Dynamic simulation of forest management normative scenarios : the case of timber plantations in the southern Chile

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Nicolas MAESTRIPIERI, Thomas HOUET*, Martin PAEGELOW*, Gilles SELLERON*, Dario TORO BALBONTIN**, Nicolas SAEZ VILLALOBOS****

**Laboratoire GEODE*

*** CNCR Chili*

**** Universidad de los Lagos, Chili*

Abstract

Accounting for spatial issues (spatially explicit simulation, geographical amenities and advantages of land use and cover changes, etc.) to build prospective scenarios is a crucial issue for better assessment of possible impacts on the environment. Such spatialized scenarios and their implications allow societies to reduce the uncertainty of the future by exploring various strategies for land use changes. Despite the wide diversity in existing scenario-building techniques, two different approaches can be distinguished (exploratory *vs.* normative) for their methodological implications. The originality in this study comes from the use of a relevant exploratory (dynamic) approach to map normative scenarios which, in most cases, are represented throughout the combination of narratives and synchronic land use and cover maps. The objective of the article is to apply this dynamic exploratory simulation approach to spatialize normative scenarios within the framework of forest management in southern Chile. In the results, two contrasting images of the future are compared, with the preservation of native forests on one hand and the spread of exotic timber plantations on the other.

Keywords

Modeling, normative scenarios, exploratory approach, multicriteria evaluation, southern Chile

1 Introduction

The promulgation of Decree Law 701 (DL 701) under the military government of Augusto Pinochet has caused profound land use and cover changes in southern Chile. The main one concerns the increase in large-scale pine (*Pinus radiata*) and eucalyptus (*Eucalyptus globulus*) plantations on cleared land but also on areas of second growth native forests (Armesto et al., 2010). From 1975 to 2007, more than 95 000 ha per year of forest were planted (afforested and reforested) nationally, reaching 2.2 million ha in 2007 (INFOR, 2008). The initial goal was to both protect eroded soil and to encourage the landowners to forest their land. DL 701 turned out to be a major driving force in intensive forestry practices oriented towards the international pulp market. Environmental and socio-economic impacts of intensive forestry in southern Chile are well known in the scientific community. They include poverty and the expulsion of the indigenous population (the Mapuche, meaning "people of the land") (Lara, 1985; Leyton Vasquez, 2009), a loss of biodiversity (Donoso, Otero, 2005) and soil and water acidification (Cannell, 1999). The conversion of native forest into timber plantations remains the most important threat in this highly recognized eco-region (Cavelier, Tecklin, 2005; Echeverria et al., 2006; Altamirano, Lara, 2010).

However, some uncertainties remain regarding the region's future, i.e. future land use and cover changes (LUCC) and their impacts. Decision making, whether in private lives or public affairs, depends on our degree of knowledge and the level of confidence we have in this knowledge (Sigel et al., 2010). This state of mind reflects the extent of uncertainty that people or societies have and can use *a posteriori* to face environmental and socio-economic issues (LUCC, silvicultural yields, climate hazards, economic crises, etc.). Uncertainty leads a society to project its plans into the future and to find points of reference in order to better control the present and to optimize its choices/strategies for the future. Thus, apprehension of differing possible futures (Phdungsilp, 2011), plausible (Wilkinson, 2009; Amer et al., 2013) or undesirable ones (Godet, 2010) makes it possible to deal with uncertain events (extreme or not) to the extent that each future may be accompanied by targeted adaptation measures.

Scenario-building methods have been generalized across the world in order to confront complex and uncertain phenomena. The method and the prospective for scenarios are closely linked to environmental and socio-political issues. Scenario approaches are used to guide land use policies, to anticipate the impact of city development and urban planning (Phdungsilp, 2011) and land use change (Oñate-Valdivieso and Bosque Sandra, 2010; Morán-Ordóñez et al., 2011) or to assess the international environment (Zurek and Henrichs, 2007). La prospective (Godet, 1986; Hatem, 1993; Roubelat, 1994) highlights environmental and socio-economic issues at multiple scales. The future is a policy "space", exploratory or normative, built by and for individuals (or groups of individuals). However, though scenarios can be applied at diverse spatial scales, they cannot simulate and localize the processes involved. Therefore the géoprospective (Gourmelon et al., 2012; Voiron-Canicio, 2012; Houet and Gourmelon, 2014) offers societies a means to organize and cope with complex and dynamic environments. The use of spatially explicit models is essential in the projection and exploration of alternative future scenarios (Mas et al., 2011). Four models are usually used in the quantification and spatial allocation of future LUCC: IDRISI CA_MARKOV, CLUE-S/Dyna-CLUE, DINAMICA EGO and Land Change Modeler (Mas et al., 2014).

The aim of this paper is to demonstrate the relevance and performance of a dynamic and spatially explicit model based on an exploratory time path in order to simulate normative prospective scenarios (unlike a standard synchronic approach). Some studies have attempted to adapt this approach. For instance, PRELUDE (Prospective Environmental analysis of Land Use Development in Europe) has adopted it with the specific aim of constructing qualitative spatially-explicit, land-use change scenarios (stories) for Europe; the scenarios are quantified using spatially explicit data from land-use simulation models (European Environment Agency, 2007). The model makes use of trends which were calculated by fitting linear regression lines through the observed data (Ewert et al. 2005). Likewise, ACCLIMAT (Adaptation au Changement CLIMatique de l'Agglomération Toulousaine) (Masson et al., 2014), presents a systemic modeling approach to urban expansion by extrapolating past tendencies.

The model combines a Markovian procedure (Markovian probability maps) and a multicriteria evaluation (MCE) approach for the spatial allocation of future LUCC. Beyond the methodological aspects, the aim is to raise the awareness of citizens, politicians and forestry stakeholders through a reflective model (as opposed to a decision-making model). This model gives the opportunity to easily project and map trends and normative (desirable or undesirable) scenarios to better understand the future forest cover changes and related impacts of current decision making.

