Monitoring, modelling and predicting timber plantations dynamics. The case of San Juan de la Costa (Chile)

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Introduction

Intensive forestry is a notable manifestation of land use/cover changes (LUCC) (Bull, 2006) characterized by its well-known environmental and socio-economic impacts at multiple scales (Arroyo *et al.*, 2000). The Chilean industrial forestry is focused on the intensification of the pulp and cellulose production, in order to improve its place into the world pulp market. The DL 701 (1974 - and its repeated updating) covering up to 75% the plantations costs, was the keystone of the forest expansion of pine and eucalyptus species. The timber plantations are mainly concentrated from the 8th Region of Bío Bío to the 10th Region de Los Lagos (Lake Region). However, their distribution is not uniform and there is a clear interregional imbalance. Given that, the corporate strategy is to expand their forest heritage, the companies actually focus on new suitable areas for afforestation, as the municipality of San Juan de la Costa. With the weakest national HDI, this municipality is particularly exposed to develop a spatially explicit model of land cover change. The goal is to develop future and contrasted scenarios in order to implement sustainable policies.

Methods

Study area

The study area is located at the north-west of the Lake Region, between parallels 73°47' and 73°18'' (western longitude) and 40°14' and 40°44' (southern latitude) (Figure 1). The native forest covering this area is part of one of the highest priority areas recognized by the World Wild Fund (WWF). According to the National Statistics Institute (INE, 2002), more than 89% of the population live in the countryside (7929 habitants). The indigenous people called "Mapuche-Huilliche" represent 62% of this rural territory. The municipality is divided by two topographical units, the Coastal range and the Piedmont.

Data and land use/cover change detection

In order to predict the future LUCC we applied a prospective scenario-based approach following Godet (1986), Hatem (1993), De Jouvenel (1999) and Houet (2008). The elaboration of the scenarios is based on a retrospective LUCC analysis of the municipality. To do this, we used three Landsat TM images (path 233, row 88) taken in 1986, 1999 and 2008.

