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Changes in land use and ecosystem services in tropical forest areas: a case study in Andes mountains of Ecuador

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ABSTRACT
Tropical Andes are subjected to severe land use/land cover (LULC) changes that significantly alter the capacity of the landscape to provide ecological functions for supporting human well-being. The aim of the study is (a) to investigate the LULC changes in the Ecological Corridor Llanaganates-Sangay (Corredor Ecológico Llanaganates-Sangay) (Central Ecuador), a buffer semi-protected area, during the period 2000–2014 and (b) to analyse their possible consequences on ecosystem services (ESs) provision. The analysis was performed using LULC maps of 2000, 2008 and 2014. ESs were analysed using the ‘landscape capacity’ index, which is based on a multi-criteria assessment framework. The study captured an extremely rapid LULC transition from croplands to pastures during 2008–2014 below the 2000-m altitude, which was followed by a respective rapid socio-economic change of the local society. The landscape index changes were insignificant showing a slight decrease (~1.92%) during 2000–2014. Although the overall coverage of natural ecosystems slightly increased during 2000–2014, it was found that the passive landscape conservation might not be sufficient to maintain ESs provision. This was justified by the different ESs contribution between forest types but also by urbanization, agriculture abandonment and pasture expansion.

1. Introduction
The provision of ecosystem services (ESs) is strictly related to land use/land cover (LULC) (Costanza et al. 1997; Metzger et al. 2006). ESs can be strongly affected by changes in LULC patterns, practices, intensity and trade-offs (Fu et al. 2015; Gissi et al. 2016; Gaglio et al. 2017). Despite the fact that LULC changes are ruled by drivers acting at regional or continental extent, the provision of ESs is relevant at different smaller scales (Hein et al. 2006). This scale mismatch results in a process of change that does not pay the proper attention to ecosystem conversions and their consequences. Moreover, ecological structures and functions vary along altitudinal gradients together with the variation of ecosystems and environmental conditions (Coûteaux et al. 2002; Kitayama and Aiba 2002; Moser et al. 2011), introducing an additional dimension to the ESs assessment framework.

The contribution of the majority of ESs to human well-being is not often considered or is underestimated, while humans are prone to exert pressures and changes in LULC with the aim to maximize the provision of one or few ESs, leading to a decline or loss of many others. This phenomenon is widespread around the globe (MA 2005; Ellis et al. 2010), but it is particularly severe in tropical regions of developing countries under the pressure of strong socio-economic changes (Lambin et al. 2003; Curatola Fernandez et al. 2015). An example is the tropical Andes of Ecuador, which are characterized by landscapes with peculiar climatic and topographic conditions where human settlements both affect and depend on natural ecosystems. This region is an extraordinary biodiversity hot-spot (Jørgensen et al. 2011; Bendix et al. 2013) that has experienced forest clearance and land degradation since centuries (Valencia et al. 1999; Etter et al. 2008; Bare and Ashton 2016).

For the mitigation of the dramatic deforestation rate of the country (Mosandl et al. 2008), Ecuadorian government promoted incentive-based policies for the conservation of native forests, such as the Socio-Bosque program (Bertzky et al. 2010), as well as the establishment of several protected areas (Keating 2007; Cuenca et al. 2016). The establishment of several protected areas is designated to conserve natural values and processes and can significantly support numerous ESs (Willemen et al. 2013). On the other hand, such conservation activities do not always guarantee the livelihood of local populations, which is mainly supported by food production from croplands, raw materials production from forests and...
livestock production based on pastures/grasslands (Kovacs et al. 2015). Despite the fact that protected areas seem to be effective for reducing deforestation in Ecuadorian Tropical Andean forests (Cuenca et al. 2016), the outcome of conservation efforts on the capacity of these areas to support human well-being needs to be investigated. Non-natural ecosystems contribute to the provision of ESs (Jose 2009; Porter et al. 2009; Breuste et al. 2013; Rodríguez-Ortega et al. 2014) for which landscapes designed for conservation should also consider these. Overall, the positive correlation between nature conservation and ESs provision is not always observed and should be assessed based on the contribution of ecological functions of both natural and non-natural ecosystems.

Moreover, when analysing the role of environmental protection in maintaining ESs provision, ecosystems variability within the landscape should also be considered. Altitudinal gradients lead to high levels of environmental heterogeneity, which are conditioning factors of LULC transitions in Latin American countries (Redo et al. 2012). In fact, part of environmental heterogeneity seems to be associated to socio-economic and demographic variables (Redo et al. 2012; Aide et al. 2013), which are the main drivers for LULC changes (Sanchez-Cuervo and Aide 2013; Nanni and Grau 2014).

The aim of this study is (a) to examine the temporal LULC changes during a 14-year period (2000–2014) considering the altitudinal dimension in the Ecological Corridor Llaganantes-Sangay (Corredor Ecológico Llanganates-Sangay [CELS], a buffer area between two national parks in the tropical Andes of Central Ecuador), and (b) to assess their consequences on the ESs provision at landscape scale considering both natural and non-natural ecosystems.

2. Material and methods

2.1. Study area

The study area is the Ecological Corridor Llaganantes-Sangay (CELS). It is a transitional area in the Central Ecuador between the Eastern Cordillera of the Andes and the western Amazon forest covering about ~42,850 ha. The study area is a buffer zone between two national parks (the Llaganantes National Park at north and the Sangay National Park at south) (Figure 1(a)) and it is shared between five municipalities (parroquias): Rio Verde (8%) and Rio Negro (47%), Cumandá (23%), Mera (19%) and La Shell (3%). The altitude ranges between 960 and 3756 m above the sea level (Figure 1(b)) and the climate belongs to the Af class (Tropical Rainforest) according

![Figure 1. (a) Location of CELS area in Ecuador, (b) altitude, (c) mean annual precipitation and (d) and mean annual temperature.](image-url)
to Köppen classification (Peel et al. 2007). The mean annual precipitation and temperature show a very steep transition to higher values towards East with ranges 2500–5500 mm/year and 9–22°C, respectively (Figure 1(c,d)). The strong relief and steep slopes favour the occurrence of highly differentiated habitats with very distinguishable zonation that results in high animal and plant biodiversity (Viteri et al. 2002).

Animal biodiversity in CELS accounts for 101 mammals, 242 birds, 49 amphibians and 30 reptiles species. Plant endemism accounts for 195 endemic species in Pastaza watershed, from which 181 have been recorded in the area between Baños and Puyo, with a perspective of increasing the record in the next years (Yáñez-Muñoz et al. 2013; Yaguache 2014).

