UNIVERSIDAD AUSTRAL DE CHILE
FACULTAD DE CIENCIAS AGRARIAS
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RETROSPECTIVE ANALYSIS OF LAND USE AND COVER (LULC) CHANGE: EXPLORING TRAJECTORIES, PROCESSES, AND ACTORS

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Tesis presentada a la Facultad de Ciencias Agrarias y a la Facultad de Filosofía y Humanidades de la Universidad Austral de Chile en cumplimiento parcial de los requisitos para optar al Grado de Magíster en Desarrollo Rural

Por:

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INTRODUCCIÓN

El principal reto de la sustentabilidad es el de conservar el delicado equilibrio entre las necesidades humanas inmediatas y el mantenimiento de la capacidad de la biósfera para suministrar bienes y servicios en el largo plazo.

Por sus implicancias en este aspecto, la ciencia del cambio del uso y cobertura del suelo (CUCS) se ha posicionado fuertemente en la agenda investigativa sobre sustentabilidad y cambio global (Bocco et al., 2001; Lambin et al., 2003) debido a los efectos que el CUCS tiene sobre fenómenos climáticos, introducción de enfermedades, contaminación, degradación, pobreza, fragmentación de bosques, y migración humana entre otros (Meyer y Turner, 1992; Houghton, 1994; Dale, 1997).

El CUCS involucra procesos ampliamente distribuidos, acelerados y significativos, provocados por la compleja interacción de acciones humanas, y factores biofísicos, socioeconómicos, políticos y culturales (Agarwal et al. 2002; Naveh, 2001; Antrop, 2006). Entender las causas del CUCS implica comprender cómo las personas toman decisiones y cómo estos factores interactúan entre ellos en contextos específicos influenciando estas decisiones (Campbell et al., 2003; Lambin et al., 2003).

En particular la situación de CUCS en el sur de Chile se inscribe dentro de una tendencia alarmante de deforestación y degradación forestal global (Verolme et al., 1999). Actualmente, existe una creciente preocupación frente al problema de disminución de los bosques nativos chilenos (Armesto et al., 1994; Armesto et al., 1997; Lara, 1996; Becerra y Faúndez, 1999; Echeverría et al., 2006).

Particularmente, en el sur de Chile la deforestación tiene varias causas. Los bosques de Chile han representado históricamente una fuente de producción de bienes como madera y leña, que reportan un beneficio directo a quiénes los explotan con una mínima inversión (Gómez, 2007). Con los años y pese a la evolución de los aparatos legales, institucionales y la innovación en incentivos de mercado para disminuir la presión sobre los bosques, la deforestación y degradación de estos se ha sostenido aunque con menor intensidad en el último tiempo (Echeverría et al., 2006), generando una fuerte variación del paisaje producto de la degradación y posterior reconversión de las áreas boscosas hacia nuevos usos productivos, como las praderas y áreas de cultivo, monocultivos forestales, y áreas urbanas e industriales (Echeverría et al. 2006; Gómez, 2007).

Estudios efectuados en las últimas décadas dan cuenta de la deforestación del bosque nativo en el sur de Chile a tasas anuales de pérdida de 1.1% y 2.7% principalmente en áreas de la Cordillera de la Costa de la X y VII Región, respectivamente. Estas tasas corresponden a un período 25 años de observación entre los años 1975 y 2000 (Echeverría, 2006). Otros análisis dan cuenta de que aproximadamente el 23% del bosque nativo presente en el año 1976 en la X región sur desapareció para el año 1999 (Echeverría et al., 2006).

Inicialmente muchos de los bosques fueron reemplazados por tierras agrícolas, sin embargo, la falta de alternativas productivas en el área ha generado una presión desmedida sobre los bosques, lo que acarrea además la degradación y pérdida de los servicios que proveen estos ecosistemas. Estos servicios incluyen, la protección de las cuencas que regulan la cantidad y calidad de las aguas; la provisión de hábitat para la diversidad biológica, incluyendo el conjunto de especies vegetales y animales que ellos albergan; la protección del suelo contra la erosión; el turismo; la fijación del carbono, entre otros (Soto y Lara, 2001).

La importancia de estudiar el cambio de uso de suelo y particularmente el que involucra la pérdida de bosque implica una comprensión profunda de las interacciones entre sistemas humanos y naturales, útil para brindar información a los planificadores para la generación de instrumentos de conservación y desarrollo.

Los dos estudios que aquí se presentan contribuyen a comprender esta problemática a partir de un estudio en la Comuna de Ancud, en la Isla de Chiloé, de la Región de Los Lagos.

El objetivo de este estudio es analizar la vinculación existente entre los procesos de cambios de uso de suelo y agentes productivos presentes en el paisaje y el territorio por medio de un análisis espacio-temporal detallado de las transiciones y trayectorias de cambio de uso acontecidas en el paisaje entre 1976 y 2007.

La hipótesis que guía esta investigación es que distintos agentes productivos tienen una influencia diferenciada en las dinámicas del paisaje y particularmente en la magnitud espacial y evolución de los cambios en la cubierta de bosque Esta influencia diferenciada estaría dada por los recursos iniciales que estos agentes manejan y sus formas de vida y producción. En el primer capítulo se exploran los agentes y su relación con el cambio de uso de suelo, a través de la construcción de una tipología espacialmente explícita de sistemas prediales que se contrastó con los procesos recientes de deforestación, recuperación forestal y expansión agrícola ocurridos en el paisaje entre los años 1999 y 2007.

Luego, en el segundo capítulo de este trabajo se analizan los procesos antrópicos de cambio del paisaje a través del análisis de la naturaleza de sus transiciones (sistemáticas o aleatorias) y del concepto de trayectorias del paisaje, donde el énfasis está puesto en el modo en que el paisaje se ha transformado entre los años 1976 y 2007. Para ello se ha elegido la comuna de Ancud como área de estudio. Las contribuciones de este estudio son las siguientes:

- El área de estudio está inserta en el archipiélago de Chiloé, un importante centro de origen de la papa, que posee una gran cantidad de agricultura tradicional y campesina. Además es una reserva extraordinaria de biodiversidad: sus bosques templados atesoran una amplia cantidad de especies vegetales y animales en peligro de extinción. Por tales motivos éste ha sido denominado por la FAO como un área SIPAM (Sistema de Importancia Patrimonial Mundial) y por la World Wildlife Fund (WWF) como uno de los 25 sitios prioritarios para la conservación mundial de los ecosistemas.

- Constituye uno de los estudios espaciales de cambio de uso de suelo de más larga data que se ha realizado en Chile, y que incorpora el concepto de trayectoria para evaluar la evolución que han tenido los cambios en el paisaje.

- Esta investigación es uno de los pocos análisis exhaustivos a nivel de predio, que vincula el cambio de uso de suelo a sistemas prediales llevado a cabo en Chile y en particular en el área de estudio.

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CAPITULO 1

LINKING FARMING SYSTEM TO LANDSCAPE CHANGE: AN EMPIRICAL AND SPATIALLY EXPLICIT STUDY IN SOUTHERN CHILE.

Documento accesible a travéz de ELSEVIER en http://www.sciencedirect.com/

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CAPITULO 2

WHAT LAND TRAJECTORIES CAN SAY ABOUT FOREST LANDSCAPE TRANSFORMATION? A CASE STUDY IN SOUTHERN CHILE.

WHAT LAND TRAJECTORIES CAN SAY ABOUT FOREST LANDSCAPES TRANSFORMATIONS? A CASE STUDY IN SOUTHERN CHILE

Abstract

Land use trajectories, refers to the past, present, and future of land use while provides relevant information of expected use. This paper explores the spatio-temporal composition of the main land-use and land-cover (LULC) change trajectories affectig native forest loss and recovery in a study area in Chiloé Island, in the Valdivian Rainforest Ecoregion, southern Chile. Our goal was threefold: i) identify and evaluate the main land transitions and trajectories affecting native forests over a 31-year period (1976-2007); ii) link transitions and trajectories to specific LULC change processes and socioeconomic events; and iii) link LULC change trajectories to specific agents and forest resources present in the landscape. The research uses a time-series of classified Landsat images of the years 1976, 1985, 1999 and 2007, and a set of spatial ecological and socioeconomic data assembled in a geographic information system. An in-depth analysis of the conventional transition matrix was used to separate landscape transitions into random and systematic. Next, all possible combinations of transitions were grouped in land trajectories (sequences of transitions) which were constructed based on a pixel-history approach. Finally, main land trajectories were linked to specific agents by means of cluster analysis. Results from change detection analysis indicate a net reduction in old growth forests throughout the study period (1976-2007), equivalent to 63,076 ha. This decrease was particularly important between 1999 and 2007 where 46,008 ha of old growth forest were lost at an annual rate of 10% (most of it was converted to secondary forest through a process of forest degradation) compared with the 11,272 ha lost in the first period at an annual rate of 1.3% and 5,795 ha in the second period at an annual rate of 0.4%. The results show that landscape persistence was significant reaching 21% of the landscape. This persistence coexisted with a continuous trend of forest loss where the most important trajectory was the early/late change of old growth forest to arboreous shrubland and secondary forets. This process of deforestation is a systematic transition in the landscape for almost the entire period of analysis and it can be attributed to forest logging practices without attention to forest management practices. Furthermore, the process was related to peasant agriculture systems. The dynamism observed through the analysis of land transitions and trajectories can be related to profound social and economic transformations occurred in the study area since the 80´s which have to do with the beginning and expanding of the globalization process in southern Chile. The study demonstrates that analyzing land-cover change trajectories over several observation years allows a better understanding of forest dynamics. In turn, identifying main types of trajectories and their spatial distribution provides an important tool for prioritizing further research needs, LULC change prediction through modeling, and landscape planning strategies.

Key words: land transitions, land change trajectories, land use change, deforestation, temperate rain forests, southern Chile.

1. Introduction

Land-use and land-cover (LULC) change is the result and a cause of diverse interactions between society and the environment (Lambin et al., 2003; Verburg et al., 2010). Because of these interactions, LULC change has become a central topic in global environmental research and rural development discussions (Antrop, 2005; Olson et al., 2008).

The aim of the recently emerged land change science is to understand the biophysical and human drivers of LULC change, and the LULC patterns and dynamics affecting the structure and function of the earth system (Rindfuss et al., 2004). Yet, a limitation of land change studies is that LULC change is often conceived as a simple and irreversible conversion from one cover type to another (Mertens and Lambin, 2000). But since human societies constantly coevolve with their environment through change, instability, and mutual adaptation, LULC change is non-linear and is associated with other societal and biophysical changes through a series of land transitions (Lambin and Meyfroidt, 2010).

These transitions have been further classified as random and systematic (Braimoh, 2006), whether they respond to coincidental unique processes of change (they are episodic) or they are due to regular or common processes of change, evolving in a consistent, progressive or gradual manner in response for example to natural population growth or changes in institutions governing access to resources (Lambin et al., 2003).

Land transitions can be combined to create a high diversity of change trajectories (Verburg, 2010), defined as trends over time among the relationships between the factors that shape the changing nature of human-environment relations and their effects within a particular region (Kasperson et al., 1995). They take widely different forms and depend on local circumstances, regional contexts, and government policies. Case studies have indicated that the specific change trajectory is a function of the specific driving factors at a certain location (Geist and Lambin, 2002; Geist et al., 2006).

Trajectories of change have also been analyzed as part of the long-run process of agricultural intensification driven by demographic phenomena, as described by Boserup (1965). Such trajectories have been characterized as defined by the stock of environmental resources and human wellbeing (Karshenas, 1994), or as a function of time, in terms of degree of sustainability of human-environment relations (Kasperson et al., 1995).

At global scales for example, two general trajectories were the one associated with frontier development -a transition from pre-settlement natural vegetation to frontier clearing, then to subsistence agriculture and small-scale farms, and intensive agriculture, urban areas, and protected recreational lands (Foley et al., 2005)- and the one associated with forest recovery from abandoned agricultural, generically called forest transition (Mather, 1992; 1997).

In this study we propose that the simultaneous consideration of land transitions (random and systematic) and change trajectories allows a better understanding of the complexity of LULC change as well as it increases the comprehension of its drivers. In turn, this knowledge can contribute to improve the prediction of likely landscape evolutions (Verburg, 2010), establish management priorities towards those areas of the landscape more vulnerable to changes that can compromise rural livelihoods and resources sustainability, and to help sketch policy or environmental management implications linked to the consequences of land use (Mena, 2008).

