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ORIGINAL ARTICLE

Last of the wild revisited: assessing spatial patterns of human impact on landscapes in Southern Patagonia, Chile

Luis Inostroza[1,2] · Ingo Zasada[3] · Hannes J. König[3]

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Abstract Human activities are continuously expanding at a global scale and having an increasing effect on the remaining natural ecosystems in remote areas, such as the Magellan Region of southern Patagonia, Chile. In addition to extensive livestock holdings, aquaculture and tourism are advancing into formerly undisturbed areas, and insufficient information on the spatial scope and intensity of these alterations is available to inform and support conservation policies. The aim of this study was to spatially analyse the degree, scope and spatial distribution of anthropogenic alterations. Accordingly, two spatially explicit indexes, the degree of anthropogenic alteration (DAA) and human influence index (HII), have been applied. The results show a significant spatial overestimation of the remaining undisturbed natural areas. Despite low population densities and extensive conservation designations, a major share of the total area has been anthropogenically altered. Depending on the measure type, between 53.1 % (DAA) and 68.1 % of the area (HII) needs to be considered as influenced by human activity in some way. Our findings challenge previous studies by the Wildlife Conservation Society (WCS and CIESIN in Last of the wild project, version 2, 2005 (LWP-2): last of the wild dataset (Geographic), NASA socioeconomic data and applications center (SEDAC), Palisades, 2005). Their worldwide assessment of pristine natural environments indicated that a much smaller part of the Magellan region has been subject to human influence. The chosen methodologies represent an opportunity to detect and monitor human influence at small spatial scales, which has heretofore remained unnoticed. Because such alterations are becoming more frequent in remote regions, the assessment approaches presented here provide important information on human–environment interactions to support land-use and nature conservation policy design. In addition, small-scale structures and different types of economic activities are considered to support policies that can protect the remaining natural areas from human encroachment. Moreover, implications of the proposed methodology for biodiversity conservation policy are discussed.

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✉ Luis Inostroza
inostroza@technotope.org

Ingo Zasada
ingo.zasada@zalf.de

Hannes J. König
hannes.koenig@zalf.de

1 Institute of Photogrammetry and Remote Sensing, Technische Universität Dresden, Helmholtzstr. 10, 01062 Dresden, Germany

2 Universidad Autónoma de Chile, Avenida Alemania, 01090 Temuco, Chile

3 Leibniz Centre for Agricultural Landscape Research (ZALF), Eberswalder Str. 84, 15374 Müncheberg, Germany

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Introduction

We are living in the Anthropocene (Crutzen 2002), and as a result of population growth, economic development and increasing demand for natural resources, human activities have advanced into the remote regions of the globe (Lambin et al. 2001; Robinson 2004; Turner 1997). Areas with the least amount of human influence, such as southern

Patagonia, often represent ecosystems that have outstanding global value for the preservation of endemic natural features, species and biodiversity (Lockwood et al. 2012); however, these ecosystems are experiencing increasing amounts of pressure related to anthropogenic transformations of land or habitat fragmentation by transportation and energy infrastructure (Sanderson et al. 2002; Riitters and Wickham 2003). Such alterations have serious consequences on an ecosystem's capacity to maintain biodiversity and provision of ecosystem services. However, targeted information is required to support sustainable land-use and conservation policies and enable the implementation of effective measures to protect these last remaining pristine areas (CBD 2000).

Spatial analysis can be used to assess anthropogenic alterations. Currently, a number of attempts at different spatial scales (local to global) have been performed to estimate anthropogenic alterations and human influence and footprints (Sanderson et al. 2002; Leu et al. 2008) and define concepts such as naturalness (Lesslie and Malsen 1995; Hill et al. 2002; Machado 2004) or hemeroby (Sukopp et al. 1990; Kowarik 1999). Therefore, different indexes and spatial mapping approaches have been developed that utilize spatial information and remote sensing data to evaluate visible forms of land transformation at different scales (Vitousek et al. 1997; Munsi et al. 2010; Meshesha et al. 2014; Palomo et al. 2014), such as deforestation, and create spatial models to estimate land-cover changes (e.g. Pontius et al. 2001; Wu et al. 2006; Evans and Kelley 2008; Verburg et al. 2009, Li et al. 2012).

The human influence on natural ecosystems can be defined in spatial terms through specific geographic proxies, such as human population density, settlements, roads and other anthropogenic elements and activities (Sanderson et al. 2002; Zasada et al. 2013), and these terms can then be integrated in a synthetic index. Attempts to classify and categorize human influence have included the human disturbance index (Hannah et al. 1995), which classifies areas as "human-dominated," "partially disturbed" or "undisturbed" and indicates that areas disturbed by human use include 75 % of the habitable surface of the earth. In this assessment, the key geographic elements are roads, major rivers and coastlines because they contribute towards resource extraction, pollution, waste disposal and natural system disruptions (Gucinski 2001; Sanderson et al. 2002). The level and intensity of human alterations are correlated with the amount of anthropogenic matter (infrastructure, buildings, machines, etc.) accumulated in environmental compartments (Inostroza 2014) and accessibility levels. The amount of disturbance to flora and fauna can then be estimated according to the distance of flora and fauna from human infrastructures (e.g. roads, pipelines and settlements), which is performed by the Global Methodology for Mapping Human Impacts on the Biosphere (GLOBIO 2002). However, this spatial assessment must be specifically focused on existing geographic singularities.

According to global assessments of the Wildlife Conservation Society (WCS) and the Center for International Earth Science Information Network (CIESIN), the remaining "wild areas" in the world have reached approximately 27 % of the total land area (WCS and CIESIN 2005). More optimistic estimations consider that almost the entire biosphere is under anthropogenic alteration and describe this as a stable state that has persisted for millennia (Ellis and Ramankutty 2008; Ellis 2013). Nevertheless, accurate descriptions and estimates of the methods by which humans use and alter land systems are indispensable; however, models and sensors generally do not provide accurate descriptions of land-cover and land-use systems (Lambin et al. 2001; Verburg et al. 2009; Breuste et al. 2013). Current classification systems confuse land cover and land use, thus producing profound misconceptions and misrepresentations of the extent of human alteration of land surfaces (Breuste et al. 2013). This situation challenges the validity of such models, especially in remote areas where land use assumes different practices and is often undetectable by standard remote sensing methods (Inostroza 2015).

In addition, there is a growing demand for science-based information and assessment tools to support sound decision making at the policy level (de Smedt 2010; Helming et al. 2011; König et al. 2014). Spatial data are increasingly used to support policy processes at different spatial scales and can help reveal the possible effects of policies (La Rosa et al. 2014; Ungaro et al. 2014). In the European Union, for example, ex-ante assessment procedures have recently become a mandatory instrument for assessing policies before implementation (Tscherning et al. 2008). However, other regions of the world, such as Latin America, are still lacking spatial information, tools and indicators for use in planning and policy procedures that support sustainable nature conservation options (Reidsma et al. 2011; König et al. 2013). In Chile, the Magellan's region is out of the scope of the national official cartography at 1:50,000. This produces an important shortcoming for territorial planning and management. Satellite imagery such as LANDSAT and others types of remote sensing provide a valuable information sources for policy and planning. However, due to various reasons (like the permanent presence of clouds) also their extent of high-quality imagery is limited and requires careful interpretations of the small-scale human alteration. In this respect, the development of environmental land-use indexes is required, which possess higher sensitivity for anthropogenic alterations beyond physical land-use change.

The first objective of our paper is to develop an easily interpretable and comprehensive spatial mapping approach to assessing human alterations in the Magellan Region of southern Patagonia (Chile). Therefore, two indexes are proposed to quantify anthropogenic alterations and assess the remaining undisturbed natural areas (RUNA) by making use of cover/use assessment along a spatiotemporal gradient: the degree of anthropogenic alteration (DAA) and human influence index (HII). Second, the results of our regional assessment will be compared with previous global estimations (WCS and CIESIN 2005) for the same region. Third, the extent to which the new regional assessment approaches can provide additional information for biodiversity conservation and evaluations will be discussed in relation to land-use management and conservation of natural ecosystems. For operational purposes, we have used the term "undisturbed natural areas" to refer to anything that has not been made or directly influenced by humans, particularly by human technology (Hunter 1996; Angermeier 2000; Machado 2004).