The CELS was established in 2002 with the support of World Wildlife Fund. Nevertheless, this area is not under a true coordinated protection as it happens in the cases of Llanganantes and Sangay National Parks. The EcoMinga and Socio-Bosque foundations established additional conservation areas within the CELS that cover only 8000 ha (19% of total area). The inclusion of additional areas in the future will depend on stakeholder awareness for implementing the development and application of proper incentives. The economy of CELS is mainly based on agricultural activities (mainly orchards and annual crops), tourism and timber production (Yaguache 2014), which support a population of about 13,000 people (INEC 2010). Puyo and Shell are the larger urban systems located at the south-east edge of the territory and they are partly expanded inside CELS with a current population of ~37 thousand people. Puyo was outside CELS territory until 2002 but a clear expansion of city boundaries inside CELS is evident during the last years.

### 2.2. CELS ecosystems along the altitudinal gradient

Distinct spatial changes in natural ecosystems occurrence and structure appear following the increase of elevation in tropical mountains (Bruijnzeel et al. 2011). Ecosystems and related functions respond to changes in environmental gradients related to altitude, such as the decrease in temperature in higher altitudes. Lower temperatures and consequent weaker microbial activity, nutrient limitations and decrease of primary decomposers limit decomposition rate at increasing altitude (Coûteaux et al. 2002; Wilcke et al. 2002), and therefore promoting soil organic carbon accumulation (Maraun et al. 2008). Above-ground biomass, leaf area index and canopy height decrease with altitude while the restricted nutrient uptake leads to an increase in root production (Kottke et al. 2008; Unger et al. 2013). Although the above general patterns are widely documented, local conditions (e.g. slopes) can affect soil properties and their role on biomass production (Moser et al. 2011). In general, the environmental conditions of CELS promote a high natural ecosystems diversity that follows altitudinal patterns, with consequent variations in ecological functions provided at landscape scale. The forests of these ecological zones are also divided in four main categories based on altitude as follows: foothill forest – FF (<1300 m), lower mountain forest – LMF (1300–2000 m), cloud forest – CF (2000–2900 m) and higher mountain forest – HMF (>2900 m) (Vargas et al. 2000; Muriel 2008). A general description of main CELS ecosystems is provided in Table 1 and Figure 2. Urban centres within CELS are limited to few villages, where inhabitants have a rural lifestyle. More complex urban zones and infrastructures are located at the eastern part of CELS, in the municipality of Shell and Puyo, in proximity of Rio Amazonas airport. Water environments are mainly represented by the river Pastaza and by very few scattered water bodies. The river Pastaza flows from the Andes to Amazonian lowlands, crossing the CELS from west to east. A significant feature of CELS is that LULC changes are regulated by a traditional type of LULC rotation of croplands to pastures rotation and vice versa, which serves the provision of different food products depending on the needs of local population.

### 2.3. LULC maps and LULC change analysis

LULC change analysis was based on LULC maps of 2000, 2008, 2014. The maps were produced by the Ministry of Environment and the Ministry of Agriculture, Livestock, Aquaculture and Fisheries of Ecuador by using LANDSAT ETM+ for 2000 (MAE 2012), LANDSAT ETM+ and ASTER for 2008 (MAE 2014) and LANDSAT 8 and RapidEye satellite images for 2014 (MAE 2015). Except the last LULC map of 2014, which was developed by supervised classification using data from field surveys (at least 30 positions were monitored for each land-use type) (MAE 2015), the other two LULC maps of previous dates (2000 and 2008) were made using unsupervised classification. Seven LULC types were considered in the LULC change analysis according to the three maps: urban, bare soil, agricultural land, water bodies, páramo, pastures and native forests. The latter was further classified in four classes (FF, LMF, CC, HMF) according to Vargas et al. (2000) and Muriel (2008). Pastures include also a small portion of grasslands–shrublands, which are also used as areas for livestock grazing.

The analysis of LULC changes was performed using LULC transition matrices (TMs). In our study, TMs were developed directly by the LULC changes between 2000, 2008 and 2014 without using...
probabilistic approaches in order to show the exact change from one LULC type to another (Wang et al. 2014; Gagliò et al. 2017). TMs compare the extent of LULC types between two time intervals (e.g. $t_1$ and $t_2$) providing the area of each LULC type that remained intact and the specific changes to other LULC types during $t_1$–$t_2$. The LULC maps of 2000, 2008 and 2014 correspond to three time intervals and for this reason, three TMs were built that correspond to the periods 2000–2008, 2008–2014 and 2000–2014.

Altitudinal patterns of LULC transitions were also investigated, according to four altitudinal zones (960–1300, 1300–2000, 2000–2900 and 2900–3756 m), which were delineated using a 30-m resolution digital elevation model. These zones were based on the altitudinal zonation between the forest classes FF (<1300 m), LMF (1300–2000 m), CF (2000–2900 m) and HMF (>2900 m) (Vargas et al. 2000; Muriel et al. 2008) (Table 1). Since the provision of forest ESs significantly varies along altitudinal zones (Becker et al. 2007; Leuschner et al. 2013), forested areas were further classified in four forest ecosystem classes according to specific altitudinal zones reported by Muriel (2008) and Vargas et al. (2000) for the study area. In this case, the specific altitudinal zones were used not only as a proxy to identify the different forest ecosystems but also to better describe the related services involved in the specific landscape transitions.

The significance of LULC changes was investigated through the comparison of proportion with $\chi^2$ test for $P$ value $\leq 0.01$, using StatGraphics Centurion XV (StatPoint Inc.). For each altitudinal range, the comparison was performed between the proportion of each LULC type of the three dates 2000, 2008 and 2014 versus the proportion of the remaining LULC types (e.g. agricultural land vs. non-agricultural land). The null hypothesis was that the extension of the two classes did not change over the three dates. Also, an analysis of means (ANOM) plot with 99% confidence was applied. This procedure was not used to denote strict statistical differences between the years (e.g. as in the case of LSD