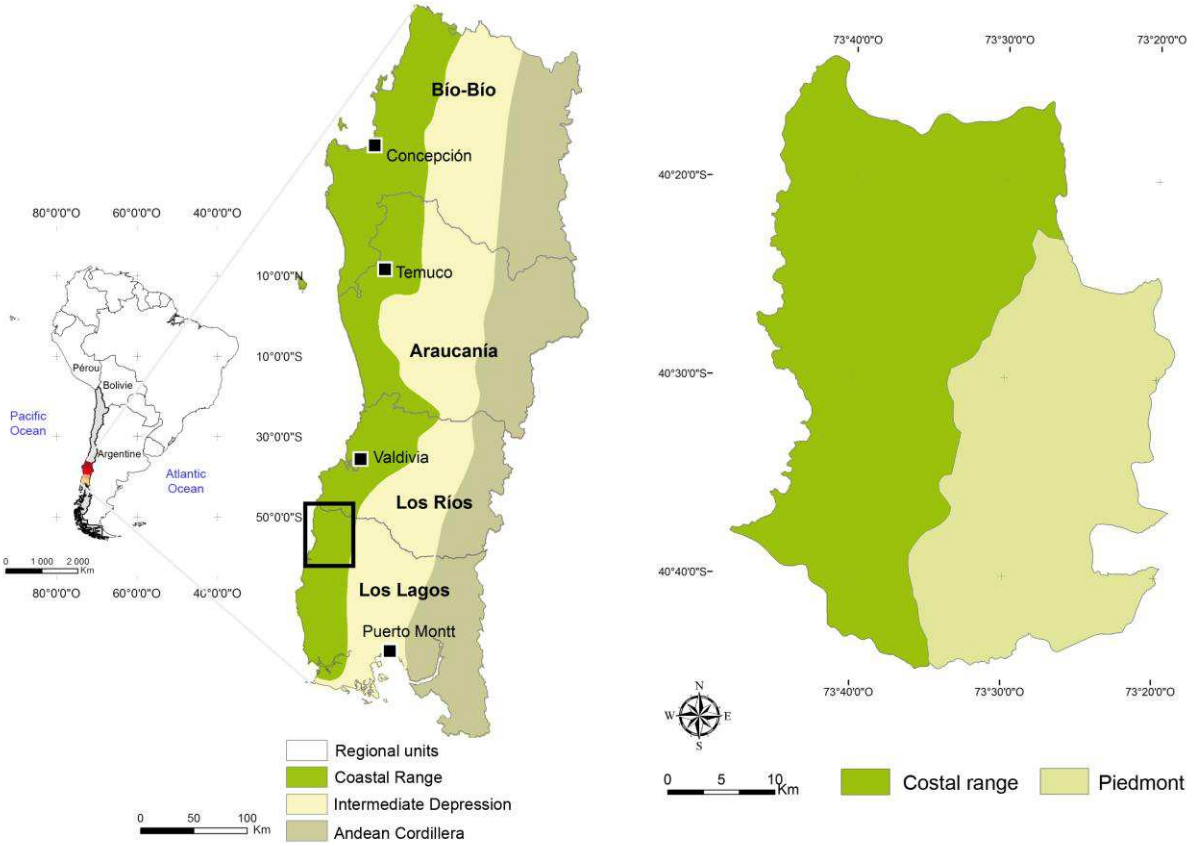

Figure 1. Location of the study area at the north-west of the Lake Region, Chile

A supervised multi-temporal classification was performed to get land use / cover (LUC) at these three dates. Four LUC classes are distinguished: timber plantations, native forest, “other” category (including second growth forest, shrubland, grassland and bare land) and open water. The “other” category allows focusing on the timber plantations and the native forest and thus simplifies the modeling process.

More than three hundred field points were taken with a GPS in order to estimate the global accuracy of each classification. Analysis of land use/cover changes (LUCC) occurs in three stages, with (i) quantifying losses and gains, the analysis (ii) of the spatial distribution of these changes, and (iii) trajectories of evolutions.

Then we have refined this analysis by the identification, characterization and weighing of many factors that have induced this expansion. Spatial analysis, expert analysis, stakeholder interviews and bibliographic revision assess drivers of timber plantation dynamics at local, regional, national and global scales.

Modeling future dynamics

Taking into account the past dynamics, the aim is reaching a vision of the future land use/cover changes (2017, 2026 and 2035), more specifically about the possible influences of multinational forest companies in a municipality where indigenous land recognition is lacking.

Two spatially explicit models are tested: CA-Markov (Eastman, 2006) and Land Change Modeler (Eastman, 2009). With CA-Markov the spatial allocation of future dynamics is supervised by Multi-Criteria Evaluation (MCE) which generates suitability maps in order to allocate Markov chain predicted quantities of changes (Paegelow and Camacho, 2008). Land Change Modeler allows an automatic calibration of the model using a multi-layer perceptron (MLP) which is an artificial neural network (ANN). The spatial allocation procedure is performed by a multi-objective land allocation (MOLA). As for CA-Markov, quantities of expected changes are predicted by Markov chain. Both model tools are used to predict LUC in 2008, based on training data from 1986-1999. This is the calibration step before prospective scenarios. 2008 predicted LUC is compared to observed LUC in 2008 by various statistical tests.

Results

Land use and cover change in San Juan de la Costa

The native forest is the predominant land cover with 110,775 ha in 1986 (71.7%), 104,322 ha in 1999 (67.5 %) and 96,857 ha in 2008 (62.7 %). They are mainly localized on the Coastal Range, and in a more fragmented way on the Piedmont (Figure 2). The "other" category shows an increase of 44% between 1986 and 1999. The timber plantations present the largest increase with 95%, covering almost 10,000 ha in 2008 and are located on the Piedmont. Finally the water resources remain stable with 408 ha (0.26%). The major change was a conversion of 12,700 ha from native forest to "other" (12% of deforestation) between 1986 and 1999 (Figure 3). At the same period, timber plantations regained 1,483 ha from native forest (1% of substitution) and 2,329 ha from "other" (5%). Between 1999 and 2008 the process of substitution of native forest and "other" became more intensive (respectively 1,883 ha and 3,803 ha).