Materials and methods

Case study area

The case study examined the Magellan Region of southern Patagonia (Chile), which encompasses a surface of circa 131,232 km^2 and has a population of 150,826 (<1.14 capita $\times$ km^{-2}), with 76 % concentrated in the capital city of Punta Arenas (Instituto Nacional de Estadísticas 2005). The climate is determined by the latitude (between 51°S and 56°S), and the strong marine influence regulates temperature. Strong winds blowing from the South Pacific collect moisture in the Andes and cold and dry air through the pampas, which causes huge rainfall differences from 4000 mm per year in the Pacific and 250 mm year in the Atlantic. The Andes Mountains represent a strong geographical barrier that produces morphological and ecosystem diversity by dividing the territory into two parts. The Atlantic side represents a wide flat territory (pampa) extending from the Andes to the Atlantic Ocean. Although drier than the Pacific side, precipitation occurs throughout the year. This characteristic of the steppe climate produces a homogeneous vegetation cover that consists of grassland with low shrub features that determines the potential of the cattle shed. As a result of cyclic glacial advances of ice sheets during the last ice age, the Pacific side is characterized by significant territorial diversity, with altitudes of approximately 2500 m in the Andes, and the glaciers, snowfields, fjords, channels and inland seas provide its characteristic morphology (IGM 1983; MOP 1994).

All of these territorial characteristics imbue the region with high ecological sensitivity (Pisano 1990). However, although large parts of the case study region still appear as natural territory untouched by human influences (Inostroza 2012), anthropogenic alterations have occurred and caused innumerable effects, many of which have remained unnoticed or in latencies until they surpass certain thresholds and are then triggered to evolve in incremental impacts (Myers 1995). Extensive ranching is a good example of these effects because the steppe ecosystem resembles a beautiful natural territory with a low level of human alteration (Garcés 2009), and anthropogenic interventions, such as buildings, roads and fences, appear dwarfed by the territorial immensity. However, almost the entire steppe ecosystem is undergoing a process of anthropogenic erosion, which has remained unnoticed (Inostroza 2012).

The huge environmental differences in Patagonia, its climate and geography have a produced a strong temporal gradient in terms of anthropogenic influence, respectively, the evolution of the socio-ecological system in the region. Before the Spanish colonization between the sixteenth and nineteenth century with the foundation of military settlements and the city of Punta Arenas at the end of the period, nomadic hunters represented early human occupation (Moss 2008). As late as in the 1880s, a more comprehensive exploitation of the steppe ecosystem arose through the introduction of extensive animal husbandry, mainly sheep farming, already raising concerns of overgrazing (Inostroza 2012; EBO 2015). In this period, the region has been further urbanized through the foundation of Puerto Natales and Porvenir as second and third largest cities as well as other minor settlements. The exploration and exploitation of the oil resources between 1945 and the 1980s marked the next stage of anthropogenic exploitation of Patagonia, pushing the frontiers of utilization further that the entire steppe ecosystem became human influenced. In addition, military use, including additional urban areas, Cerro Sombrero and Villa Tehuelches, gained importance. The current stage of exploitation is dominated by tourism activities, which along with an increasing importance of Punta Arenas also put the former mountainous areas along the coastline under increased pressure (Schlüter 2001; Inostroza 2012).

Today, due to its ecological value, the region is subject to extensive nature protection schemes. More than the half of the area (67,385 km^2) is protected by legislation according to the national system of protected areas of the state (SINIA 2015). Whereas certain national parks have attempted to control human activities, like the Torres del Paine, others allow visitors and certain types of economic activities. All of the protected areas are administered by CONAF (national forestry corporation), a state agency that reports to the Ministry of Agriculture. One of the main objectives of CONAF is to enhance the development of tourism in protected areas. Comprehensive land-use regulations that allocate activities in the territory are not in place, and the government and administrations only address specific aspects of land use in a sectorial way. Environmental impact assessments (EIAs) are only mandatory for large projects and do not influence land-use policy.

Global assessment of human influence by the wildlife conservation society (WCS)

The first step included performing an assessment of the undisturbed natural area in the region by analysing the database from the WCS and CIESIN (2005). Undisturbed natural areas are considered to be biomes with a HII value of less than or equal to 10. The raster file containing the degree of human influence for the entire continent was downscaled using standard GIS processing, and the original raster file was transformed into a vector file, re-projected and adjusted to the current land-cover classification which has been developed by Inostroza (2012, 2015) to produce a spatial data set representing all of the regional ecosystems and ecotopes.

Degree of anthropogenic alteration (DAA)

The first approach determines the DAA, which represents the total anthropogenic elements and/or cumulative spatial effects likely to be measured or detected empirically in a given ecotope, and the DAA index defines an ecotope as the smallest homogeneous spatial unit. Ecotopes containing any human activity, anthropogenic elements or spatial effects have been altered and are no longer undisturbed. Under this spatial approach, anthropogenic alterations are initially distributed following the landscape's matrix (homogeneities) and reflect the ecosystems' transformations in terms of the spatial structure of the ecosystem.

According to the concept of socioeconomic metabolism, in which human systems exchange matter and energy with nature to reproduce themselves physically (Fischer-Kowalski 1998; Grünbühel et al. 2003), we distinguish different types of anthropogenic alterations along a gradient from undisturbed natural ecosystems to intensively transformed urbanized areas (see Fig. 1 for illustration). The first phase is referred to as colonization activities, and it is characterized by sporadic economic activities of primary production (e.g. aquaculture) and raw materials and tourism activities used on a concessional basis. The process is connected to a decreasing degree of naturalness because environment is increasingly controlled by human intervention (Grünbühel et al. 2003; Machado 2004). Colonization is followed by appropriation, where the indirect use of the environment intensifies, such as through excavation and quarrying of minerals and fossil fuels and extensive forms of animal husbandry. The phase of ruralization promotes increasingly permanent and direct forms of land use, particularly agriculture, which results in ecosystems that are dominated by humans and have a low degree of naturalness. Urbanization represents the last phase of anthropogenic alteration. The environment is characterized by built-up structure, and the intensity of resource consumption is particularly high, requiring a net inflow of energy and raw materials from outside areas.

To reflect the metabolic gradient, three types of variables (accounting for a total of 18 variables) were quantified (Table 1 and Eq. 1): anthropogenic elements (cities, roads, fences, lights, infrastructure, etc.); economic activities (mining, oil wells, forestry, aquaculture, tourism, cultural attractions, etc.) and other anthropogenic elements or effects (inhabitants, livestock, erosion, etc.). In the case of appropriation–colonization activities, the measured magnitude was their presence because they change the undisturbed natural condition of the site. Thus, the values were considered to be Boolean, with a value of 0 for ecotopes that did not include the specific activity and 1 for ecotopes that did include the activity. Variables with higher levels of human transformation were quantified in their respective units: km for vectors (fences, roads) and km^2 for areal variables (management plans, mining exploration, etc.). Variables were separated into different groups according to their characteristics: (1) exploitation mining was separated from exploration; (2) operational aquaculture was separated from non-operational; (3) touristic attractions were separated into cultural attractions with the presence of infrastructure or natural sites; and (4) similar activities such as fishing and aquaculture were integrated into a single variable. To obtain final values for each ecotope, all of these variables were measured in relative terms (concentration) and summed using the equation,

$$d_j = \sum_{i=1}^{n} (a_{ij}/s_j) \tag{1}$$

where d_i is the nominal value of the Degree of Anthropogenic Alteration in ecotope j; a is surface in km^2 of activity i in ecotope j (Table 1) and s is surface of ecotope j. The nominal d value was later transformed with linear normalization.

Determining a DAA that includes several variables that are not currently assessed in other methods, such as the land-cover/land-use vegetation cadaster (CONAF-CONAMA 2006), can provide measurements that include a larger scope of current forms of human alterations in addition to typical land-cover measures.

