Ecosystem Services 36 (2019) 100875

Contents lists available at ScienceDirect

Ecosystem Services

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

Linking inequalities and ecosystem services in Latin America☆

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ARTICLE INFO

Keywords:
Socio-ecological systems
Inequality
Environmental justice
Rural migration
Social-ecological traps
Environmental governance
Poverty
Land grabbing

ABSTRACT

Latin America exhibits one of the highest rates of biodiversity and ecosystem services (ES) loss worldwide along with a remarkable asymmetry in the access to ES benefits (ecosystem services inequality, ESI hereafter). The objective of this manuscript is to propose and validate a conceptual model to understand the links between ESI and ecosystem services supply. First, previous ES frameworks were expanded to acknowledge the role of the unequal access to ES on socio-ecological system dynamics. Second an ESI conceptual model was posed to testing feed-back mechanisms between ESI and natural capital. Finally, independent information and expert opinions on ten case studies of five Latin American countries were used to quali-quantitatively validate the ESI model. The most rated ESI impacts were landscape and seascape transformations driven by the markets, overuse of natural capital, ecosystems degradation, and biodiversity loss. This study highlights that ESI may enhance the vulnerability of the socio-ecological systems, describing a self-reinforcing mechanism that differentially affects the well-being of the most economically disadvantaged beneficiaries (ESI traps). However, while the occurrence of ESI traps was inferred for half of the examined cases, remaining cases suggest that potential ESI traps did not operate, or that they were dampened by governance mechanisms.

☆ Special Issue on the state of the art of Ecosystem Services Research and Practice in Latin America-Journal Ecosystem Services.

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https://doi.org/10.1016/j.ecoser.2018.12.001
Received 18 May 2018; Received in revised form 19 November 2018; Accepted 1 December 2018
Available online 07 December 2018

1. Introduction

The concept of inequality, whether social (e.g., gender, class), economic (e.g., income) or environmental (e.g., exposure to environmental risk, lack of access to ES) has started to be acknowledged in the ecosystem services (ES) literature, generally associated to the analysis of social distribution of ES benefits, poverty alleviation, and environmental justice (e.g., Adekola et al., 2015; Chaudhary et al., 2018; Daw et al., 2011). Despite of the wide concern about the inequality prevalence in Latin America (ECLAC, 2018; Bustamante et al., 2018), the links with the provision and distribution of ES and social benefits has been largely omitted in research and planning (e.g., Fearnside, 2001; Sant'Anna, 2017), with exception of studies on the ability to pay for ES to reduce inequality and alleviate poverty (Balvanera et al., 2012; Grieg-gran et al., 2005; Grima et al., 2016; Pascual et al., 2014) or the negative impacts of such mechanisms on equality, equity and justice (see a Glossary in the Appendix A, Supplementary material, for definitions).

Inequality is usually addressed through premises which are not ideologically or politically neutral (Kull et al., 2015; Sikor et al., 2013), and its analysis is a necessary and challenging next step in socio-ecological system research (Coomes et al., 2016). Given the controversial views on equality and environment interactions over the past decades (Baland et al., 2007; Baland and Platteau, 1999; Boyce, 2002; Dayton-Johnson and Bardhan, 2002; Laurent, 2011; Martinez-Alier, 2003), and the clear evidence on the relationships between indicators of socio-economic inequality (Gini index of income) and natural capital loss (biodiversity loss) (Holland et al., 2009; Mikkelson et al., 2007), there is a need for a better understanding about the mechanisms behind observed patterns and their contradictions.

When different types of inequality are addressed separately, as is still the case in most Latin American countries, there is a clear risk of policy deficiencies and failures (Adams et al., 2004). Current understanding gathered from the usual static, aggregated, and ahistorical studies, could be benefited by systemic analysis of long lasting social and economic inequalities and vulnerabilities that configure complex social-ecological dynamics. Therefore, the integration of inequality issues within natural capital and ES governance, is needed to avoid interventions that can further increase inequalities, poverty and vulnerability, leading to different social-ecological syndromes and traps.

Latin America hosts numerous cases in which inequalities occur. Among different inequality types, here we distinguished and labelled the unequal access to ES benefits, as the ES inequality (hereafter ESI, see a Glossary in Appendix A, Supplementary material). Some of these cases may provide useful information for a better understanding the causes and consequences of ESI at local scales. We aim to contribute to this understanding by proposing and validating a conceptual model that integrates social, economic and ecological mechanisms linking natural capital dynamics and social distribution of ES, with focus on vulnerable people of rural Latin America.

