Land Use Policy 47 (2015) 1–11

Contents lists available at ScienceDirect

Land Use Policy

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

Weakening the Brazilian legislation for forest conservation has severe impacts for ecosystem services in the Atlantic Southern Forest

Gisele G. Alarcon[a,b,*], Yohannes Ayanu[b], Alfredo C. Fantini[a], Joshua Farley[c], Abdon Schmitt Filho[d], Thomas Koellner[b]

[a] Plant Genetic Resource Doctorate Program, Faculty of Agronomy, Santa Catarina Federal University, Rodovia Admar Gonzaga, 1346, Itacorubi, 88.034-001 Florianópolis, SC, Brazil
[b] Faculty of Biology, Chemistry and Geosciences, University of Bayreuth, BayCEER, Universitätsstrasse30 Building GEO II, Room 1.17/1, 19 95447 Bayreuth, Germany
[c] Gund Institute, University of Vermont, 617 Main Street, Burlington, VT 05405, USA
[d] Laboratory of Silvopastoral Systems, Faculty of Agronomy, Santa Catarina Federal University, Rodovia Admar Gonzaga, 1346, Itacorubi, 88.034-001 Florianópolis, SC, Brazil

ARTICLE INFO

Article history:
Received 12 May 2014
Received in revised form 23 February 2015
Accepted 14 March 2015

Keywords:
Atlantic forest
Ecosystem services
Modeling
Environmental policies

ABSTRACT

The Atlantic Forest is a global hotspot of biodiversity that may be on the verge of ecological collapse. Current changes in forest legislation have increased the debate concerning policy impacts on land-use and the consequences for biodiversity conservation and ecosystem services provision. This paper evaluates the impact of three environmental policy options (National Forest Act from 1965-NFA65, Business as Usual-BAU, National Forest Act from 2012-NFA12) on land-use patterns and ecosystem services in the southern Atlantic Forest. InVEST (the Integrated Valuation of Environmental Services and Tradeoffs tool) was used to model ecosystem services. Synergies and tradeoffs between commodities, erosion regulation, carbon storage and habitat for biodiversity were assessed with the Spearman Correlation Test. The NFA65 produced the largest gains for forest ecosystem services, while BAU favored commodities expansion. The NFA12 approaches the baseline, contributing less to the provision of ecosystem services and biodiversity conservation.

Introduction

The rapid degradation of forest ecosystems compromises the long term provision of ecosystem services (MEA, 2005). Agriculture is a major threat to Brazil's forests but also a major driver of economic growth, which takes precedence over environmental protection and ecosystem services in national policies (Martinelli and Filoso, 2009; Martinelli et al., 2010a; Tollefson, 2010; Sparovek et al., 2011). Conservation of the Atlantic Forest – the most threatened ecosystem in Brazil – is regulated by the National Forest Act (NFA), originally promulgated in 1965, and the Atlantic Forest Law (Brasil, 2006). However, poor enforcement of both policies has resulted in the continued loss of Atlantic Forest remnants (INPE and SOS Mata Atlântica, 2011), threatening the ecosystem's resilience (Lees and Peres, 2008; Galetti et al., 2010; Metzger et al., 2010).

The Atlantic Forest Law regulates the conservation of the Atlantic Forest biome, while the NFA regulates conservation of natural ecosystems across all Brazilian states, in public and private properties. Unfortunately, in 2012 the National Congress voted to weaken the NFA from 1965 (NFA65). The debate under the NFA65 reform resulted in an intense mobilization by civil society and the Brazilian scientific community. Different sectors worked on technical reports emphasizing the negative implications of the NFA65 change when faced with the demands from the agribusiness sector (Instituto Socioambiental, 2012; Via Campesina Brasil, 2011; ABEMA, 2012; ANA, 2012). There was also an effort by the Brazilian scientific community to warn of the impacts that the NFA65 change could have on the natural ecosystems resilience and provision of ecosystem services (Develey and Pongiluppi, 2010; Galetti et al., 2010; Metzger et al., 2010; Nazareno et al., 2011; SBPC, 2011; Sparovek et al., 2011; Ferreira et al., 2012); however, it had a low impact on the policy makers (Ferreira et al., 2012).

* Corresponding author at: Corresponding author at: Universidade Federal de Santa Catarina, Centro de Clências Agrárias, Rodovia Admar Gonzaga, 1346, Bairro Itacorubi, 88.034-001 Florianópolis, SC, Brazil. Tel.: +55 4832335199.
E-mail addresses: giselegalarcon@yahoo.com (G.G. Alarcon), joshua.farley@uvm.edu (J. Farley), abdon.filho@ufsc.br (A.S. Filho), thomas.koellner@uni-bayreuth.de (T. Koellner).

http://dx.doi.org/10.1016/j.landusepol.2015.03.011
0264-8377/

The final version of the reformed NFA approved by the Congress was subjected to veto and modifications by President Rousseff in May 2012 (Brasil, 2012a,b), though it still resulted in fewer obstacles to increased agricultural expansion into forests and other natural ecosystems. The impacts of policy changes have been modeled extensively for the Amazon (Nepstad et al., 2008; Soares-Filho et al., 2006), but recently studies simulating the impacts of policy changes on the Atlantic Forest have increased in number (Teixeira et al., 2009; Ditt et al., 2010; Garcia et al., 2013).

While there was a weakening of the NFA65, Brazilian policy makers have also been developing incentive-based policies to reward landowners for the ecosystem services generated by forest conservation, complementing legal mandates affecting land-use in the Atlantic Forest. One approach directed towards landowners is payments for ecosystem services (PES). Approximately 80 such programs targeting the Atlantic Forest reward forest restoration and biodiversity conservation (Guedes and Seehusen, 2011; Pagiola et al., 2012). One of the main challenges for incentive based policies is to understand the tradeoffs expected at local, regional and global scales between ecosystem services and financial returns across different ecosystems under different policy scenarios (Goldstein et al., 2012).

The goal of this article is to use spatially-explicit models of land-use change and ecosystem services to improve the understanding of the tradeoffs and their mutual interactions, and based on this to discuss the implications for the policies at stake (Chan et al., 2006; Nelson et al., 2009; Goldstein et al., 2012; Su and Fu, 2013). Specifically, the spatially-explicit InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) modeling tool (Tallis et al., 2011; Sharp et al., 2014) is applied to evaluate the impact on ecosystem services caused by changes in land-use and land-cover patterns associated with three different policy options for the southern Atlantic Forest. The results inform a discussion on policy options that can balance the apparently conflicting goals of economic growth and conservation of ecosystem services and the expected impacts of the NFA65 reform on ecosystem services provision. A case study approach was adopted. The Chapecó Ecological Corridor was established in 2010 in Santa Catarina State, southern Brazil, to protect relevant biodiversity areas. As highlighted by the Chapecó Ecological Corridor Management Plan, the analysis focuses on provisioning services (i.e. commodities in the region with the greatest market potential), carbon storage, erosion regulation, as well as habitat for biodiversity (FATMA, 2009).

Methods and materials

Study site

The Atlantic Forest is mainly distributed along the Brazilian coast and is a global biodiversity hotspot. Originally it covered 1,315 million hectares, however policies favoring agricultural expansion and urbanization since colonial times have reduced forest cover by 85% from its original extent (Ribeiro et al., 2009). Actually the Southern Brazilian states together contain 34% of the forest remnants (INPE and SOS Mata Atlântica, 2014).

In spite of the high level of fragmentation, the remaining forest exhibits high diversity and endemism, including more than 20,000 species of plants, 261 of mammals, 688 of birds, 280 of amphibians and many more not yet described by science (Myers et al., 2000). Within Santa Catarina State, the Atlantic Forest covers an estimated 27% of its original distribution, and remaining forest structure is considered highly disturbed and degraded by logging, road openings, burning and extensive cattle farming (Vibrans et al., 2013). Enforcement of the laws regulating Atlantic Forest management has increased since 2006, but has failed to halt illegal deforestation (Alarcon et al., 2010; Siminski and Fantini, 2010).

Table 1
Permanent preservation areas (PPA) width according to the National Forest Act from 1965. The widths established independently to properties' size.

Rivers' width (m)	PPA's width (m)
up to 10	30
10–50	50
50–200	100
200–600	200
>600	500

The Chapecó Ecological Corridor (CEC) covers nearly 500 thousand hectares in the west of Santa Catarina state, southern Brazil (Fig. 1). The landscape is characterized by continuous remnants of Araucaria Forest and mixed Deciduous Forest in the lower areas, these two forest types have been reduced to 22% and 16%, respectively, of their original cover (Vibrans et al., 2013). At higher altitudes (1000–1350 m) native grasslands are interspersed with patches of Araucaria Forest. Agriculture and pasture account for 50% of total land-use. Corn, soya and wheat are cultivated in the plain areas, while pasture is mainly located on the steeper slopes. The region supports the highest density of pork production in Latin America. The Chapecó water-basin also provides water for nearly 800 thousand inhabitants (FATMA, 2009).