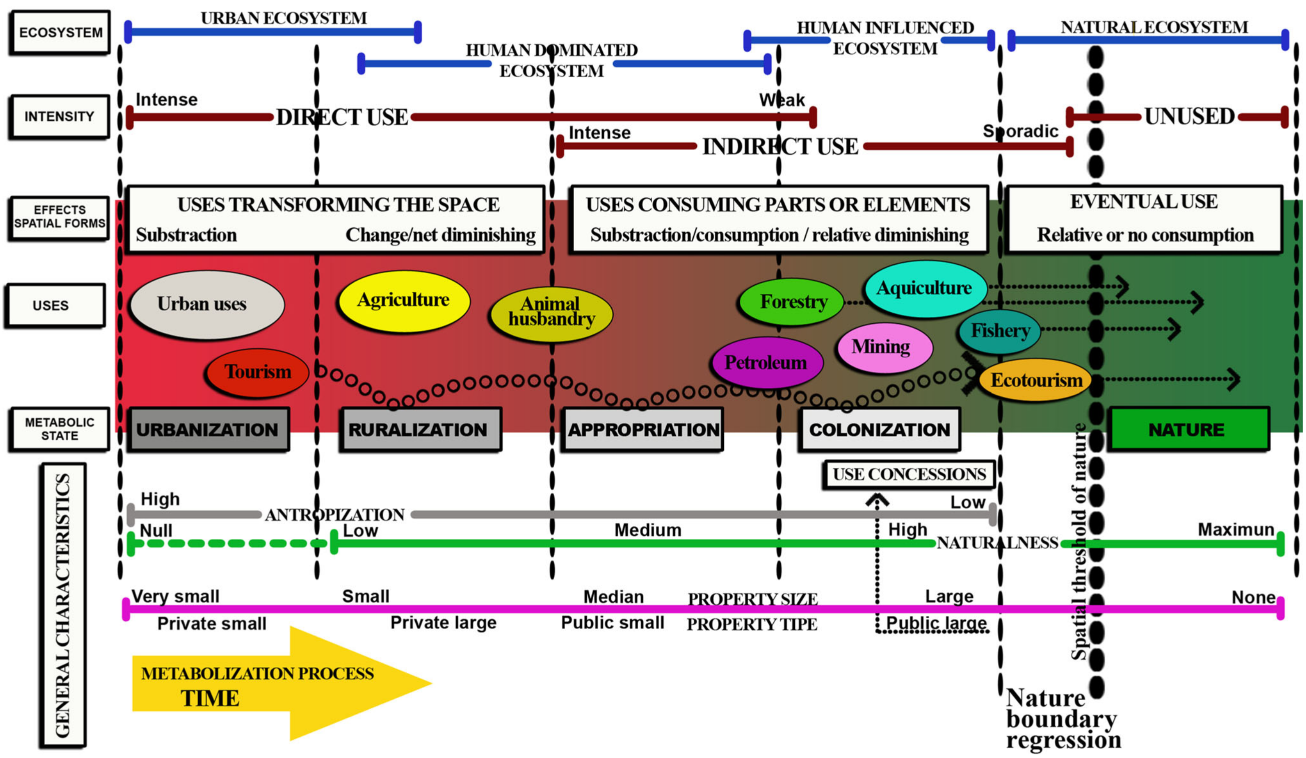

Fig. 1 Metabolic intensities and human activities along a spatial gradient

After normalization, the resulting DAA corresponds to an intensity gradient from 0, which represents ecotopes without human intervention or in unchanged wild conditions, to 1, which represents ecotopes with a high degree of anthropogenic changes (Table 1). The DAA can be understood as the probability of finding human alteration in an ecotope. To facilitate the interpretation, the results were grouped into four categories representative an intensity gradient, which implies a correlation between the metabolic state and intensity of human alterations and reflects the spatiotemporal structure presented in Fig. 1.

Human influence index (HII)

As a second approach, the HII was proposed to depict the spatial extent of human activities and show current changes in the human occupation frontier. This index uses the same theoretical framework as the approach by WCS and CIESIN (2005) but is geographically determined, and it accounts for almost all of the current economic activities within the case study region; therefore, it can provide a fine-scale spatial assessment of their scope of influence.

Human activities are represented by the presence of (1) elements built by humans, such as infrastructure and built-up structures; (2) geographical features that allow for human influence, including coast lines or geologic elements, such as extractions sites; and (3) planning zones and specific project sites. The conjunction of these human activities can reflect the scope of socioeconomic metabolism and provide spatial consistency with other measures, such as the regional ecological footprint (Inostroza 2005). Therefore, the HII was calculated using 13 variables (Table 2) that reflect the available data up to the year 2003 on the aforementioned types of human activities, and it corresponds to a normalized gradient where 1 indicates the highest degree of human influence, i.e. urban core, and 0 indicates no influence within undisturbed natural areas. We apply Eq. 1 but using a spatial overlay function rather than ecotope as it was for DAA.

Accessibility and coast variables were adjusted according to the terrain's geomorphology. To measure the area of influence of roads, the overall distance a person could walk in 1 day in a difficult-to-traverse ecosystem, such as a dense forest, was estimated as 15 km (see e.g. Wilkie et al. 2000). Certain territories are inaccessible because of steep slopes, glaciers or other obstacles that limit accessibility from either the shore or roads; inaccessible areas were spatially discounted. Because the influence of a road depends on the hierarchy and amount of traffic passing along the road, land accessibility was normalized by weighting the road network hierarchy using the classification of the Ministry of Public Works (MOP). Secondary

Table 1 Metabolic states, variables and data sources for DAA

Metabolic state	Main features	Value	Description	Variables intensidad de antropizacion								
				Variable	Unit	Measured element	Categories	Description	Data type	Source	Type	Year
Urban ruralization	Big cover changes maximum degree of conversion of nature	10.8 year 0.99 0.6 year 0.8	Cities and highly urbanized suburban areas generated by tourism, industrial establishments or others Hinterlands of cities, rural areas with farming and/or livestock with significant degrees of modification	1. Roads 2. Erosion 3. Urban population	km^2 Factor inhab/km^2	The road surface according to their hierarchy Degree of anthropogenic erosion The sum of inhabitants of human settlements	40 m 30 m 20 m 10 m	Highway Secondary paved roads Secondary not paved roads Other not paved roads Erosion factor (SAG) Total population divided by the ecotope surface	Vector line Vector polygon Vector polygon	MOP SAG INE—CENSUS	Vector Area Area	2002
Appropriation	Appropriation of organic inputs, permanent presence of human elements in the environment	0.4 year 0.6	Areas of extensive farming, sparsely urban or anthropic elements	4. Rural housing 5. Fences 6. Sheeps 7. Lighthouses 8. Harbours 9. Aquaculture (operative) 10. Cultural touristic hot spot	house/km^2 km/km^2 sheeps/km^2	The sum of rural households in the district by census geographic unit The sum of kilometres of fences (fences) The animals per plot according to parcel data Number of lighthouses Infrastructure of human origin, such as docks and ramps Places where aquaculture concessions are operational Cultural or anthropogenic attractions		Fence kilometres per km^2 Number of sheep per km^2 Number of lighthouses per km^2 Number of facilities per km^2 Number of existing aquaculture concessions per km^2 Number of cultural attractions per km^2	Vector polygon Vector line Data set Vector point Vector point Vector point Vector point	INE—CENSUS PRDU SAG-INE MOP MOP SERNAPESCA—GORE SERNATUR	Area Vector Coordinate Coordinate Coordinate Coordinate	2002

Table 1 continued

Metabolic state	Main features	Value	Description	Variables intensidad de antropizacion								
				Variable	Unit	Measured element	Categories	Description	Data type	Source	Type	Year
Extractive colonization	Colonizing extracting activities generating metabolic inputs, permanent presence	0.2 year 0.4	Scattered holdings, low presence and / or anthropogenic changes little apparent perceived as natural areas	11. Forestry management plans 12. Mining exploitation concessions 13. Fishing 14. Oil wells	km^2 Unit/ km^2	The sum of km^2 of mining and forestry Fishing activities Oil/gas extraction activities		Operating area of forest management plans per km^2 Surface of mining concessions per km^2 Places of extraction of artisanal and industrial fishing per km^2 Number of operating oil wells per km^2	Vector point Vector polygon Vector point Vector point	CONAF SERNAGEOMIN SERNAPESCA ENAP	Area Area Coordinate Coordinate	
Colonization	Colonization, flashing presence of human elements in the natural environment	0.01 year 0.2		15. Mining exploration concessions 16. Tourist landing 17. Tourist natural attractions 18. Aquaculture (inoperative)	km^2 Unit/ km^2	The current prospecting territory Areas authorized for disembarking tourists Non-cultural tourist attractions Places where Aquaculture concessions are not operational		Surface of mining exploration concessions per km^2 Number of tourist landing zones per km^2 Number of other various touristic attractions per km^2 Number of inoperative aquaculture concessions per km^2	Vector polygon Vector point Vector point Vector point	SERNAGEOMIN SERNATUR SERNATUR SERNAPESCA—GORE	Area Coordinate Coordinate	
Natural		0	Undisturbed natural areas without the presence of human elements or any use									