### Table 1. Main LULC types and their ecological functions inside CELS region.

| LULC type | Description | Typical vegetation species | Main ecological functions |
|-----------|-------------|---------------------------|--------------------------|
| Agricultural land | Mainly orchards, located along water courses. Monocultures with fertilizers and pesticides application | Solanum quitoense, Solanum betaceum | Food provision |
| Pastures | Both cultivated and natural grasslands for feeding livestock. Stabling of animals is not performed while animal grazing is free following a rotation system by moving the animals from one to another area | Pennisetum clandestinum, Lolium perenne | Food supply to livestock for meat and milk production |
| LULC type | Description | Typical vegetation species | Main ecological functions |
| Paramo | Typical ecosystem of Tropical Andes, located above 3400 m a.s.l. Vegetation can reach 50 cm height. Deep A-soil horizon where organic matter accumulation is favoured by the cold and wet climate and low atmospheric pressure (Hofstede et al. 2002; Buytaert et al. 2007). The humic and dark soils have excellent water infiltration and retention capacity (Buytaert et al. 2005, 2007) | Perennials ericaceous plants (e.g. Poaceae) | Water regulation, medicinal resources |
| HMF | Trees can reach 10–15 m of height with thick and sometimes gnarled trunks, with adventitious roots occupying up to 70 m². Very steep slopes (>15°) affect soil organic carbon content | Clusia spp. in lower part (3200–3330 m). Sclerophyllus in upper part | Erosion prevention |
| CF | Trees reach a height of 15–25 m. The underwood is very rich and epiphytes and mosses are very abundant. Persistent presence of fog at the vegetation level, which significantly reduces incident solar radiation and evapotranspiration. The frequent contact between canopy and clouds increases water interception (i.e. horizontal rain) and water input to the system (Bendix et al. 2004; Célleri and Feyen 2009) | Melastomataceae, Solanaceae, Myrsinaceae, Aquifoliaceae, Araliaceae, Rubiaceae and several fern families | Water regulation, erosion prevention, biodiversity |
| LMF | The canopy height can reach 20–35 m tall with sporadic trees of 40 m. Composed by different layers such as canopy, subcanopy, shrub and herbaceous species. Epiphytes are more abundant than in lower altitudes, while lianas decrease in abundance and diversity (Valencia 1995) | Lauraceae, Rubiaceae, Melastomataceae and occasionally Moraceae | Aboveground biomass (carbon storage, charcoal and timber production) |
| FF | Forest transition between the foothills of Eastern Cordillera and Amazon forest. Substrate mainly composed by volcanic rocks and sediments of recent origins. The canopy height reaches 30 m and subcanopy and undergrowth are very dense (Vargas et al. 2000). The flatter zones near the River Pastaza are characterized by alluvial and terraced sediment deposits newly formed with high percentages of soil organic carbon. It presents extremely high biodiversity (Titra 1999; Yáñez-Muñoz et al. 2010; Reyes-Puig et al. 2013) | Saurauia, Hedysosmum, Brunellia, Weinmannia | Aboveground biomass (carbon storage, charcoal and timber production), biodiversity, soil regulation |

HMF: Higher mountain forest; CF: cloud mountain forest; LMF: lower mountain forest; FF: foothill forest.
test in ANOVA) but to provide indications about the direction of the significant changes based on the deviation from the grand mean of the ANOM plots. Thus, the three codes a, b and c were used to denote the location of the proportion values from the three dates: above, inside and below the 99% confidence limits of ANOM plots (Fedrigotti et al. 2016).

Additionally, the annual rate of change for each LULC type was calculated by using the following equation (Puyravaud 2003):

$$\gamma = \left( \frac{1}{(t_2 - t_1)} \right) \times \ln \left( \frac{A_2}{A_1} \right)$$

(1)

where $\gamma$ is the annual rate of change of a given LULC, $A_1$ and $A_2$ are the area extension of a given ecosystem at the time $t_1$ and $t_2$, respectively.

2.4. ESs change assessment

According to the cascade model (Haines-Young and Potschin 2010), the provision of ESs depends on ecological functions that are exploited by humans to support their own well-being. Although the so-called ES delivery chain includes potential ESs stock (capacity), actual supply (flow) and beneficiaries (users demand) (Egarter-Vigl et al. 2017), different mapping methods use proxies to assess the ecological function of LULCs (ESs capacity) assuming that they are directly or indirectly exploited by humans. For example, the 'benefit transfer' method is based on the assumption that a given spatial unit provides a set of ecological functions (e.g. Costanza et al. 1997, 2014; de Groot et al. 2012). The method proposed by Balthazar et al. (2015) is an adaptation of benefit
transfer approach including the framework proposed by Koschke et al. (2012), where a set of ecological functions is used to assess the ESs provision (Kremen 2005). This method allows combining qualitative and semi-quantitative indicators to obtain a comprehensive index sensitive to LULC changes, which expresses the overall capacity of a landscape to sustain the human well-being. Thus, the ESs analysis was performed at landscape level and the consequences of LULC change on ESs provided by CELS were assessed through the concept of ‘landscape capacity’ index (B Burkhard et al. 2009; Koschke et al. 2012; Balthazar et al. 2015). This index uses a multi-criteria assessment framework, which is based on important biophysical indicators related to specific ESs for the development of a normalized score that avoids subjectivity due to qualitative expert judgment (Balthazar et al. 2015).

A scoring matrix of 11 indicators was developed for 7 LULC types: 2 non-natural (agricultural land and pastures) and 5 natural (foothill mountain forest, lower mountain forest, cloud mountain forest, higher mountain forest and paramo grassland) (Table 2). Other LULC types observed in CELS such as urban sites, bare soils and water environments were included in the maps but they were not considered in the ESs assessment. The rivers were not included in the ES assessment due to the lack of data for biophysical indicators. A main problem of ES assessment for the rivers of the study area is that the main courses have intermitted flow regulated by upstream dams while the small streams have very small area coverage and high discharge acting as intermediate links for ESs transfer among other land uses. In general, the riverbeds are mainly composed by large stones and when the discharge is low, large stony surfaces appear mainly in the west lowland part.

The 11 ecological indicators (Table 2) were selected according to their importance for the human well-being and data availability (MA 2005). Only peer-reviewed studies, technical reports and documents were considered in order to assign the bio-physical values to each indicator. Field surveys and personal communication from official sources were used to assess the number of touristic sites, the number of plant species used for medicinal resources and livestock supply capacity (see Supplementary material, sources and details about indicators presented in Table 2). When no local studies were present, we considered studies performed at national scale or studies carried out in similar environments (Andean regions).