2 Materials and methods

2.1 Study area and context

The municipality of San Juan de la Costa is located in the northwest of the 10th Lake Region (73°47'–73°18'W and 40°14'–40°44'S) in the province of Osorno in southern Chile (**Fig. 1**). Even if the rate of afforestation with exotic species (*Pinus radiata D.Don* and *Eucalyptus globulus* Labill.) is considerably lower than those measured in the 8th and 9th Regions, the ecological equilibrium is threatened. Indeed, more than 70% of the municipality's area is covered by native forest (*Nothofagus pumilio*, *Nothofagus dobeyi*, *Fitzroya cupressoides*). The Valdivian Rainforest Ecoregion (35°S–48°S) is among the highest priority ecosystems for conservation worldwide due to its rich diversity, degree of endemism, and critical conservation status (Nahuelhual et al., 2007). Another major problem is that of land tenure; since the 90's, lands have been accumulated and concentrated in the hands of major landowners and forest companies. The forestry sector is dominated by four companies: Forestal Tornagaleones S.A. (Nueva Group), Forestal Anchile Ltda. (Daio Paper Corporation), Forestal Valdivia S.A. and the Forestal Los Lagos S.A. (Angelini Group). Together, these companies hold 14 000 ha while 880 small landowners live on 7 430 ha of fragmented lands.

The land tenure issue, the lack of territorial development strategies in San Juan de la Costa and the support for afforestation through DL 701 affect the living conditions of the small landowners and Mapuche communities. The municipality is described as one of the poorest in Chile, with the country's lowest Human Development Index (HDI) in 2003 (0,510) (PNUD, 2004).

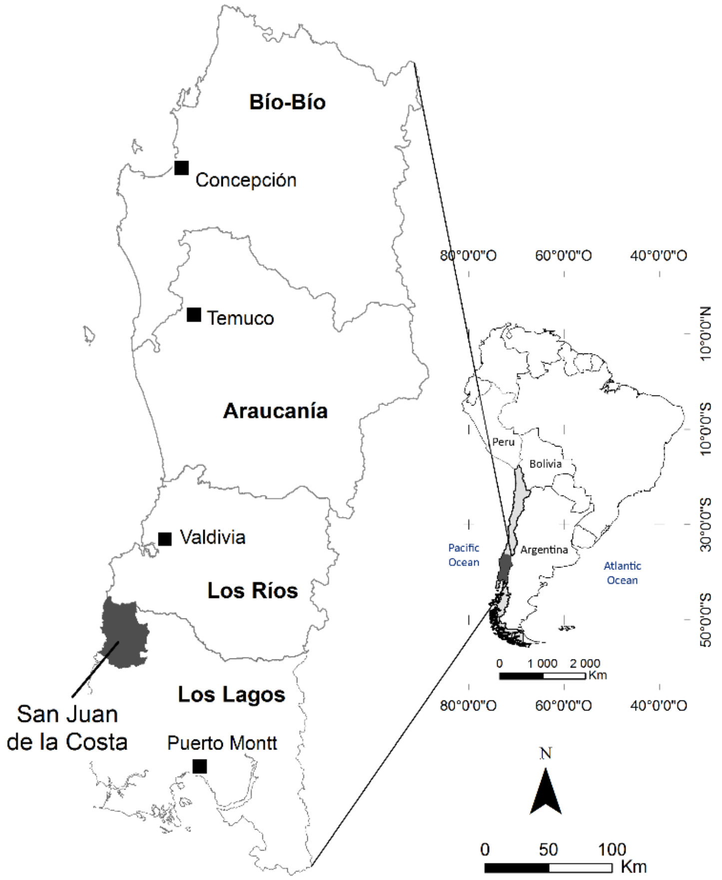

Fig. 1 Municipality of San Juan de la Costa (10th Lake Region - Chile)

2.2 Methodological approach

2.2.1 Land use and cover changes (LUCC) processes and driving factors

The monitoring of timber plantations and native forests at multiple scales is essential to a better understanding of the forest industry in southern Chile. Even if scenarios are constructed on a communal scale, it is necessary to relocate these local dynamics within the trends of a regional and national context. Medium (MODIS) (Paegelow et al., 2012) and high (LANDSAT) (Selleron, 2001; Maestripieri and Paegelow, 2013) resolution satellite imagery have been used for this. Indeed, the broad patterns observed at a regional scale do not highlight the multiplicity and complexity of variables which influence timber plantation dynamics (land tenure, topography, soil quality, land cover and road network) at the local level.

The main results show a concentration of timber plantations to the west of the Pan-American Highway and along the Pacific Ocean due to the presence of ports. Monoculture expansion follows a north-south gradient along the Pre-Costal Range (or Piedmont) with a high frequency of change (Echeverria et al., 2006; Paegelow et al., 2012). In San Juan de la Costa, plantations present the largest increase (+95%) between 1986 and 2008, covering almost 10,000 ha in 2008 (Maestripieri et al., 2013). These dynamics are driven by multiple processes and influenced by environmental, social, political, economic and technical factors operating on multiple levels. These driving forces are identified and ranked through a systemic analysis coupled with participative interviews. Among other events, the enactment of DL 701 in 1974 (and its updating in 1998) led to a boom in the forestry sector due to the creation of support mechanisms and forestry insurance for small landowners. From an economic point of view, the low profitability of the native forests as a marketable resource (Cruz and Schmidt, 2007), afforestation costs, property taxes and land ownership have always played an important role. Indeed, it affects (directly or indirectly) the sale and / or the rental of small and medium holdings by forest enterprises.