Table 2 Variables and data sources for the HII

Category	Variable	Method	Range (km)	Unit	Description	Data type	Source
Presence of anthropic elements	1. Main roads	Buffer	0–15	Normalized	Highway	Vector line	MOP
	2. Secondary roads and paths	Buffer	0–5	Normalized	Secondary roads and paths	Vector line	MOP
	3. Urban centres	Buffer	0–15	Normalized	Urban centres	Vector point	PRDU
	4. Villages	Buffer	0–2	Normalized	Villages	Vector point	INE—CENSUS
	5. Rural population		Districts	inhab/km^2	Rural population	Data set	INE—CENSUS
Generating influence Geographical features making it susceptible of anthropogenic influence	6. Coast	Buffer	0–2	Normalized	Coast line	Vector line	PRDU
	7. Mineral deposits	Buffer	0–2	Normalized	Mineral deposits	Vector point	SERNAGEOMIN—LC
	8. Thermal	Buffer	0–2	Normalized	Thermal	Vector point	SERNAGEOMIN—LC
Zonifications and projects	9. Aquaculture areas	Buffer	0–2	Normalized	Aquaculture areas	Vector point	SERNAPESCA—GORE— LC
	10. Touristic zones	Ponderation		Normalized	Touristic zones	Vector polygon	SERNATUR—LC
	11. Oil/gas exploration blocks	Booleano	0–2	Normalized	Oil/gas exploration blocks	Vector polygon	ENAP —LC
	12. Maritime routes	Buffer	0–2	Normalized	Maritime routes	Vector line	PRDU
	13. Projected roads	Buffer	0–5	Normalized	Projected roads	Vector line	MOP

roads were normalized into two ranges, and different intensities of accessibility and population centres were normalized into five ranges, from 0–2, 2–5, 5–10, 10–15 and more than 15 km accounting for very high, high, medium, low and no accessibility, respectively.

The location of metallic and nonmetallic mineral deposits was determined using the online geological information system from the ministry of Chilean mining (SERNAGEOMIN 2010, http://sigeo.sernageomin.cl/). The online system does not allow digital information to be downloaded; thus, the location of the mineral resources was transferred manually to a point SHP file, containing the UTM coordinates, resource type, site or operation size, and situation (i.e. exploration/exploitation).

Comparing WCS data base with DAA and HII indexes

The original WCS and CIESIN (2005) approach delineated four different classes: Magellanic subpolar forests, Patagonian steppe, rock and ice, and Valdivian temperate forests. These classes did not fully represent the observed situation in Patagonian region. For instance, despite the major relevance of wetlands to the regional ecosystem, their assessment has not included the wetlands class, which accounts for 23 % of the total surface (Inostroza 2008). Thus, the geoprocessing approach was conducted to identify the misclassified areas. To allow for comparisons of the final classification with equivalent ecotopes in current databases, the Magellanic subpolar forest and Valdivian temperate forest classes were merged into one: forest. The resulting forest category, which did not include wetland areas, was used in the analysis. With this geoprocessing, it was ensured the comparability of WCS and CIESIN data set with DAA and HII data sets.

Results

Global assessment of human influence by the wildlife conservation society (WCS)

The spatial assessment based on the WCS and CIESIN (2005) data set revealed that 73.9 % of the total territory within the case study region can be considered undisturbed natural area (96,962 km^2) (Fig. 2). Over that total area more than half (62.4 %) is classified as forest land. Wetlands cover the second major portion (22.3 %), and steppe, rock and ice have only minor shares. The spatial extension of undisturbed natural area according to this approach is shown in Fig. 2. Percentages are given in Table 3.

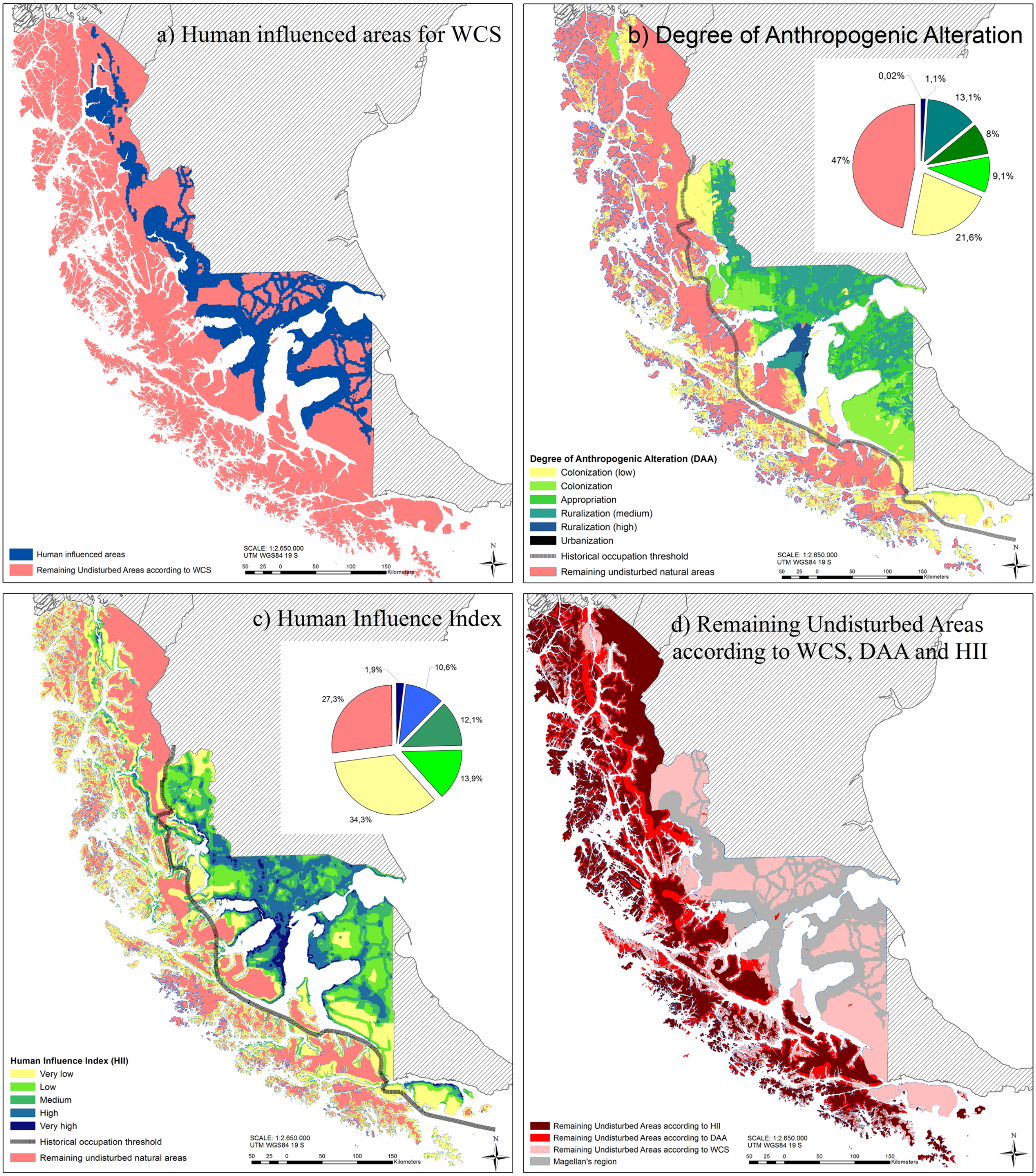

Fig. 2 All three assessment approaches and the comparison between them. Original spatial data set for developing **a** from WCS and CIESIN (2005)

Degree of anthropogenic alteration (DAA)

Applying the DAA index, our findings revealed a territory under anthropogenic alteration of 53.1 % of the total area of the study region (69,629 km^2). The RUNAs in terms of ecosystems are given in Table 3. In terms of metabolic states, areas of colonization predominate, covering approximately one-third (30.8 %) of the total

Table 3 Share of ecotopes composing the DAA and HII

Ecotope	WCS and CIESIN (%)	DAA (%)	HII (%)
Steppe	8.5	40.7	33.3
Forest	62.4	19.7	25.3
Wetlands	22.3	22.8	27.2
Bare rocks, snow and glaciers	6.7	13.3	11.0
Water, others, without info	0.01	3.3	3.2
	100.0	99.8	100.0

territory. The more intensively transformed areas of ruralization and appropriation follow with 14.2 % and 8 %, respectively, whereas urbanized areas are marginal (see Fig. 2).