Policy options mapping

A land-use/land-cover (LULC) map based on SPOT 4 images from 2005 with 10 m resolution provided baseline data for mapping each policy option (FATMA, 2009). Three main policies were selected as follows (see electronic supplementary material Fig. S1 for a magnification of the distribution of land cover for the policy options in Fig. 2):

Policy Option 1: Enforcement of the National Forest Act of 1965. The NFA65 mandated conservation and restoration of native forest cover in ecologically sensitive Permanent Preservation Areas (PPA), which include hilltops, slopes over 45%, buffer forest along rivers and around springs (Table 1). The PPAs were mapped using ArcGis 10 and converted in the model to native ecosystems, according to the criteria established by the National Council on Environment CONAMA Resolution no. 303/2002 (CONAMA, 2002).

Although the NFA65 is forgone, its modeling represents an attempt to provide scientific basis to discuss its reinstatement. Moreover, the NFA65 is a policy closer to an ideal scenario for biodiversity conservation and ecosystem services provision (Teixeira et al., 2009; Metzger, 2010; Metzger et al., 2010; Sparovek et al., 2011) and therefore could improve comparison with the other policy options.

- Policy Option 2: Business as usual (BAU). The BAU model assumes a continuation of the negligible enforcement of existing policies and continued deforestation considering the decades following the NFA65 promulgation (Cardoso Da Silva and Tabarelli, 2000; INPE and SOS Mata Atlântica, 2003, 2009, 2011; Ribeiro et al., 2009). Specifically, it assumes that the average deforestation rate from the period 2000–2012 for the Atlantic Forest in Santa Catarina (INPE and SOS Mata Atlântica, 2011) will remain constant for 45 years (2005 to 2050). The total area to be deforested was distributed in the landscape according to the proportion of forested area in each municipality. In this sense, municipalities with larger forested areas had the largest proportion of deforestation. Forests were substituted by the main agricultural activities developed in the region: grains, pasture and pine monoculture. These three land-use types constitute important commodities within Brazil's boundaries as well as internationally as they are part of the

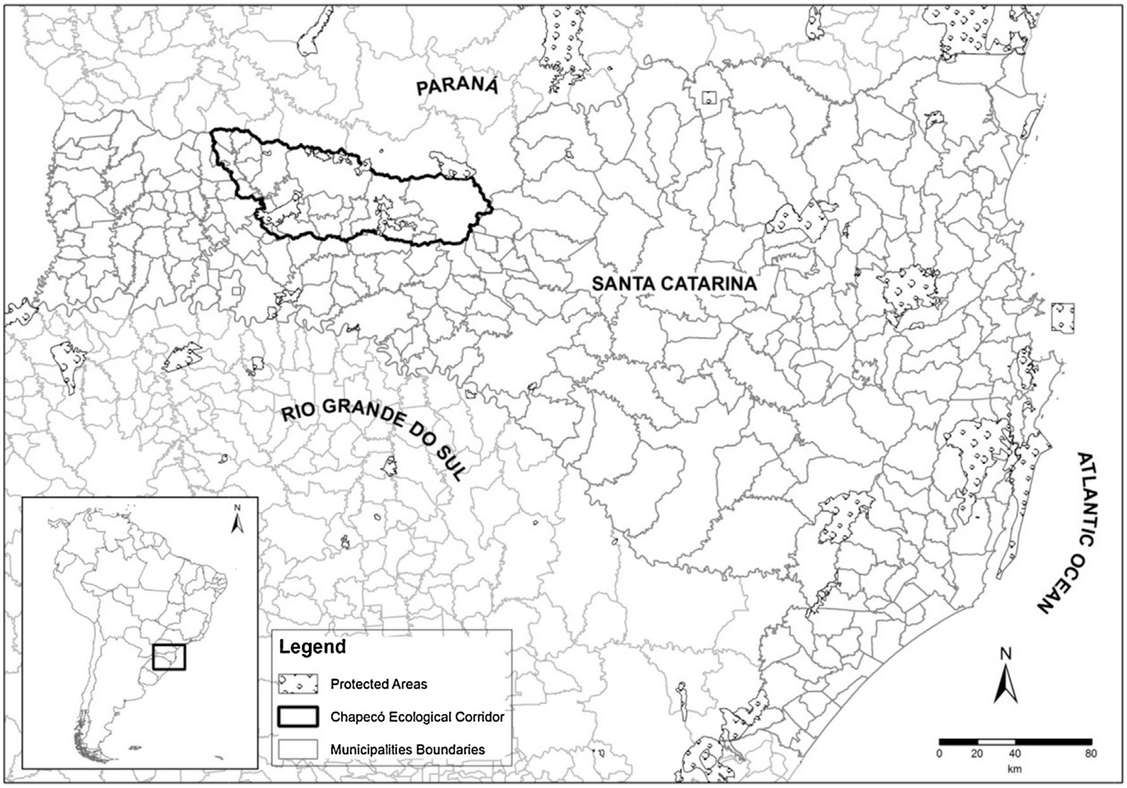

Fig. 1. Chapecó Ecological Corridor (CEC) location in Santa Catarina, Brazil.

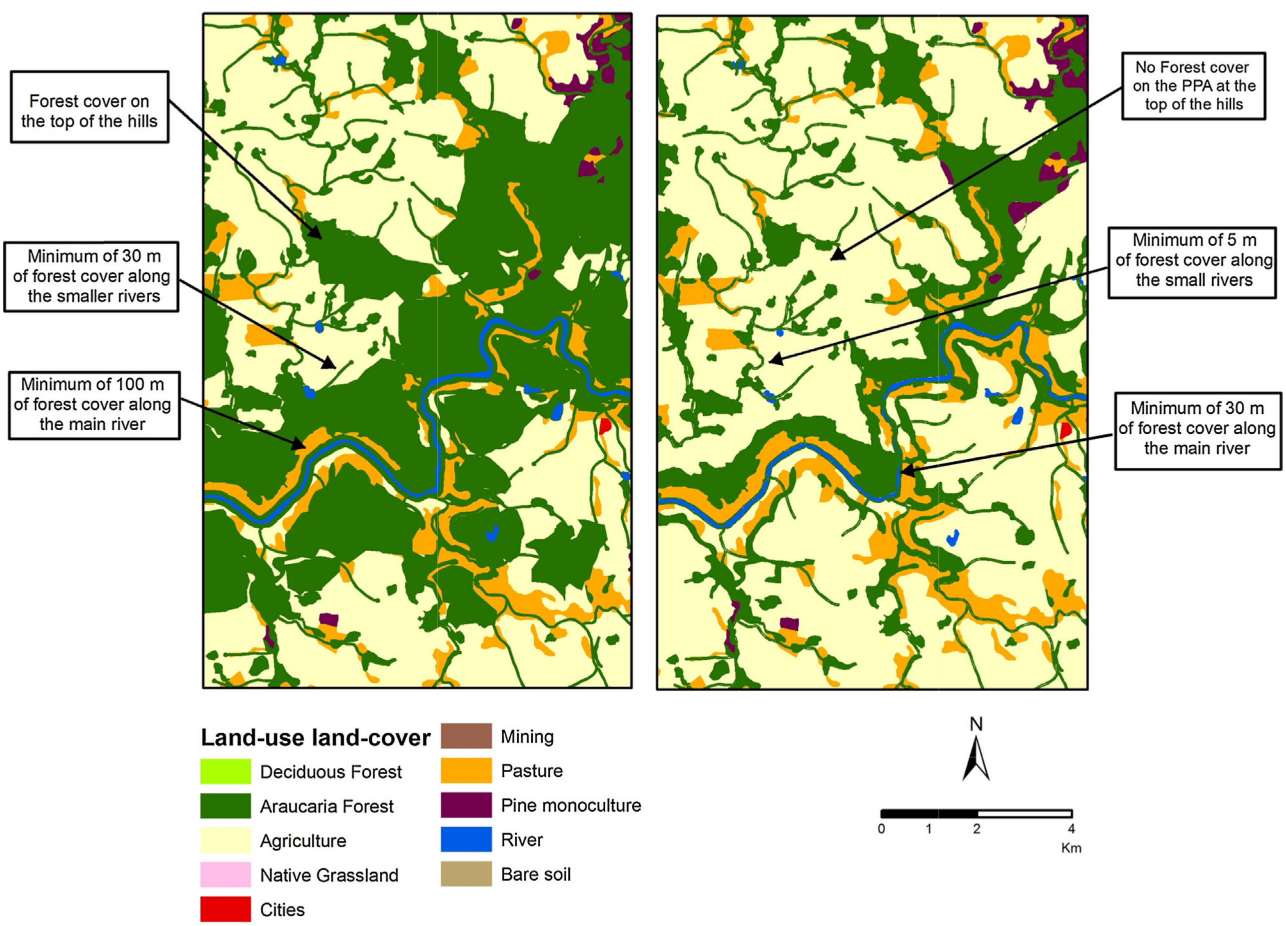

Fig. 2. Zoom at the spatial distribution of Permanent Preservation Areas PPA for the 1965 (left) and 2012 (right) National Forest Acts policy options.

Table 2
Permanent preservation areas (PPA) width according to the properties' sizes (based on fiscal modules—FM) in the National Forest Act from 2012.