2.2.2 Scenarios

Multiple scenario typologies exist giving rise to possible semantic confusion. Numerous authors (Bishop et al., 2007; Stewart, 2008) have confirmed this, including van Notten *et al.* (2003, p.424) who stated that "*one drawback of existing typologies is that their categorization of scenarios is rather broad. Consequently, a variety of scenario types are often clustered within the same category*". One such type, however, the explorative scenario (abductive inference), can be recognized due to the inferential base of its scenario construction. It begins with a given situation in the present and moves forward into the future, responding to the question "*What may happen if …?*" (Teixera et al., 2009; Liu et al., 2013). According Fabrice Hatem (1993, p. 231) it allows us "*to highlight, in a systematic way, the most likely tendencies*". The normative scenario (inductive inference) describes a probable or desirable (or undesirable) future and moves backward to the present, i.e. retrospectively. It responds to the question *"How can a specific target be reached?"* (**Fig. 2**).

Inference	Abduction		Induction	
Scenario method	Explorative		Normative	
Path time	★ FORECASTING →		← BACKCASTING ★	
	Present	Future	Present	Future
Spatial representation methods	Explorative		Hypothesis	Retrospective
				← Image of the future
	Hypothesis →	Image of the future		GIS
				Explorative
	Markovian chains and multicriteria evaluation (MCE)			→ Image of the future
				MCE

Fig. 2 Inference, time path and spatial representation of prospective scenarios

Author's note: Non-coupled models (independent) can only represent an exploratory dynamic approach (Mas et al., 2014).

In this study, two normative and contrasting scenarios are presented, each with strong disruptions and a low degree of occurrence. Each hypothesis is developed based on (i) ground-level knowledge of the Chilean forestry sector, (ii) participatory interviews with stakeholders, (iii) expert analysis, (iv) informal discussions and rumors and (v) tempered imagination. Spatial rendering is also based on this modeling approach. Finally, the scenarios could only be built thanks to the stakeholders' involvement.

"Ecocentric" normative scenario

The "ecocentric" normative scenario is one of conservation. Forest production as it existed in 2008 is finished. An economic recession at the international and national level causes a decline in the forest sector marked by a strong increase in forest product prices. At Pricewaterhouse Coopers' 22nd Annual Global Forest & Paper Industry Conference held in May 2009 in Vancouver a clear concern was expressed concerning the international economic recession using terms such as "*economic tsunami*", "*pessimistic forecasts*", "*the dismal year*" or "*survive the downturn*" (PwC, 2009, Global Forest). The Chilean myth (Latin America's "jaguar") based on the neoliberal economic model cannot counter the devastating effects of the economic crisis. Large landowners such as timber companies sell their land which is redistributed among indigenous Mapuche people (Indigenous Law N° 19.253 art. 20, a), b) and c), page 19 (CONADI, 2008). Forested areas with native species are expanding throughout the municipality and, for the most part, are under sustainable management. Only fragments of exotic species plantations remain in the Piedmont. In this scenario, the time horizon is 2035 so as to take into account the growth of native tree species (30 years for *Nothofagus dombeyi*) (Cubbage et al., 2007).

"Intensive" normative scenario

In this scenario the forest sector is booming worldwide and the country's forest policy (DL 701) encourages owners (both small owners and multinationals) to increase production. The 10th Lake Region has seen the commissioning of the Coastal Road (*Ruta Costera*) and the construction of a new cellulose plant (**Fig. 3**). This Coastal Road is a project that may, according to the Ministry of Public Works (*Ministerio de Obras Publicas* - MOP), generate significant benefits such as greater access to isolated areas, reduction in travel time and contributions to the development of tourism in the area. Conversely, the road encourages deforestation in the Piedmont of the Coast Range (Maestripieri and Paegelow, 2013) and plays a major role in the dynamics of LUCC, particularly the spread of monocultures. Its absence is the reason why (i) native vegetation remains relatively unexploited and is deteriorating, and (ii) industrial plantations are not expanding in Coast Range areas.

The expansion of plantations in this scenario is extremely great, whereas native forest degradation is systematic. The time horizon is set for 2026, which corresponds to two rotation cycles of eucalyptus from the last available date (2008).