Regarding the spatial distribution, three general patterns of anthropogenic alterations emerge. First, major areas of urbanization and high and medium ruralization are concentrated on the Brunswick Peninsula in the centre of the region in the vicinity and hinterland of Punta Arenas City. In particular, the steppe ecosystems in this area have been substantially transformed. Second, the eastern part of the region is characterized by a high degree of appropriation and ruralization because this area has been traditionally under human encroachment, mainly through extensive livestock farming (ranging). Third, important anthropogenic alterations have occurred on the Pacific islands in a scattered pattern from north to south and covering a broad spectrum of ecosystems. Driven by the expansion of (low) colonization activities, mainly aquaculture and tourism, these transformations move beyond the historical occupation threshold into previously undisturbed natural areas that have been relatively unaffected by legal area designations for nature protection (forest reserve).

Human influence index (HII)

Based on the HII assessment, approximately 68.1 % of the total area (89,387 km^2) is under some form of human influence, leaving only 31.9 % of the land as undisturbed natural area (see Fig. 2; Table 3). The most intensive human influences can be found along the coastal areas of central south Patagonia, where the cumulative effect of natural as well as infrastructural and settlement-based accessibility of the land is greatest. High-intensity activities are spreading into the northern part of the case study region, whereas on both sides of the Straits of Magellan (mainland and Isla Grande de Tierra del Fuego), low- to medium-intensity human influences prevail, particularly along transportation routes. However, the HII also identifies economic activities, such as aquaculture and tourism, which have advanced into the Pacific area beyond historical occupation thresholds (see Fig. 2). In terms of human influence variations in different types of ecosystems, strong differences have been determined (Table 3). The ecosystems under human influence are mainly steppe (33.3 % of the total human-influenced area), forest (25.3 %) and wetlands (27.2 %). Those three ecosystems are of high ecological value in the region. Bare rocks, snow and glaciers areas only account for 11 % of the total human-influenced area (Table 3). These shares indicate that the spatial structure of human influence in terms of ecosystems being influenced is highly relevant and might have an important ecological effect.

Variations in RUNAs between the WCS/CIESIN, DAA and HII indexes

As Fig. 2 reveals, all three assessment approaches indicate that the large parts of the case study area are anthropogenically altered and influenced by humans because of the current pattern of land-use and specific features of current economic activities. However, differences in spatial extent have been found for the various approaches. The WCS and CIESIN (2005) approach identifies 96,962 km^2 (73.9 %) as undisturbed natural area, whereas the anthropogenic alteration degree (DAA) and HII identify significantly smaller areas of 61,603 km^2 (46.9 %) and 41,844 km^2 (31.9 %), respectively.

Differences are also observed in terms of affected ecosystems (see Fig. 3). In both indexes (DAA and HII), the RUNAs are mostly bare areas, such as rocks, snow and glaciers. These ecotopes have low ecological capacity for sustaining ecosystem functions compared with steppe or forest. The remaining areas free of human influence adopt a relict form that is highly fragmented, whereas areas with increased ecological capacity, such as steppes, forests and wetlands, present increased alterations and signs of influence compared with those covered by snow and glaciers. The largest difference occurs for the forest category, where the share of undisturbed natural areas has decreased from over 60,000 km^2 (WCS) to 13,833 km^2 (DAA) and 5207 km^2 (HII). Overestimations of the natural land by the WCS and CIESIN methodology have also been found for wetlands and steppe, especially for the latter, which presents significant differences based on the approach used. WCS and CIESIN calculated that at least 6 % of the steppe

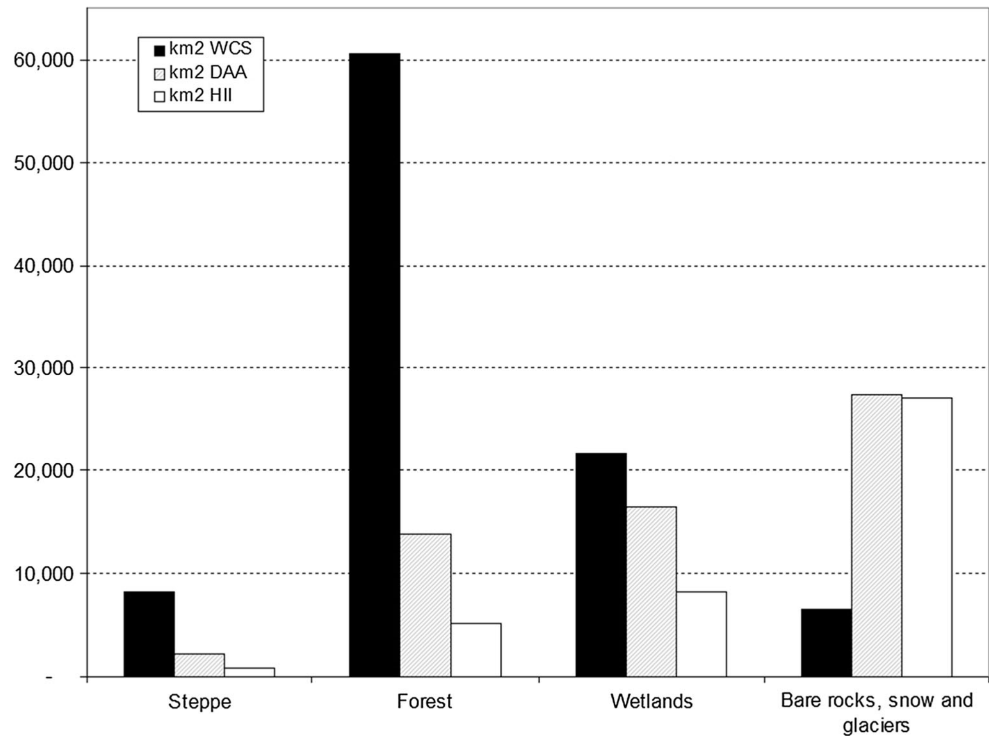

Fig. 3 Undisturbed areas in the different ecosystem categories

area was undisturbed, whereas the HII calculated this value as less than 3 %. However, bare rock areas, snow and glaciers were underestimated by the WCS and CIESIN assessment. For the steppe, forest and wetlands large areas have been influenced, although large portion of the bare rocks, snow and glaciers can still be considered untouched by human influence (Fig. 4). These undisturbed natural areas are primarily found along the mountain range in the western part of the mainland and on the Pacific islands (Fig. 2).

Discussion

Comparison of DAA and HII: differences and challenges

The application and downscaling of current global approaches, such as for the methodology of the Wildlife Conservation Society (WCS and CIESIN 2005), represents a starting point for spatial assessments of the scope and effects of human activities on land surfaces. Although global models are important for showing global trends, they are limited in regional application because of important methodological shortcomings, including the high number of assumptions that have not been geographically determined. The results in this paper revealed that undisturbed natural areas have been overestimated by global assessment approaches. The WCS approach identified the Magellan Region as one of the last "wild" natural regions in the world, and the HII and DAA have shown that this area shares similar levels of human influence as found in more densely populated regions in terms of the spatial scope of economic activities. Only the extremely remote, inaccessible and topographically difficult areas of the region are free of anthropogenic transformations.