The calculation of the landscape capacity index according to Balthazar et al. (2015) is performed by the following steps. In order to allow merging of indicators of different nature, the values of each indicator are standardized between 0 (no relevant capacity) and 5 (very high relevant capacity): 

\[ I_{\text{norm}} = \left( \frac{I - I_{\text{min}}}{I_{\text{max}} - I_{\text{min}}} \right) \times 5 \]  

where \( I_{\text{norm}} \) is the standardized value from 0 to 5, \( I \) is the indicator value for a given ecosystem, \( I_{\text{max}} \) and \( I_{\text{min}} \) are the maximum and minimum values observed for the indicator, respectively. The overall potential of each LULC type is calculated as the sum of the standardized values of each indicator:

Table 2. Indicators used for the estimation of landscape capacity index and their relations to specific ESs in the study area.

| Ecosystem services | Agricultural land | Pastures | Paramo | HMF | CF | LMF | FF | Indicators (unit) | References |
|--------------------|------------------|---------|-------|-----|----|-----|----|------------------|------------|
| Food production    | 1808             | 97      | 64    | 67  | 67 | 122 | 122 | Monetary prices  | Guayasamin Guanga (2015), Grimes et al. (1994), Kocian et al. (2011) |
| Medicinal resources| 0                | 0       | 14    | 9   | 8  | 4   | 6  | No. of species    | Ministero di Agricultura, Granaderia, Acuacultura y Pesca (pers. comm.) |
| Livestock supply   | 0                | 4       | 0     | 0   | 0  | 0   | 0  | Cattle density    | Balthazar et al. (2015), Crespo et al. (2010), Fleischbein et al. (2006) |
| Water regulation   | 646              | 648     | 933   | 741 | 837| 748 | 748 | Discharge         | MAE (2014), Molina et al. (2008), Ochoa-Cueva et al. (2015) |
| Erosion prevention | 43.0             | 20.0    | 100.0 | 97.6| 97.6| 98.3| 98.2| Vegetation cover  | WWF Ecuador (2014), MAE (2014), Potthast et al. (2010), Hofstede et al. (2002), WWF (2014) |
| Soil structure     | 17.4             | 16.0    | 20.8  | 15.8| 15.8| 16.6| 27.6| Organic matter    | Moser et al. (2011), Hall et al. (2012), Lopez-Ulloa et al. (2005) |
| Soil carbon storage| 77               | 80      | 204   | 121 | 160| 112 | 106| Organic matter    | MAE (2014), McGroddy et al. (2015) |
| Above-ground       | 102.0            | 41.0    | 54.1  | 105.1| 105.1| 123.1| 122.8| Biomass          | Jorgensen et al. (2011), Ministero di Agricultura, Granaderia, Acuacultura y Pesca online database |
| Biodiversity       | 39               | 15      | 2000  | 2800| 3000| 2700| 2500| Vascular plant richness | Burkhard et al. (2009) |

HMF: Higher mountain forest; CF: cloud mountain forest; LMF: lower mountain forest; FF: foothill forest.
where $P_i$ is the potential of an $i$ LULC type to provide the considered indicator, and $I_{norm \ ij}$ is the standardized indicator value (Equation (2)) of an $i$ LULC type for a $j$ ES. Then, the landscape capacity index is calculated for each LULC type as follows:

$$L_i = A_i \times P_i$$  \hspace{1cm} (4)

where $L_i$ is the landscape capacity of $i$ LULC type, $A_i$ the area coverage of the $i$ ecosystem (ha) and $P_i$ (Equation (3)) is the potential of the $i$ LULC type. It has to be noted that all the ESs were equally weighted to calculate the index. Finally, the total landscape capacity index is calculated as follows:

$$L = \sum L_i$$  \hspace{1cm} (5)

where $L$ is the total landscape capacity index and $L_i$ the landscape capacity for the $i$ LULC type (Equation (4)). The landscape capacity index is calculated for each of the three dates (2000, 2008, 2014), in order to assess the temporal variation of the ESs provided at landscape scale as consequence of the LULC changes occurred in the CELS.

Finally, the contribution of each LULC type to the total landscape capacity ($L$) was calculated as follows:

$$R_i = \frac{P_i \times A_i}{L}$$  \hspace{1cm} (6)

where $R_i$ is a ranking index, which expresses the contribution of the $i$ LULC type to the total landscape capacity ($L$). The use of the specific index is based on the simplified version of elasticity coefficient or coefficient of sensitivity provided by Aschonitis et al. (2016) after recalculation of the terms in the original function provided by Kreuter et al. (2001). Aschonitis et al. (2016) found that the initial form of elasticity–sensitivity coefficient could be simplified because the ESs prices are considered always stable without being affected by changes in the demand.

### 3. Results

#### 3.1. LULC changes

The maps of LULC for 2000, 2008 and 2014 are given in Figure 3. The TMs of LULC changes are given in Table 3 while the absolute, relative and annual rate of LULC changes are given in Table 4. Table 4 also includes the respective changes in the different forest classes (FF, LMF, CF and HMF). The most important changes during the whole period 2000–2014 were related to (a) agricultural land and pasture coverage rotations and (b) urban areas expansion (Tables 3 and 4). During 2000–2008, agricultural land gained 1138.64 ha, mainly from pastures and forest conversion. This trend was completely inverted during 2008–2014 when the 92.65% of the agricultural land

![Figure 3](image_url)
| LULC type   | Agricultural lands | Bare soils | Native forests | Paramo | Pastures* | Urban | Water bodies | Loss | Total 2000 |
|------------|--------------------|------------|---------------|--------|-----------|-------|--------------|------|------------|
| Agricultural lands | 3320.57a | 8.36b | 203.31b | 0.00b | 234.91b | 17.99b | 13.97b | 478.54b | 3799.10b |
| Bare soils   | 4.93a | 49.55a | 29.98a | 0.00 | 1.92 | 6.44 | 9.56 | 32.83 | 102.38 |
| Native forests | 649.38a | 45.1a | 34124.69a | 3.78 | 397.45 | 7.47 | 16.24 | 1078.83 | 35203.52 |
| Paramo      | 0.00 | 0.00 | 393 | 97.47b | 7.15 | 0.00 | 0.00 | 11.08 | 108.55 |
| Pastures*   | 916.55a | 2.44 | 381.67 | 0.00 | 1175.81 | 30.98 | 29.90 | 1361.55 | 2537.35 |
| Urban       | 1.65 | 0.00 | 0.30 | 0.00 | 7.33 | 0.73 | 103.24a | 0.55 | 3.23 | 106.47 |
| Water bodies | 44.67a | 37.83 | 21.83 | 0.00 | 31.18 | 7.05 | 804.68b | 142.56 | 947.25 |
| Gain        | 1617.18d | 53.14 | 641.02 | 3.78 | 673.34 | 69.94 | 7022 |  |  |
| Total 2008  | 4937.74a | 102.70 | 34765.71 | 101.25 | 1849.15 | 173.18 | 87490 |  |  |