The goal of this study is threefold: i) Identify and evaluate the main transitions and trajectories affecting native forest cover over a 31-year period (1976-2007); ii) link transitions and trajectories to specific LULC change processes; and iii) link trajectories to farming system and landscape resources. We select a study area in the municipality of Ancud in Chiloé Island, located in the Valdivian Rainforest Ecoregion.

Unlike previous studies conducted elsewhere focusing on land transitions and land trajectories (Mertens and Lambin, 2000; Pontius et al., 2004; Braimoh, 2006), our analysis extends the time scale and discusses the nature of the transitions within specific trajectories. Furthermore, previous studies conducted in Chile have ignored complex sequences of land cover changes, as they have simply measured the conversions from one category to another (Wilson et al., 2005; Echeverría et al., 2008; Altamirano et al., 2010). The underlying assumption in such studies is that the change is permanent and that forest for example will remain absent for a long period. Finally, the study links these changes to real agents living and interacting in the landscape.

Southern Chile and particularly Ancud municipality are scenarios suited for studies that underpin our understanding of the complex interactions between LULC change and transformation of the rural landscape in developing countries as well as the livelihoods related with them. Until the early 1970's, the study area remained largely isolated from the continent; later, in the 80's, this territory was strongly affected by industrial growth and globalization pressures. At present, a dichotomy exists between a development strategy based on the expansion of large-scale industrial aquaculture (salmon farming and mussel farming) and an endogenous growth strategy based on the cultural heritage and local tourism (Díaz et al., 2010). In 2008 FAO proposed Chiloé Island as one of the five pilot sites for Globally Important Agricultural Heritage System (GIAHS) (FAO, 2008), and described it as a "remarkable land use system and landscape, which is rich in globally significant biological diversity evolving from the co-adaptation of a community with its environment and its needs and aspirations for sustainable development" (FAO, 2003). Traditional landscapes like this are changing at an increasing speed and therefore an important cultural heritage is being lost. New landscapes are gradually or sometimes abruptly, replacing traditional ones (Antrop, 2005).

As far as we know, this research represents the longest time-span and detailed spatio-temporal analysis of LULC change, and specifically forest cover change, conducted in southern Chile.

2. Conceptual background LULC change: linking land transitions land change trajectories to landscape processes.

In the broadest sense, a land transition is understood as a process of system change in which the structural character of the system is transformed (Mertens and Rotmans, 2002). More narrowly, the concept refers to any change in land use systems from one state to another one—e.g., from a system dominated by marginal agriculture to a system with industrial tree plantations in response to market demand or new institutions. In this study, a land transition is understood as a specific land cover change occurred between two observation years and it is evaluated at the pixel level.

Following Pontius et al. (2004) and Braimoh (2006), we separate transitions in random and systematic. Random transitions are defined as those influenced by unintentional or exceptional processes of change. They can be intermittent, short-term events characterized by fast and sudden changes, followed or not by ecosystem recovery, depending on resilience and feedback mechanisms (Tucker et al., 1991; Lambin et al., 2003). Random transitions are usually driven by factors that act suddenly, such as spontaneous migration, land conflicts, or economic shocks (Barbier, 2000; Braimoh, 2006; Lambin et al., 2003).

Systematic transitions on the other hand are due to usual processes of change. They tend to evolve steadily or gradually, being dictated by more permanent forces such as population growth, market expansion, or changes in institutions governing access to resources (Lambin et al., 2003).

In the statistical sense, a land cover category is said to gain randomly from others if the gains are in proportion to the availability of those losing categories. Similarly, the land cover category is said to lose randomly to others if such losses are in proportion to the size of other gaining categories. Any large positive or negative deviation from those proportions is referred to as a systematic landscape change (Braimoh, 2006).

In turn, we understand a land trajectory as a succession of land-cover types for a given sampling unit over more than two observation years (Mertens and Lambin, 2001). From a methodological standpoint, trajectories are the temporal sequence of land cover classes at the pixel level that are described through classified images assembled in a time series (Mena, 2008). In this study, for four observation years (1976, 1985, 1999 and 2007), a trajectory will be a sequence of three random and/or systematic transitions and is identified through a pixel-history approach.

Land-use and land-cover change is then the result of specific land transitions and trajectories, and is a spatial property observed at the scale of a landscape. It is the sum of many small, local-scale changes (transitions) in land allocation that reinforce or cancel each other (Lambin et al., 2003).

At the landscape level, LULC change can be associated with specific processes of change, which in turn result in specific spatial landscape patterns. Following Marin et al. (*In press)*, we recognize the existence of seven main LULC-change processes involving forest change in the study area. They can be further classified in human-driven and natural landscape processes. Among the former we have: i) deforestation which can be driven by clearcutting as in the case of logging for woodchip and intense logging (which reflects in transitions where old growth and secondary forests change to shrublands), or it can also be driven by forest clearing for agricultural purposes (change from old growth or secondary forest to agricultural land); ii) forest degradation by logging (change from old growth to secondary forest); iii) afforestation (any land cover to plantation); and iv) urbanization (change from any land cover to urban ground). Among natural processes, we have: i) forest re-growth from abandoned agricultural and pasture land; ii) old growth forest regeneration from secondary forest; and iii) secondary forest regeneration from shrublands.

Finally, LULC change and processes (and the resulting landscape patterns) are the product of multiple decisions resulting from interactions between diverse agents, who act under certain conditions, anticipate future outcomes of their decisions, and adapt their behaviors to changes in external (e.g., the market) and internal (e.g., their aspirations) conditions (Lambin et al., 2003). These conditions can be represented by a set of biophysical, socioeconomic, political and cultural drivers (Bürgi et al., 2004) that work gradually and factors that happen intermittently. They can be slow variables, with long turnover times, which determine the boundaries of sustainability and collectively govern the land use trajectory (declining rural population), or fast variables, with short turnover times (such as price shocks and climatic events). Biophysical drivers may be as important as human drivers. The former define the natural capacity or predisposing conditions for land use changes. The set of abiotic and biotic factors that determine this natural capacity varies among localities and regions (Bürgi et al., 2004).

3. Study area

3.1 Location, demographics and economic activities

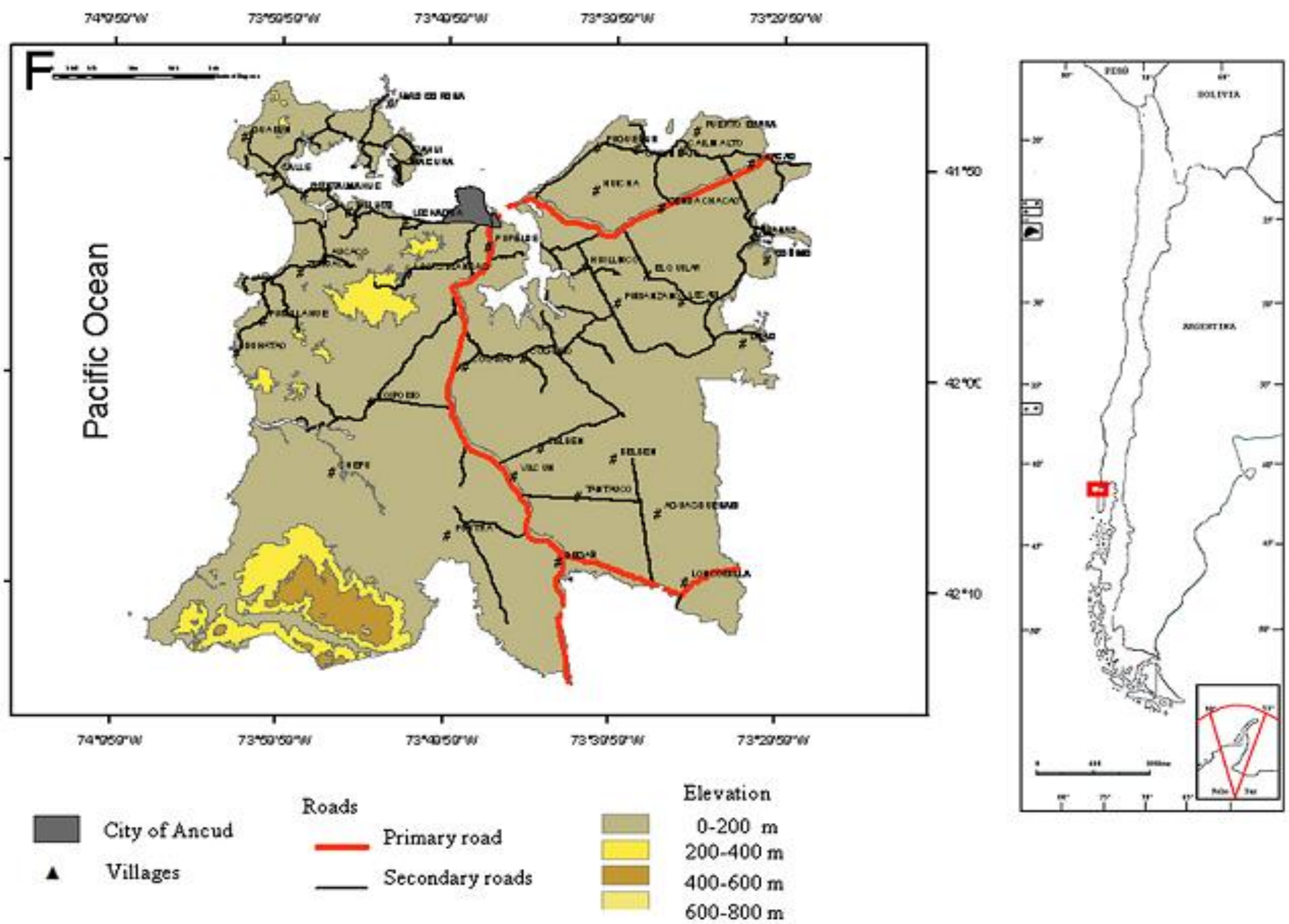
The municipality of Ancud (73º 15’ and 74º 15’ W and 41º 50’ and 42º 15’ S) is located in the northern part of Chiloé Island (Figure 1) and is part of the Valdivian Temperate Rainforest Ecoregion (Di Castri and Hajek, 1976).

Ancud covers a territory of 172,400 ha of which less than 1% is classified as urban. During the last decades, Ancud has experienced a rapid expansion particularly during the 80´s with an annual population growth rate that reached 2.4% between 1982 and 1992. This rate decreased to 0.6% in the following decade (1992-2002). At present, total population reaches 39,946 people (INE, 2002). Of this 31.7% is rural and the remaining 61.3% is urban. The percent of rural population has decreased continuously from 41.9% (12,325 people) in 1982 to 37.1% (13.921 people) in 1992 and 31.7% (12,654 people) in 2002 (INE, 1982, 1992, 2002). According to the Municipality Regulating Plan (Plan Regulador Comunal, PRC, 2008), these changes in population composition are due mainly to the migration of young people and to the aging of rural population, accompanied by the dispersion of communities with difficult access to basic services.

An important part of the municipality (11,776 ha; 6.8%) is publicly protected by Chiloé National Park (Figure 1). The remainder of the rural territory is comprised of 2,854 farms, most of them under individual land tenure and with a farm area that ranges between 0.03 ha and 4,658 ha (CIREN-CORFO, 1999).

Farming is severely constrained by geographic and agroclimatic conditions with a mean annual temperature of 9.9ºC, annual rainfall of 3, 046.8 mm, and 74.3% of soils with limitations for agriculture.

Fig 1. Map of the study area



Source: Carmona et al. 2010

Due to these limiting agro-ecological circumstances, the study area can be considered marginal in terms of agricultural production, although agriculture continues to be a relevant source of rural income. Also, these natural conditions have led to farming systems and rural livelihoods mostly oriented around self-sufficiency, which combine a variety of activities such as small-scale fishing, timber logging, livestock breeding, and of small land holdings (28.1 ha in average) (Barret et al., 2002; Ramírez et al., 2009).

A recent study conducted in Ancud municipality concluded that 94% of the farm properties corresponded to peasant agricultural systems, which managed reduced amounts of land, pastures, and livestock. The remaining 6% was represented by forestry-based systems and more specialized dairy farms (Carmona et al., 2010).