There are two important aspects that explain the high variability among the different assessment approaches. The first pertains to the spatial scale of assessment, which plays an important role in estimating the scope of human activities. In certain cases, human impacts cannot be depicted at higher global scales, such as the impacts from transportation and other linear infrastructures. As an analytic approach that goes beyond land-use/land-cover-based assessments, the HII can provide valuable additional information on the role of small-scale structures and their effects on the actual state of naturalness of an ecosystem. Similarly, the DAA approach provides information on economic activities, which are also often not represented by detectable land cover. However, despite the small spatial scope of such activities, their spatial dispersion indicates the systematic process of anthropogenic territorial modifications.

The second aspect, which is even more relevant than the first, is the need to include a specific set of economic activities that occur in the geographic location being assessed. This aspect varies significantly according to the location of natural resources and other socioeconomic

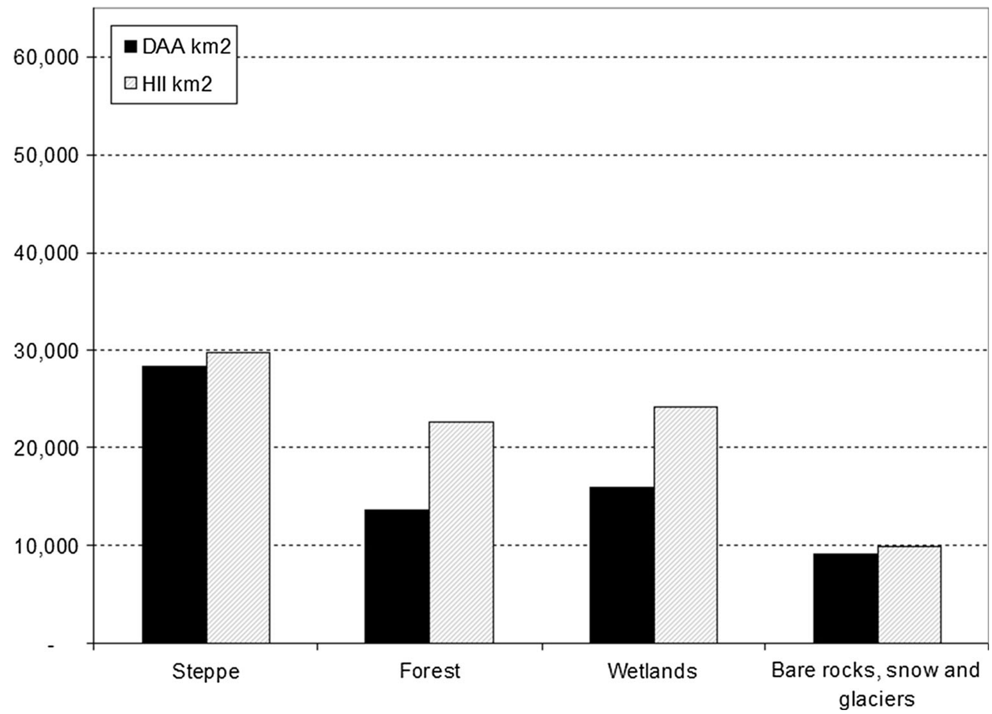

Fig. 4 DAA and HII in the different ecosystem categories

features specific to a location. In general, global assessments provide weak depictions of geographically determined features because they normally overuse simplifications, such as homogenized parameters and single estimators.

Magnitude differences between the indexes highlight a trend of territories being incorporated into the socioeconomic metabolism, a process that is consistent with the historical evolutionary pattern of economic activities (Inostroza 2012). This progression shows a systematic reduction in natural boundaries. The confrontation between anthropogenic and natural ecosystems is asymmetric, with the former widening borders at the expense of the latter.

However, the holistic approach to assessing anthropogenic alterations (DAA) and human influence (HII) requires specific data. To accurately illustrate the intensity and spatial extent of anthropogenic alterations in an ecosystem, it is necessary to account for a broad and diverse set of elements and effects. In this research, an exhaustive revision of all possible methods of using ecosystems has been developed and includes activities that are normally ignored in similar studies, such as fisheries, aquaculture, mining and forestry. Such data are currently available, even in Latin American countries; however, the data are distributed across a large number of institutions. Such information fragmentation makes it difficult to construct integrated data sets with different technical characteristics, such as datum and spatial resolution, and increases the time required to perform similar assessments. In addition, because the spatial information required to build these indicators is geographically specific, the replicability and comparability of DAA and HII assessments are high, which is an important characteristic of the proposed indicators.

Combining land-use models with socio-ecological assessments

Common sense can be found in the academic debate surrounding changes in anthropogenically driven or urban land use that occur below the surface of changes in land cover, such as the conversion of natural areas into farmland or even urban areas (Verburg et al. 2009; Bomans et al. 2010; Breuste et al. 2013; Inostroza 2015). Because land-use classifications mostly rely on land-cover data and use criteria that do not reflect the extent of human appropriation (Inostroza 2012), standard land-use/land-cover models are not capable of showing the actual extent of land-use changes (Breuste et al. 2013, Inostroza 2015), which challenges the validity of such models, especially in remote areas, where land use assumes different practices and is often undetectable by standard remote sensing methods. Therefore, a stronger link between land-cover-based models and socioeconomic, stakeholder-based assessments is required (König et al. 2010). A combined representation within a common theoretical framework can overcome challenges found in the current sectorial approaches and provide support for policies and decision making. The particular strength of DAA assessments is the integrative metabolic approach, where activities accounted for in the spatial calculation are understood in terms of their sociometabolic role and as processes. The differentiation of metabolic states (see Fig. 1) can account for human activities and reflect their operations. The spatial scope of anthropogenic modifications is increasing, and the metabolic states depicted by this index can determine the spatial–temporal progression and evolution of such states.

Lessons learned to support nature conservation and land-use policy and planning

There have been increasing demands for improved information on the state of ecosystems and ongoing processes of land-use change, particularly for land-use and natural resource planning and biodiversity conservation policy (see Loidi 1994; Edarra Indurain 1997; Meaza and Cardiñanos 2000). The degree of anthropogenic alteration and human influence as well as naturalness represent important evaluation criteria in several fields of conservation and land-use planning (see Jacobi and Scott 1985; Lambin et al. 1999; Machado 2004) and are particularly important in areas such as the Magellan Region, where transformations generally occur at a small scale and in a scattered pattern. Here, land-cover-based approaches would not provide valuable information (usually unintended) because the land transformations cannot be assessed at larger spatial scopes and intensities. The proposed assessment approaches can improve the descriptions of land use and be used to design conservation policies. However, these types of ad hoc assessments present a larger potential for use in strategic environmental assessments (SEAs) and environmental impact assessments (EIAs) in the context of approval processes for economic projects and concessions. As categories, anthropogenic alterations and human influence refer more directly to the effect of socioeconomic activities. Further application options can include elaborating upon suitability matrixes (see Gomez Orea 2002), designing development limitations and zoning (Theberge 1989; Machado et al. 2004) and establishing conservation priorities (Margules and Usher 1981). In the case of wildlife management, such indexes can be used to guide translocations, introductions or re-introductions of living organisms (IUCN 1987), assess habitat quality (Jacobi and Scott 1985) and prioritize initiatives for ecological restoration (Anderson 1991).

Conclusions

In this paper, we have shown that only certain remote areas of the Magellan Region included remain undisturbed by human influence. Accordingly, the region is far from a pristine natural environment as shown in the global assessment by WCS and CIESIN (2005). Results indicated that more than 68.1 % of the total regional surface is affected to some degree by direct human transformation or subjected to pressure by various economic activities. These patterns constitute the paradox of one of the most sparsely populated and protected regions of Chile. Patagonia is a highly sensitive environment with low ecosystem homoeostasis. Therefore, the described spatial scope of anthropogenic alteration and human influence becomes important not only in terms of magnitude but also ecologically terms because of the ecological characteristics of the exploited ecosystems. These findings raise questions on the convenience of the National Conservation System (SNASPE) as a preservation mechanism and indicate that new methods of preserving the uniqueness of this special territory must be found.