Property size	River's width	PPA's width
Up to 1 FM	Independent	5 m
1FM until 2 FM	Independent	8 m
2 FM until 4 FM	Independent	15 m
>4 FM < 10 FM	<10 m	20 m
Other cases	>10 m	Extension corresponding to half of the river's width size (minimum of 30 m, maximum of 100 m)

bundle of agricultural commodities exported by Brazil. It was assumed that the proportion of such land-uses for each municipality in the baseline map would be maintained along the 45 year timeframe for this policy option (Fig. S1). Initial secondary forests were primarily deforested, followed by advanced secondary and primary forests. The deforestation followed certain criteria according to previous studies developed in Santa Catarina state (Alarcon et al., 2010; Zuchiwschi et al., 2010) (see electronic supplement material):

- Policy Option 3: Enforcement of the National Forest Act of 2012 (NFA12). PPA were mapped in conformity with the guidelines established by the law no. 12.651 and its Provisional Measure no. 571 (Brasil, 2012a,b) in ArcGis 10. PPA of rivers and springs were converted to natural ecosystems, while PPA of slopes above 45° and hilltops were kept under the original (baseline map) land-use and land-cover type according to the law criteria. To address the PPA width's variations considering the properties' sizes (fiscal module—FM[1]), the average size of the rural properties defined in the Chapecó Ecological Corridor Management Plan were used (Karam and Araújo, 2007) (Table 2). Rivers were separated by order by Strahler classification in the HidroFlow software (UERJ, 2007) and buffered according to the PPA width classes (Brasil, 2012a).

Analysis of ecosystem service changes and correlations

The InVEST tool was used to model the ecosystem services of carbon storage, habitat quality and erosion regulation, while ArcGIS 10 was used to simulate the provision of agricultural commodities and non-timber forest products (NTFPs). It was assumed that existing and restored Araucaria forests produce NTFPs, deciduous forests will generate no revenue, and remaining land will be allocated toward commodities. The data were run in 100 × 100 m resolution, and included the following ecosystem services:

- Non-timber forest products provision: Araucaria seeds (*Araucaria angustifolia*), an edible nut extensively harvested in the south of Brazil, and mate (*Ilex paraguariensis*), a tea popular in the Southern Cone, are the major commercial NTFP. It was assumed that all areas under Araucaria Forest can potentially produce the same amount of Araucaria nuts and mate per hectare/year (Table S1). The estimated income from the NTFP is based on data from Da Silva (2006) and de Andrade (2002). It was chosen the mean mate yield per hectare year obtained for a non-technified system including management techniques such as acquisition or production of seedlings for the herbal densification, protection of the seedlings, mowing and tree pruning every three years with machete (de Andrade, 2002). The values of Araucaria nuts were adjusted to 2011 based on the cumulative inflation rate for the period and for mate the data for 2011 was obtained from CEPA (2012).
- Commodity provision: Soya, milk and pine monoculture (*Pinus* spp.) are the main commodities produced at the study site. Soya and milk productivity and income were estimated per hectare for each municipality based on data provided by two local cooperatives and from secondary data from CEPA (2012) for the same period (Table S2). For pine monoculture the rotation period of 15 years for *Pinus taeda* and *Pinus elliottii* and the production of 38 m^3/ha/year for the region were considered (BRACELPA, 2010). Data on the mean profits for these species were provided by the Brazilian Center of Intelligence on Forests. Data used came from the sale of logs higher than 30 cm from the south and southeast region of Brazil, which is around US$ 22 per cubic meter (FLORESTAS, 2012).
- Carbon storage model: Table S3 provides data for below and above ground biomass, including soil and dead organic matter for all LULC types. The model generates an aggregated estimate of total carbon storage in each grid cell and across the whole landscape. Local data was used when available, complemented when necessary with data from nearby regions.
- Erosion regulation model: the model calculates the average annual soil loss and sediment transport for each parcel of land using the Universal Soil Loss Equation (USLE) at the pixel scale. For the USLE equation local data was provided, supplemented by regional data when necessary (Tables S4 to S7).
- Habitat quality model: produces habitat quality maps based on information about the LULC and threats to biodiversity, according to Baan et al. (2012). The threats include urban areas, cattle, agriculture, primary and secondary roads, and pine tree monoculture (Tables S8 and S9).

The Kruskal Wallis post hoc test was used for a pairwise comparison of ecosystem goods and services under different policy options using the function "kruskalmc" of the "pgirmesss" package in R language v. 2.15.1 (R Core Team, 2013). As data were not normally distributed, the nonparametric Spearman Correlation Test was also applied in order to identify synergies and tradeoffs among the goods and services analyzed for each policy option. The correlation was pixel based (100 m × 100 m, total of 516 thousand pixels). After extracting the correlation coefficient, a second analysis of Spearman Correlation was done to compare the pattern between the policy options using the function "cortest" and "ks" of the "stats" package in R language v. 2.15.1 (R Core Team, 2013). Cumulative R was calculated as the sum of all correlation coefficients of one ecosystem service with all others (Jopke et al., 2014). Negative values of cumulative R indicate conflicting ecosystem services, whereas positive values show synergistic ones.

Results

Impacts of environmental policy changes on LULC patterns

According to the baseline map, the CEC has 56% of its area under agricultural uses, of which 30% is grains. 48% of the PPA along rivers and springs should be recovered within the NFA12 and 54% within the NFA65. Nevertheless, adding the PPA of slopes under 45 degrees, hilltops and the wider strips of PPA, the NFA65 would result in a total forest gain of 80 thousand hectares. Araucaria Forest increased by 60% and Deciduous Forest by 54% within this policy option. The conversion of PPA along rivers and around riverheads resulted in a 13% reduction in native grasslands (Overbeck et al.,

[1] In Brazil the properties' sizes are classified based on standard lot measures called fiscal modules (*Módulo Fiscal*). The fiscal module was established by Law No. 6.746/1979. It is expressed in hectares and it is variable according to each municipal district, taking into account the predominant type of land-use in the municipality, the concept of family property between others.

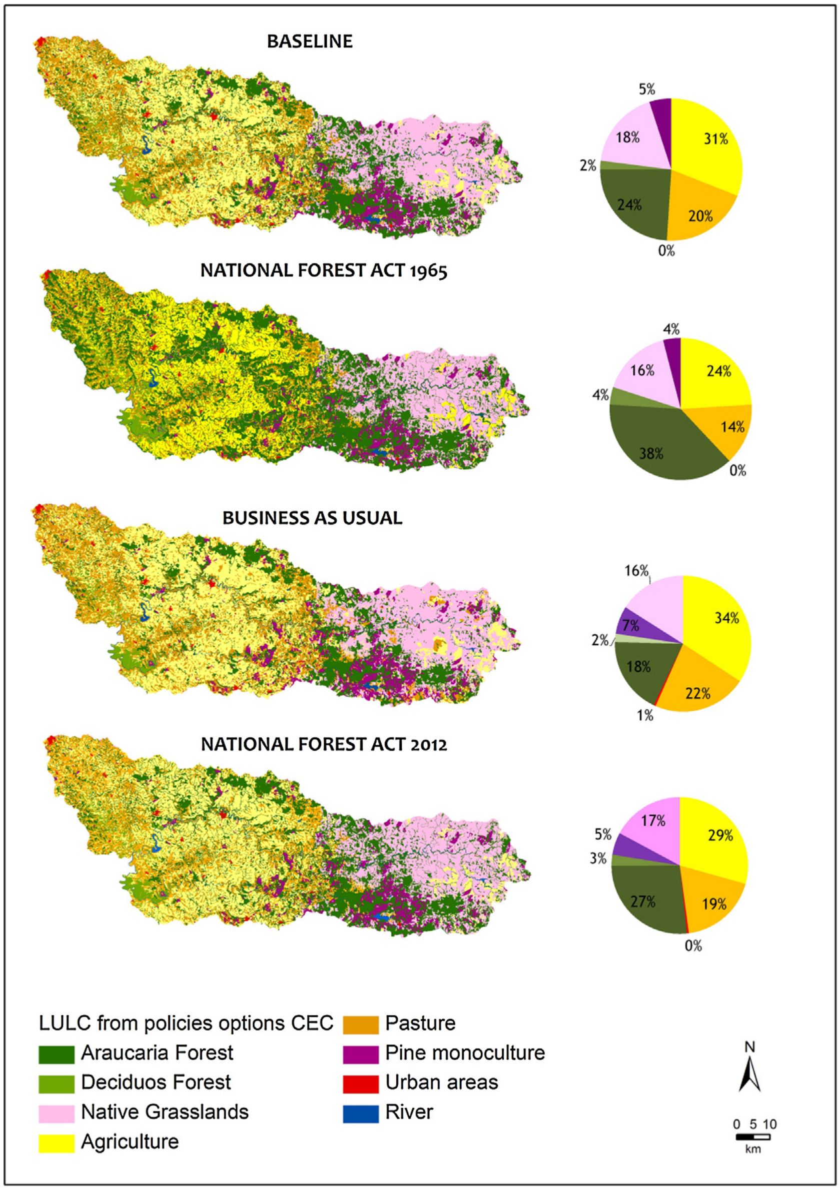

Fig. 3. Policy options mapped at the Chapecó Ecological Corridor (CEC), Santa Catarina, Brazil. The graphs on the side of each policy option map represent the respective land-use and land-cover types' percentages.

2007), while areas in agriculture, pasture and pine tree monoculture were reduced by 21%, 28% and 24%, respectively (Fig. 3).

In the BAU scenario, the annual deforestation rate of 0.5% resulted in the loss of 28,000 ha of forest and 10,000 ha of grasslands in 50 years, a lack of monitoring information and the rapid advance of agricultural activities over the native grasslands suggests this may be an underestimation for this unprotected ecosystem (Overbeck et al., 2007). Deforestation resulted in the loss of small corridors between forested areas especially in the western and central part of the study site (Fig. 3).