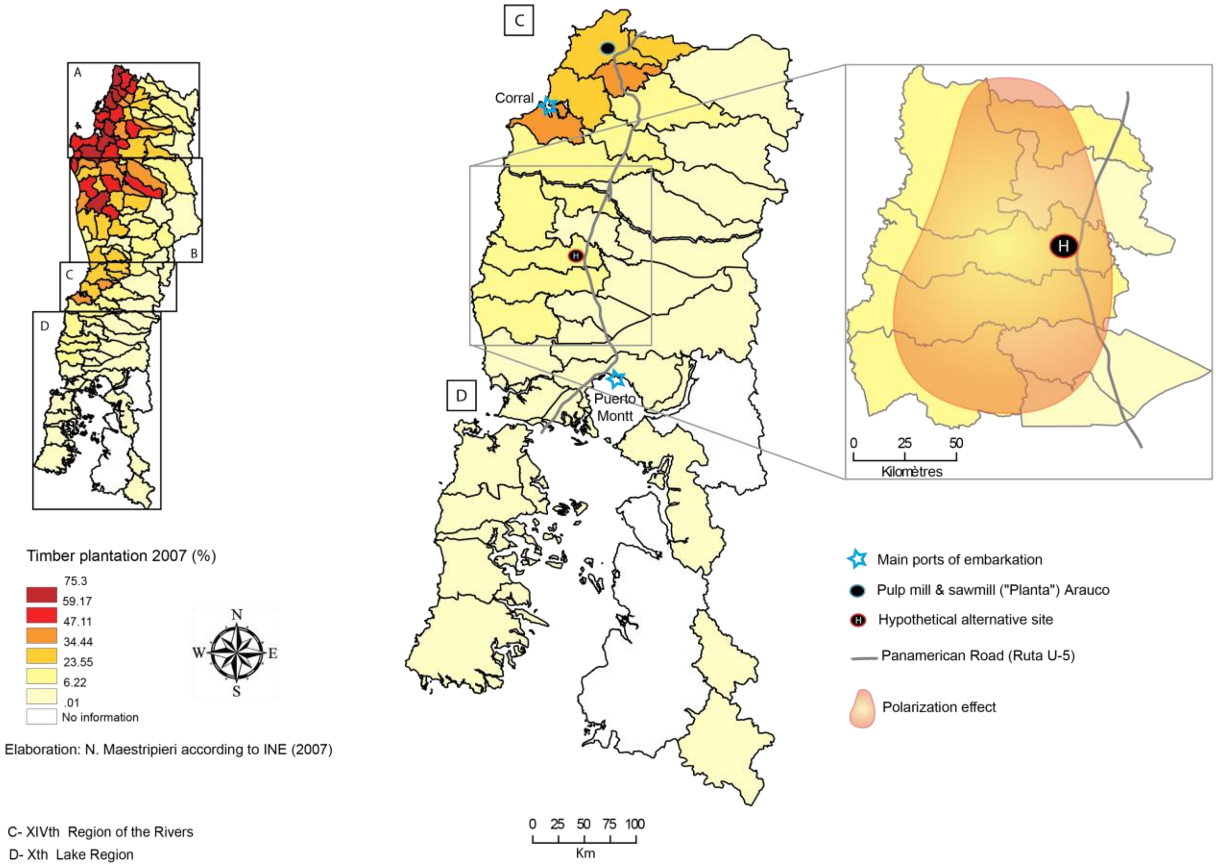

Fig. 3 Hypothetical implantation of cellulose plant in the 10th Region

2.2.3 *Mapping the scenarios*

Normative scenarios are of inductive inference (non-demonstrative); they are narrative, qualitative and the spatial representation of the hypothesis is synchronic. For instance, Houet et al. (2008) used a Geographic Information System (GIS) to map a normative scenario. According to the authors, the GIS facilitates the transfer of knowledge between stakeholders and managers. Such tools can help to locate and represent land cover and landscape pattern changes with multicriteria, attributive and/or spatial queries. Therefore, we use IDRISI's CA_MARKOV model which is based on an inductive pattern approach (Mas et al., 2014), but in our study their spatial representation responds to an abduction inference. Both scenarios follow an exploratory spatial modeling process (from present to future) while the assumptions of future LUCC are derived from a participatory approach for the normative scenarios. Trend assumptions are often derived from the model itself.

CA-Markov is a predictive model (Houet and Hubert-Moy, 2006; Paegelow et al., 2015) combining Markovian chain analysis, multicriteria evaluation and spatial filtering techniques, and is described as a cellular automata procedure (CA) (Eastman, 2006). Markovian chains analyze two land cover images at different times and produce two transition matrices (probability and surface area in pixels for persistence and transition) and a set of conditional probability images. They are used to estimate a future state based on the observed past changes (Antoni, 2006). Estimated changes are allocated using the MCE procedure to estimate the probability maps of the transitions from one land cover to another (Paegelow and Camacho Olmedo, 2005). The model is calibrated to the San Juan de la Costa study site using two supervised land cover classifications for 1986 (t_0) and 1999 (t_1) and has been validated by comparing the 2008 simulation with an existing 2008 land cover map (t_2) (Maestripieri and Paegelow, 2013).

Mapping scenario hypotheses depends on the MCE procedure and more specifically on the weight attributed to each driving factor in the modeling. The objective of the MCE is to generate suitability or probability maps integrating a set of measurable and mappable criteria. These maps can be used to develop specific land use strategies. The modeler controls the process by identifying and characterizing the driving forces with an expert approach.

2.2.4 Multicriteria evaluation technique

Eleven criteria, divided into three groups, are integrated within the multicriteria process. The first group (3 factors) represents socio-economic parameters: (1) Distance from Road Network (DRoNet) – (2) Land Tenure (LdTen) and (3) Distance from Coastal Road (DCoRo)[1]. The second group expresses environmental parameters (6 factors): (4) Land Use (LU) – (5) Distance from Existing Land Cover features (DExLC) – (6) Altitude (ALT) – (7) Slope (SLP) – (8) Coast Range (CoR) – and (9) Pre-Coast Range (Pre-CoR). Finally, the last group is formed by two constraining criteria: (10) Urban Area (UA) – and (11) Hydrological Network (HydNet). A constraint means that concerned land cannot be used for a land cover change objective while other factors express variable land cover change suitabilities.

Because each factor is expressed in its proper unit they must be standardized using fuzzy membership functions to become comparable. Standardization signifies the recoding of original values (degrees, meters, per cent) to suitability values on a common scale from 0 (lowest suitability) to 255 (best suitability) (Paegelow and

[1] This criterion is exclusively used in the intensive scenario.

Camacho Olmedo, 2005). Factors may be standardized by linear, sigmoid, j-shaped or empirical functions that may be individually implemented to fit the relationship between original values and their related suitabilities.

For instance, in order to model the suitability values of plantations in our calibration model (Maestripieri and Paegelow, 2013), distance from road network (DRoNet) is standardized using a monotonically decreasing sigmoidal function with two control points established at 260 m (min) and 2900 m (max). These points are determined through retrospective analysis (between 1999 and 2008) using observed LUCC and their driving forces. This function is better than the j-shaped function because values reach 0 at 2900 meters (**Fig. 4**). Thus, areas located near existing roads (from 0 to 260 m) have a value of 255 (here membership function is equal to 1, which is to say that the probability of any change in LUCC is equal to 100%). From 260 m to 2900 m, the value decreases gradually from 255 to 0 (the membership function decreases gradually from 1 to 0) and once beyond 2900 m is equal to 0.