By integrating the occurrence of economic activities with land-use and socioeconomic indicators, such as population density, the proposed indexes can depict the expansion pattern of socioeconomic metabolism, which incorporates more territory into the human ecosystems. Because these processes are occurring in one of the most fragile regions of the country, the patterns and intensities of current economic activities and land uses, such as farming and forestry, must be redefined. In addition, important land-use transformations that are not considered in current land-use evaluations, such as mining, tourism, and aquaculture must be included, and a careful assessment of their location patterns and spatial relationships with protected and ecologically fragile areas is vital.

The DAA and HII indexes spatially characterize the amount of land that is currently being used in the Magellan Region as well as the intensity of land use and amount of undisturbed natural territory that remains. Based on these results, the current perception of the Magellan Region as an undisturbed natural region should be re-evaluated. The degree and extent of human influence have a high spatial scope; therefore, the expected future environmental impacts are relevant. The presented methodology can help provide similar spatial assessments in other remote areas by downscaling global assessments and improve policy measures for the conservation of the last remaining undisturbed natural areas of the world.

References

Anderson JE (1991) A conceptual framework for evaluating and quantifying naturalness. Conserv Biol 5(3):347–352. doi:10.1111/j.1523-1739.1991.tb00148.x

Angermeier PL (2000) The natural imperative for biological conservation. Conserv Biol 14(2):373–381. doi:10.1046/j.1523-1739.2000.98362.x

Bomans K, Steenberghen T, Dewaelheyns V, Leinfelder H, Gulinck H (2010) Underrated transformations in the open space–the case of an urbanized and multifunctional area. Landsc Urban Plan 94(3–4):196–205. doi:10.1016/j.landurbplan.2009.10.004

Breuste J, Haase D, Elmqvist T (2013) Urban landscapes and ecosystem services. In: Wratten S, Sandhu H, Cullen R, Costanza R (eds) Ecosystem services in agricultural and urban landscapes. Wiley, Hoboken, pp 83–104

CBD (2000) Convention on biological diversity. http://www.cbd.int/convention/guide/default.shtml. Accessed 5 Nov 2014

CONAF-CONAMA (2006) Catastro de uso del suelo y vegetación, región de Magallanes y Antártica Chilena. Monitoreo y actualización, Santiago

Crutzen PJ (2002) The "anthropocene". J Phys IV France 12(10):1–5. doi:10.1051/jp4:20020447

de Smedt P (2010) The use of impact assessment tools to support sustainable policy objectives in Europe. Ecol Soc 15(4):30–39

Edarra Indurain A (1997) Botanica ambiental aplicada: las plantas y el equilibrio ecologico de nuestra tierra, 2nd edn. EUNSA, Pamplona

Ellis EC, Ramankutty N (2008) Putting people in the map: anthropogenic biomes of the world. Front Ecol Environ 6(8):439–447. doi:10.1890/070062

Ellis EC, Kaplan JO, Fuller DQ, Vavrus S, Klein Goldewijk K, Verburg PH (2013) Used planet: a global history. Proc Natl Acad Sci USA 110(20):7978–7985. doi:10.1073/pnas.1217241110

Encyclopædia Britannica Online (EBO), s. v. "Patagonia", Accessed 19 Aug 2015, http://www.britannica.com/place/Patagonia-region-Argentina

Evans TP, Kelley H (2008) Assessing the transition from deforestation to forest regrowth with an agent-based model of land cover change for south-central Indiana (USA). Geoforum 39(2):819–832. doi:10.1016/j.geoforum.2007.03.010

Fischer-Kowalski M (1998) Society's metabolism. J Ind Ecol 2(1):61–78. doi:10.1162/jiec.1998.2.1.61

Garcés E (2009) Tierra del Fuego Como paisaje cultural extremo. Conserva 13:95–108

Gomez Orea D (2002) Ordenacion territorial. Mundi-Prensa, Madrid

Grünbühel CM, Haberl H, Schandl H, Winiwarter V (2003) Socioeconomic metabolism and colonization of natural processes in SangSaeng Village: material and energy flows, Land use, and cultural change in Northeast Thailand. Hum Ecol 31(1):53–86. doi:10.1023/A:1022882107419

Gucinski, H. (2001) Forest roads: a synthesis of scientific information. DIANE Publishing

Hannah L, Carr JL, Lankerani A (1995) Human disturbance and natural habitat: a biome level analysis of a global data set. Biodivers Conserv 4(2):128–155. doi:10.1007/BF00137781

Helming K, Diehl K, Kuhlman T, Jansson T, Verburg PH, Bakker M, Pérez-Soba M, Jones L, Verkerk PJ, Tabbush P, Morris JB, Drillet Z, Farrington J, LeMouél P, Zagame P, Stuczynski T, Siebielec G, Sieber S, Wiggering H (2011) Ex ante impact assessment of policies affecting Land use, part B: application of the analytical framework. Ecol Soc 16(1):27–34

Hill MO, Roy DB, Thompson K (2002) Hemeroby, urbanity and ruderality: bioindicators of disturbance and human impact. J Appl Ecol 39(5):708–720. doi:10.1046/j.1365-2664.2002.00746.x

Hunter M Jr (1996) Benchmarks for managing ecosystems: are human activities natural? Conserv Biol 10(3):695–697. doi:10.1046/j.1523-1739.1996.10030695.x

Inostroza L (2005) La huella Urbana y ecológica de Magallanes. Una mirada sobre nuestra insostenibilidad. Rev Urbano 8:28–40

Inostroza L (2008) Turismo en la Patagonia: una Amenaza para la Integridad Ecológica del Medio Natural. Cuad Invest Urbanística 56:122

Inostroza L (2012) Patagonia, Antropización de un Territorio natural. Cuad Invest Urbanística 83:86

Inostroza L (2014) Measuring urban ecosystem functions through "Technomass"—a novel indicator to assess urban metabolism. Ecol Indic 42:10–19. doi:10.1016/j.ecolind.2014.02.035

Inostroza L (2015) El mito de pristinidad y los usos efectivos del territorio de la región de Magallanes, Patagonia Chilena: forestal, minería y acuicultura. Estud Geográficos LXXVI:141–175

Instituto Geográfico Militar (IGM) (1983) Geografía de Chile Tomo II Geomorfología, Santiago de Chile

Instituto Nacional de Estadísticas (2005) Ciudades, Pueblos, Aldeas y Caseríos. Available at: http://www.ine.cl/canales/usuarios/cedoc_online/censos/pdf/censo_2002_publicado_junio_2005.pdf

International Union for Conservation of Nature (IUCN) (1987) The IUCN position statement on translocation; introductions, reintroductions and re-stocking, approved by the 22nd Meeting of the IUCN Council, Gland, Switzerland, 4 September 1987. http://www.iucn.org/themes/ssc/pubs/policy/index.htm. Accessed 5 Nov 2014

Jacobi JD, Scott JM (1985) An assessment of the current status of native upland habitats and asso- ciated endangered species on the island of Hawai'i. In: Stone CP, Scott JM (eds) Hawai'I's terrestrial ecosystems: preservation and management. University of Hawaii Cooperative National Park Resources Studies Unit, Honolulu, pp 1–21

König HJ, Schuler J, Suarma U, McNeill D, Imbernon J, Damayanti F, Dalimunthe SA, Uthes S, Sartohadi J, Helming K, Morris J (2010) Assessing the impact of land use policy on urban-rural sustainability using the FoPIA approach in Yogyakarta, Indonesia. Sustainability 2(7):1991–2009. doi:10.3390/su2071991

König HJ, Uthes S, Schuler J, Zhen L, Purushothaman S, Suarma U, Sghaier M, Makokha S, Helming K, Sieber S, Chen L, Brouwer F, Morris J, Wiggering H (2013) Regional impact assessment of land use scenarios in developing countries using the FoPIA approach: findings from five case studies. J Environ Manage 127(Supplement):S56–S64

König HJ, Zhen L, Helming K, Uthes S, Yang L, Cao X, Wiggering H (2014) Assessing the impact of the sloping land conversion programme on rural sustainability in Guyuan, Western China. Land Degrad Dev 25(4):385–396. doi:10.1002/ldr.2164

Kowarik I (1999) Natürlichkeit, Naturnähe und Hemerobie als Bewertungskriterien. Handbuch für Naturschutz und Landschaftspflege (eds W. Konold, R. Böcker & U. Hampicke), V-2·1, pp. 1–18. Ecomed, Landsberg, Germany