A large part of the municipality (78,111 ha) is covered by native forests (Carmona et al., 2010). These temperate rain forests are characterized by their high degree of endemism, including relicts of ancient biotas largely lost or transformed by Pleistocene climate change (Armesto et al., 1996; Villagrán and Hinojosa, 1997). The present rural landscape has been shaped by a recent history (less than 200 years) of widespread use of fire and logging to clear land for pastures and selective logging of many forests patches (Willson and Armesto, 1996: Torrejón et al., 2004). As a result, in the rural landscape old-growth forest stands are part of a mosaic of bogs, remnant, and secondary forests, shrublands and exotic plantations and artificial grasslands.

Despite the trends and threats described above, in 2008, Chiloé Island was proposed by FAO as one of the five GIAHS pilot sites (FAO, 2008) for its outstanding land use system and landscape, its rich biological and cultural diversity, nomination that was ratified by the Chilean Government in 2010. Chiloé Island is one of the Vavílov centers of origin of crop diversity such as for example potato (*Solanum tuberosum*) and strawberry (*Fragaria chiloensis*).

Around 200 documented varieties of native potatoes are still managed today, together with a variety of garlic that is unique to the Archipelago and an indigenous horse race, the hardy Caballo Chilote. Furthermore, the Island has been classified as one of the 25 priority areas for ecosystem conservation in the world (FAO, 2008).

The methodology used in this study comprised the following steps: i) LULC changes were quantified with remote sensing techniques based on satellite images. An in-depth analysis of the conventional transition matrix was used to separate landscape transformations into random and systematic transitions; ii) spatio-temporal landscape dynamics were assessed by constructing land trajectories (sequences of land transitions) based on a pixel-history approach; iii) Spatial clusters were constructed based on predominant trajectories, type of predominant transitions (systematic or random), predominant forest type, entropy of the landscape, and farming system type. We describe these steps bellow.

4.1 LULC change assessment and construction of transition matrices

To assess LULC change, we relied on a multi-temporal satellite imagery. This data included four Landsat scenes for the years 1976 (MSS), 1985 (TM), and 1999 (ETM+), which had been previously classified by Echeverría (2005) and a scene for the year 2007 (ETM+) previously classified by Carmona et al. (2010). Measures of accuracy assessment for these images can be found in Echeverría et al. (2008), Carmona et al. (2010), and Díaz et al. (2011).

Based on the previous analysis, the following categories of land cover were identified: (i) agricultural land, including crops and pastureland (APL); (ii) shrubland (SH), corresponding to a land cover type where trees cover less than 10% and shrubs cover between 10% and 75% of the area (CONAF et al., 1999); (iii) arboreous shrubland (ASH), which is an intermediate successional stage between shrubland and secondary forest (CONAF et al., 1999); (iv) secondary forest (SF), tree crown cover over 25%, and in most cases over 50% composed mainly by species like *Drymis winteri* and *Embothrium coccineum*; (v) old growth forest (OGF); vi) exotic plantations (PL), composed almost exclusively of *Eucalyptus spp*. which meet a minimum area requirement of 0.5 ha, tree crown cover of at least 25% of the land area, and a total height of adult trees above 2 m (FAO, 2001); and vii) other uses (OU), mainly urban land.

Since the focus of the research was on LULC changes involving native forests, forest cover in any of the years of the satellite images were masked, while pixels without forest cover in any given year were excluded from the analysis. The spatial resolution used was 30x30m and all land cover maps were analyzed to assess LULC change.

The analysis of land transitions was performed using Land Change Modeler ArcGIS (9.3) extension. The analysis was developed between consecutive satellite images using transition matrices, which is the most conventional method for assessing land cover change. A filter of 0.25 ha was applied for each transition analyses thus avoiding possible errors of image accuracy. An in-depth analysis of the conventional transition matrix was used to separate landscape transformations into random and systematic transitions for each time interval (1976-1985; 1985-1999; and 1999-2007).

Following Pontius (2004), transition matrices represent the area of the landscape that suffered transitions from class *i* to class *j* between two-year images.

Thus the notation

$$C_{ij}\ (i \neq j)$$

indicates the proportion of the landscape that experienced a transition from class *i* to class *j* between t_1 and t_2. The main diagonal element represented by

$$C_{jj}$$

indicates the proportion of land classes that exhibits persistence of class *j*. The proportion of the landscape that indicates a class *i* at t_1 is represented by:

$$c_i +$$

and is given by:

(1)

$$c_i + = \sum_{i=1}^{n} \mathrm{C_{ij}} \qquad (i \neq j)$$

In turn, the proportion of the landscape that indicates a class *j* at t_2 is represented by

$$c +_j$$

and is given by:

(2)

$$c +_j = \sum_{j=1}^{n} \mathrm{C_{ij}} \qquad (i \neq j)$$

Analyses emerging from this matrix are: i) Net Change: the difference among land cover classes between t_1 and t_2 (a negative net change implies that the land cover category is losing more than is gaining from others category and vice versa, positive net change implies that a category is gaining more than is losing from others category). ii) Swap: a specific kind of change that indicates a change in the location of a category, while the quantity remains the same. The concept of swap change allows avoiding underestimations of the total change on the landscape (Van Doorn, 2006). It is possible for example that change occurs in such a way that gains and losses of a class are the same, and consequently net change will be zero, which might conceal the true dynamics of the landscape. The amount of swap is calculated using the formula:

(3)

$$S_j = 2 * \min(\mathrm{C_{j+}} + \mathrm{C_{jj}}, \mathrm{C}_{+j} - \mathrm{C_{jj}})$$

Total change for each category is represented by net change (gains minus losses) and swap changes that represent simultaneous gains and losses of a category.

Also annual rates of change were calculated using the formula proposed by FAO (1996):

(4)

$$P = [100/(t_2 - t_1)] * \ln [S_2 / S_1]$$

Where:

P : corresponds to the annual percent of change of a single land cover.

S_1: represent the area of the specific land cover under analysis in $t_{1.}$

S_2: represent the area of the specific land cover under analysis in t_2

t_1 and t_2: respectively corresponding to the years of the satellite images.

4.2 Identification of random and systematic transitions

We focused on detecting random and systematic changes from the transition matrix, specifically those related to looses of native forest. We followed the three steps proposed by Braimoh (2006). This analysis was performed for the time intervals: 1976-1985; 1985-1999, and 1999-2007.

The first step computes the expected loss using the formula proposed by Pontius et al. (2004) in equation 2:

(5)

$$l_{ij} = (c_{i+} - c_{ii})(c_{+j} / (1 - c_{+i})), \qquad \forall \ i \neq j$$

Eq. (5) assumes the loss of each class and the proportion of each class in the second period are given a priori. The loss is then distributed in each row across the other classes relative to their proportions in t_1.

The second step computes the differences between the observed proportions and the expected proportions under a random process of loss equivalent to that of gains. The higher the positive difference between the observed proportion and the expected proportion under a random process of loss for the transition between classes X and Y, the higher is the inclination of class X to systematically lose to class Y. In turn, the higher a negative difference between the observed proportion and the expected proportion under a random process of loss for the transition between classes X and Y, the higher the aversion for class X to systematically lose to class Y.

The third step, computes the ratio of the difference between observe and expected value and expected value to account for the level of systematic change that present a transition respect its expected value.

In summary, losses from a land category were calculated as the difference between the land cover in the first year of an interval (e.g. 1976) minus the persistence during the interval (e.g. 1976-1985). Two features were used to identify the most systematic transitions: i) the magnitude (ha) of positive or negative deviations from zero between observed and expected values; the higher difference between observed and expected values, the larger the area affected by systematic transition, the largest area propensity to lose (positive difference), adverse to lose (negative difference); ii) the magnitude of the systematic ratio respect expected value (Pontius et al., 2004).

4.3 Linking land trajectories to agents

Using map algebra and following Mena (2008), we created categorical maps that contained the pixel history that represented LULC change trajectories at the pixel-level. The four observation years (1976, 1985, 1999, and 2007) were retained for the definition of these trajectories and all trajectories were used to identify potential clusters. The objective of this analysis was to identify sectors that could be grouped according to the type of transitions and trajectories that they contained and the type of agents they related to.

We performed a multivariate statistical analysis which was carried out in two steps: i) factor analysis through a spatial principal component analysis (PCA, IDRISSI extension); and ii) spatial cluster analysis (Cluster, IDRISSI extension).

To perform PCA analysis we relied on the following main data: i) LULC change trajectory maps previously constructed; ii) transitions map (showing systematic level); and iii) a spatially-explicit typology of farming systems of the municipality of Ancud constructed by Carmona et al. (2010). Additionally we used a map of dominant forest types obtained from a cadastral map of vegetation (“Catastro”) at scale 1:100,000 (CONAF, Corporación Nacional Forestal, et al.

1999) which allowed us to identify the type of forest resources subjected to change. Catastro is a nationwide inventory of native forest cover that is a GIS-based data set of thematic maps derived from aerial photographs and satellite imagery developed between 1994 and 1997 (CONAF et al., 1999). Finally, we also constructed entropy layers for each period of analysis as indicators of landscape fragmentation, using the Land Change Modeler extension (ArcGis 9.3)

5. Results

5.1 LULC change assessment: net change, swap and total change

The area of the landscape involved in forest dynamics between 1976 and 2007 represented 75% of the entire rural area of Ancud municipality. This is the relevant area of analysis in this study and all the results presented in this section are based on it.

Land cover types for each year of the satellite images are presented in Figure 2. It can be observed that the dominant landscape change in the 31-year period was the loss of OGF, which decreased from 79% of the landscape (100,125 ha) in 1976 to only 29% by 2007 (37,049 ha).

Secondary forest, with an initial area of 13,071 ha, decreased from 10% of the landscape in 1976 to 6% in 1985 (7,115 ha) and 5% (5,909 ha) in 1999. However, between 1999 and 2007 this trend changed and SF increased from 5,909 ha to 37,049 ha (32% of landscape).

Results from change detection analysis indicate a net reduction in OGF throughout the study period (1976-2007), equivalent to 63,076 ha (sum of net change in each period Table 1). This decrease was particularly important between 1999 and 2007 where 46,008 ha of OGF were lost at an annual rate of 10% compared with the 11,272 ha lost in the first period at an annual rate of 1.32% and 5,795 ha in second period at an annual rate of 0.48% (Table 1).

In contrast, SF exhibited a positive net change of 27,165 ha. The largest net change in SF was registered in the third period with an increase of 34,327 ha and an annual increase rate of 23.97%. It is important to remark that the overall positive net change of SF is exclusively due to gains occurred between 1999 and 2007. During the first and second periods, net change in SF was negative reaching 5,956 ha in first period and 1,206 ha in second period, with annual rates of loss of 6.75% and 1.32%, respectively (Table 1).

During the first and second periods, total change in OGF was largely represented by swap changes with 63% (between 1976 and 1986) and 83% (between 1985 and 1999), while net change was 37% and 17%, respectively. In the third period, this situation reversed and net change became the most relevant (83%) as compared to swap (17%). Secondary forest (SF) followed the same trend, corroborating the high dynamism of forest cover in the first two periods (Table 1).

Figure 2. Land cover types in 1976, 1985, 1999 and 2007, involved in forest change in Ancud municipality.