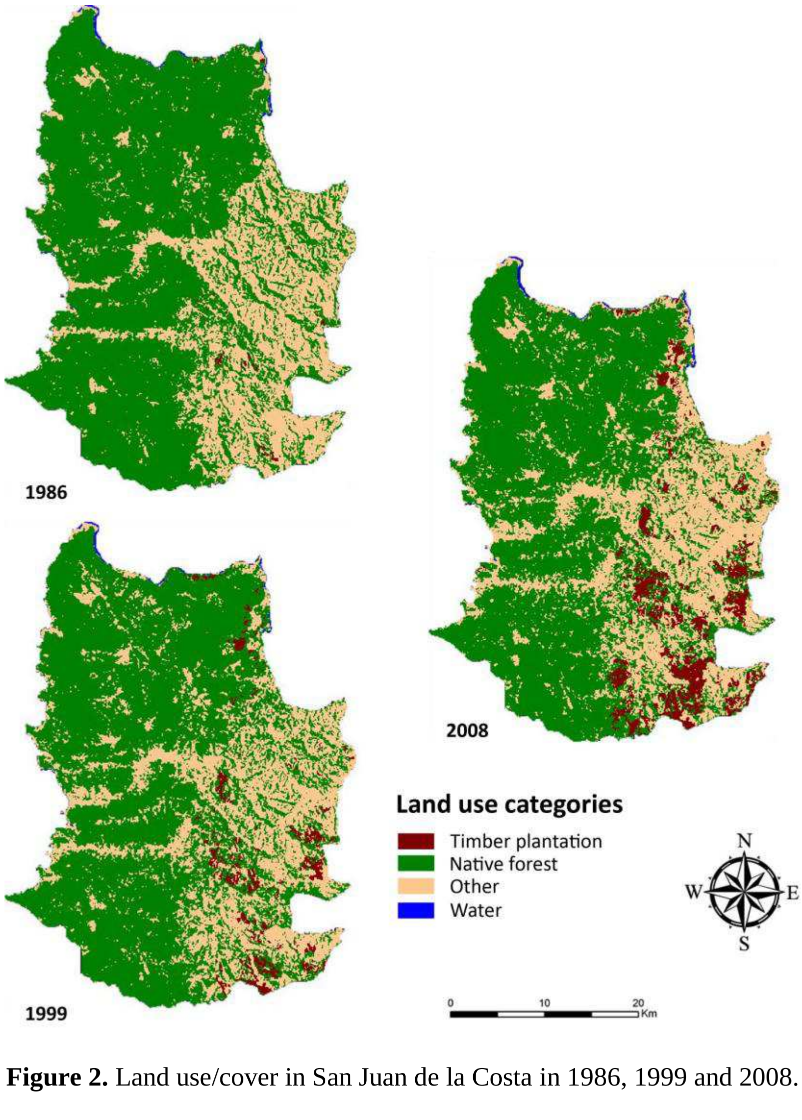

Figure 2. Land use/cover in San Juan de la Costa in 1986, 1999 and 2008.

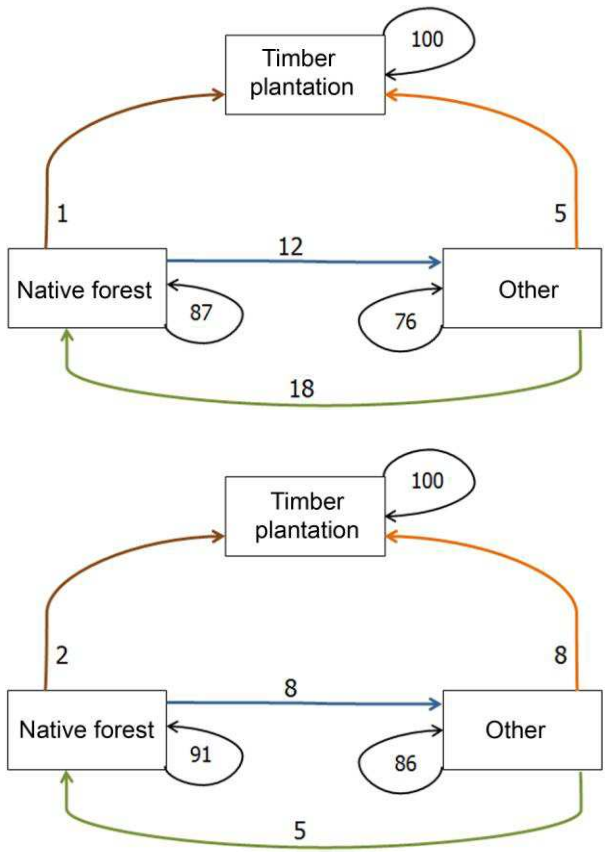

Figure 3. LUCC for 1986-1999 (up) and 1999-2008 (bottom) (in percent). The loops represent persistence and the arrows changes.