Lambin EF, Baulies X, Bockstael N, Fischer G, Krug R, Leemans EF, Moran EF, Rindfuss RR, Sato Y, Skole D, Turner II, BL, Vogel C (1999) Land-use and land-cover change (LUCC): implementation strategy. IGBP Report no. 48 IHDP Report no. 10. IGBP, Bonn

Lambin EF, Turner BL, Geist HJ, Agbola SB, Angelsen A, Bruce JW, Coomes OT, Dirzo R, Fischer G, Folke C, George PS, Homewood K, Imbernon J, Leemans R, Li X, Moran EF, Mortimore M, Ramakrishnan PS, Richards JF, Skånes H, Steffen W, Stone GD, Svedin U, Veldkamp TA, Vogel C, Xu J (2001) The causes of land-use and land-cover change: moving beyond the myths. Glob Environ Change 11(4):261–269. doi:10.1016/S0959-3780(01)00007-3

LaRosa D, Lorz C, König HJ, Fürst C (2014) Spatial information and participation in socio-ecological systems: experiences, tools and lessons learned for land-use planning. IForest Biogeosci For 7:386–389. doi:10.3832/ifor0093-007

Lesslie R, Malsen M (1995) National wilderness inventory handbook of procedures, content and usage, 2nd edn. Australian Government Publishing Service, Canberra (Australia)

Leu M, Hanser SE, Knick ST (2008) The human footprint in the west: a large-scale analysis of anthropogenic impacts. Ecol Appl 18(5):1119–1139. doi:10.1890/07-0480.1

Li S, Verburg PH, Lv S, Wu J, Li X (2012) Spatial analysis of the driving factors of grassland degradation under conditions of climate change and intensive use in Inner Mongolia. China. 12:461–474

Lockwood M, Worboys G, Kothari A (Eds.) (2012) Managing protected areas: a global guide. Routledge

Loidi J (1994) Phytosociology applied to nature conservation and land management. In: Song Y, Dierschke H, Wang X (eds) Applied vegetation ecology. East China Normal University Press, Shangai, pp 17–30

Machado A (2004) An index of naturalness. J Nat Conserv 12(2):95–110. doi:10.1016/j.jnc.2003.12.002

Machado A, Redondo C, Carralero I (2004) Ensayando un índice de naturalidad en Canarias. In: Fernández-Palacios JM, Morici C (eds) Ecología insular. Asociación Española de Ecología Terrestre, Las Palmas (Canary Islands), pp 413–438

Margules C, Usher MB (1981) Criteria used in assessing wildlife conservation potential: a review. Biol Conserv 21(2):79–109. doi:10.1016/0006-3207(81)90073-2

Meaza G, Cardiñanos JA (2000) Valoración de la vegetación. In: Meaza G (ed) Metodología y prácticade la biogeografía. Edicionesdel Serbal, Barcelona, pp 199–272

Meshesha DT, Tsunekawa A, Tsubo M, Ali SA, Haregeweyn N (2014) Land-use change and its socio-environmental impact in Eastern Ethiopia's highland. 14:757–768

MOP Ministerio de Obras Públicas (1994) Atlas ambiental de Chile, Santiago de Chile

Moss C (2008) Patagonia: a cultural history. Signal books, Oxford

Munsi M, Malaviya S, Oinam G, Joshi PK (2010) A landscape approach for quantifying land-use and land-cover change (1976–2006) in middle Himalaya. 10: 145–155

Myers N (1995) Environmental unknowns. Science 269(5222):358–360. doi:10.1126/science.269.5222.358

Palomo I, Martin-Lopez B, Zorrilla-Miras P, Garcia Del Amo D, Montes C (2014) Deliberative mapping of ecosystem services within and around Doñana National Park (SW Spain) in relation to land use change. 14: 237–251

Pisano E (1990) Labilidad de los ecosistemas terrestres Fuego-patagónicos. An Inst Patagonia 19(1):17–26

Pontius RG, Cornell JD, Hall CAS (2001) Modeling the spatial pattern of land-use change with GEOMOD2: application and validation for Costa Rica. Agric Ecosyst Environ 85(1–3):191–203. doi:10.1016/S0167-8809(01)00183-9

Reidsma P, König H, Feng S, Bezlepkina I, Nesheim I, Bonin M, Sghaier M, Purushothaman S, Sieber S, van Ittersum MK, Brouwer F (2011) Methods and tools for integrated assessment of land use policies on sustainable development in developing countries. Land Use Policy 28(3):604–617. doi:10.1016/j.landusepol.2010.11.009

Riitters KH, Wickham JD (2003) How far to the nearest road? Front Ecol Environ 1(3):125–129. doi:10.1890/1540-9295(2003)001[0125:HFTTNR]2.0.CO;2

Robinson J (2004) Squaring the circle? Some thoughts on the idea of sustainable development. Ecol Econ 48(4):369–384. doi:10.1016/j.ecolecon.2003.10.017

Sanderson EW, Jaiteh M, Levy MA, Redford KH, Wannebo AV, Woolmer G (2002) The human footprint and the last of the wild. Bioscience 52(10):891. doi:10.1641/0006-3568(2002)052[0891:THFATL]2.0.CO;2

Schlüter R (2001) The impact of tourism on the patagonian coast, Argentina. Int J Hosp Tour Adm 1(3–4):53–71. doi:10.1300/J149v01n03_04

SERNAGEOMIN (2010) Servicio Nacional de Geología y Minería. http://sigeo.sernageomin.cl/. Accessed 21 Feb 5 Mar 2010

Sistema Nacional de Información Ambiental (SINIA). http://www.sinia.cl/1292/w3-article-26200.html. Accessed 12 Dec 2015

Sukopp H, Hejny S, Kowarik I (eds) (1990) Urban ecology. Plants and plant communities in urban environments. SPA Publishing House Academic Publications, The Hague

Theberge JB (1989) Guidelines to drawing ecologically sound boundaries for national parks and nature reserves. Environ Manag 13(6):695–702. doi:10.1007/BF01868309

Tscherning K, König H, Schößer B, Helming K, Sieber S (2008) Ex-ante impact assessments (IA) in the European Commission—an overview. In: Helming K, Pérez-Soba M, Tabbush P (eds) Sustainability impact assessment of land use changes. Springer, Berlin-Heidelberg, pp 17–33

Turner BL (1997) The sustainability principle in global agendas: implications for understanding land-use/cover change. Geogr J 163(2):133–140. doi:10.2307/3060176

Ungaro F, Zasada I, Piorr A (2014) Mapping landscape services, spatial synergies and trade-offs. A case study using variogram models and geostatistical simulations in an agrarian landscape in North-East Germany. Ecol Indic 46:367–378. doi:10.1016/j.ecolind.2014.06.039

Verburg PH, van de Steeg J, Veldkamp A, Willemen L (2009) From land cover change to land function dynamics: a major challenge to improve land characterization. J Environ Manage 90(3):1327–351335. doi:10.1016/j.jenvman.2008.08.005

Vitousek PM, Mooney HA, Lubchenco J, Melillo JM (1997) Human domination of Earth's ecosystems. Science 277(5325):494–499. doi:10.1126/science.277.5325.494

Wildlife Conservation Society (WCS) and Center for International Earth Science Information Network (CIESIN) Columbia University (2005). Last of the wild project, version 2, 2005 (LWP-2): last of the wild dataset (Geographic). Palisades, NY: NASA socioeconomic data and applications center (SEDAC). http://sedac.ciesin.columbia.edu/data/set/wildareas-v2-last-of-the-wild-geographic. Accessed 08 April 2014

Wilkie D, Shaw E, Rotberg F, Morelli G, Auzel P (2000) Roads, development and conservation in the Congo Basin. Conserv Biol 14:1614–1622

Wu Q, Li HQ, Wang R-S, Paulussen J, He Y, Wang M, Wang B-H, Wang Z (2006) Monitoring and predicting land use change in Beijing using remote sensing and GIS. Landsc Urban Plan 78(4):322–333. doi:10.1016/j.landurbplan.2005.10.002

Zasada I, Loibl W, Köstl M, Piorr A (2013) Agriculture under urban influence: a spatial analysis of farming systems in the EU. Eur Countrys 5(1):71–88