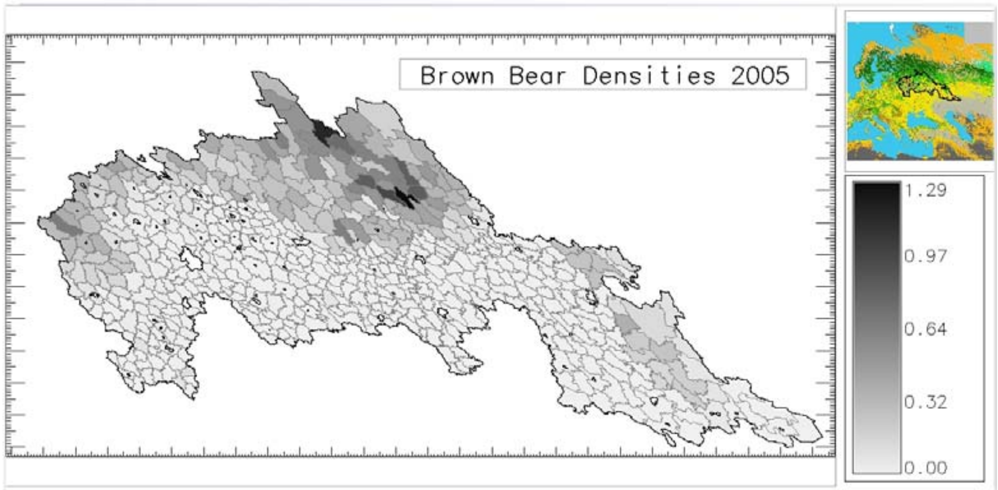

Figure 7. Brown Bear (Ursus arctos) density distribution (Bears/km^2) on European Russia for the year 2005. Data collected by Russian hunting authorities (Y.P. Gubar)

I will use the land abandonment map for the years 2001-2008 made from MODIS (500 m. resolution) obtained in chapter II and ancillary information for the year 2000 will as predictor variables for habitat selection.

Ancillary information will include urban areas, main roads and railroads (From 1:500,000 digital map of the Russian Federation), rural population density (1991 and 2001) taken from the Russian Federation Agriculture Census. Multiple regression models will be conducted to analyze the effect of the human disturbance, forest fragmentation (at four scales), and dispersal on brown bear density (response variable).

Indicators of human disturbance will include: urban area, road density, rural population density (1991 and 2001) and distance from the nearest administrative center. Habitat variability quantifying forest fragmentation indices at different scales and dispersal through a cost-path analysis will be assessed based on MODIS land cover. A correlation matrix will be used to scrutinize variables for collinearity. The best model will be selected using a stepwise procedure (Chatterjee & Hadi 2006). Hierarchical partitioning analysis will be used to determine the most influential variables in the model (Mac Nally 2000). Model Residuals will be checked for spatial autocorrelation with a semivariogram. If errors are correlated, a spatial autoregressive model will be fit (Wagner & Fortin 2005).

As in chapter 2, I will use morphological characterization of the forest class to determine the amount of patches, edge and core areas per rayon (Vogt et al. 2007). Using this approach Core, Patch, Perforated and Edge classes for forest + scrubland and scrubland will be calculated within 1.5, 2.5, 5, 10 and 15 Km from the border. Once the fragmentation indexes for each pixel are calculated, I will calculate the total amount of each component of the landscape per rayon.

Cost-path analysis will be conducted by regressing travel cost against bear density. An extra test for a “null” travel cost model analysis will be conducted and compared with the cost based analysis. Cost-path distance represents the cumulative cost entailed when bears disperse from northern source populations to the South. My assumption is that travel cost is a determined by both the distance and the likelihood of human disturbance which is captured in a cost surface map. Cost surface maps represents travel cost assigned based on its ability to support wildlife crossing/establishment. Cost-path analysis assigns a value (cost) to each pixel in a land cover maps. Cost values are typically based on expert knowledge and published literature. However, these assigned travel cost values are rarely validated.

I will conduct a sensitivity analysis of travel cost values to improve the predictive power of Cost-path analysis for Brown Bear distributions in European Russia. In the first step, I will also use expert knowledge and literature to assign, a travel cost value to each land cover class. Travel cost values for each land cover class will be incrementally changed, from the lowest to the highest possible values (0 – 1000). Cost-path analysis is going to be calculated using each one of those values (1000 for each land cover). Brown Bear distributions will be regressed against each of those cost-path assessments and I will compare the correlation coefficient, slope and standard deviation. Finally I will test “null” model for travel cost analysis and compare it with the cost based analysis

Outcomes

I will have multiple selection models with information on the effect of the human disturbance, forest fragmentation (at four scales), and dispersal on brown bear density (response variable). The datasets that results will include an analysis of the brown bear population from 1985 to 2005 describing the most influential variables explaining brown bear densities. This chapter is going to be submitted for publication to Conservation Biology, the Journal of Animal Ecology, or Biological Conservation.