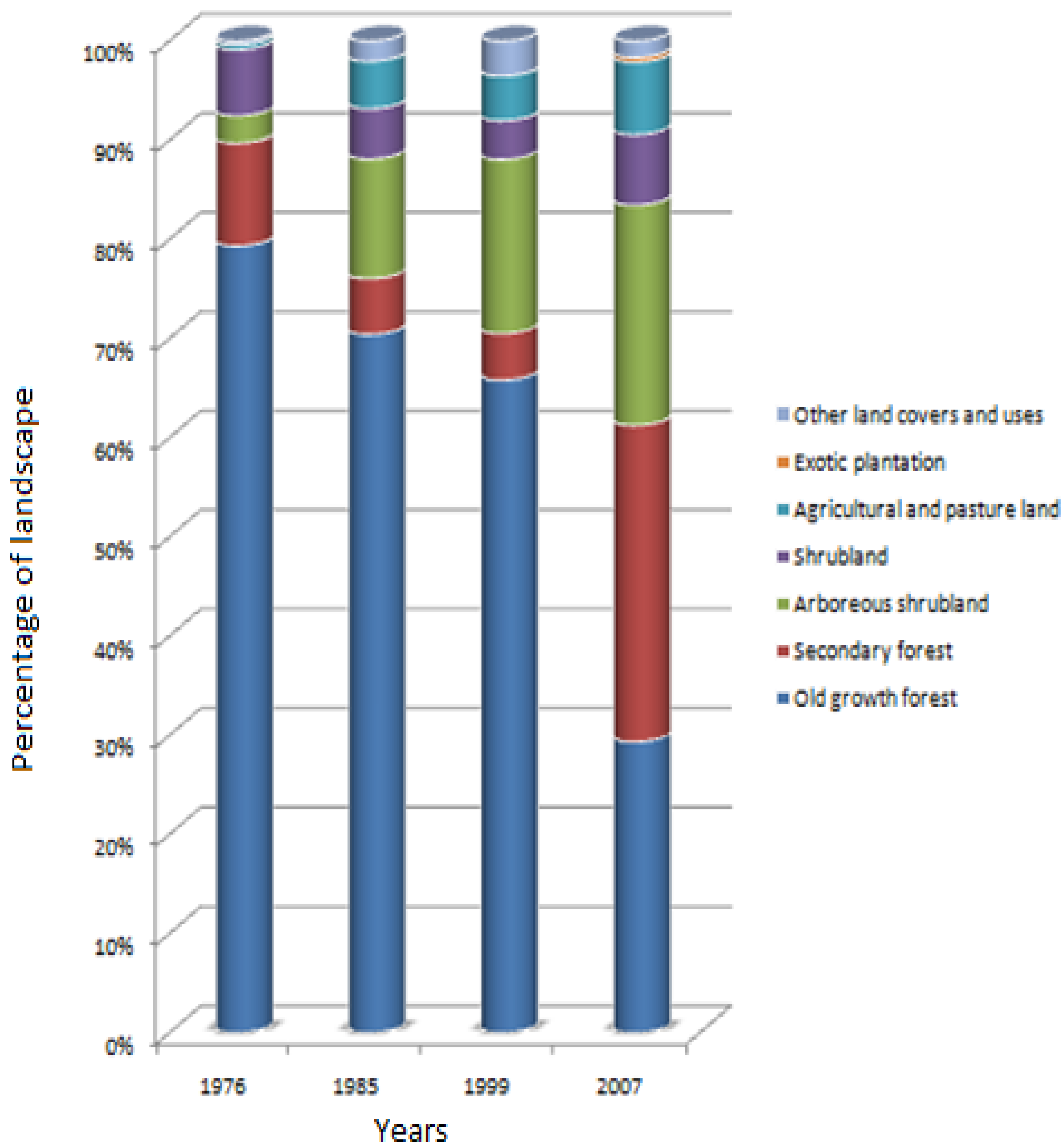


Table 1. Summary of main categories net changes and swap changes in hectares (regular font numbers; first line) and percentages (bold numbers; second line), and change rates (%) of each land category.

Period	1976-1985	1985-1999	1999-2007	1976-1985	1985-1999	1999-2007	1976-1985	1985-1999	1999-2007	1976-1985	1985-1999	1999-2007
Land category	Net change			Change rate			Swap			Total Change		
OGF	-11,272 **37%**	-5,795 **17%**	-46,008 **83%**	-1.32%	-0.48%	-10.09%	18,885 **63%**	29,162 **83%**	9,546 **17%**	30,157 **100%**	34,957 **100%**	55,554 **100%**
SF	-5,956 **30%**	-1.206 **14%**	34,327 **85%**	-6.75%	-1.32%	23.97%	13,748 **70%**	7,482 **86%**	6,276 **15%**	19,704 **100%**	8,688 **100%**	40,603 **100%**
ASH	11,726 **67%**	6,946 **32%**	5,874 **19%**	16.36%	2.68%	2.93%	5,697 **33%**	15,046 **68%**	24,423 **81%**	17,423 **100%**	21,992 **100%**	30,297 **100%**
SH	-2,030 **15%**	-1,468 **15%**	4,040 **40%**	-3.06%	-1.86%	7.48%	11,378 **85%**	8,490 **85%**	6,072 **60%**	13,408 **100%**	9,958 **100%**	10,112 **100%**
APL	5.411 **89%**	-341 **4%**	3,523 **37%**	25.17%	-0.41%	6.01%	653 **11%**	8,402 **96%**	5,875 **63%**	6,064 **100%**	8,061 **100%**	9,398 **100%**

In the case of ASH in first period, net change (67% of total change) dominated over swap, whereas in the second and third periods swap was the most important change (68% and 81%, respectively), indicating the higher dynamism of this land category during the latter periods. In turn, SH present its most dynamic period between 1975 and 1999, with a swap change of 85% in both periods, decreasing to 60% in the third period. This high percentage of swap in the case of shrublands can be associated to contradictory dynamics as agriculture expansion and abandonment, and to clearcutting for woodchip and forest regeneration.

5.2 Inter-category LULC change transitions

In the previous section, changes were described in terms of increases and decreases in land cover areas and also in terms of the gains and losses of the category (net change and swap). In this section, we describe the composition of these changes in terms of the type of transition (random or systematic) and the amount of land involved in each transition, for the main land covers and the three consecutive periods.

Tables 2, 3 and 4 show the transitions occurred in each time interval focus principal in loss of native forest. For each land category, the first row shows the observed transition value, as determined from satellite images. The second row shows the expected value of losses (left) if changes were to occur randomly. The third row shows the difference between the observed and expected values. The last row shows the ratio between this difference and the expected value; this ratio indicates how much more systematic a transition is respect to what we would expect from a random process.

5.2.1 Old growth forest dynamics

Between 1976 and 1985 (Table 2), 62.93% of OGF persisted while losses reached 16.42%. These losses relate to processes of forest degradation comprising the change from OGF to SF (4.20%) and processes of deforestation, comprising the changes of OGF to ASH (6.17%), SH (2.72%), APL (2.09%) and OU (1.24%). During this period, the analysis of the transition matrix showed that when OGF loses, is systematically replaced by ASH and APL, which is supported by the difference between the observed and expected values (3.97% and 1.70% respectively). In turn, these percentages imply that the change of OGF to ASH was 1.8 times higher than expected, while the change from OGF to APL was 4.3 times higher than expected from a random process.

The change of OGF to SF had the second most important observed value; however the amount of change was 0.5 times lower than the expected value, showing that when old growth forest loses is not systematically replaced by secondary forest (Table 2).

Table 2. Main categories transition matrix 1976-1985. First row in bold, shows the observed transitions between categories; Second row in italic letter, shows the expected value for a random transition; Third row shows the difference between observed and expected value; Four row shows the ratio showing how systematic a transition is respect to expected.

	OGF	SF	ASH	SH	APL	OU	EP	Total 1976	Loss
	62.93%	**4.20%**	**6.17%**	**2.72%**	**2.09%**	**1.24%**	**0.00%**	**79.35%**	**16.42%**
	%62.93	8.23%	2.20%	5.31%	0.39%	0.29%	0.00%	79.35%	16.42%
	0.00%	-4.04%	3.97%	-2.59%	1.70%	0.96%	0.00%	0.00%	0.00%
OGF	0.0	-0.5	1.8	-0.5	4.3	3.3	0.0		
	2.91%	**0.19%**	**4.82%**	**1.35%**	**0.63%**	**0.46%**	**0.00%**	**10.36%**	**10.17%**
	9.00%	0.19%	0.31%	0.76%	0.06%	0.04%	0.00%	10.36%	10.17%
SF	-6.09%	0.00%	4.51%	0.59%	0.57%	0.42%	0.00%	0.00%	0.00%
	-0.7	0.0	14.4	0.8	10.2	10.2	0.0		
Total 1985	**70.41%**	**5.64%**	**12.05%**	**5.07%**	**4.78%**	**2.04%**	**0.00%**	**100.00%**	**35.44%**
	79.36%	9.39%	3.21%	6.81%	0.73%	0.49%	0.00%	102.74%	
	-8.95%	-3.76%	8.85%	-1.74%	4.05%	1.55%	0.00%	-2.74%	
Gains	**7.48%**	**5.45%**	**11.55%**	**4.51%**	**4.55%**	**1.91%**	**0.00%**	**35.44%**	
	16.43%	9.20%	2.70%	6.25%	0.49%	0.36%	0.00%	32.74%	
	-8.95%	-3.76%	8.85%	-1.74%	4.05%	1.55%	0.00%	-8.85%	

Table 3. Main categories transition matrix 1985-1999. First row in bold, shows the observed transitions between categories; Second row in italic letter, shows the expected value for a random transition; Third row shows the difference between observed and expected value; Four row shows the ratio showing how systematic a transition is respect to expected.

	OGF	SF	ASH	SH	APL	OU	EP	Total 1985	Loss
	54.27%	**2.45%**	**8.91%**	**2.21%**	**1.20%**	**1.36%**	**0.00%**	**70.41%**	**16.15%**
OGF	54.27%	3.08%	6.58%	2.77%	2.61%	1.11%	0.00%	70.41%	16.15%
	0.00%	-0.62%	2.33%	-0.55%	-1.41%	0.25%	0.00%	0.00%	0.00%
	0.0	-0.2	0.4	-0.2	-0.5	0.2	0.0		
	3.44%	**1.72%**	**0.24%**	**0.05%**	**0.08%**	**0.10%**	**0.00%**	**5.64%**	**3.92%**
SF	2.71%	1.72%	0.72%	0.16%	0.19%	0.14%	0.00%	5.64%	3.92%
	0.73%	0.00%	-0.48%	-0.11%	-0.10%	-0.05%	0.00%	0.00%	0.00%
	0.3	0.0	-0.7	-0.7	-0.5	-0.3	0.0		
Total 1999	**65.82%**	**4.68%**	**17.56%**	**3.90%**	**4.51%**	**3.51%**	**0.01%**	**100.00%**	**35.73%**
	68.90%	5.75%	14.62%	3.74%	4.61%	2.04%	0.00%		
	-3.08%	-1.07%	2.94%	-0.18%	-0.10%	1.47%	0.01%		
Gains	**11.55%**	**2.96%**	**11.47%**	**3.36%**	**3.33%**	**3.05%**	**0.01%**	**35.73%**	**0.00%**
	42.71%	-4.03%	-8.53%	-3.16%	-3.43%	-1.57%	0.00%		

Table 4. Main categories transition matrix 1999-2007. First row in bold, shows the observed transitions between categories; Second row in italic letter, shows the expected value for a random transition; Third row shows the difference between observed and expected value; Four row shows the ratio showing how systematic a transition is respect to expected.

	OGF	SF	ASH	SH	APL	OU	EP	Total 1999	Loss
OGF	**25.58%**	**25.06%**	**10.68%**	**1.52%**	**2.28%**	**0.65%**	**0.05%**	**65.82%**	**40.24%**
	25.58%	5.51%	0.67%	4.60%	5.32%	4.14%	0.01%	65.82%	40.24%
	0.00%	19.54%	-9.99%	-3.08%	-3.03%	-3.48%	0.04%	0.00%	0.00%
	0.00	3.54	-0.48	-0.67	-0.57	-0.84	4.96		
SF	**1.91%**	**2.20%**	**0.37%**	**0.05%**	**0.12%**	**0.04%**	**0.00%**	**4.68%**	**2.49%**
	1.72%	2.20%	0.46%	0.10%	0.12%	0.09%	0.00%	4.68%	2.49%
	0.19%	0.00%	-0.09%	-0.05%	0.00%	-0.06%	0.00%	0.00%	0.00%
	0.11	0.00	-0.19	-0.49	0.01	-0.61	24.28		
Total 2007	**29.36%**	**31.89%**	**22.21%**	**7.11%**	**7.31%**	**1.64%**	**0.49%**	**100.00%**	**60.34%**
	40.45%	8.65%	30.46%	1.72%	8.41%	4.81%	0.33%		
	-11.09%	23.24%	-8.25%	0.89%	-1.10%	-3.17%	0.16%		
Gains	**3.78%**	**29.69%**	**14.33%**	**5.61%**	**5.12%**	**1.32%**	**0.49%**	**0.00%**	**60.34%**
	14.87%	6.45%	22.58%	0.22%	6.22%	4.81%	0.33%		
	-11.09%	23.24%	-8.25%	0.89%	-1.10%	-3.49%	0.16%		

During the second period (Table 3), 54.27% of the area covered by OGF in 1985 persisted by 1999, while losses represented 16.15%. Alike the first period, between 1985 and 1999 the largest losses of OGF were represented by the change to ASH (8.91%) and SF (2.45%). In this period, the observed value of losses in OGF was remarkably similar to the expected values (differences for all values were near 0), except for the change of OGF to APL that was -1.09%, which implies that this change occurred 0.5 times less than expected. This indicates the existence of factors in this period which are slowing down the expansion of agriculture on native forests.