(b) Period 2008-2014

| LULC type   | Agricultural lands | Bare soils | Native forests | Paramo | Pastures* | Urban | Water bodies | Loss | Total 2008 |
|------------|--------------------|------------|---------------|--------|-----------|-------|--------------|------|------------|
| Agricultural lands | 270.47 | 7.09 | 1494.40 | 0.00 | 3021.82 | 53.55 | 90.42 | 4667.27 | 4937.74 |
| Bare soils   | 0.00 | 1.12 | 33.22 | 0.00 | 19.78 | 0.01 | 48.47 | 101.57 | 102.70 |
| Native forests | 23.01 | 18.61 | 33502.70 | 2.77 | 1095.14 | 59.83 | 63.65 | 1263.01 | 34765.71 |
| Paramo      | 0.00 | 0.00 | 3.56 | 90.66 | 7.02 | 0.00 | 0.00 | 10.99 | 101.25 |
| Pastures*   | 65.30 | 0.33 | 246.60 | 13.73 | 1342.22 | 164.37 | 16.59 | 506.93 | 1849.15 |
| Urban       | 2.92 | 0.00 | 11.31 | 0.00 | 73.13 | 81.98 | 3.84 | 91.20 | 173.18 |
| Water bodies | 1.11 | 12.25 | 70.65 | 0.00 | 153.30 | 1.96 | 635.63 | 239.27 | 87490 |
| Gain        | 92.34 | 38.28 | 18598.96 | 16.50 | 4370.20 | 279.71 | 222.97 |  |  |
| Total 2014  | 362.81 | 39.41 | 35362.55 | 107.16 | 5712.41 | 361.69 | 85860 |  |  |

(c) Period 2000-2014

| LULC type   | Agricultural lands | Bare soils | Native forests | Paramo | Pastures* | Urban | Water bodies | Loss | Total 2000 |
|------------|--------------------|------------|---------------|--------|-----------|-------|--------------|------|------------|
| Agricultural lands | 238.21 | 2.89 | 1145.86 | 0.00 | 2314.62 | 40.67 | 56.86 | 3500.90 | 3799.10 |
| Bare soils   | 0.00 | 6.00 | 449.47 | 0.00 | 31.72 | 5.97 | 19.72 | 102.38 | 102.38 |
| Native forests | 27.79 | 19.76 | 33383.31 | 9.39 | 1531.29 | 160.37 | 71.62 | 1820.21 | 35203.52 |
| Paramo      | 0.00 | 0.00 | 3.71 | 97.77 | 7.08 | 0.00 | 0.00 | 10.78 | 108.55 |
| Pastures*   | 89.72 | 3.47 | 699.29 | 0.00 | 1594.30 | 103.76 | 46.81 | 943.05 | 2537.35 |
| Urban       | 0.00 | 0.05 | 4.74 | 0.00 | 53.43 | 45.56 | 2.70 | 60.91 | 106.47 |
| Water bodies | 7.10 | 13.24 | 80.67 | 0.00 | 179.97 | 5.37 | 660.90 | 286.35 | 947.25 |
| Gain        | 124.61 | 39.41 | 19792.4 | 9.39 | 4118.11 | 316.13 | 197.70 |  |  |
| Total 2014  | 362.81 | 39.41 | 35362.55 | 107.16 | 5712.41 | 361.69 | 85860 |  |  |

*The diagonal bold values show the area coverage of a LULC type, which remained intact during each period.
*The values of each row, except the bold ones, show how many hectares of a specific LULC type were converted to another LULC type (e.g. 23491 ha of agricultural lands were converted to pastures during 2000–2008).
*Loss: The total sum of the values of each row, except the bold ones, which provides the total area of a specific LULC type which was converted to other LULC types (e.g. 478.54 ha of agricultural lands were converted to other LULC types during 2000–2008).
*Total area of a LULC type at the beginning of the study period (e.g. the total coverage of agricultural lands was 3799.10 ha in 2000).
*The values of each column, except the bold ones, show how many hectares of a specific LULC type were gained (e.g. agricultural lands gained 1617.18 ha after conversion of pastures to the specific LULC during 2000–2008).
*Gain: The total sum of the values of each column, except the bold values, which provides the total area which was gained for a specific LULC type (e.g. agricultural lands gained a total area of 1617.18 ha during 2000–2008).
*Total area of a LULC type at the end of the study period (e.g. the total coverage of agricultural lands was 4937.74 ha in 2008).
of 2008 was lost. After 2008, pastures showed the higher relative gain (208.92%) among all LULC types. During 2000–2008, deforestation occurred with an annual rate of 0.16%, while during 2008–2014, afforestation processes where observed with an annual forest gain of 0.28%. New fragmented urban zones were settled along the Pastaza river during 2000–2008, while the intense urbanization during 2008–2014 was due to the expansion of Mera, Shell and Puyo towns in the south-eastern part of CELS. Urban areas showed the most important relative increase in the total period (239.71%) during 2000–2014 (Tables 3 and 4).

The aforementioned general changes were not evenly distributed along altitudinal ranges (Table S.1 in the Supplementary material). The results of ANOM analysis based on the altitudinal zonation are given in Table 5. Human activities related to LULC typologies, such as agricultural land, pastures and urban areas, are mainly located in 960–1300 and 1300–2000 m zones. Therefore, these two altitudinal zones were mostly affected by LULC changes. Agricultural land significantly expanded during 2000–2008 versus forested areas within the 960–1300-m zone and versus pastures within 1300–2000 m zone (Tables 3–5), while during 2008–2014, an extensive decrease occurred at all altitudinal levels. Loss of agricultural land at 960–1300 m was due to a shift of land-use activity towards pastures, while afforestation phenomena were detected only at 1300–2000 m. In fact, pastures expansion within 960–1300 m zone affected the foothill forest causing further deforestation process during 2008–2014. Significant increase of forested areas was also observed in the 2000–2900-m zone, where cloud forest colonized previously cultivated land, pastures and bare soil. The LULC type of pastures is the only one showing significant changes in the upper altitudinal zone (2900–3756 m) (Table 5) because their coverage in this zone during 2000 was zero (Table S.1). Higher altitudes are less accessible for human activities, which are the main drivers of changes.