LUCC driving forces

The LUCC are influenced by a wide range of environmental and social factors (direct and indirect). According to Eric Lambin and Helmut Geist (2007), these factors have an influence on land use decisions "*across a wide range of spatial scales, from household level decisions that influence local land use practices, to policies and economic forces that can alter land use regionally and even globally*". Succinctly the main drivers are the Decree Law 701, land ability, afforestation costs, property taxes, land property, cultural factors (household consumption), unemployment, poverty, migration, slope, altitude, road network (accessibility), distance from existing land cover, distance from ports, social conflicts, etc.

Scenarios and future land use/cover dynamics

The first is a business as usual scenario (SC-TEND), based on the assumption that previous tendencies will continue. It reaches to 2017 in order to fit the time-frame used during the calibration of the model (9 years). Land availability, DL 701 update (2012), bio-energy, and the approval of the native forest law are taken into account. Results show an increase of timber plantation (15,590 ha, + 58%), while native forest decline remarkably (90,184 ha, - 7%) and the "other" category slightly increases (48,295 ha, + 2%)[1].

The next two prospective scenarios are developed for 2035 because they take more time to implement themselves, given the growth of native species.
The sustainable scenario (SC-SUST) is based on a sustainable vision of the resource management, the recognition of the indigenous lands with the setting up of development

[1] Open water is not modelized because of its persistence between 1986-1999 and 1999-2008.

politics. SC-SUST integrates suggestions of the Agrupación de Ingenieros Forestales por el Bosque Nativo (AIFBN), the Mapu Lahual Territory Project, incentive to agroforestry, promotion and distribution of native forest resources (firewood). This scenario (i) stimulates the native forest expansion regaining new areas (100,600 ha, + 3%), (ii) decreases the exotic species expansion after an increase in 2017 and 2026 (10,600 ha, + 8%) and shows a reduction of the "other" category (42,700 ha, - 8%).
The third scenario is a preservation scenario (SC-0P) with an eco-centric vision. Assumptions include relocation of forest companies which leave the municipality, public demand in environmental advantages, protected areas planning and ecotourism. This scenario shows a net increase of native forest (119,500 ha, + 23%) and the timber plantations collapse (5,400 ha, - 45%).
At last the intensive scenario (SC-2E) called "Sembremos Futuro" (in radical opposition with the previous scenario) is based upon an increase of the incentive for afforestation, making the assumption that international pulp market and competition explodes, land abandonment by small landowners, establishment of a pulp/cellulose factory in the region and redefinition of the routing of Coastal Range Road linking Valdivia to Puerto Montt. It extends the trend of sustained manner until 2026. The plantation areas could reach more than 54,973 ha (+ 456 %), while the native forest could fall below of 71,930 ha (- 26%).

The spatial rendering of each scenario is realized by CA-Markov. Even if both models give acceptable results as for spatial allocation – at least visually –, CA-Markov turns out to be more efficient than LCM for the baseline dynamics. The statistical operations show this model presents better results. Furthermore, conceptually, it gives more leeway – to build backcasting scenario – and to measure the relative importance of the criteria (assignation of weighting factors).

Conclusion

Prospective modeling, and more precisely the spatial dimension, proves to be an advantage to model spatial interactions between environmental and socio-economic dynamics, which was largely lacking in the municipality of San Juan de la Costa. These four scenarios give contrasting visions of future land use/cover dynamics, and represent a basis of reflection in order to suggest efficient environmental policies. "*What we support is prospective thinking, that means to prepare oneself to anticipated changes (pre-activity) and to promote actions leading to the desirable objectives (pro-activity)*" (Godet, 1990, p.731).

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