The change of OGF to EP (afforestation rather than deforestation) is important to notice. Although plantations appear in the landscape only in 1999 and with a small area, the change from OGF to EP occurred 1.2 times more than expected.

Between 1999 and 2007 (Table 4), OGF persistence was 25.58% while losses reached 40.24% and gains 3.78%. As in previous periods, SF (25.06%) and ASH (10.68%) had the largest observed values of losses. The differences between observed and expected values for all transitions involving OGF were large and negative with exception of the change to SF and EP. Secondary forest had a large positive difference of 19.54% which indicates that the change from OGF to SF was 3.54 times than expected. In turn, although the area of EP was still small compared to other land covers, the transition of OGF to this category was highly systematic occurring 4.96 times than expected from a random process.

5.2.2 Secondary forest dynamics

Between 1976 and 1985 (Table 2), SF losses reached 10.7%, while persistence was only 0.19%. Transition analysis reveals that when SF loses, it is systematically replaced by ASH (deforestation) with a large positive difference of 4.51% between expected and observed values, indicating that this change happened 14.4 times more than expected from a random process (Table2).

Another large difference during this period was associated to the change from SF to OGF (forest regeneration), but this difference was negative showing that this regeneration was 0.7 time less than expected. Other values were near zero which is due to the extent of the areas affected rather than to a small difference between observed and expected values. Thus for example, the change from SF to APL was 10.2 times higher than expected but it involved only 0.63% of the landscape.

During the second period (Table 3), all losses in SF cover exhibited small and negative differences between observed and expected values, which is an evidence of non-systematic processes behind these changes. An exception was the change of SF to OGF with a small and positive difference, implying that forest regeneration was 0.2 times higher than expected. Small and positive differences were observed for the change of APL to SF, which occurred 0.7 times more than expected.

Between 1999 and 2007 (Table 4) losses of SF to all other land covers did not exhibit large differences between observed and expected values. As in the case of OGF, while the area involved in the change of SF to EP was small, the change happened 24.28 times more than expected, showing that the expansion of this new land use and cover occurred in the landscape in a highly systematic way.

5.3 Composition of main LUCC change trajectories

A total of 247 different trajectories were identified affecting areas that ranged from 27,714 ha to 0.5 ha. A summary of all trajectories is found in Appendix A. In this section we present the most relevant trajectories in terms of area and processes. They are grouped according to a temporal criteria that accounts for when the LULC change process happened, classifying by early (between 1976 and 1985) or later (from 1985 to 2007) according to the strong arrival of globalization in the country.

5.3.1 Persistence

As expected, the most notorious feature of the landscape was persistence. Long term persistence comprised (1976-2007) comprised 21.9% of the landscape. Largest area of this trajectory (11,751 ha of 27,714 ha) were located in Chiloé National Park, which actually accounts for the largest area of old growth forest in the municipality of Ancud.

After overall persistence most relevant trajectories are those involving short term forest persistence (1976-1999) accounting for 18.45% and 6.48% of landscape.

5.3.2 Early deforestation and forest degradation trajectories

These trajectories involved the loss of OGF and SF, mainly to APL, ASH and SH during the first period. And also the degradation of OGF to SF as a consequence of unsustainable logging practices.

Early agriculture expansion (the one that took place between 1976 and 1985) involved 5.738 ha. Most of this area came from deforestation of OGF (2,638 ha) only 795 ha from deforestation of SF. In early stages, OGF loss was highly systematic as it was explained in the previous section.

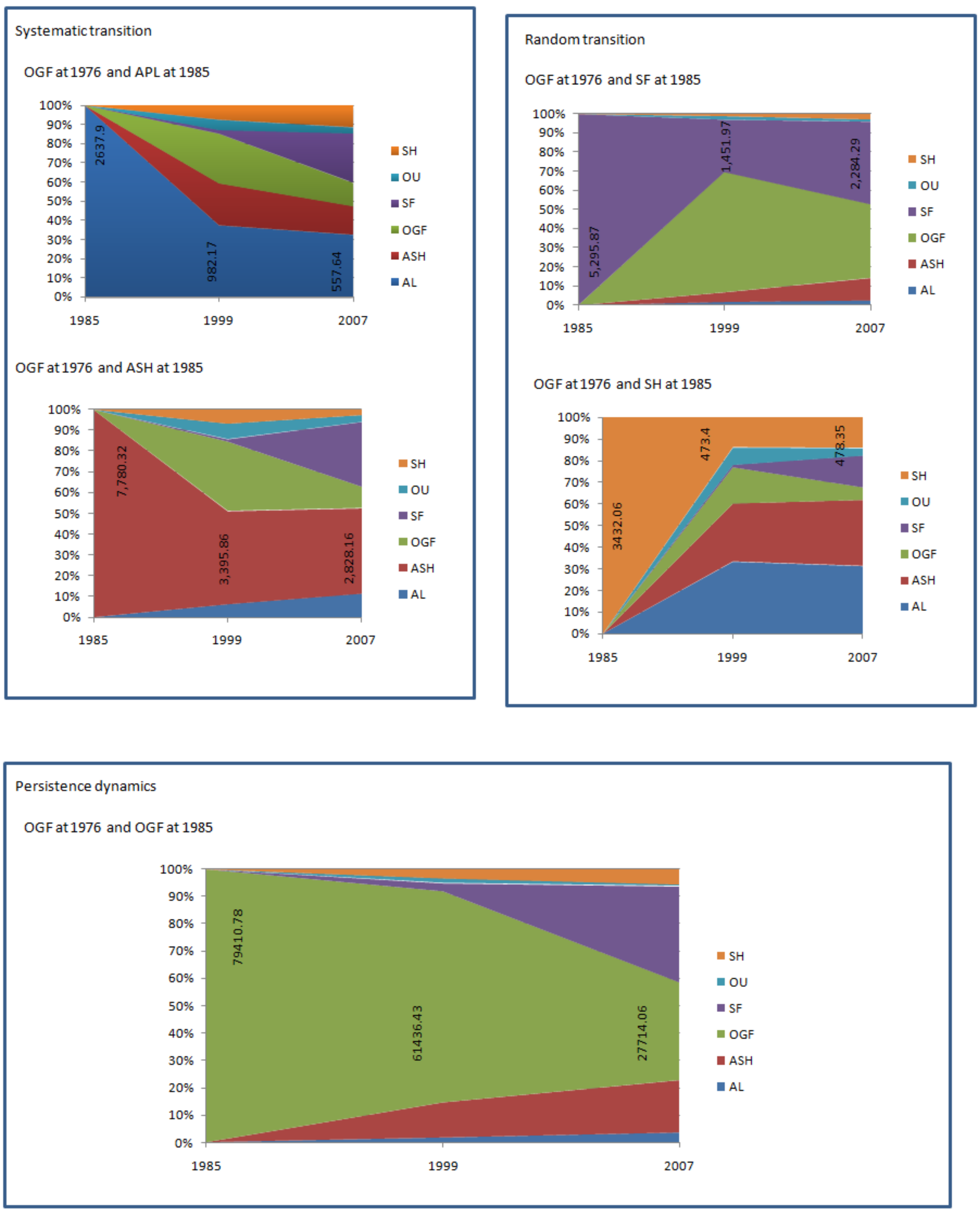
Of the total area OGF area converted to APL by 1985, only a 20.7% (557.64) continued to be permanent APL until 2007. In turn, 21% (555.45 ha),of the area cleared for agriculture in the first period was abandoned and replaced by SH by 1999 and only 166.5 ha experienced forest regrowth by 2007 while the rest remained as shrublands. Other 27.9% of the area initially cleared (731.1 ha) was subjected to a rapid forest recovery by 1999; almost half of this area remained as forest by 2007. In turn, 15.8% of the area initially cleared persisted as APL by 1999 changing to shrublands (10.9%), forest (4.3%), other uses (0.6%) and exotic plantations (0.1%).

Hence early deforestation by expansion of agriculture does not end, as we would have expected, in permanent agriculture, which could be associated to a more systematic transition. Rather, early deforestation is followed by the recovery of natural vegetation which is associated to the abandonment of farming, a process that is taking place in a random manner in later periods.

Figure 3. Main LULC change trajectories following initial transitions. Left panel shows trajectories starting from a systematic transition: Right panel shows trajectories starting with a random transition.

Axis x: year; Axis Y: evolution of the percentage of a land category for a given trajectory; Numbers within each graph indicate the area (ha).

Comparission of most important trajectories from systematic and random transitions occurring between the years 1976 and 1985.



Other deforestation processes are driven either by logging or clear-cutting. In the case of early clear-cutting, 19,001 ha were subjected to deforestation between 1976 and 1985, with native forests changing to both types of shrublands. Of this area 12,780.5 ha corresponded to OGF.

The transition of OGF to ASH (7,780.32) was highly dynamic between 1976 and 1985. More than half of this area still persisted as shrubland by 1999 (4,113.45 ha) and 33% persisted as such by 2007 (2,577.15 ha). In turn 1657.2 ha experienced forest regrowth by 1999 and persisted as forest by 2007. In turn only 449.9 ha of the initially deforested to ASH, were converted in later periods to APL; 768.42 ha experienced forest regrowth by 1999 but were cleared for APL by 2007. Other 190.35 ha were cleared for agriculture between 1985 and 1999 (a highly systematic transition) and then abandoned in the last period.

5.3.3 Late deforestation and forest degradation trajectories

During the first period 79,411 ha of OGF persisted; of this area 77% was still covered by OGF by 1999; 2.8% changed to SF; 1.8% were converted to other uses; 16.24% to SH, 1.7% to APL and the remaining to EP.

Of the OGF area in 1999, 45% persisted by 2007, 37% changed to SF, 15% was deforested and changed to SH and 1.18% was replaced by APL, while 0.4% and 0.02% was converted to OU and EP, respectively.

In the case of the area initially degraded to SF, large areas were regenerated back to OGF (52.83%) by 1999, while an important amount persisted as SF. Only 0.69% was cleared for APL and 6.7% was deforested to SH.

5.4 Spatial distribution of landscape trajectories

In previous sections we characterized the nature of land trajectories and transitions within them. In this section we describe the results from the spatial analyses of trajectories. We aim at linking main trajectories of forest cover change to specific agents represented by the four type of farming systems and the forest resources they manage. Identifying where specific trajectories are taking place allows us to identify areas most vulnerable to LULC change and areas of forest recovery.

Based on the results of factor analysis, we obtained spatial components for further scrutiny. These components were constructed following the criteria of an eigenvalue greater than 0.5, and from the five variables described in previous sections represented as information layers (i.e i trajectory map, transition map (showing systematic transition); farming systems map; forest type map, and entropy map). These five spatially explicit variables were contained in four spatial components that explained 81.9% of the total variation each of them with an own value greater than 0.75. In turn, cluster analysis indicated the existence of five clusters whose characteristics are summarized in Table 5.

Cluster 1 comprised the largest area with 36,097.6 ha. Two were the predominant trajectories, one of persistence of OGF and late forest degradation, and one of early deforestation. This is consistent with the presence of evergreen forest species such as *Drymis winteri* which is one the first species to colonize after a disturbance, forming secondary forests. Near 76% of the farming systems associated with this cluster corresponded to peasant agricultural systems as characterized by Carmona et al. (2010). Although this cluster comprises zones with the least area protected under Chiloé National Park (1.47%), it exhibits a high percentage of persistence and concentrated the most systematic transitions. Of all transitions occurred over the study period 49.52% were systematic transitions. Overall, the predominant LULC change process within this cluster was forest degradation which can be associated to selective logging and clear cutting. Also this cluster presented a high level of entropy indicating the presence of areas with a great landscape fragmentation (Appendix II)

Cluster 2 comprised an area of 25,312.86 ha. An important percentage (33%) of the area is protected under Chiloé National Park, which explains the high persistence of evergreen old growth forests (60.56%). This cluster is characterized by the predominance of commercial agriculture farming systems (37.86%) and the almost absence of peasant agricultural systems (less than 1%). Outside the National Park this cluster is highly concentrated in about 8 polygons that can be identified clearly in the landscape (Figure 2). In this zone the persistence of forest cover can be associated with the presence of farming systems with large areas of native forest ranging between 802 ha and over 4,000 ha. In consequence this cluster presented the lowest degree of fragmentation indicated by a low range of entropy (See map on Appendix II).