Compared to the NFA65, the NFA12 registered a lower increase in forested areas. If all the PPA along rivers and springs were recovered according to the guidelines of this new regulation, it would result in an increase of 17 thousand hectares of Araucaria and Deciduous Forest altogether or an increase of forested areas by 13% compared to the baseline. On the other side, it would also represent a decrease of 4%, 6% and 3% of areas intended for grains, pasture and pine monoculture, respectively (Fig. 3).

Ecosystem services provision under different policy options

The three policy options and the baseline showed significant differences for all ecosystem goods and services ($p < 0.001$), with the exception of pine monoculture for the policies baseline and NFA12 (Table S10). The NFA65 produced the largest gains for all forest based goods and services (carbon, mate, araucaria nuts, habitat quality) and erosion regulation, the BAU produced the largest gains for production of agricultural commodities, while the NFA12 assumed a middle position between the two policies and the baseline (Fig. 4, Table 3). Carbon stock increased 17% in the NFA65 policy and 10% in the NFA12, when compared with the baseline. In the BAU, there was an 8% loss of carbon stock.

The NFA65 generated 60% more araucaria nuts and mate compared to the baseline while the NFA12 generated 13% more of both. Araucaria nuts and mate have consolidated markets in Brazil, and their increased output in the NFA65 scenario would be worth US$ 48 million and US$ 13 million in the NFA12 scenario, for the whole

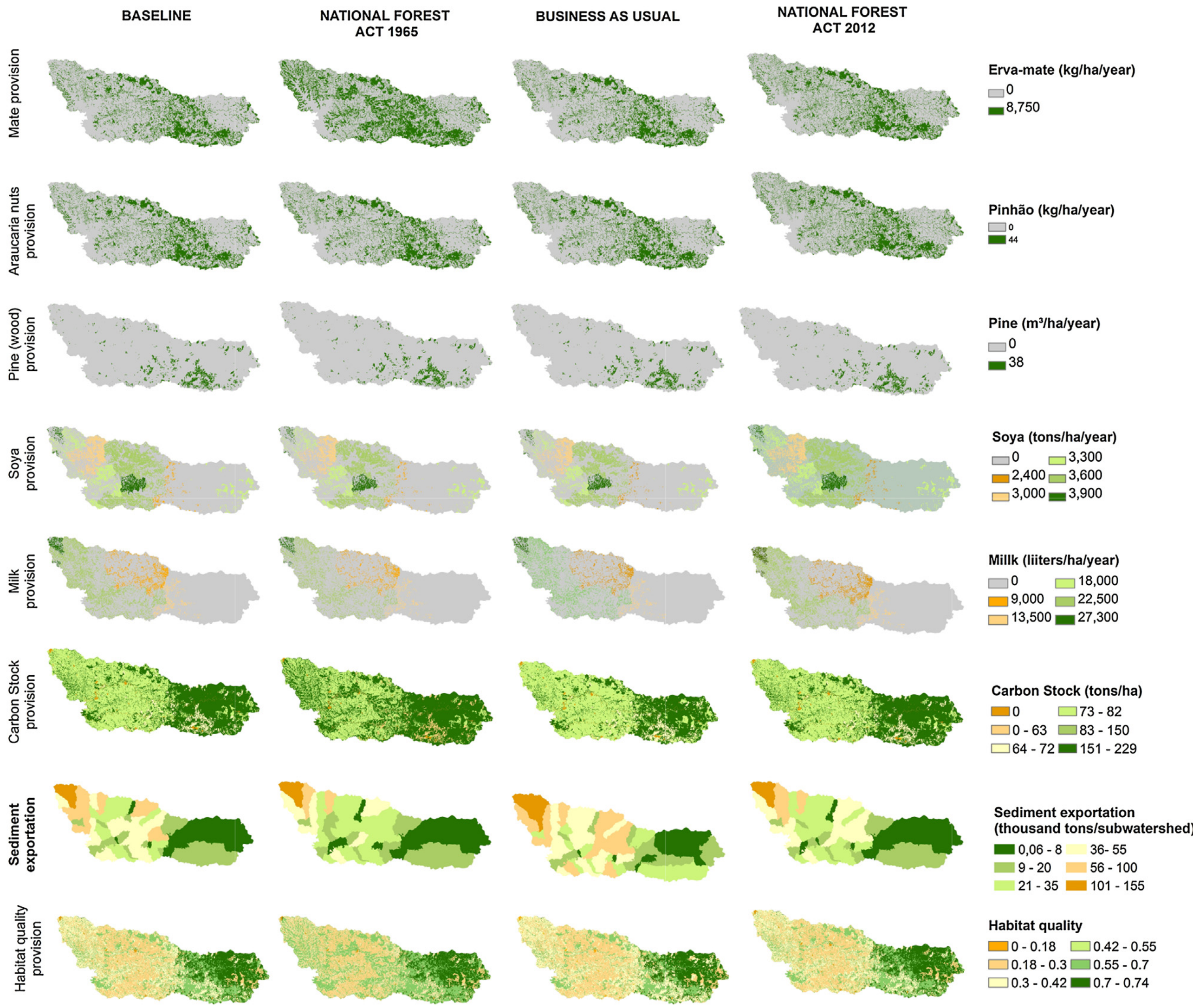

Fig. 4. Maps of ecosystem goods and services provision change for each policy option.

case study site annually. The NFA65 showed the greatest increase in habitat quality, especially within the PPA, which remained poorly forested with extensive edge effects in the other two policy options, especially in the more fragmented central region of the CEC. In all three policy options and the baseline, the native grasslands had the highest score for habitat provision, resulting from their connectivity, extension and lower edge effect.

The BAU results in the greatest decrease in erosion regulation, resulting in 83% greater soil exportation per hectare (4.7 t/ha) compared to the baseline (3.9 t/ha). The full implementation of the NFA65 would result in a decrease of 30% in soil exportation (2.7 t/ha) while the NFA12 of 17% (3.2 t/ha). Production of pine monoculture and soya in the BAU increased by 24% and 21%, respectively, compared to the baseline scenario and would generate an additional annual net income of US$ 6 million (pine) and US$ 20 million (soya) compared to current production. Growth in pasture area would yield an additional US$ 7.5 million in annual net income from dairy production for small and medium landholders. On the other hand, the conversion of the baseline scenario into the NFA65 resulted in a loss of 32 thousand hectares for grain cultivation, representing a loss of US$ 35 million/year (values for 2011). If the three main commodities (grains, pine and milk) are considered,

Table 3
Total ecosystem services supplied per policy option in the whole region of 500 thousand hectares.

Ecosystem goods and services	Baseline	National Forest Act 1965	Business as usual	National Forest Act 2012
Mate (Mkg^{-1} year^{-1})	1057.3	1695.6	820.3	1193.1
Araucaria nuts (Mkg/year)	5.3	8.6	4.2	6.0
Pine (Mm^3/year)	1.1	0.8	1.3	1.0
Soya (Mt/year)	514.6	407.0	578.1	495.7
Milk (Ml/year)	848.2	610.7	958.0	794.7
Carbon stock (Mt/year)	65.4	76.6	60.3	72.0
Erosion regulation (t sediment/ha/year)	3.9	2.7	4.7	3.2
Habitat quality (index × 10^3)	231.7	256.0	216.6	238.3

Mkg: million kg.

the total aggregated economic loss with the full implementation of the NFA65 would be US$ 58,30 million/year. The conversion from the baseline to the NFA12 accrued 80% less economic losses (US$ 11 million/year) compared to the NFA65.

Synergies and trade-offs between ecosystem services

All of the seven ecosystem goods and services analyzed for the policy options were pairwise plotted (Fig. S2). Overall the 21 pairwise sets kept the same pattern of correlation coefficients between policy options ($r \geq 0.77$). The correlation was classified as weak ($r < 0.3$), moderate ($0.3 \leq r < 0.5$) and high ($r \geq 0.5$) (Table S13). Mate and araucaria nuts occurred in the same structure of LULC (Araucaria Forest) and therefore had the highest correlation (Spearman coefficient, $r = 1$). Overall, tradeoffs were observed between commodity provisioning and all other services, with the exception of the tradeoff of soya and milk with erosion regulation. The highest negative correlation was recorded between soya and habitat quality in all three policy options and the baseline ($-0.45 \leq r \leq -0.15$). Pine monoculture had a weak and negative correlation with all of the other ecosystem services, with the exception of carbon, where the correlation was negative but moderate ($-0.012 \leq r \leq -0.42$) within the baseline, BAU and NFA65, and weak but positive within the NFA12 (Fig. S2, Table S13). The main synergies observed were between the provisioning services of NTFP and carbon, and between habitat and carbon. In most cases the services were highly positively correlated (Fig. S2, Table S13). The cumulative R between −2.16 and −1.65 shows that provisioning of soya is in all scenarios the most conflicted ecosystem service. Contrarily, provision of mate and araucaria nuts are the most positive ones (R cumulative between 1.09 and 1.14, see Table S14).