During the time span considered, and particularly during the period 2008–2014, LULC changes analysis showed a general migration of human activities to the

![Table 4. LULC changes observed in CELS during 2000–2008, 2008–2014 and 2000–2014 (total period).](image)

| LULC type         | 2000–2008 Absolute changes (ha) | 2000–2008 Relative changes (%) | 2000–2008 Annual rate of change (Equation (1)) (%) |
|-------------------|---------------------------------|---------------------------------|--------------------------------------------------|
| Urban             | 66.71                           | 255.22                          | 6.08                                             |
| Bare soil         | 32.3                            | 65.91                           | 0.04                                             |
| Agricultural land | 1138.64                         | –3436.29                        | 3.24                                             |
| Water bodies      | –72.34                          | –88.65                          | –0.99                                            |
| Paramo            | –7.30                           | –1.39                           | –0.87                                            |
| Pastures          | –688.21                         | 3175.06                         | –3.95                                            |
| Forest            | –437.81                         | 159.03                          | –0.16                                            |
| HMF               | –9.92                           | –7.38                           | –0.14                                            |
| CF                | –4.56                           | 66.75                           | –0.01                                            |
| LMF               | 128.83                          | –80.78                          | 0.07                                             |
| FF                | –552.17                         | –811.12                         | –1.39                                            |

Absolute changes are expressed in ha, relative and annual changes in percentages. Annual change rates were calculated according to Equation (1). The forest area extension is given by the sum of the four forest ecosystems in which was further classified (see Table 2). HMF: Higher mountain forest; CF: cloud forest; LMF: lower mountain forest; FF: foothill forest.

![Table 5. LULC changes analysis using analysis of means at 99% confidence level.](image)

| Altitude (m a.s.l.) | $\chi^2$ (df = 2) | $P$ value | Urban 2000 | Urban 2008 | Urban 2014 | Bare soil 2000 | Bare soil 2008 | Bare soil 2014 | Agricultural land 2000 | Agricultural land 2008 | Agricultural land 2014 | Forest 2000 | Forest 2008 | Forest 2014 | Water bodies 2000 | Water bodies 2008 | Water bodies 2014 | Paramo 2000 | Paramo 2008 | Paramo 2014 | Pastures 2000 | Pastures 2008 | Pastures 2014 |
|---------------------|-------------------|-----------|------------|------------|------------|----------------|----------------|----------------|----------------------------|--------------------------|----------------------|------------|-------------|------------|----------------|----------------|----------------|-------------|-------------|-------------|--------------|--------------|--------------|
| 960–1300            | 178.9             | <0.0001   | c          | a          | 45.91      | a              | a              | a              | a                          | a                        | a                     |            |              |            |                |                |                | a           |              |              | a             | a             | a             |
| 2900–3756           | 0.50              | 0.7744    | b          | b          | 2.63       | 0.2687        | b              | b              | b                          | b                        | b                     |            |              |            |                |                |                | a           |              |              | a             | a             | a             |
| 2000–2900           | 54.85             | <0.0001   | c          | c          | 13.12      | 2073.69       | c              | c              | a                          | <0.0001                  | a                     | a          |              |            |                |                |                |              |              |              | b             | a             | a             |
| 960–1300            | 87.52             | <0.0001   | a          | a          | 2132.4     | <0.0001       | a              | a              | a                          | <0.0001                  | a                     | a          |              |            |                |                |                |              |              |              |              |              |              |
| 2900–3756           | 0.0985            | 1.0000    | b          | b          | 0.32       | 0.8529        | b              | b              | b                          | b                        | b                     |            |              |            |                |                |                |              |              |              | b             | b             | a             |
| 2000–2900           | 4.1               | 0.1278    | b          | b          | –          | –              | –              | –              | –                          | –                        | –                     |            |              |            |                |                |                |              |              |              |              |              |              |
| 1300–2000           | 3.65              | 0.1660    | b          | b          | –          | –              | –              | –              | –                          | –                        | –                     |            |              |            |                |                |                |              |              |              |              |              |              |
| 960–1300            | 7.48              | 0.0237    | a          | b          | –          | –              | –              | –              | –                          | –                        | –                     |            |              |            |                |                |                |              |              |              |              |              |              |

The three codes a, b and c were used to denote the location of the proportion values from the three dates: above, inside and below the upper and lower 99% confidence limits.
lower altitudes, resulting in the re-naturalization of uplands.

Regarding the water bodies, the only significant change was a decrease within the lower altitudinal belt during 2000–2008 (Table 5) probably caused by the establishment of upstream dams for hydroelectric power generation.

### 3.2. Changes in ESs

The consequences of LULC changes in ESs provision were assessed through the quantification of a set of indicators to calculate the landscape capacity $L$ index.

Table 6 presents the standardized values (Equation (2)) used for the calculation of the $L$ index. The capacity to support ecological functions in CELS expressed by $P_i$ (Equation (3)) for each LULC type is also given in Table 6. The natural ecosystems show higher $P_i$ in comparison to the anthropic ones. Foothills present the larger potential to support human well-being, followed by the other forest types and paramo grassland. Pastures have the lower potential, mainly related to livestock supply, while their potential for other indicators is limited. Agricultural lands present more than double $P_i$ value in comparison to pastures but less than half value if compared with natural ecosystems (Table 6).

The difference between the $P_i$ values of agricultural land and pastures is mainly due to differences in soil-related functions and above-ground biomass production. The intensive grazing activity of cattle causes the decrease of soil coverage and organic matter content with detrimental effects on erosion prevention, soil structure and soil carbon storage. Marked differences in above-ground biomass can easily be identified because of the intensive characteristics of grazing management adopted by breeders, which do not allow the growing of trees and shrubs. Contrary, agricultural land in CELS is characterized by a considerable extension of orchards, which provide a good amount of above-ground biomass. Different values on scenic quality are due to the different scores proposed by Burkhard et al. (2009) for these two ecosystems.

The landscape capacity index for each LULC type $L_i$ (Equation (4)) and the total value $L$ (Equation (5)) for 2000, 2008 and 2014 are given in Table 7. The total landscape capacity $L$ decreased by 0.42% during 2000–2008, by 1.51% during 2008–2014 and by 1.92% during 2000–2014. These $L$ changes were quite small and mainly regulated by the transitions between agricultural lands and pastures, and urban areas expansion. The high and almost constant coverage of natural LULC types during 2000–2014 (84.71% for 2000, 83.50% for 2008 and 84.87% for 2014) was the main reason of small $L$ changes. The % contribution of each ecosystem type $R_i$ (Table 7) showed the importance of lower mountain forests (LMF) with a contribution ranging between 57% and 60% during the period 2000–2014.