Cluster 3 comprised 30,116.43 ha and its main land trajectories are of persistence of old growth forest, with forest degradation occurring only recently. Coincidently, the predominant forest types are *Nothofagus dombeyi* and Evergreen (42.64% and 42.63%, respectively).

An important feature of cluster 3 is that most of these persistence trajectories are taking place under peasant agricultural systems (58.07% and 35.7%) with complete absence of commercial agriculture systems and low presence of forestry oriented systems. Comparing this result with the dynamics of cluster 1, is possible to infer that peasant agricultural systems, which manage 64.6% of the landscape, are responsible for both forest loss and forest persistence, which is consistent with the results obtained by Carmona et al. (2010). Also both are responsible for high degrees of landscape fragmentation which can be related with the successive atomization of farm properties, which in average range between 20 and 30 ha. Cluster 4 comprised the smallest area with 15,386.13 ha and is largely represented by Chiloé National Park (93.52% of the area). Consequently the two main trajectories were of persistence of Evergreen old growth and secondary forest.

Cluster 5 comprised 19,275.48 ha and is similar to cluster 1 in terms of trajectories with old growth forests being replaced directly by arboreous shrubland which is an indication of intense logging practices. In this case, near 67% of the area was under peasant agricultural systems but also an important part (22.97%) was under commercial agriculture systems, which is somewhat unexpected.

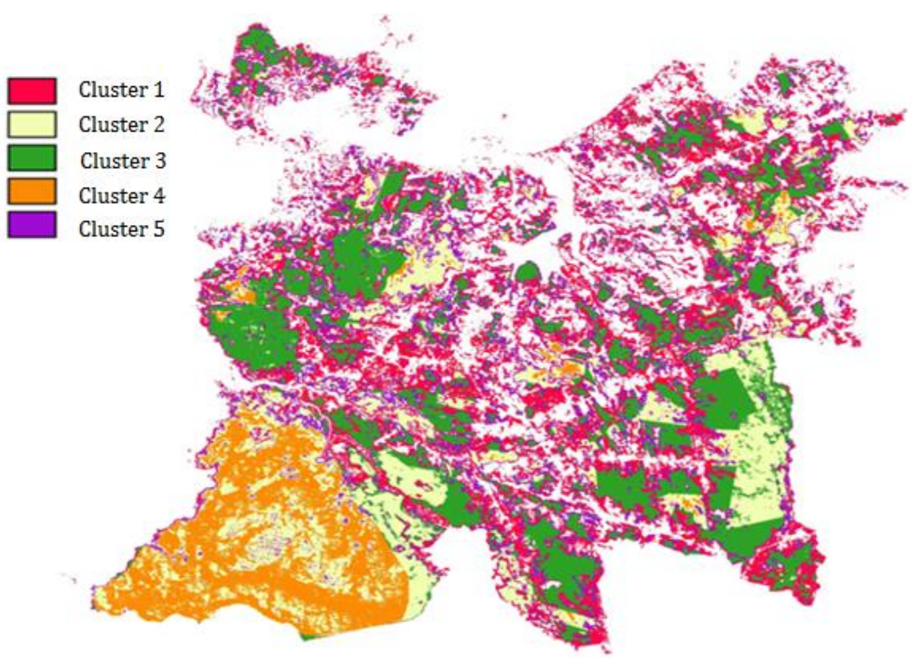
Table 5. Characteristics of each of the five clusters identified in the study area according to main LULC change trajectories, transitions and ecological and socioeconomic attributes.

Attributes	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**	**Cluster 5**
Total area	36,097.47	25,312.86	30,116.43	15,386.13	19,275.48
Proportion of land cover persistence	27.90%	60.56%	60.79%	97.74%	8.84%
Most important trajectory in terms of hectares in landscape	OGF-OGF-OGF-SF	OGF-OGF-OGF-SF	OGF-OGF-OGF-OGF	OGF-OGF-OGF-OGF	OGF-OGF-OGF-ASH
Second most important trajectory	SF-ASH-ASH-ASH	OGF-OGF-OGF-OGF	OGF-OGF-OGF-SF	OGF-OGF-OGF-SF	OGF-OGF-ASH-ASH
Proportion of main trajectory	6.09%	32.20%	30.35%	72.98%	9.03%
Proportion of secondary trajectory	3.41%	23.01%	27.78%	24.62%	5.93%
Proportion of highest systematic transitions	49.52%	26.74%	31.41%	2.26%	48.88%
Secondary forest with dominant species like *Drimys winteri*	70.00%	11.10%	7.07%	2.50%	18.66%
Secondary forest with dominant species like *Tepualia stipularis* forest	6.56%	7.61%	4.74%	8.21%	5.19%
Secondary forest with dominant species of the Myrtaceae family	3.04%	7.19%	2.93%	2.31%	3.08%
Old growth forest and secondary forest of *Nothofagus dombeyi*	13.56%	29.23%	42.64%	3.97%	36.31%
Evergreen old growth and secondary forest	6.85%	44.87%	42.63%	83.02%	36.77%
Proportion of the area under subsistence farming systems	38.23%	0.00%	58.07%	0.00%	35.19%
Level of entropy	Appendix II				

Table 5 (continue). Characteristics of each of the five clusters identified in the study area according to main LULC change trajectories, transitions and ecological and socioeconomic attributes.

Attributes	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
Proportion of the area under multifunctional farming systems	38.04%	0.84%	35.79%	0.00%	31.74%
Proportion of the area under forest-oriented systems	3.87%	28.20%	6.14%	0.00%	4.61%
Proportion of the area under commercial agriculture farming systems	18.38%	37.86%	0.00%	6.48%	22.97%
Proportion of the area under Chiloé National Park Large area entropy value	1.47%	33.10%	0.00%	93.52%	5.49%

Figure 4: Spatial distribution of landscape trajectories linked to actors and process



6. Discussion and conclusions

Using a combination of techniques, which included an in-depth analysis of the conventional transition matrix to identify random and systematic transitions, the construction of land trajectories based on a pixel-history approach, and cluster analysis to identify spatio-temporal configuration of the main land trajectories, we provide a detailed description of native forest dynamics over a 31-year time horizon.

The simultaneous analysis of land transitions and change trajectories over a long temporal scale allowed us to obtain a deep comprehension of the high complexity of deforestation and forest degradation in the study area, which cannot be understood by analyzing forest loss as a simple and irreversible conversion from forest to non-forest cover (Mertens and Lambin, 2001).

Overall, successive observations highlight the dynamic character of land-cover changes involved in forest dynamics, with a high diversity of land transitions (between 42 and 49 per period) and change trajectories (247), Overall, remote-sensing observations revealed the predominance of landscape old growth forest persistence on one hand, and a continuous trend of deforestation and forest degradation, on the other hand. In several studies, persistence has been recognized as the dominant landscape trajectory, even in areas of rapid urban expansion (Pontius et al., 2004) or highly dynamic rural landscapes such as the one studied here. Other transitions were highly cyclical, showing intermediate reversals (e.g. old growth forest to arboreous shrubland, then a regrowth to old growth forest and then degradation to secondary forest) whereas some others were very “stable” (e.g. persistence of old growth forest in the first period and then permanent afforestation with exotic plantations until the end of study period).

Between 1976 and 2007, 31.7% of the original forest cover (old growth and secondary forest) was lost. Nonetheless, we also found important evidence of forest recovery which is consistent with previous findings (Díaz et al., 2011). Between 1976 and 2007 6,693.3 ha (5.3% of the area under analysis) regenerated back to forests from different intermediate states. Some of the trajectories that reflect this cyclical dynamics are: i) the successive transitions from shrubland to arboreous shrubland, from this to secondary forest (forest regrowth) and from secondary forest to old growth forest (forest regeneration); and ii) the change from shrubland to old growth forest, followed by old growth forest persistence and finally ending in forest degradation to secondary forest.

Also a recently observed transition was the highly systematic change of forest and shrubland covers to exotic plantations. Although still circumscribed to a small area, this transition is occurring much more than expected from a random process. This implies that plantation expansion is responding to a specific set of new drivers, most likely economic factors and institutions governing access to resources (Lambin et al., 2003). Plantations, mainly of *Eucalyptus spp* increased from 8.73 ha in 1999 to 615.51 ha in 2007. Of this more than half replaced native vegetation (old growth forest, secondary forest, and shrubland) and the remaining corresponded to afforestation on marginal agricultural land and flooded areas. Unlike LULC trajectories where reversals are possible, LULC change towards plantations is mostly irreversible with effects that remain spatially “fixed” in the landscape (Alvarado, 2009). Furthermore, plantations can lead to homogenous landscape composition and structures (single species, similar age and density of stands), with large extension and spatial continuity. Plantations are causing a large number of environmental and social conflicts that represent one of the most contentious issues of contemporary sustainable development approaches in many countries such as Chile were plantation state has increased in the last decades (Gerber and Veuthey 2010).

We find that the expansion of agriculture continues to be an important driver of deforestation although slash and burn agriculture has been proscribed by law. Although the major impact of agricultural expansion in the landscape and particularly on forests occurred in the first period, between 1999 and 2007 we found that as much as 3,028 ha (3.4% of the remaining forest in 1999) was replaced systematically by pastures and agriculture land.

From the detailed analysis of these trajectories and the most important transitions within them, is possible to observe that the first and last periods were mostly dominated by systematic transitions. Conversely, the intermediate period (1985-1999), was dominated by random transitions. This was also a very dynamic period, where the amount of swap change was very high. For example in the case of old growth forest, swap change reached 83%, which implies that a large amount of forest was being lost in certain areas but was simultaneously regenerating in other places. The predominance of random transitions indicates that specific socioeconomic and/or political events took place during this period which manifested in sudden changes in the landscape. These results are largely consistent with the recent history of the study area.

The trajectories occurring in the study area were sufficiently different to produce diverse responses that are shown in the cluster analysis, such that some trajectories can be clearly linked to particular agents and the type of forest resources being transformed.

Cluster 1 and 5, both dominated by peasant agricultural systems, concentrated deforestation and forest degradation, processes that were highly systematic in the landscape, and are also the agents responsible for high degrees of landscape fragmentation.

In clusters 2, 3 and 4 the dominant trajectory was forest persistence. One of them is represented by Chiloé National Park and the other two are located in the two coasts. The west coast comprises large forest farms (e.g farms over 4,000 ha located in the south west limit of Ancud), where the predominant forest type is *Nothofagus* forest. These farms have been characterized as having improved probabilities of reaching forest product markets as they possess a better entrepreneur capacity, a superior forest resource in terms of quality, and a more aggregated supply (Emanuelli, 2006).

The east coast comprises small peasant agricultural systems that have been able to conserve their forests over time. Clusters such as this with forest stability should be taken into consideration to form part of corridors for restoration efforts (Mena, 2008). It is well know that connectivity is vital to achieve real and effective forest conservation. Furthermore, connectivity can be important for recreational purposes and planning.

Nonetheless, a common feature of clusters 2 and 3 (also cluster 5) is the late forest degradation from old growth forest to secondary forest which reflects logging practices that affect forest sustainability. Most importantly, this change reflects a new threat to Evergreen old growth forest which until recently had persisted. This late degradation was a highly systematic change and occurred at the highest rate during this period. The loss of old growth forest during the last period reached 10.9% (mostly due to forest degradation). This rate was comparatively higher than the previous periods where the loss of old growth forest reached 1.32% and 0.48%, respectively.