Discussion

Impacts of environmental policy changes on LULC patterns

In line with other research, changes of environmental policies influenced LULC patterns with significant impacts on ecosystem goods and services provisioning (De koning et al., 2007; Liu et al., 2008; Swetnam et al., 2011; Goldstein et al., 2012). The National Forest Act from 1965 NFA65 was the most relevant policy option for the conservation of natural ecosystems and provisioning of ecosystem goods and services, while the Business as Usual BAU scenario resulted in the largest losses.

Brazilian environmental policies play an important role for the conservation of the Atlantic Forest, but it is still inefficient even in regions with special attention and high conservation efforts like the study site. The enforcement of the NFA65 in the Chapecó Ecological Corridor would encompass an additional 80 thousand hectares of forested areas in important ecological regions, enhancing the Araucaria Forest and, especially, the Deciduous Forest. Respectively only 22% and 16% remain of the original extent of these forested ecosystems, mostly disturbed by logging, road construction and cattle (Vibrans et al., 2011, 2013). The enforcement of the NFA65, in addition to increased habitat, would help restore ecosystem structure and functions, and improve connectivity among remnants across the landscape.

The National Forest Act from 2012 NFA12 represented gains in forested areas and provisioning of ecosystem services compared to the BAU scenario, but significantly less than the old Forest Act (NFA65). The need for restoration of narrower strips of Permanent Preservation Area PPA and the possibility to leave hilltops, slopes between 25 and 45°, plateaus and areas above 1800 m (protected under the NFA65) under agricultural use can cause significant negative impacts not only in ecosystem services provisioning and biodiversity conservation (Lees and Peres, 2008; Develey and Pongiluppi, 2010; Galetti et al., 2010; Garcia et al., 2013), but also on soil exportation and groundwater recharge areas (ANA, 2012). It is expected that the enforcement of the NFA12 will result in 63 thousand hectares less to be restored along rivers and springs. Considering the whole biome, the NFA12 reduces the restoration target by 6 million hectares, affecting significantly the Atlantic Forest Restoration Pact (Calmon et al., 2011). While the approval of the NFA12 might create the means to enforce this policy implementation and result in some restoration along rivers and springs, it reduces the chances that this restoration will add effectively to habitat provision and biodiversity conservation (Metzger et al., 2009; Metzger, 2010; Garcia et al., 2013).

On the other hand, the BAU would lead to the conversion of forested areas (21%) and native grasslands (11%) into agriculture. The estimated deforestation rate was low compared to the typical rates observed in the Amazon biome, but it was higher compared to the South American and global rates for the same period (FAO, 2011). The enforcement of the Atlantic Forest regulation, in place since 2006, strongly restricts forest management, but its enforcement has failed to halt illegal deforestation (Siminski and Fantini, 2010). In the Atlantic Forest biome, the persistence of a BAU situation could eventually lead its ecosystems to fall below ecological thresholds, as highlighted by several scientists (Lees and Peres, 2008; Teixeira et al., 2009; Galetti et al., 2010; Metzger, 2010). In the case of native grasslands, the conversion rate under the BAU was underestimated due to the lack of monitoring information and the rapid advance of agricultural activities in this unprotected ecosystem type (Overbeck et al., 2007). Without law enforcement, this ecosystem conversion could be much higher than what was projected for the BAU situation.

Both NFAs and the BAU policies represent potential changes in the income from forest and agricultural products. Under both NFAs, the additional Araucaria Forest cover would provide farmers an equivalent of US$ 1570/ha/year from the exploitation of araucaria nuts and mate. Such an estimate is based on management techniques including acquisition or production of seedlings for the herbal densification, mowing, and tree pruning every three years (de Andrade, 2002). The management system, whether technological or more rudimentary, can significantly influence the income derived from these NTFPs. Depending on the management techniques, the income generated by the exploitation of araucaria nuts and mate could be competitive with the net income generated by soya (US$ 1088/ha/year) and pine monoculture (US$ 1096/ha/year). Nevertheless, markets for these commodities are much larger and in rapid growth in Brazil (Martinelli and Filoso, 2009; Tollefson, 2010). Carbon markets could raise the income generated by the NTFPs exploitation within the CEC and the Atlantic Forest biome in the Southern Cone, making the forest remnants even more competitive. Voluntary carbon markets and other funding for ecosystem services provisioning through PES programs are expanding rapidly in the Atlantic Forest, but the income generated for farmers is still very modest (US$ 33 to US$ 370/ha/year) (Guedes and Seehusen, 2011; Pagiola et al., 2012; Dos Santos et al., 2012). Regarding the markets for avoided deforestation, most projects under development in Brazil are restricted to the Amazon, with few resources reaching the Atlantic Forest (Venter et al., 2009).

Synergies and tradeoffs between ecosystem services

Tradeoffs were observed between crop and pine production as well as other ecosystem services. The same pattern was observed in different case studies around the world (Nelson et al., 2009; Raudsepp-Hearne et al., 2010; Ayanu et al., 2011; Goldstein et al., 2012; Jopke et al., 2014), as well as in global projections (Foley et al., 2005; Nelson et al., 2010). In this study soya was negatively correlated with carbon and habitat quality. Raudsepp-Hearne et al. (2010) found a strong negative correlation between carbon sequestration and crop production in Montreal, Canada, and Goldstein et al. (2012) found the same pattern between carbon storage and the economic profits of agriculture in Hawaii. Pine production also demonstrated a weak and moderate negative correlation with all other ecosystem services with the exception of carbon within the NFA12 policy. Cultivation of soya and pine monocultures results in complete substitution of natural ecosystems in order to guarantee the exclusive production of one or two provisioning services. When LULC management actions favor few or only one ecosystem service, they can cause unwanted or unexpected declines of the other services (MEA, 2005). Normally farmers are motivated by fast profits and are not worried and/or not aware of losing other ecosystem services that might interfere with their production levels in the long term (Rodríguez et al., 2006; Bennett et al., 2009). In Brazil, the rapid expansion of the agribusiness sector can, with the support of government programs and subsidies, bring a short pathway to profit despite the international instability of prices. Public policies are in place to foster sustainable practices, however they still play a secondary role (Tollefson, 2010).

Synergies between ecosystem goods and services were also observed. Araucaria nuts, mate, carbon and habitat quality were positively correlated in all three policy options and the baseline. The correlation between carbon and araucaria nuts and mate is primarily related to the high values of carbon stock found in the Araucaria Forest, particularly the carbon above and in the soil compared to the other LULC types in the study site. Synergies between habitat for biodiversity and carbon have been assessed in several studies at local and global scales with different and sometimes opposite outcomes (Naidoo et al., 2008; Nelson et al., 2009; Larsen et al., 2011; Izquierdo and Clark, 2012). In this case study, the positive correlation between these ecosystem services is most likely related to their dependency on the land-cover types. The highest scores for habitat for biodiversity and carbon were both found in the natural ecosystems (forests and grasslands). Synergies and tradeoffs between ecosystem services vary across scales and may be dependent on the ecosystem type (Raudsepp-Hearne et al., 2010). In this sense, a decision to favor one or multiple ecosystem services must be preceded by a comprehensive evaluation of their dynamics at the local or regional scale.

An overall difference in the pairwise correlations between the policy options was not detected in this study, likely because the policies changes analyzed were mainly related to the increase/decrease of natural ecosystems in the landscape. The change between each policy does not interfere with management practices within each LULC. For instance, full implementation of the NFA12 policy could enforce monitoring and decrease forest disturbance, but will not imply the adoption of management practices necessary to increase NTFP production. The same situation was observed in the agricultural lands, where none of the policies modeled interfered with tillage or other agronomic practices. Due to the importance of management practices within each land-use to foster ecosystem goods and services as well as biodiversity, we suggest that further research focuses on modeling changes in environmental policies including changes on management practices in order to help and inform decision makers.

Constraints of PES programs under weak environmental legislation

In Brazil, many PES programs were seen as market based instruments to compensate for the poor enforcement of the NFA legislation. In the Atlantic Forest such programs are related to the reforestation of riverheads, riparian zones and steep slope areas (Guedes and Seehusen, 2011; Pagiola et al., 2012). PES programs gave farmers the opportunity to reforest PPAs in return for economic incentives, which normally are below the opportunity costs (Zanella, 2011; Pagiola et al., 2012). Full implementation of the NFA12 could be a driving force to stimulate land-use decisions within the Atlantic Forest and PES could take an important role by compensating farmers for economic losses and reforestation activities (Ditt, 2008; Pagiola et al., 2012). However, for three PES programs investigated along the Atlantic Forest the opportunity cost was considered an important variable in influencing farmers' decisions on how to manage their properties. Farmers with higher opportunity costs tended to participate less in PES programs (Zanella, 2011). The lack of information about ecosystem services relevance and the preference for short term economic benefits were also considered as major factors influencing farmers' decisions on land-use patterns. These were previously highlighted by Silvano et al. (2005) in Rio de Janeiro and by Alarcon (2014) in Santa Catarina as possible constraints for farmers' participation in PES programs.

The recent approval of the new NFA (NFA12) established the obligation of farmers to enroll on the Rural Environmental Register (*Cadastro Ambiental Rural*, CAR) and on the Program of Environmental Regularization (*Programa de Regularização Ambiental*, PRA). Such conditions might influence the farmers decision on enrolling in PES programs focused specifically on the areas demanded by the new legislation, as observed by Alarcon (2014) in the study site.