Preliminary results

Regarding the cost path analysis our preliminary results show that the cost values assigned by experts were close but not identical to the optimal values when using the regression coefficients of the bear density models as our criterion (R-square 0.48 based on expert knowledge, versus 0.57 maximum when changing forest cost value).

Forest, particularly core forest, proves to be valuable on explaining distribution. Human variables were all negatively correlated. Rural population declines in the 1990s have not resulted in a brown bear population surge. Weakening institutions and potentially increasing poaching may have offset habitat improvements.

Preliminary results show that Brown bear densities were well correlated with the dispersal and habitat variables, even more at smaller scales (1 to 5 Km.). Multivariate models captured two thirds of the variation and human disturbance is the most limiting factor for brown bears in European Russia. Southern populations may be population sinks. Contrary to expectation, the strongest increase occurred in the 1980’s though, not the 1990’s (**Figure 7**).

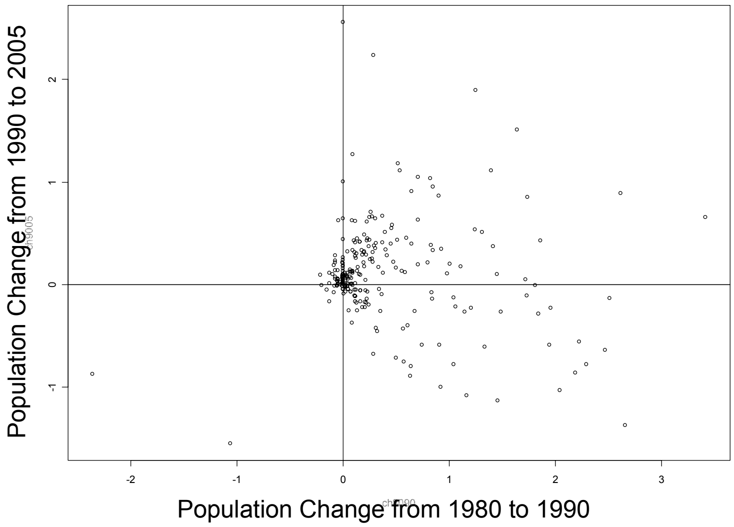

Figure 7. Brown Bear (Ursus arctos) population increases in European Russia. Own elaboration, based on data collected by Russian hunting authorities.

Relevance

Brown bears population will likely continue to increase. There is strong evidence that brown bear populations in the South are linked to Northern source populations via dispersal. We suggest that validation of travel cost values is both important, and computationally feasible following the approach outlined here. Based on our bear density models, we can now assess more accurately the effects of rural population declines, and forest succession on abandoned farm fields for future bear populations in European Russia. Increasing forest cover may reduce travel costs and increase dispersal in the future. Increasing forest cover on abandoned farm fields may provide additional bear habitat in the future. Detailed mapping of abandoned fields will allow us to project future brown bear habitat and population patterns. Ultimately, socio-economic changes and resulting agricultural abandonment offers new opportunities for conservation.

General Relevance

Eastern Europe provides a unique natural experiment to test forest transition and land use transition theories. My research will look at both forest transition and land use transition theories and analyze them on the case of socialist countries after the breakdown of the USSR. The breakdown of the USSR was a consequence of a sudden political change which together with globalization leads to farmland abandonment. Cultural, economic and political decisions were different in each of the former Soviet Union countries after they became independent. My dissertation will contribute to Land Use Science discipline by providing empirical evidence on how divergences on socio-economics and political decisions in the region are reflected on land cover dynamics. Legacy patterns on land cover and sudden changes are issues not fully integrated on the land use transition theory nor forest transition theory. I am testing both legacy patterns of land cover and sudden recent changes after a 40 year period of sharing the same policies in the former socialist countries. Forest regrowth on abandoned farmland is reportedly widespread but has not been accurately quantified; my project will provide rates, spatial distribution and patterns of land abandonment in the former socialist countries. There is the possibility that legacies and sudden changes modify the forest transition “u” shape. Land use transition theory can integrate better sudden changes and legacies on land cover as well as by describing better under which conditions it is possible that transition revert to early stages. My dissertation will define a general method to detect land abandonment and the effect of political decisions over the extent, pace and patterns of land abandonment.

The development of novel methods to assess LULCC will improve decision making. My dissertation will contribute to remote sensing field by adding a method to map land abandonment with the possibility to extend the method to map other LULC dynamics (e.g. cropland shifting, forest succession). My dissertation will state the limitations of remote sensing while classifying land abandonment.

Eastern Europe offers a prime example to analyze the consequences of land cover change on wildlife through the assessment of LULCC and focal species. Analysis of brown bear population and their response to land abandonment opens a new line of research on the analysis of wildlife under rapid LULCC. The increase in numbers of brown bears in the European part of Russia is a compelling fact that must be known by conservation scientist and decision makers. Analysis and prediction of the relationship between habitat loss and fragmentation patterns with focal species are incipient topics being developed in science.

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