Land use changes are closely related to the socioeconomic and political changes occurred in the territory in the last decades. Until de 60's Chiloé Island was isolated from the continent, with an economy that can be considered almost autarchic and remittance was common from other regions of the country. Early in the 70's the Island experienced a notable change regarding emigration, from high rates in previous decades to almost zero in the following decade. Also during the 70's, agriculture suffered a crisis characterized by low potato production (a fundamental staple commodity) added to a livestock price crisis, that meant an increase in bovine heads (Bravo, 2004). These events are consistent with the systematic opening of the forest frontier to clear land for agriculture. In an area such as Ancud, characterized as marginal for agriculture, the way to compensate production decreases was and continues to be the opening of new land at expenses of forests and shrublands. Alike many other areas of the country dominated by forests, Chiloé has been characterized by orienting its development, overlooking what is evident in its landscape, the native forests. Historically, people have looked preferentially to the sea, "fighting" forests, which persist and regenerate, invading agricultural lands (Otero et al., 1996). The 80's is the decade that experienced the arrival of salmon farming and mussel farming and transnational processing industries, all which deeply influenced the culture, the landscape and the territory (Ramírez et al., 2009). Rural migration rates and urban population increased, thus expanding the demand for firewood, among other forest goods and services. The 80's were also the decade of the "woodchips exporting boom" which started in the early 80's and lasted until the mid 90's leading to abrupt deforestation. The change of old growth forest and secondary forest to shrubland between 1985 and 1999 is an indication of this, as timber extraction for woodchip production involved clearcutting (unlike firewood extraction).

These complex interactions can explain why the second period of the analysis concentrates the random transitions and also the reversals in several trajectories. Also the high swap change of this period can be attributed to these events.

The third period coincides with a larger effort of successive governments to manage the territory in view of the disequilibrium occurred in the previous period. In the landscape, the systematic forces that had shaped the forest in the past manifested themselves again as systematic changes and new cycles of forest loss after recovery in the second period. During this period, clearing for agriculture continues to be a force shaping the landscape, occurring mostly and systematically at expenses of shrubland, nonetheless preventing forest recovery from intermediate successional states (Armesto et al., 2009; Carmona et al., 2010; Marin et al. In Press).

Besides allowing for a better understanding of the process of deforestation and forest degradation in this region and their relation with socioeconomic and political processes, the spatial relationships analyzed in this study also allow us to formulate hypothesis on the role of agents and globalization forces with respect to LULC change. Overall, our results suggest that peasant agricultural systems are largely responsible for systematic processes of deforestation and forest degradation which coincides with previous studies (Carmona et al., 2010). This outcome is at the center of the debate about the relationship between poverty and environmental quality (Smith, 2006). In the study area peasant agricultural systems –the traditional rural livelihoods in the study area- are exerting an increasing pressure on their forest resources, driven by an expanding demand for firewood of an also increasing urban population (Marin et al., In Press). These farming systems can be characterized by a “forest farming continuum” typical of areas where land scarcity exercises a pressure on resource use and short fallow shifting cultivation is likely to appear as a type of rotational system (e.g. forest-shrubland-pasture-crop or forest-pasture-shrubland)

The results reflect the conflicting interactions between the physical and human systems in the study area. The type of trajectories described is characterized by a separation in physical and/or human dynamics. In this type of transition, a modification creates a separation within one of the dynamics. In the case of a separation within the human dynamics, the values and uses continue to co-evolve with the physical dynamics for a part of the population, while for another part of this population, land and natural processes are becoming out of phase. This could be the case of current rural landscapes faced with the increasing arrival of urbanites, and the associated changes in values and uses. The same separation could occur within the physical dynamics. For example, the fragmentation of a forest could lead to the creation of two islands; the first one able to sustain its natural processes and the second, with a smaller area, unable to react to human activities. In that landscape-trajectory type, the interactions become progressively conflicting and the future is more uncertain.

A key question to address is how to generate the incentives that move individuals from conflicting interactions with their natural system, towards landscape trajectories of complementary interactions between physical and human dynamics, without the regulatory presence of the governments (i.e., van on logging).

In our civilization, land is private property and the usufruct is an important right for the landowner, which implies a free of use of the land and determines also its value. Landscape is therefore a difficult thing to manage as it consists of numerous pieces of land owned by many people who all have particular interests. In the study area, the dynamics described involve a total of 2,746 land owners comprised in four farm types that manage between 0.5 and over 4,000 ha of land. However, this same landscape is considered as a common heritage and as such transgresses property boundaries (Antrop, 2005). In fact, the GIAHS project is expected to help the design of policies for the recognition and conservation of fundamental resources, effort in which rural and indigenous communities play an active role and are recognized as the main custodians of this global heritage (Koohafkan, 2009).

Overall, the trends observed reveal that the institutional factors for forest management and conservation (e.g. forest management plans, private protected areas, firewood certification, GIAHS project, among others) have not yet provided a sustainable answer to forest loss.

Appendix A: Landscape trajectories and its area between year 1976 and 2007.

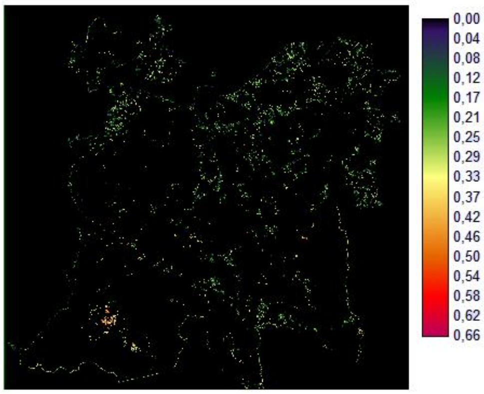
Hectares	1976	1985	1999	2007
27714,06	OGF	OGF	OGF	OGF
23290,02	OGF	OGF	OGF	SF
8313,39	OGF	OGF	OGF	ASH
4711,77	OGF	OGF	ASH	ASH
2290,14	OGF	OGF	ASH	SF
1667,34	OGF	ASH	ASH	ASH
1532,88	OGF	OGF	ASH	SH
1485,18	OGF	SF	OGF	SF
1334,79	OGF	SF	OGF	OGF
1203,03	OGF	OGF	SH	SH
1202,49	OGF	OGF	SF	OGF
1111,05	OGF	OGF	OGF	SH
1107,63	OGF	ASH	OGF	SF
890,28	OGF	OGF	SF	SF
829,98	OGF	ASH	ASH	SF
777,15	OGF	OGF	ASH	OGF
752,49	OGF	OGF	ASH	APL
740,16	OGF	OGF	SH	ASH
730,26	OGF	OGF	OGF	APL
685,8	OGF	SF	SF	SF
661,86	OGF	SF	SF	OGF
660,87	OGF	ASH	OGF	ASH
632,34	OGF	SH	APL	APL
571,05	OGF	ASH	ASH	SH
557,64	OGF	APL	APL	APL
551,52	OGF	OGF	APL	APL
503,01	OGF	OGF	OU	ASH
496,08	OGF	OGF	SH	APL
486,81	OGF	ASH	OGF	OGF
422,55	OGF	OGF	APL	ASH
409,32	OGF	SH	ASH	ASH
364,41	OGF	SF	OGF	ASH
291,06	OGF	OGF	OU	SF
272,88	OGF	OGF	OU	SH
260,55	OGF	OGF	OGF	OU
260,28	OGF	APL	ASH	ASH
236,61	OGF	SH	APL	ASH
229,41	OGF	APL	OGF	ASH
226,71	OGF	ASH	ASH	APL
223,2	OGF	ASH	APL	APL
215,55	OGF	ASH	OU	ASH
213,75	OGF	OU	OGF	SF
210,42	OGF	APL	APL	ASH
206,55	OGF	APL	OGF	SF
193,5	OGF	OGF	OU	APL
189,63	OGF	SH	OGF	SF
187,38	OGF	OU	OGF	OGF
179,37	OGF	ASH	SH	SH
176,22	OGF	OGF	APL	SH
161,01	OGF	SH	OGF	ASH
159,93	OGF	ASH	ASH	OGF
159,39	OGF	ASH	SH	ASH
156,96	OGF	SH	SH	APL
149,85	OGF	SH	ASH	SF
148,86	OGF	OU	ASH	ASH
143,73	OGF	OGF	ASH	OU
143,55	OGF	SH	ASH	SH
139,86	OGF	SH	SH	ASH
137,52	OGF	ASH	OGF	APL
135	OGF	OU	OGF	ASH
132,21	OGF	OGF	APL	SF
129,24	OGF	SH	APL	SH
128,07	OGF	OGF	SF	ASH
125,37	OGF	SH	ASH	APL
124,38	OGF	SH	SH	SH
122,49	OGF	OGF	SH	SF
117,54	OGF	APL	ASH	APL
115,2	OGF	SF	ASH	ASH
114,84	OGF	ASH	APL	ASH
112,32	OGF	ASH	SH	APL
110,43	OGF	APL	OGF	OGF
110,25	OGF	OU	APL	APL
103,59	OGF	ASH	OU	SH
102,87	OGF	ASH	ASH	OU
100,89	OGF	SH	OGF	OGF
100,35	OGF	APL	OGF	APL
98,37	OGF	ASH	OU	SF
97,29	OGF	APL	ASH	SF
95,13	OGF	ASH	OGF	SH
91,71	OGF	APL	SH	APL
87,93	OGF	APL	APL	SF
84,6	OGF	SH	OU	ASH
83,52	OGF	SH	APL	SF
81,81	OGF	OGF	OU	OU
79,11	OGF	APL	APL	SH
78,75	OGF	OGF	OU	OGF
78,39	OGF	SH	OGF	APL
76,95	OGF	ASH	OU	APL
75,15	OGF	SF	SF	ASH
71,91	OGF	SH	OU	APL
63,99	OGF	SF	ASH	SF
63,18	OGF	ASH	APL	SH
63,09	OGF	OU	OU	APL
60,93	OGF	OU	ASH	SF
54,27	OGF	OGF	APL	OGF
53,37	OGF	SF	OGF	SH
53,37	OGF	OU	OGF	APL
52,2	OGF	OU	OU	ASH
51,12	OGF	APL	ASH	OGF
51,12	OGF	ASH	OU	OU
50,04	OGF	APL	SH	ASH
49,95	OGF	OU	ASH	APL
48,6	OGF	SH	OU	SH
48,33	OGF	ASH	SF	SF
48,24	OGF	APL	OU	APL
47,79	OGF	SF	OGF	APL
45,72	OGF	APL	ASH	SH

45,45	OGF	OU	ASH	SH
45,27	OGF	ASH	OGF	OU
45,18	OGF	OU	APL	ASH
45,09	OGF	OU	OU	OU
44,28	OGF	SH	ASH	OGF
43,11	OGF	SF	ASH	SH
42,93	OGF	ASH	APL	SF
42,39	OGF	OGF	SH	OU
39,96	OGF	APL	OU	ASH
39,15	OGF	OU	OGF	SH
39,06	OGF	OU	SH	APL
37,98	OGF	ASH	ASH	EP
36,54	OGF	SF	OGF	OU
34,29	OGF	OGF	SH	OGF
34,2	OGF	SF	APL	APL
32,94	OGF	OU	SH	ASH
32,94	OGF	APL	SH	SH
32,13	OGF	SH	ASH	OU
32,04	OGF	ASH	SH	SF
31,95	OGF	SH	APL	OU
31,77	OGF	SH	OU	SF
31,23	OGF	SH	OGF	SH
29,34	OGF	OGF	ASH	EP
29,25	OGF	SF	OU	SF
29,16	OGF	OU	OU	SF
28,35	OGF	SH	SH	SF
27,9	OGF	APL	SF	SF
27,54	OGF	SH	OU	OU
27,45	OGF	SH	APL	OGF
27,09	OGF	OGF	SF	APL
26,82	OGF	OU	ASH	OGF
26,82	OGF	SF	OU	ASH
26,55	OGF	APL	APL	OGF
26,55	OGF	OU	SH	SH
25,92	OGF	OU	OU	OGF
25,56	OGF	OGF	APL	OU
24,84	OGF	APL	OGF	SH
24,12	OGF	SF	APL	ASH
23,67	OGF	OU	APL	SH
23,4	OGF	ASH	OU	OGF
22,86	OGF	OU	OU	SH
22,77	OGF	SF	ASH	OGF
22,5	OGF	SH	SF	SF
21,15	OGF	SF	SH	SH
20,88	OGF	OGF	SH	EP
20,16	OGF	ASH	SH	OU
20,07	OGF	OU	OGF	OU
17,55	OGF	APL	APL	OU
17,1	OGF	OGF	OGF	EP
16,74	OGF	SF	SH	ASH
16,29	OGF	APL	OU	SF
15,75	OGF	OGF	SF	SH
15,12	OGF	SF	APL	SF
15,03	OGF	SF	ASH	APL
14,49	OGF	ASH	SF	OGF
14,31	OGF	SF	OU	APL