It is most likely that if a BAU policy took place, farmers' interest in PES programs would change. Most PES programs in the Atlantic Forest have been developed under a BAU atmosphere (low enforcement of the NFA65) but with growing restrictions coming from command and control actions developed by state and federal environmental agencies in the last years. In this context, it is highly likely that PES schemes under weak legislation in Brazil could be subject to opportunity costs and their success relies on farmers' ecological consciousness and willingness to designate part of their land for conservation. The situation is particularly bad in the southern Atlantic Forest region, where farmers are more structured, infrastructure is more developed and consequently opportunity costs are higher. It is important to highlight that high opportunity costs will have more influence on restoration activities, as the Atlantic Forest law restricts the cutting of advanced secondary and primary forests. PES programs based on bundles of ecosystem services in high biodiversity priority areas in the Atlantic Forest could compete with high opportunity costs, but the scale of such programs would reach far fewer areas.

Constraints of the methodological approach

There are some important caveats in the methodological approach of this paper that should be taken into consideration. Regarding the LULC map, three issues must be considered. First, the LULC map was based on a 2005 spot image, but for the last ten years the study site has suffered rapid changes in land use and land cover due to the expansion of commodities subsidies and the rise of food prices (Martinelli et al., 2010b). Second, the BAU map was modeled considering the maintenance of the same main agriculture activities (soya, pine and pasture for dairy production). New commodity subsidies focused on different products could result in different expected income and larger changes of land-use and land-cover patterns, in turn affecting opportunity costs. These aspects were not captured by this study. Third, the deforestation trend was assumed to keep the same pace as the previous decade. Nevertheless, in the next years, the new National Forest Act (NFA12) might interfere with this rate, modifying the trend observed between 2002 and 2012. Such changes were not included or simulated on the LULC map.

Another important aspect is related to the income calculated for each ecosystem good analyzed. The forest products income was underestimated. The Deciduous Forest was not included in the analysis and it could generate important revenue for famers, increasing the total potential income from forests' products as a whole. For the commodities chosen, the mean value used in the models, especially for pine productivity and for milk production, can cause spatial distortions on the income estimated. For example, income from milk production can vary from US$ 45/ha/year to 3400/ha/year, depending on the management practices adopted (Alarcon, 2013). Soya income has much less variation but the rotational aspect of this crop production can add to the final income. Farmers planting soya have two harvests per year, one of soya and the other one is variable mainly consisting of wheat, beans, triticale or oat. In this sense, besides profiting from the soya, farmers have another annual income using the same area, which can sometimes double their profit depending on the crop chosen.

To conclude, the last important aspect is related to the modeling approach. Uncertainty in modeling ecosystem services based on a landscape approach has recently draw attention from the scientific community (Hou et al., 2013; Hamel and Guswa, 2014). Nevertheless, efforts to provide more certainty within such models are still quite rare (Viglizzo and Frank, 2006; Egoh et al., 2008; Naidoo et al., 2008; Goldstein et al., 2012; Izquierdo and Clark, 2012; Ziv et al., 2012). As ecosystem services modeling is considered a new science and efforts are towards influencing decision making (Goldstein et al., 2012) methods to tackle uncertainty are in debate and many papers have been published with scientific rigor under an uncertainty atmosphere (Seppelt et al., 2011; Hou et al., 2013). The Invest tool has important constraints regarding ecosystem service modeling (Nelson et al., 2009; Tallis et al., 2011); however, its use to model ecosystem service provision and variation has largely increased worldwide (Nelson et al., 2009; Goldstein et al., 2012; Izquierdo and Clark, 2012; Hamel and Guswa, 2014). In this study relevant aspects were taking into consideration in order to minimize model results uncertainty (Hou et al., 2013). It was used reliable LULC map with a spatial resolution of 10 m; LULC classes were diversified including the two types of tropical forest ecosystem in the region and the native and anthropic pasture lands; most of the ecosystem services selected to be modeled were easily quantifiable (carbon, mate tea, soya, milk, Araucaria nuts and pine); and most of the data used were coming from south of Brazil and specifically from the Atlantic Forest biome. However, in some cases global data were used as well as data coming from non-published work or even from other regions of the country. The precision of the results might have being affected accordingly. An accuracy table is provided in the electronic Supplement material (Table S14).

Conclusions

The increase in native vegetation under the NFA policy dating back to 1965, could significantly enhance ecosystem services, while the BAU increases the likelihood that the Atlantic Forest will surpass irreversible ecological thresholds (Lees and Peres, 2008; Metzger et al., 2009; Galetti et al., 2010). One policy favors forest conservation and the other economic growth. The NFA12 also enhances ecosystem services compared to the BAU, but it is closer to the baseline situation. To determine which of these policy options is best requires comparison of the marginal benefits of conservation with the opportunity costs of decreased commodity production. Since ecosystem services generate benefits at the local, regional and global levels, the relative values of costs and benefits depend on the scale of analysis.

Landowners will prefer conservation only if the net returns to reforestation exceed the net returns to commodity production (Amigues et al., 2002; Arriagada et al., 2009; Buckley et al., 2012) or if they are forced to (Arriagada et al., 2009; Alarcon, 2014). There are three basic policy options that can affect this ratio. One option is PES. The values paid in PES projects within Brazil are not competitive enough with the income generated by commodities. PES based on carbon offsets could increase the potential income generated by PES programs. Native forests in the study site store approximately 80 more tons of carbon per hectare than pasture, cropland or pine which over 50 years amounts to only three tons per year. Carbon payments net transaction costs would have to exceed at least US$ 300 per ton to make the NFA65 competitive with the BAU. A second option is to increase the returns to NTFPs by either developing new products or increasing the markets for such products. A third option is to increase the penalties for failure to comply with the existing laws, which would of course be less effective with a switch to the NFA12, which requires fewer protected areas.

The NFA65 would result in significantly more forested areas within the Atlantic Forest, and in decrease of agricultural production. The NFA12 should result in significantly less forests compared with the NFA65, but it is expected that it will improve the enforcement of PPAs' restoration (specifically along rivers and springs) as well as the other law devices. The CAR (Rural Environmental Registry) and the PRA (Program of Environmental Regularization) are expected to make it possible to identify farmers which are in an illegal situation and they intend to provide enough structure to foster restoration and monitoring. Nevertheless, the width of the PPA along rivers and springs do not follow scientific recommendations, making these forests strips highly susceptible to edge effects and much less efficient in restraining river sedimentation. In the BAU, such effects are enhanced.

Which of these policy options makes most sense depends on their cost and benefits for Brazil and for the world. If Brazil expands PES schemes to reward farmers for complying with a more restricted forestry law, or penalizes farmers for failure to comply, it will likely increase forest cover at the expense of short-term economic growth. While it is true that the continued degradation of the Atlantic Forest may have unacceptable economic costs in the future, politicians are likely to ignore such long-term impacts. Brazil is currently investing significant resources into agricultural R&D but primarily in conventional agriculture, which increases opportunity costs, undermining its efforts to promote conservation (Martinelli et al., 2010a,b; Ferreira et al., 2012). In contrast, investing in R&D in agroecosystems that increase returns to NTFP, or that enhance ecosystem services provided on existing farmland, would help Brazil meet its dual goals of growth and conservation.

The only policy option available at a global level is some form of payment. Global markets in soya, beef, dairy and timber are very well developed, while global payments for other ecosystem services are negligible. However, a serious dilemma arises if global PES schemes are at the expense of food production. The demand for food is highly inelastic, which means that very small decreases in quantity lead to large increases in price, and dramatic increases in malnutrition. While ecosystem services are essential, so is food, and there may be no acceptable tradeoffs between the two. A contribution to landscape planning that can simultaneously increase food production and other ecosystem services could be a win–win strategy.

This paper has demonstrated how changes in environmental policies can affect LULC patterns and ecosystem services within the Atlantic Forest, and discussed the challenges to reduce the tradeoffs between economic growth and ecosystem services maintenance. It is essential that further research is done in the next years to understand ecosystem service losses or gains within the NFA change and if they have or have not interfered with food production in the Atlantic Forest and the other Brazilian biomes.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.landusepol.2015.03.011.

References

ABEMA (Associação Brasileira de Entidades Estaduais de Meio Ambiente), 2012. Nota da ABEMA sobre a proposta de Código Florestal. Associação Brasileira de Entidades Estaduais de Meio Ambiente, http://www.abema.org.br [www document].

Alarcon, G.G., Beltrame, Â.V., Karam, K.F., 2010. Conflitos de interesse entre pequenos pridutores e a conservação de Áreas de Preservação Permanente na Mata Atlântica. Floresta 40, 295–310.

Alarcon, G.G., 2013. Opportunity costs and willingness of farmers to receive economic incentives for forest conservation at the Chapecó Ecological Corridor: a comparative analysis with amounts paid on payment for ecosystem services programs in Brazil. In: Tecnhical Report. EPAGRI, Florianópolis.

Alarcon, G.G., 2014. É pagando que se preserva? Limitações e oportunidades do pagamento por serviços ambientais como instrumento de conservação de recursos florestais no Corredor Ecológico Chapecó. Universidade Federal de Santa Catarina, Florianópolis, Santa Catarina (PhD Thesis).

Amigues, J., Boulatoff, C., Desaigues, B., Gauthier, C., Keith, J., 2002. The benefits and costs of riparian analysis habitat preservation: a willingness to accept/willingness to pay contingent valuation approach. Ecol. Econ. 43, 17–31.