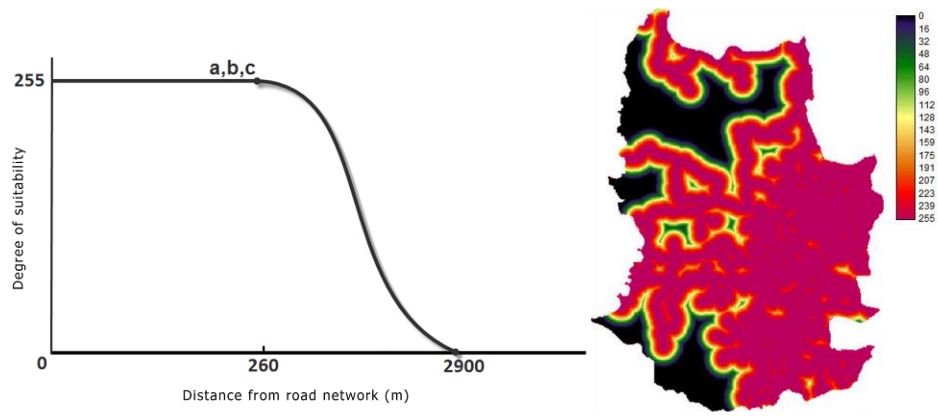

Fig. 4 Standardization of distance from road network

The weighting factor is based on the technique of pairwise comparison within a context of decision making called Analytical Hierarchy Process (AHP) (Saaty, 1977). Each type of land cover (timber plantations, native forest and other) is an objective. Weights reflect the importance of one factor over all others and they control how each of these factors contributes to the land cover change allocation (Eastman, 2006). The relative weight of each factor is calculated by the eigenvalue method, indicating the priority level for each element in the hierarchy (Wolfslehner et al., 2005). The pairwise comparison matrix (**Tab. 1**) allows each pairwise comparison to be rated. Usually, variables are ranked on a 9-point scale but we chose a 17-point scale in order to refine and detail the comparison between factors. Each cell represents the rating of the row factor relative to the column factor (Eastman, 2009). We discussed these values with the interviewees who determine the importance of comparing one factor to another. In addition, we analyzed the interactions between changes observed (for instance in native forest to timber plantation) and driving forces (land tenure, proximity to road, and so on) (Maestripieri and Paegelow, 2013).

	LU	LdTen	CoR	Pre-CoR	DExLC	DRoNet	SLP	ALT	DCoRo
LU	1								
LdTen	9	1							
CoR	2	1/3	1						
Pre-CoR	6	1/2	2	1					
DExLC	6	1/3	3	1/2	1				
DRoNet	3	1/4	2	1	1/2	1			
SLP	1/2	1/3	1/2	1/2	1/3	1/3	1		
ALT	1/4	1/7	1/2	1/4	1/4	1/3	1/3	1	
DCoRo	5	1/2	3	2	3	2	3	3	1
Eigenvalue	0.04	0.27	0.06	0.14	0.13	0.10	0.05	0.03	0.19
Consistency ratio: 0.08 (acceptable)									

Tab. 1 Pairwise comparison matrix – Intensive scenario (objective PLANTATION)

Finally, an Ordered Weighted Averaging technique (OWA) is applied. With this technique compensation between factors and the level of risk-taking can be controlled, thus providing control over the degree of optimism (risk attitude). Attitude to risk ranges from 1 (no risk taken and no compensation between factors) to 5 (maximum risk taken and no compensation), by way of average risk taken and total compensation between factors (between AND and OR Boolean) (**Fig. 5**). The weighting is applied differently to each pixel according to the classification of skills, the lowest (1st row) to the highest (last row) (Paegelow and Camacho Olmedo, 2005). For a more detailed procedure of multicriteria evaluation and OWA, see Gemitzi et al. (2007).

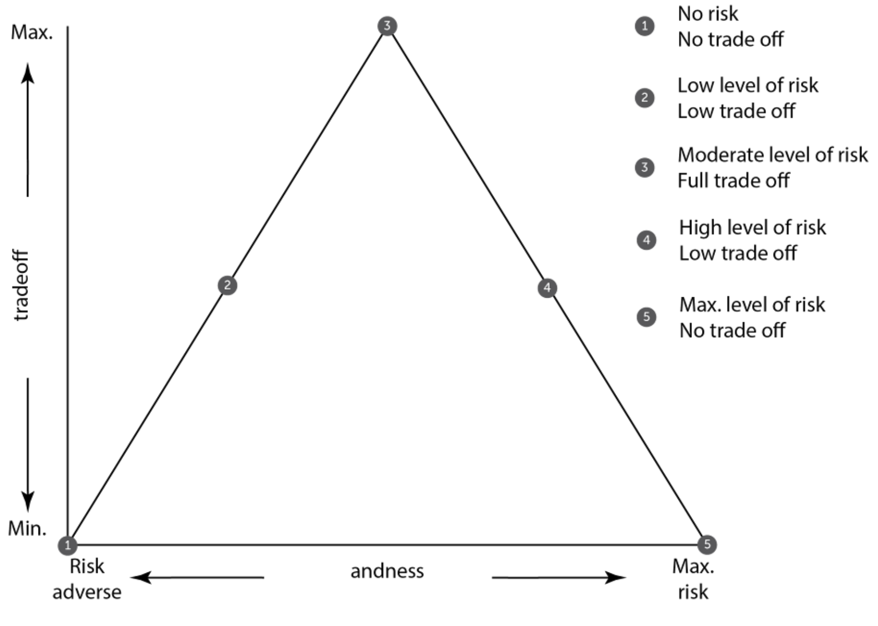

Fig. 5 Decision strategy space

3 Results

3.1 Exploratory approach

3.1.1 "Ecocentric" normative scenario

This scenario (**Fig. 6**) excludes the creation of new exotic plantations and expects existing plantations to be reforested after clearcutting. The lowest suitability value (0) was therefore assigned to pixels corresponding to land owned by forestry companies. A very low suitability (20) was assigned to small and medium landowners and a rather low suitability (75) to big landowners.