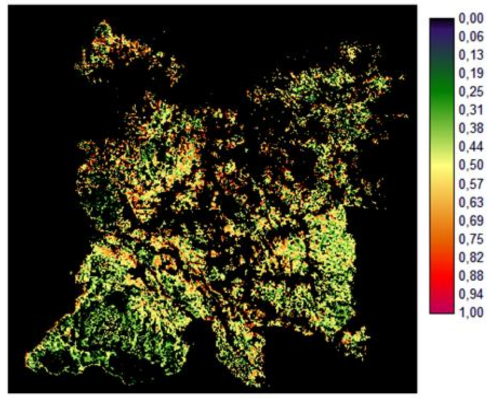
13,68	OGF	ASH	APL	OGF
13,68	OGF	APL	OU	SH
13,41	OGF	APL	OU	OU
13,32	OGF	APL	SH	SF
13,32	OGF	SH	OGF	OU
13,23	OGF	SH	ASH	EP
13,05	OGF	OU	APL	SF
12,96	OGF	SF	OU	SH
12,51	OGF	SF	SF	APL
12,33	OGF	ASH	APL	OU
12,24	OGF	SF	SH	APL
11,97	OGF	SH	SH	OU
11,34	OGF	OGF	SF	OU
11,25	OGF	SH	SF	OGF
11,07	OGF	APL	OGF	OU
10,44	OGF	APL	SF	OGF
10,26	OGF	SF	APL	SH
10,17	OGF	ASH	SF	ASH
10,08	OGF	OU	ASH	OU
9,72	OGF	APL	SF	ASH
9,54	OGF	SF	SF	SH
8,46	OGF	OGF	OU	EP
8,46	OGF	SF	OU	OU
8,01	OGF	SH	OU	OGF
7,92	OGF	SF	OU	OGF
7,74	OGF	APL	ASH	OU
7,47	OGF	SH	SH	OGF
7,29	OGF	ASH	SH	EP
7,11	OGF	OU	APL	OU
7,02	OGF	ASH	SH	OGF
7,02	OGF	APL	OU	OGF
7,02	OGF	OU	SF	SF
6,93	OGF	OU	SH	SF
6,93	OGF	SF	ASH	OU
6,84	OGF	OU	SF	OGF
6,48	OGF	SF	SF	OU
6,3	OGF	ASH	OGF	EP
5,94	OGF	ASH	OU	EP
5,58	OGF	SF	APL	OGF
5,4	OGF	OU	APL	OGF
5,22	OGF	SH	SF	ASH
5,13	OGF	OGF	APL	EP
4,77	OGF	APL	SH	OGF
4,59	OGF	SF	SH	SF
4,41	OGF	SH	SH	EP
4,23	OGF	APL	SF	APL
4,23	OGF	SH	APL	EP
4,05	OGF	ASH	SF	APL
3,6	OGF	OGF	EP	OGF
3,6	OGF	SH	OU	EP
3,6	OGF	APL	SH	OU
2,97	OGF	APL	APL	EP
2,97	OGF	OU	SH	OU
2,79	OGF	OU	ASH	EP
2,61	OGF	SF	APL	OU
2,25	OGF	ASH	SF	SH

2,07	OGF	OU	SH	OGF
1,71	OGF	SH	SF	APL
1,71	OGF	SF	OGF	EP
1,71	OGF	SH	OGF	EP
1,62	OGF	SF	ASH	EP
1,44	OGF	OU	SF	ASH
1,44	OGF	APL	SH	EP
1,35	OGF	SF	SH	OGF
1,35	OGF	SH	SF	SH
1,35	OGF	APL	ASH	EP
1,35	OGF	ASH	APL	EP
1,35	OGF	OU	OU	EP
1,35	OGF	SF	SH	OU
1,26	OGF	APL	SF	SH
1,17	OGF	APL	OU	EP
1,08	OGF	OGF	EP	SF
1,08	OGF	OU	SF	APL
1,08	OGF	OU	APL	EP
1,08	OGF	ASH	SF	OU
1,08	OGF	SH	SF	OU
0,9	OGF	SF	EP	OGF
0,9	OGF	OU	SH	EP
0,81	OGF	OGF	SF	EP
0,63	OGF	APL	OGF	EP
0,63	OGF	SF	SF	EP
0,63	OGF	SF	SH	EP
0,54	OGF	ASH	SF	EP

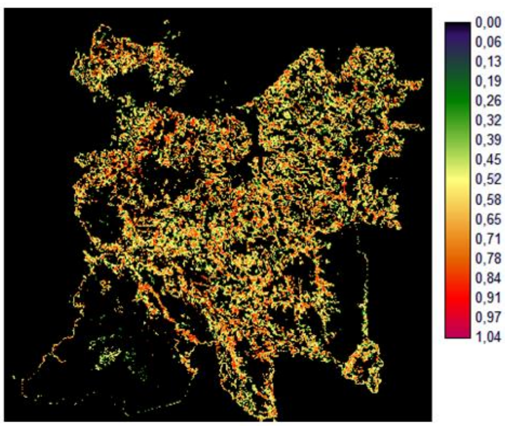
Appendix B: Landscape entropy for different kinds of clusters



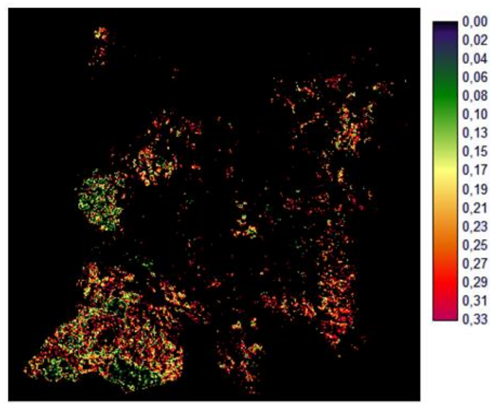
Entropy present in Cluster 1



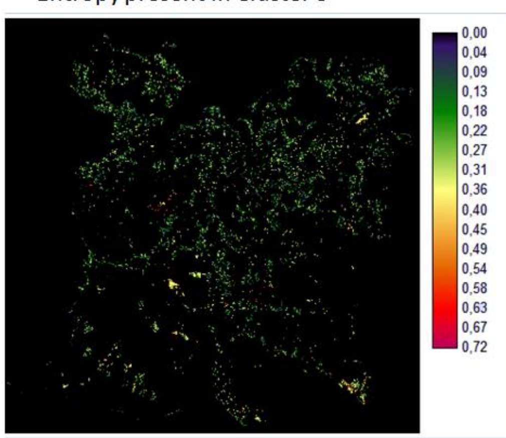
Entropy present in Cluster 2



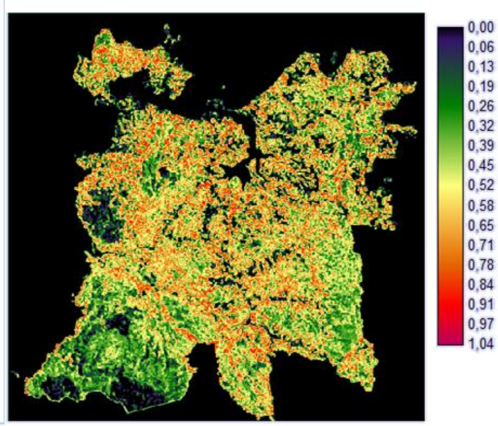
Entropy present in Cluster 3



Entropy present in Cluster 4



Entropy present in Cluster 5



Normalized entropy for year 2007

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CONCLUSIONES

Este trabajo representa una importante exploración del cambio de uso de suelo, que incorpora análisis de actores, estudio de procesos a través de la naturaleza de sus transiciones, y una visión histórica provista por las trayectorias. En ambos capítulos se lograron los objetivos de investigación propuestos, brindando información espacial de importancia para la generación de instrumentos de planificación rural.

En el primer capítulo, se combinaron datos espaciales y no espaciales los que fueron analizados usando estadística multivariada (análisis factorial y de clusters) y herramientas de SIG. Se identificaron cuatro sistemas prediales donde la mayor parte corresponde al segmento de agricultura familiar campesina. Diez variables permitieron la diferenciación de estos sistemas, entre las que se cuentan factores productivos, técnicos y socioeconómicos. Si bien existe una distribución mayoritariamente heterogénea de sistemas prediales en el espacio fue posible identificar áreas de mayor concentración de ciertos sistemas prediales. La mayor concentración de los predios tipo I (subsistencia) y II (pluriactividad) ocurre en zonas costeras y aquellas aledañas al parque nacional teniendo gran influencia en los procesos de deforestación y recreciemiento forestal Chiloé. La mayor concentración de los predios tipo III (predios forestales) ocurre en la parte sur y sur oeste de la comuna, en cercanías del parque nacional Chiloé, teniendo gran influencia en la degradación y persistencia de los bosques. Los predios tipo IV (producción de leche y ovinos) se concentra en los suelos más aptos para la agricultura en la parte central de la comuna, asociados mayormente a los procesos de expansión agrícola. Esta tipología representa una herramienta relevante para la planificación del territorio por cuanto da cuenta de la concentración de los recursos naturales y asocia tipos de propietarios al uso de dichos recursos.

En el segundo capítulo, se explora la composición espaciotemporal de los cambios de uso y cobertura de suelo a través de un análisis de transiciones y trayectorias. A partir del análisis detallado fue posible observar que los períodos primero y el último fueron dominados principalmente por las transiciones sistemáticas. Por el contrario, el período intermedio (1985-1999), estuvo dominada por las transiciones aleatorias. Este también fue un período muy dinámico, donde la cantidad de swap o intercambio fue muy alta en la composición del cambio. Prueba de esto, es que el swap para el bosque secundario llegó al 83%, lo que implica que una gran cantidad de bosques se están perdiendo en algunas zonas, pero era a la vez la regeneración en otro lugar. El predominio de las transiciones al azar indica que los acontecimientos socioeconómicos específicos y / o político se llevó a cabo durante este período se manifiesta en cambios repentinos en el paisaje. Estos resultados son bastante coherentes con la historia reciente de la zona de estudio.

Se observó un cambio en el paisaje bastante dinámico, con una alta diversidad de las transiciones (entre 42 y 49 por período) y trayectorias (247), algunas de las cuales fueron cíclicas, que muestran retrocesos intermedios (por ejemplo, SF-OGF-OGF-APL). Por el contrario, algunos de ellos eran muy "estable" (por ejemplo, OGF-APL-APL-APL).

Además, fue posible diferenciar las trayectorias a través de los patrones espaciales que presentaron y vincularlas a agentes y a los recursos específicos sujetos a cambio, obteniendo cinco diferentes cluster espaciales que brindan información valiosa para la planificación.

El conocimiento de la secuencia de cambios que ha tenido lugar en la composición espacial del paisaje constituye una poderosa herramienta para la gestión del territorio en general, y de áreas de bosque nativo en particular. En este contexto, las variaciones temporales en la configuración de la cobertura de suelo y los usos antrópicos dados a éste establecen procesos, de en torno a los cuales se pueden diseñar las estrategias de aprovechamiento sostenible y mantenimiento de la biodiversidad que constituyen las grandes líneas de gestión de los paisajes forestales. Dependiendo de la escala territorial en la que se trabaje tendrán distinta importancia unos u otros agentes modeladores del paisaje detectados en el estudio, y distinto significado los instrumentos de gestión que se apliquen.

En base a lo anterior es posible decir que este tipo de estudio tiene un gran potencial de proveer visiones más precisas de las dinámicas sociales y ecológicas de zonas rurales. Esta información es valiosa para generar planes de desarrollo que logren integrar tanto la conservación de los recursos naturales como el desarrollo social. El desafío de integrar realidades sociales y ecológicas, implica lidiar con un repertorio de enfoques que deben ser hibridados para una mejor comprensión de las dinámicas de los sectores rurales.