From a qualitative point of view, even when the total landscape capacity ($L$) does not suffer any

### Table 6. $I_{norm}$ values (Equation (2)) for the ecosystem functions and total potential $P_i$ of each ecosystem to provide ecological functions (Equation (3)).

| Ecosystem service                  | Agricultural land | Pastures  | Paramo | HMF   | CF   | LMF   | FF   |
|-----------------------------------|-------------------|-----------|--------|-------|------|-------|------|
| Food production                   | 5.00              | 0.09      | 0.00   | 0.01  | 0.01 | 0.17  | 0.17 |
| Medicinal resources               | 0.00              | 0.00      | 5.00   | 3.21  | 2.86 | 1.43  | 2.14 |
| Livestock supply (bovine)         | 0.00              | 5.00      | 0.00   | 0.00  | 0.00 | 0.00  | 0.00 |
| Water regulation                  | 0.00              | 0.03      | 5.00   | 1.66  | 3.33 | 1.78  | 1.78 |
| Erosion prevention                | 1.44              | 0.00      | 5.00   | 4.85  | 4.85 | 4.89  | 4.89 |
| Soil structure                    | 0.67              | 0.08      | 2.11   | 0.00  | 0.00 | 0.33  | 5.00 |
| Soil carbon storage               | 0.00              | 0.12      | 5.00   | 1.73  | 3.27 | 1.38  | 1.14 |
| Above-ground biomass              | 3.71              | 0.00      | 0.80   | 3.90  | 3.90 | 5.00  | 4.98 |
| Biodiversity (vascular plants)    | 0.04              | 0.00      | 3.32   | 4.66  | 5.00 | 4.50  | 4.16 |
| Scenic quality                    | 1.25              | 0.00      | 3.75   | 5.00  | 5.00 | 5.00  | 5.00 |
| Recreation/education (tourism)    | 0.00              | 0.00      | 1.67   | 2.00  | 3.33 | 5.00  | 3.33 |
| $P_i$                             | 5.33              | 31.65     | 27.03  | 31.55 | 29.47| 32.59 |

HMF: Higher mountain forest; CF: cloud mountain forest; LMF: lower mountain forest; FF: foothill forest.

### Table 7. Landscape capacity index for each ecosystem type $L_i$ (Equation (4)) and its total value $L$ (Equation (5)) for 2000, 2008 and 2014.

| Ecosystem type     | $L_i$ 2000 | $L_i$ 2008 | $L_i$ 2014 | $L$ 2000 (%) | $L$ 2008 (%) | $L$ 2014 (%) |
|--------------------|-----------|-----------|-----------|--------------|--------------|--------------|
| Agricultural land  | 46008.94  | 59798.44  | 43938.84  | 4.07         | 5.32         | 0.40         |
| Pastures           | 13529.41  | 9859.82   | 30459.13  | 1.20         | 0.88         | 2.75         |
| Paramo             | 3435.95   | 3204.74   | 3391.89   | 0.30         | 0.28         | 0.31         |
| HMF                | 24094.21  | 23826.09  | 23894.69  | 2.13         | 2.12         | 2.16         |
| CF                 | 222530.54 | 222386.70 | 224636.23 | 19.71        | 19.78        | 20.28        |
| LMF                | 648853.07 | 652649.79 | 668916.22 | 57.46        | 58.04        | 60.39        |
| FF                 | 170827.45 | 152831.79 | 151888.18 | 15.13        | 13.59        | 13.71        |
| Total $L$          | 1129279.58| 1124557.37| 1107580.18| 100.00       | 100.00       | 100.00       |

Also the ranking index $R_i$ is reported (Equation (6)).
significant changes, the LULC transitions determine qualitative changes in ESs provision. For example, the transition from agricultural land to pastures implies the change in provisioning services, with a decrease in crop-derived food and an increase in meat and milk production. Moreover, this transition causes a decrease in erosion prevention and soil structure maintenance, since croplands guarantee good and constant soil coverage compared to pastures subjected to intensive grazing.

No significant total L change could be detected also when the loss of forest at lower altitudes is offset by forest gain at higher altitudes. Nonetheless, a qualitative change in the indicators set, and therefore in ES provision capacity, occurs, since different functions are carried out by different forest ecosystems. Forest expansion at upper altitudes (HMF and CF) offers higher protection against soil erosion and better regulation of runoff, while the decrease of forested habitat at lower altitude (LMF and FF) results in loss of biodiversity, carbon storage (i.e. climate change mitigation) and potential for recreational services. The latter is higher for natural LULC types at lower altitudes, whose touristic sites are more accessible if compared with those located at higher and steeper zones.

### 3.3. Transitions of agricultural land to pasture

One of the most interesting issues of this research study is that LULC changes in CELS were regulated by an extremely high transition between different types of anthropic ecosystems. LULC transitions, where croplands, pastures and secondary vegetation replace each other, are commonly observed in the Andean region (Rodríguez Eraso et al. 2013), as well as in all the tropical part of South America (Wassenaar et al. 2007). The transition from agricultural land to pasture was the most relevant LULC change and mainly occurred during 2008–2014 covering an area of 3004.8 ha, equal to 7.02% of the total area (Figure 4). From the 3004.8-ha, the 69% was already agricultural land, 20% was covered by pastures and 11% was forest during 2000. This indicates that 31% of this area experienced a double conversion (pastures-agricultural-pastures or forest-agricultural-pastures) during 2000–2014. The forest loss during 2000–2008 was mainly observed in the altitudinal zone of 960–1300 m (foothill forest).