ANA (Agência Nacional das Águas), 2012. Avaliação da definição de faixa de largura mínima para as áreas de proteção permanente ao longo dos cursos d'água, do ponto de vista dos recursos hídricos. Agência Nacional das Águas, http://arquivos.ana.gov.br [www document].

Arriagada, R.A., Sills, E.O., Pattanayak, S.K., Ferraro, P., 2009. Combining qualitative and quantitative methods to evaluate participation in Costa Rica's program of payments for environmental services. J. Sustainable For. 28, 343–367.

Ayanu, Y.Z., Nguyen, T.T., Marohn, C., Koellner, T., 2011. Crop production versus surface-water regulation: assessing tradeoffs for land-use scenarios in the Tat Hamlet Watershed, Vietnam. Ecosyst. Serv. Manage. 7, 231–244 (International Journal of Biodiversity Science).

Baan, L., Alkemade, R., Koellner, T., 2012. Land use impacts on biodiversity in LCA: a global approach. Int. J. Life Cycle Assess. 18, 1216–1230.

Bennett, E.M., Peterson, G.D., Gordon, L.J., 2009. Understanding relationships among multiple ecosystem services. Ecol. Lett. 12, 1394–1404.

BRACELPA (Associação Brasileira de Celulose e Papel), 2010. Relatório de Sustentabilidade 2010, http://www.bracelpa.org.br [www document].

Brasil, 2006. Lei no. 11.428 de 22 de dezembro de 2006, http://www.planalto.gov.br [www document].

Brasil, 2012a. Lei no. 12.651 de 25 de maio de 2012, http://www.planalto.gov.br [www document].

Brasil, 2012b. Medida Provisória n° 571 de 25 de maio de 2012, http://www.planalto.gov.br [www document].

Buckley, C., Hynes, S., Mechan, S., 2012. Supply of an ecosystem service—farmers' willingness to adopt riparian buffer zones in agricultural catchments. Environ. Sci. Policy 24, 101–109.

Calmon, M., Brancalion, P.H.S., Paese, A., Aronson, J., Castro, P., da Silva, S.C., Rodrigues, R.R., 2011. Emerging threats and opportunities for large-scale ecological restoration in the Atlantic forest of Brazil. Restor. Ecol. 19, 154–158.

Cardoso Da Silva, J.M., Tabarelli, M., 2000. Tree species impoverishment and the future flora of the Atlantic forest of northeast Brazil. Nature 404, 72–74.

CEPA (Centro de Socioeconomia e Planejamento Agrícola), 2012. Preços Médios Mensais dos Produtos Vegetais Recebidos pelos Produtores em Santa Catarina-2006/2012, http://cepa.epagri.sc.gov.br [www document].

Chan, K.M., Shaw, A., Cameron, M.R., Underwood, D.R., Daily, E.C.G.C., 2006. Conservation planning for ecosystem services. PLoS Biol. 4, e379.

CONAMA (Conselho Nacional do Meio Ambiente), 2002. Resolução CONAMA no 303 de 20 de Março de 2002, http://www.mma.gov.br [www document].

Da Silva, C.V., 2006. Aspectos da obtenção e comercialização de pinhão na região de Caçador-SC. Master Thesis. Universidade Federal de Santa Catarina, Florianópolis.

de Andrade, F.M., 2002. Exploração, manejo e potencial socioeconômico da Erva-Mate. In: Simões, L.L., Lino, C.F. (Eds.), Sustentável Mata Atlântica: a exploração de seus recursos florestais. SENAC, São Paulo, SP, pp. 19–34.

De koning, G.H.J., Benítez, P.C., Muñoz, F., Olschewski, R., 2007. Modelling the impacts of payments for biodiversity conservation on regional land-use patterns. Landscape Urban Plann. 83, 255–267.

Develey, P.F., Pongiluppi, T., 2010. Impactos potenciais na avifauna decorrentes das alterações propostas para o Código Florestal Brasileiro Introdução Reserva Legal. Biota Neotropica 10, 2–5.

Ditt, E.H., Mourato, S., Ghazoul, J., Knight, J., 2010. Forest conversion and provision of ecosystem services in the Brazilian Atlantic Forest. Land Degrad. Dev. 21, 591–603.

Ditt, E.H., 2008. Integration of Ecosystem Services and Policy to Manage Forest and Water Resources Around the Atibainha Reservoir in Brazil. Imperial College London, London (PhD Thesis).

Dos Santos, R.F., Vivan, J.L., 2012. Pagamento por Serviços Ecossistêmicos em perspectiva comparada: recomendações para tomada de decisão. In: Technical Report. Projeto Apoio aos Diálogos Setoriais UE—Brasil, Brasília.

Egoh, B., Reyers, B., Rouget, M., Richardson, D.M., Le Maitre, D.C., Van Jaarsveld, A.S., 2008. Mapping ecosystem services for planning and management. Agric. Ecosyst. Environ. 127, 135–140.

FAO (Food and Agriculture Organization of the United Nations), 2011. State of the World's Forests 2012. FAO, Rome.

FATMA (Fundação do Meio Ambiente), 2009. Implementação dos Corredores Ecológicos Chapeco e Timbó. In: Technical Report. FATMA, Florianópolis.

Ferreira, J., Pardini, R., Metzger, J.P., Fonseca, C.R., Pompeu, P.S., Sparovek, G., Louzada, J., 2012. Towards environmentally sustainable agriculture in Brazil: challenges and opportunities for applied ecological research. J. Appl. Ecol. 49, 535–541.

FLORESTAS (Centro de Inteligência em Florestas), 2012. Cotações de preços para produção madeireira 2012, http://www.ciflorestas.com.br [www document].

Foley, J.A., Defries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570–574.

Galetti, M., Pardini, R., Duarte, J.M.B., Silva, V.M.F.da, Rossi, A., Peres, C.A., 2010. Mudanças no Codigo Florestal e seu impacto na ecologia e diversidade dos mamíferos no Brasil. Biota Neotropica 10, 47–52.

Garcia, L.C., Silveira, J., Matsumoto, M., Sanna, T., Silva, F., Padovezi, A., Sparovek, G., Hobbs, R.J., 2013. Restoration challenges and opportunities for increasing landscape connectivity under the New Brazilian Forest Act. Braz. J. Nat. Conserv. 11, 181–185.

Goldstein, J.H., Caldarone, G., Duarte, T.K., Ennaanay, D., Hannahs, N., Mendoza, G., Polasky, S., Wolny, S., Daily, G.C., 2012. Integrating ecosystem-service tradeoffs into land-use decisions. PNAS 109, 7565–7570.

Guedes, F.B., Seehusen, S.E. (Eds.), 2011. Pagamento por Serviços Ambientais na Mata Atlântica. Ministério do Meio Ambiente, Brasília.

Hamel, P., Guswa, A.J., 2014. Uncertainty analysis of a spatially-explicit annual water-balance model: case study of the Cape Fear catchment, NC. Hydrol. Earth Syst. Sci. Discuss 11, 11001–11036.

Hou, Y., Burkhard, B., Müller, F., 2013. Uncertainties in landscape analysis and ecosystem service assessment. J. Environ. Manage. 127, S117–S131.

INPE (Instituto de Pesquisas Espaciais), Fundação SOS Mata Atlântica, 2003. Atlas dos remanescentes florestais da Mata Atlântica. Período 1995–2000. In: Technical Report. INPE, SOS Mata Atlântica, São Paulo, SP.

INPE (Instituto de Pesquisas Espaciais), Fundação SOS Mata Atlântica, 2009. Atlas dos remanescentes florestais da Mata Atlântica. Período 2005–2008. In: Technical Report. INPE, SOS Mata Atlântica, São Paulo, SP.

INPE (Instituto de Pesquisas Espaciais), Fundação SOS Mata Atlântica, 2011. Atlas dos remanescentes florestais da Mata Atlântica. Período 2008–2010. In: Technical Report. INPE, SOS Mata Atlântica, São Paulo, SP.

INPE (Instituto de Pesquisas Espaciais), Fundação SOS Mata Atlântica, 2014. Atlas dos remanescentes florestais da Mata Atlântica. Período 2012–2013. In: Technical Report. INPE, SOS Mata Atlântica, São Paulo, SP.

Instituto Socioambiental, 2012. Código Florestal: projeto aprovado pelo Congresso Nacional é um retrocesso para o país e merece veto integral, http://www.socioambiental.org [www document].

Izquierdo, A.E., Clark, M.L., 2012. Spatial analysis of conservation priorities based on ecosystem services in the Atlantic Forest Region of Misiones. Argent. For. 3, 764–786.

Jopke, C., Kreyling, J., Maes, J., Koellner, T., 2014. Interactions among ecosystem services across Europe: bagplots and cumulative R reveal synergies, trade-offs, and regional patterns. Ecol. Indic. 49, 46–52.

Karam, K.F., Araújo, G.P., 2007. Diagnóstico socioeconômico do Correor Ecológico Chapecó, SC. In: Technical Report. FATMA, Florianópolis.

Larsen, F.W., Londoño-Murcia, M.C., Turner, W.R., 2011. Global priorities for conservation of threatened species, carbon storage, and freshwater services: scope for synergy? Conserv. Lett. 4, 355–363.