The "pessimistic" strategy is chosen for the stated objective PLANTATION (n°2 – **Fig. 5**) (**Tab. 2 and 3**). An area of 5400 ha is allocated to plantations in 2035. Native forest does not change within big and very big (forestry companies) properties but change can occur in small and medium properties (suitability 255). The objective NATIVE FOREST opts for "optimistic" strategy (n°4) by giving greater order weight to the pixels having a value of high suitability, such as properties and distance from existing native forests. Finally, the objective OTHER incorporates the land tenure and gives a high suitability for forestry companies to promote the emergence of non-forested areas. Strategy n°4 is applied to give greater weight to the land tenure factor.

	LU	LU	CoR	Pre-CoR	DExLC	DRoNet	SLP	ALT
LU	1							
LdTen	7	1						
CoR	⅓	1/7	1					
Pre-CoR	⅓	1/7	2	1				
DExLC	⅓	1/6	4	½	1			
DRoNet	½	1/6	3	2	2	1		
SLP	⅓	1/6	2	⅓	2	½	1	
ALT	¼	1/7	⅓	¼	½	½	⅓	1
Eigenvalue	0.1504	0.4577	0.0430	0.0896	0.0627	0.0999	0.0656	0.0312
Consistency ratio: 0.08 (acceptable)								

Tab. 2 Pairwise comparison matrix – Ecocentric scenario (objective PLANTATION)

Order Weight	0.4	0.25	0.15	0.1	0.06	0.03	0.01	0
Rank	1st	2nd	3rd	4th	5th	6th	7th	8th

Tab. 3 Order weight assignment – Ecocentric scenario (objective PLANTATION) – Low level of risk, low trade off

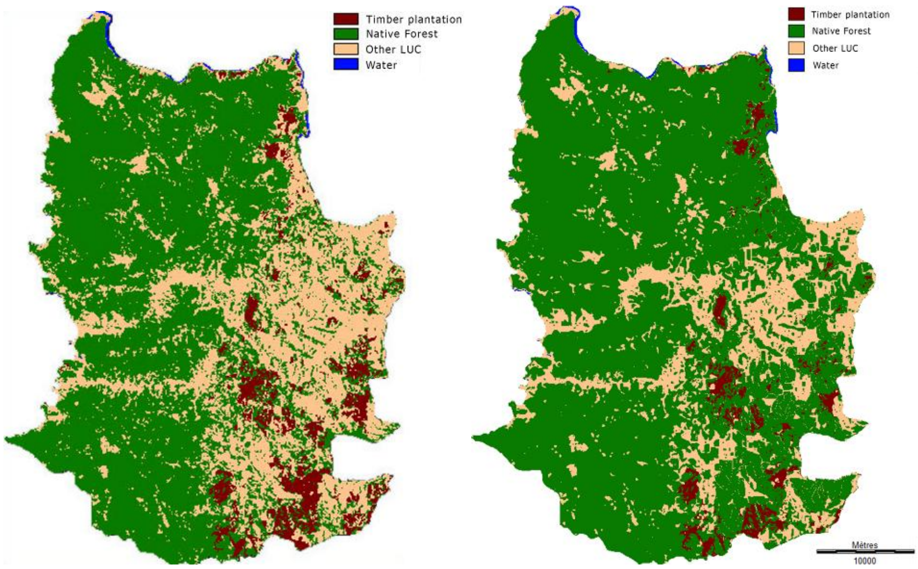

Fig. 6 Land cover in 2008 (left) and preservation normative scenario in 2035 (right)

3.1.2 Intensive normative scenario

In this scenario (**Fig. 7**) the stated objective PLANTATION gives a maximum suitability for all types of properties (LdTen) and opts for the optimistic strategy (n°4), giving order weight to the pixels having a value of very high suitability. The determination of the surface area is based on the average annual rate of afforestation and reforestation between 1999 and 2008 (9.98% per year). This variation allows projection of their area 18 years later (54,973 ha in 2026).

The same operation is performed by integrating the factor Coastal Road (DCoRo) in the model and assigning a high order weight. For instance, Land Tenure (LdTen) has an eigenvector of 0.27 while Costal Road has 0.19 (**Tab. 1 and 4**). The objective NATIVE FOREST assigns a lower suitability to the land use "other", reducing the likelihood of seeing native forest.

Order Weight	0	0.01	0.03	0.05	0.07	0.09	0.15	0.25	0.35
Rank	1st	2nd	3rd	4th	5th	6th	7th	8th	9th

Tab. 4 Order weight assignment – Intensive scenario (objective PLANTATION) – High level of risk, low trade off