### 4. Discussion

The LULC changes observed in CELS highlight the typical pathway of changes in Ecuadorian Andean mountains. Deforestation typically occurs for wood or charcoal extraction (for 1 or 2 years), then the land parcel is converted to agriculture (2–5 years) and then to pasture (7–10 years), before returning the land to fallow for another 1–5 years (Luoma 2004). Rodríguez Eraso et al. (2013) described general patterns of change for Colombian Andes where

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Figure 4. Agricultural land converted to pastures during 2008–2014.
abandoned agricultural areas evolve to secondary vegetation, where the latter is converted to pastures. The scarce amount of secondary vegetation observed in all the three LULC maps suggests that the conversion from agricultural land to pastures during 2008–2014 occurred very fast. In general, even when short time intervals were considered for the comparison of LULC, some intermediate stages between LULC changes could not be detected due to the very fast regeneration capacity of CELS ecosystems. Natural regeneration in tropical Andes is influenced by several factors related to the previous land use and management, such as seed availability and dispersion, presence of remnant vegetation, soil structure, light and water availability (Guariguata and Ostertag 2001; Günter et al. 2007; Lozada et al. 2007). In CELS, the natural regeneration in a native forest dominated landscape is fostered by the proximity of natural environment to cropland and pastures, the favourable temperatures and the constant precipitation throughout the year, resulting in up to 2 m of pioneer species growing after only 2 years (Yaguache 2014). Even though transitions in both directions between pastures and croplands are common in tropical landscapes (Wassenaar et al. 2007; Rodríguez Eraso et al. 2013), the massive conversion of agricultural land into pastures during 2008–2014 highlights the important role of this transition to respective changes in socio-economic conditions of the local population. In the case of agricultural land, the cultivation of Naranjilla, the most widespread cultivation in CELS, provides good yields between the second and fourth year but falls markedly after, forcing producers to abandon the plantation for about 10 years (Bajaña and Viteri 2002). Moreover, Naranjilla crops require the application of agro-chemicals in order to cope pests and fungal attacks (Ochoa and Ellis 2005), which affect economic profits. Conversely in the case of pastures, the cattle production offers economic flexibility and lower financial risks (Wassenaar et al. 2007), even if pasture degradation may occur in time as well (Fearnside 1989). Thus, conversion to pastures seems to be more economically sustainable in comparison to agricultural land since the economic contribution of the latter is reduced due to overexploitation and unsustainable practices, which decrease the soil fertility very fast.

Since anthropic environments are focused on the exploitation of one market-oriented ES (e.g. food production), the provision of other functions in the case of cultivated areas and pastures is just a ‘side effect’ that depends on management practices, which are not considered by farmers and breeders. The protection of mountain natural ecosystems and biodiversity seems to be already effective in CELS, despite the high deforestation rate detected at the country scale in Ecuador (Mosandl et al. 2008). Thus, strategies for supporting farmers towards more sustainable practices are needed, with the aim to avoid agricultural land abandonment and to manage the croplands capacity to support a wider set of ecological functions. These targets are partially discussed in the Landscape Restauration Plan of CELS (Yaguache 2014), which shapes the objective of improving the supply of ecosystem goods and services as well as to strengthen ecosystems resilience and adaptation capacity to climate change. The Plan also suggests the development and implementation of better productive practices and restoration priorities for the 37% of croplands and pastures during the next years, with the goal to increase productivity and to improve hydrological and biodiversity conditions in croplands and pastures. Namely, it suggests the use of mixed permanent crops (e.g. mandarins) with annual ones, the maintenance of orchards multicultures and dispersed trees in pastures (Yaguache 2014). If these measures were applied and extended to all agricultural lands and pastures, both market and non-market ESs provided by CELS would be significantly increased with noticeable benefits for the local population. Mixed crop systems, such as those with fruit trees and annual crops, can improve the ecological functions and sustain farmer’s economic profits by reducing the need of chemicals applications. Unlike annual monocultures, the mix of permanent and annual crops provides a continuous vegetation coverage, which is found to exert a fundamental role in preventing soil erosion in Ecuadorian Andes (Molina et al. 2008). Permanent crops lead to an increase on soil organic matter content (Blanco-Canqui 2010), which significantly boosts soil fertility and regulates soil-water dynamics and microbial activities (Lal 2004). The maintenance of tree species diversity in orchards systems could avoid land degradation caused by monocultures of Naranjilla. Diverse and multi-strata orchards can provide additional benefits for biodiversity and biological control (Simon et al. 2009). In general, mixed crops show a better capacity to capture and use biophysical resources (Jahansooz et al. 2007) and to limit disease and pest organism (Perrin 1977; Sapoukhina et al. 2010), leading to a decrease in agrochemicals’ requirements.

Regarding natural ecosystems, the analysis showed that foothill forest has the larger potential for ESs provision, while the lower mountain forest exhibits the greater contribution in ESs due to its large coverage. Taking into account these observations, forest management should consider these attributes in order to maintain a high contribution of non-market ESs, which sustain ecological quality. Fuelwood and charcoal are important forest products in Ecuador (Luoma 2004), and for this reason, alternative approaches to mitigate deforestation for such purposes are needed. An alternative approach for
obtaining such products could be the use of trees in pastures. This practice was also found to be effective at reducing soil erosion (White and Maldonado 1991), improves biodiversity, and provides shade and protection to livestock (Luoma 2004).

The uneven LULC changes of CELS determined by altitude are in line with the situation of other mountainous regions of Latin America (e.g. Redo et al. 2012; Nanni and Grau 2014). Nanni and Grau (2014) observed that the interaction between agriculture modernization, human demography and complex topographic gradients of northwestern Argentina has resulted in processes of both forest recovery in uplands and deforestation in lowland areas. Redo et al. (2012) observed that forest transitions in Central America were significantly associated to socio-economic development, but with strong asymmetry in rates and directions of change, which were largely dependent upon the biome where change was occurring. These asymmetric patterns of forest change should be evaluated during the development of strategies for conserving biodiversity and ecosystem services.

Finally, some limitations concerning the method used for ESs assessment should be considered. The benefit transfer approach does not consider the spatial position of ecosystems, simplifying the landscape description based on a simple sum of ecosystems. Moreover, possible bias can be introduced when data from different sources are collected. The landscape index minimizes the effect of such bias but also other effects associated to intra and inter-site variability, by normalizing the indicators (Equation (2)). At the same time, when altitudinal variability is considered, it provides an acceptable approximation of ESs variation.

5. Conclusions

This study provided a description of LULC and ES changes in the CELS region. Although a 14-year study period may seem a relative short timespan for LULC change analysis, the study captured an extremely rapid LULC transition from croplands to pastures followed by a respective rapid socio-economic change of the local society, suggesting also its high degree of adaptability. This study provided a description of LULC and ESs changes in the CELS region. Although a 14-year study period may seem a relative short timespan for LULC change analysis, the study captured an extremely rapid LULC transition from croplands to pastures followed by a respective rapid socio-economic change of the local society, suggesting also its high degree of adaptability. The framework applied in this study could support current and future plans of environmental and ESs governance. Moreover, more detailed future field studies are required in order to improve the knowledge of how the different ecosystems of CELS support ecological functions, according to environmental gradients (e.g. altitude). Finally, LULC changes also differentiate the interaction between ecosystems. Thus, the weights assigned to ecosystems functions should be updated considering the knowledge and experience gained by stakeholders and associated institutions participating in management plans.

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