Lees, A.C., Peres, C.A., 2008. Conservation value of remnant riparian forest corridors of varying quality for amazonian birds and mammals. Conserv. Biol. 22, 439–449.

Liu, J., Li, S., Ouyang, Z., Tam, C., Chen, X., 2008. Ecological and socioeconomic effects of China's policies for ecosystem services. PNAS 105, 9477–9482.

Martinelli, L.A., Filoso, S., 2009. Balance between food production, biodiversity and ecosystem services in Brazil: a challenge and an opportunity. Biota Neotropica 9, 21–25.

Martinelli, L.A., Naylor, R., Vitousek, P.M., Moutinho, P., 2010a. Agriculture in Brazil: impacts, costs, and opportunities for a sustainable future. Curr. Opin. Environ. Sustainabil. 2, 431–438.

Martinelli, L.A., Joly, C.A., Nobre, C.A., Sparovek, G., 2010b. A falsa dicotomia entre a preservação da vegetação natural e a produção agropecuária. Biota Neotropica 10, 323–330.

MEA (Milennium Ecosystem Assessment), 2005. Ecosystems and human well-being. In: Synthesis. Island Press, Washington, DC.

Metzger, J.P., Martensen, A.C., Dixo, M., Bernacci, L.C., Ribeiro, M.C., Teixeira, A.M.G., Pardini, R., 2009. Time-lag in biological responses to landscape changes in a highly dynamic Atlantic forest region. Biol. Conserv. 142, 1166–1177.

Metzger, J.P., Lewinsohn, T.M., Joly, C.A., Verdade, L.M., Martinelli, L.A., Rodrigues, R.R., 2010. Brazilian Law: full speed in reverse? Science 329, 276.

Metzger, J.P., 2010. O Código Florestal tem base científica? Conserv. Nat. 8, 1–7.

Myers, N., Mittermeier, R.A., Mittermeier, C.G., Da Fonseca, G.A., Kent, J., 2000. Biodiversity hotspots for conservation priorities. Nature 403, 853–858.

Naidoo, R., Balmford, A., Costanza, R., Fisher, B., Green, R.E., Lehner, B., Malcolm, T.R., Ricketts, T.H., 2008. Global mapping of ecosystem services and conservation priorities. PNAS 105, 9495–9500.

Nazareno, A.G., Feres, J.M., de Carvalho, D., Sebbenn, A.M., Lovejoy, T.E., Laurance, W.F., 2011. Serious new threat to brazilian forests. Conserv. Biol. 26, 5–6.

Nelson, E., Mendoza, G., Regetz, J., Polasky, S., Tallis, H., Cameron, R., 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Front. Ecol. Environ. 7, 4–11.

Nelson, E., Sander, H., Hawthorne, P., Conte, M., Ennaanay, D., Wolny, S., Manson, S., Polasky, S., 2010. Projecting global land-use change and its effect on ecosystem service provision and biodiversity with simple models. PLoS ONE 5, 1–22.

Nepstad, D., Soares-filho, B.S., Merry, F., Lima, A., Moutinho, P., Carter, J., Bowman, M., Cattaneo, A., Rodrigues, H., Schwartzman, S., Mcgrath, D.G., Stickler, C.M., Lubowski, R., Piris-cabezas, P., Rivero, S., Alencar, A., Almeida, O., Stella, O., 2008. The end of deforestation in the Brazilian Amazon. Science 326, 1350–1351.

Overbeck, G.M.S., Fidelis, A., Pfadenhauer, J., Pillar, V., Blanco, C., Boldrini, I., Both, R., Forneck, E., 2007. Brazil's neglected biome: the South Brazilian Campos. Perspectives in plant ecology. Evol. Syst. 9, 101–116.

Pagiola, S., Glehn, H.C., Von, Taffarello, D. (Eds.), 2012. Experiências de Pagamentos por Serviços Ambientais no Brasil. Secretaria do Meio Ambiente do Estado de São Paulo, São Paulo, SP.

R Core Team, 2013. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Viena.

Raudsepp-Hearne, C., Peterson, G.D., Bennett, E.M., 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. PNAS 107, 5242–5247.

Ribeiro, M.C., Metzger, J.P., Martensen, A.C., Ponzoni, F.J., Hirota, M.M., 2009. The Brazilian Atlantic forest: how much is left, and how is the remaining forest distributed? Implications for conservation. Biol. Conserv. 142, 1141–1153.

Rodríguez, J.P., Beard, T.D., Bennett, E.M., Cumming, G.S., Cork, S.J., Agard, J., Dobson, A.P., Peterson, G.D., 2006. Trade-offs across space, time, and ecosystem services. Ecol. Soc. 11, 28–42.

SBPC (Sociedade Brasileira para o Progresso da Ciência), 2011. O Código Florestal e a Ciência: contribuições para o diálogo. Academia Brasileira de Ciências, http://www.abc.org.br [www document].

Seppelt, R., Dormann, C.F., Eppink, F.V., Lautenbach, S., Schmidt, S., 2011. A quantitative review of ecosystem service studies: approaches, shortcomings and the road ahead. J. Appl. Ecol. 48, 630–636.

Silvano, R.A.M., Udvardy, S., Ceroni, M., Farley, J., 2005. An ecological integrity assessment of a Brazilian Atlantic Forest watershed based on surveys of stream health and local farmers' perceptions: implications for management. Ecol. Econ. 53, 369–385.

Siminski, A., Fantini, A.C., 2010. A Mata Atlântica cede lugar a outros usos da terra em Santa Catarina, Brasil. Biotemas 23, 51–59.

Soares-Filho, B.S., Nepstad, D.C., Curran, L.M., Cerqueira, G.C., Garcia, R.A., Ramos, C.A., Voll, E., McDonald, A., Lefebvre, P., Schlesinger, P., 2006. Modelling conservation in the Amazon basin. Nature 440, 520–523.

Sparovek, G., Giaroli, A., Pereira, D.O., 2011. The revision of the Brazilian Forest Act: increased deforestation or a historic step towards balancing agricultural development and nature conservation? Environ. Sci. Policy 16, 65–72.

Su, C., Fu, B., 2013. Evolution of ecosystem services in the Chinese Loess Plateau under climatic and land use changes. Global Planet. Change 101, 2013.

Swetnam, R.D., Fisher, B., Mbilinyi, B.P., Munishi, P.K.T., Willcock, S., Ricketts, T., Mwakalila, S., Balmford, A., Burgess, N.D., Marshall, A.R., Lewis, S.L., 2011. Mapping socio-economic scenarios of land cover change: a GIS method to enable ecosystem service modelling. J. Environ. Manage. 92, 563–574.

Tallis, E.H., Ricketts, T., Guerry, A., Wood, S., Sharp, R. (Eds.), 2011. InVEST 2.4.0. The Natural Capital Project, Standford, p. 342.

Sharp, R., Chaplin-kramer, R., Wood, S., Guerry, A., Tallis, H., Ricketts, T. (Eds.), 2014. InVEST 3.0.1. The Natural Capital Project, Standford.

Teixeira, A.M.G., Soares-filho, B.S., Freitas, S.R., Metzger, J.P., 2009. Modeling landscape dynamics in an Atlantic Rainforest region: Implications for conservation. For. Ecol. Manage. 257, 1219–1230.

Tollefson, J., 2010. The global farm. Nature 466, 554.

UERJ (Universidade Estadual do Rio de Janeiro), 2007. Hydroflow Software, http://www.labgis.uerj.br/hydroflow/index.htm [www document].

Venter, O., Laurance, W.F., Iwamura, T., Wilson, K.A., Fuller, R.A., Possingham, H.P., 2009. Harnessing carbon payments to protect biodiversity. Science 326, 1368.

Via Campesina Brasil, 2011. A Defesa do Codigo Florestal e a produção de alimentos, http://abeef.org.br [www document].

Vibrans, A.C., Sevegnani, L., Uhlmann, A., Schorn, L.A., Sobral, M.G., de Gasper, A.L., Lingner, D.V., Brogni, E., Klemz, G., Godoy, M.B., Verdi, M., 2011. Structure of mixed ombrophyllous forests with *Araucaria angustifolia* (Araucariaceae) under external stress in Southern Brazil. Rev. Biol. Trop. 59, 1371–1387.

Vibrans, A.C., McRoberts, R.E., Moser, P., Nicoletti, A.L., 2013. Using satellite image-based maps and ground inventory data to estimate the area of the remaining Atlantic forest in the Brazilian state of Santa Catarina. Remote Sens. Environ. 130, 87–95.

Viglizzo, E.F., Frank, F.C., 2006. Land-use options for Del Plata Basin in South America: Tradeoffs analysis based on ecosystem service provision. Ecol. Econ. 57, 140–151.

Zanella, M.A., 2011. Why do Farmers Join Payment for Environmental Services (PES), Schemes? Humbolt University, Berlin (Master Thesis).

Ziv, G., Baran, E., Nam, S., Rodríguez-Iturbe, I., Levin, S.A., 2012. Trading-off fish biodiversity, food security, and hydropower in the Mekong River Basin. PNAS 109, 5609–5614.

Zuchiwschi, E., Fantini, A.C., Carlos, A., Peroni, N., 2010. Limitações ao uso de espécies florestais nativas pode contribuir com a erosão do conhecimento ecológico tradicional e local de agricultores familiares. Acta Bot. Brasil. 24, 270–282.