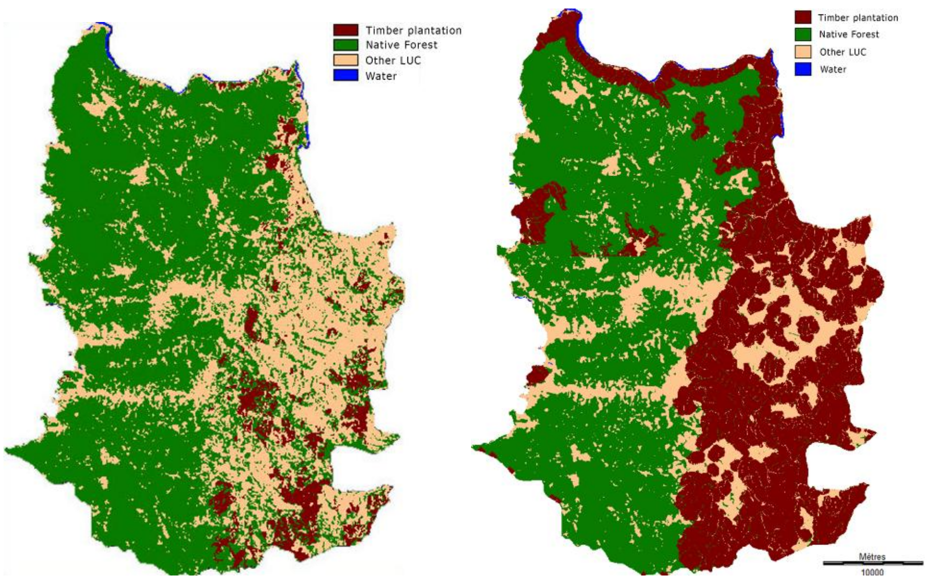

Fig. 7 Land cover in 2008 (left) and intensive normative scenario in 2026 (right)

3.2 Scenarios analysis and comparison

The “ecocentric” scenario shows the expansion of native forest in the foothills of the Coast Range (to the east) and replaces mainly areas categorized as "other" (+19,824 ha) (**Fig. 8**). Some of the exotic plantations are replaced by native species (-2,855 ha) and others LUC (-1,633 ha). After having recovered their lands, the autochthonous communities systematically reforested their parcels with native species and have implemented a sustainable management policy in order to develop the value of forest resources.

Inversely, the intensive scenario offers a perfect demonstration of the invasion of timber plantations in the Coast Range foothills, leaving few lands unforested (**Fig. 9**). The major change is a conversion of both native forest and other LUC to timber plantation (22,039 ha and 23,045 ha, respectively). The construction of the Coastal Road located on the west side of the municipality reinforces the existing road network and improves accessibility to surrounding lands for timber companies, a process that generates the development of large timber plantations within the Coast Range (+3,000 ha). This scenario highlights the environmental (habitat fragmentation) and social (Mapuche territory) damages that can be caused.

The factor “Land Tenure” is decisive in both scenarios. Alone, the land-tenure factor alone does not explain all forest dynamics, yet it carries a decisive weight. In southern Chile landowners are in a situation of oligopsony, which is to say that they are totally dependent on the demand by a small number of processing industries owned by large forest groups. In addition, due to market conditions (competitiveness, increase in land prices, etc.) small landowners have to sell or rent their land. Thus, due to capitalization and land concentration, five very large landowners share 14,201 ha, while 880 small landowners live on 7,430 hectares of fragmented lands. The land-tenure variable thus allows the spatial representation of the emergence of new industrial plantations in the future (sale, spatial dynamics).

Available digital data indicate a concentration of lands in the coastal foothills which influences the spatial allocation of native forest and plantations in this area. Conversely, the Coast Range is very weakly affected by this variable but depends heavily on the development of new transportation infrastructure.

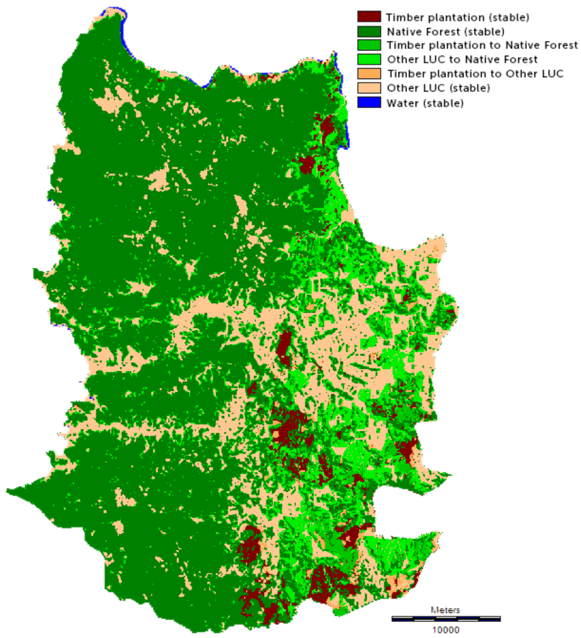

Fig. 8 LUCC between 2008 and 2035 (ecocentric scenario)

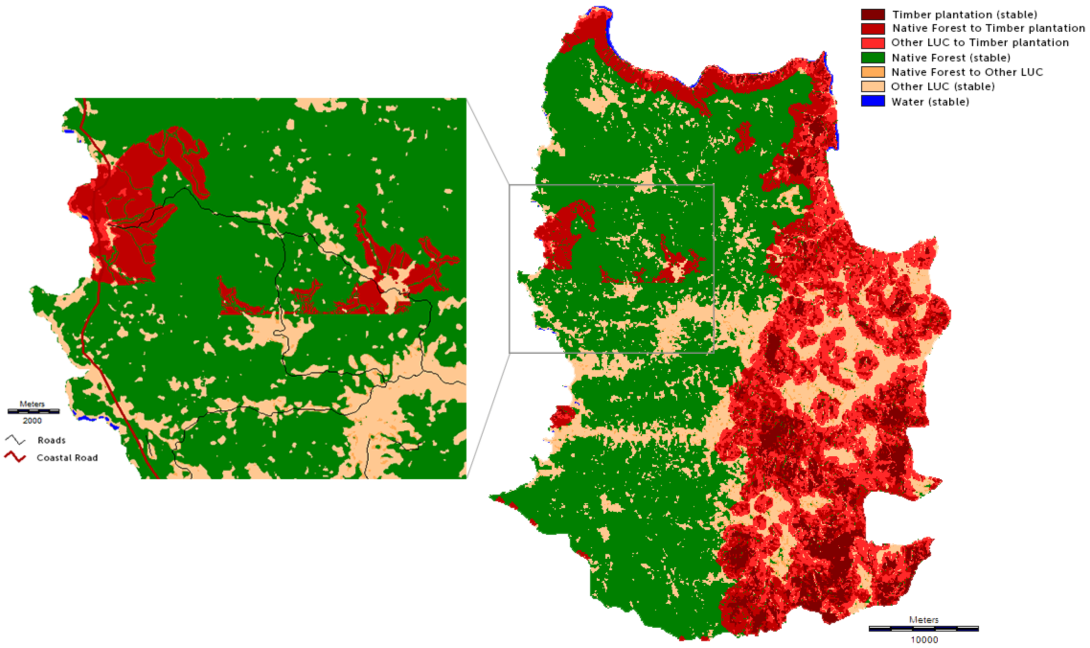

Fig. 9 LUCC between 2008 and 2035 (intensive scenario)

4 Discussion and conclusion

4.1 Modeling recommendations

The simulated maps provide a better image of the assumptions presented in each scenario, yet several limitations have been identified. Implementation of an exploratory approach to spatialize a normative scenario does not affect its relevance. However, it may be legitimate to consider these scenarios as exploratory in an extreme situation that does not break away from past trends. According to Börjeson et al. (2006) a marginal adjustment in a current development is insufficient, and a trend break is necessary to reach the target. In this sense, the exploratory approach is limited because the modeler is dependent on the ability of the model to vary the simulation parameters (for e.g. rotation cycles and deforestation in real time).

We have seen that multicriteria evaluation enables factors to be weighted in order to integrate hypotheses, but especially to approach a desired image as closely as possible. Moreover, when compared to other methods, this approach encourages the participation of stakeholders and provides a great flexibility in modeling. For instance with Land Change Modeler (LCM), the user introduces relevant drivers while the type and strength of the LUCCs are determined with a multilayer perceptron, which is an automatic machine learning algorithm

(Paegelow et al. 2015). Even if LCM can update variables at each simulation step, this neuronal network excludes the stakeholders and does furnish sufficient flexibility when weighing different factors.

The image of the ecocentric scenario forest cover projected for 2035 clearly provides a learning experience, though it does not completely break with the land use/cover logic observed in 2008. The conception of normative scenarios is not a problem, yet its spatial rendering still depends on the available data and the performance of the model used.

This approach can therefore be seen as a combination of a qualitative and narrative-based normative approach for the building of scenarios, and also of the exploratory approach to account for various hypotheses and to map the scenario. The model fulfills our expectations because it can spatially represent normative scenarios.

In a prospective approach, the choice of model is an important step (Mas et al., 2014) and should take into account several criteria. Thus, after developing the image of a desired future and having presented the different assumptions, the modeler must be sure to have an available and complete database that will ensure the spatial representation of each assumption stated.

During the simulation process, the model must be developed to break with the land use/cover observed at the last known date in order to differentiate itself from contrasting exploratory scenarios. This implies a "real time" intervention in the simulation process to modify the parameters. In addition, it is important to incorporate new or updated variables (for e.g. cadastral parcels) at key moments of the simulation and which have been predetermined.

4.2 Conservation implications

In southern Chile, the conservation implications of this study are highly significant for forest management. The Valdivian forests in Chile (and in Argentina) are the only temperate rainforests in South America and are part of the 25 biodiversity hotspots for conservation priorities (Myers, Mittermeier et al., 2000). Even though we can observe and quantify pressures on the native forest in San Juan de la Costa, the heritage of this forest will remain a faunistic and floristic ecological continuum for at least 30 years. However, fragmentation and forest degradation may have a strong impact on “*the flora and fauna existing in the remnant* *forests, due to change in composition of assemblage and change in ecological processes*" (Echeverria et al., 2006).

Decree Law 701 has promoted the expansion of timber plantations, particularly amongst big landowners and to a very small extent amongst small and medium landowners. González (2008) states that it is an interpretative element from a combination of several variables such as economic incentives, trade and sectoral policies, and stabilization policies. The reasons, and these sales are many, belong to both the problem of unproductive soil marked by crop rotation (Cruz and Schmidt, 2007), and the inability of small land owners (pine and eucalyptus plantations) to earn profits from their crops.

Policy issues regarding land tenure will have to be dealt with in the short and medium terms. The Chilean government seeks to develop and optimize the forest sector on a regional (South American) and international scale, but must take into account the rights of indigenous peoples (Indigenous and Tribal Peoples *Convention 169*). Indeed, the conditions of the Mapuche as a socio-economic and cultural group are threatened by this capitalization and accumulation of land that is taking place to their detriment.

These models, too, must be seen as a tool for reflection and debate, and not a turnkey solution. Spatial evaluation of normative and contrasting scenarios shows a strong interest in the anticipation of future LUCC. They highlight the areas that require conservation priorities in order to maintain a strong ecological connectivity.

We maintain that policy debate and "projects of long-term conservation and short-term sustainable forest production should be undertaken in agreement with local stakeholders (small landowners and indigenous communities)". According to Donato Bergandi (2014) "heedless of philosophical-political references, an international politico-economical oligarchic caste is largely united around dealing with environmental issues based on the sustainable development model, which is an expression of a utilitarian, anthropocentric perspective." Therefore, it is essential to force the political class to reconnect with a bottom-up approach rather than a top-down approach. Programs of biodiversity conservation have emerged in the 10th Lake Region such as the Private Protected Area Program (*Áreas Protegidas Privadas*) focused on the protection of natural areas, the conservation of biodiversity and the enjoyment of nature (Sepúlveda, Villarroel et al., 2006).

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