Many of the inequalities observed in Latin America have their roots in past dynamics, related to the different development and governance strategies adopted in the region over centuries, from colonialism to neoliberalism. The massive transference of Latin American wealth to Europe in the late 1800s and early 1900s, marked the beginning of the colonial capitalist system. This plundering of resources strengthened the nascent accumulation of capital that enabled the industrial revolution. Since then, Latin America entered a trajectory characterized by economic concentration at the expense of the dispossession of pre-existing indigenous people and marginalization of working classes including rural peasants (Gligo, 2001; Martínez-Alier et al., 2016).

After the exacerbation of pre-existing inequalities by neoliberal policies which have dominated the region over the late last century (e.g., Eakin and Lemos, 2006; Hoffman and Centeno, 2003; Liverman and Vilas, 2006), most of Latin American countries were able to reduce their inequality indicators during the early 21 century, partly due to progressive transfer policies (Lustig et al., 2012). However, as part of the globalization phenomena (Young et al., 2006), the commodity export growth model, seems to be so resilient in Latin America as the inequalities it creates (Burchardt and Dietz, 2014; Grugel and Riggirozzi, 2012; Gudynas, 2009).

The impacts of globalization on human societies and their environments have been widely discussed (e.g., deFries et al., 2013; Meyfroidt et al., 2013; Richards et al., 2012; Young et al., 2006). While some positive globalization influences are posed for ecosystems conservation, they usually come at the expense of privatizations, emigration or displacement of rural communities (Fairhead et al., 2012; Grau and Aide, 2008). In the case of Chile, economic policies focused on the privatization of water (Molinos-Senante and Sala-Garrido, 2015), planted forests (Manuschevich, 2016), and fisheries have limited the distribution of ecosystem service benefits at local scales. In turn, in Argentina, Bolivia, Brazil, Colombia and Paraguay, a significant concentration and foreignization of land has taken place, producing impacts on the environment and the livelihoods of many rural people living in the region, including deforestation, afforestation, and dispossession by displacement of the rural poor (Borras et al., 2012; Liverman and Vilas, 2006).

The ESI conceptual model proposed here offers a systemic view of the reciprocal influences between ESI and actual or potential loss of natural capital, relying on published information, and expert knowledge on ten case studies from five Latin American countries. Specifically, we uphold that the reduction in ES supply and access to ES benefits by the most vulnerable people, can negatively influence the conservation and recovery of the remaining natural capital, feeding back to perpetuate poverty and inequality. For this purpose, (i) we developed an ESI framework, by expanding previous ES frameworks to include the role of the unequal access to ES on socio-ecological systems; (ii) we proposed an ESI conceptual model was posed for testing mechanisms of ESI impact on the performance of socio-ecological systems; and (iii) we used independent information and expert opinions about ten case studies to quali-quantitatively validate the ESI conceptual model.

2. Ecosystem services inequality (ESI) framework

The ESI framework (Fig. 1) relies on four existing approaches, directly connected to socio-ecological systems and their dynamics: (a) The socio-ecological system framework (McGinnis and Ostrom, 2014; Ostrom, 2009); (b) ES supply cascade (Haines-Young and Potschin, 2011); (c) the ES approach (Turner and Daily, 2008); (d) the socio-ecological vulnerability framework (Metzger et al., 2006; Turner et al., 2003), and (e) the theory of access to natural resources (Ribot and Peluso, 2003).

The ESI framework was based on ontological (the way things are), epistemological (how things are or work), and methodological (framework building and operationalization) assumptions (Jabareen, 2009). Our main ontological assumption was that environmental inequalities and socio-economic inequalities are related and influence socio-ecological system dynamics. One of our epistemological assumptions was that ESI can be variably explained by distinct sources of access, and lastly, our methodological assumption were that complex relations between ESI and natural capital can be framed by two basic steps: (i) selecting the main components (including concepts) to represent the interlinks and feed-backs between ESI and natural capital conservation, recovery or loss, and socio-ecological vulnerability, and (ii) ESI framework delineating using a consensual selection of these components and their interactions (Boumans and Martini, 2014).

Main components and interactions of the ESI framework were selected from four existing approaches, directly connected to socio-ecological systems and their dynamics: (a) The socio-ecological system framework (McGinnis and Ostrom, 2014; Ostrom, 2009); (b) ES supply cascade (Haines-Young and Potschin, 2011); (c) the ES approach

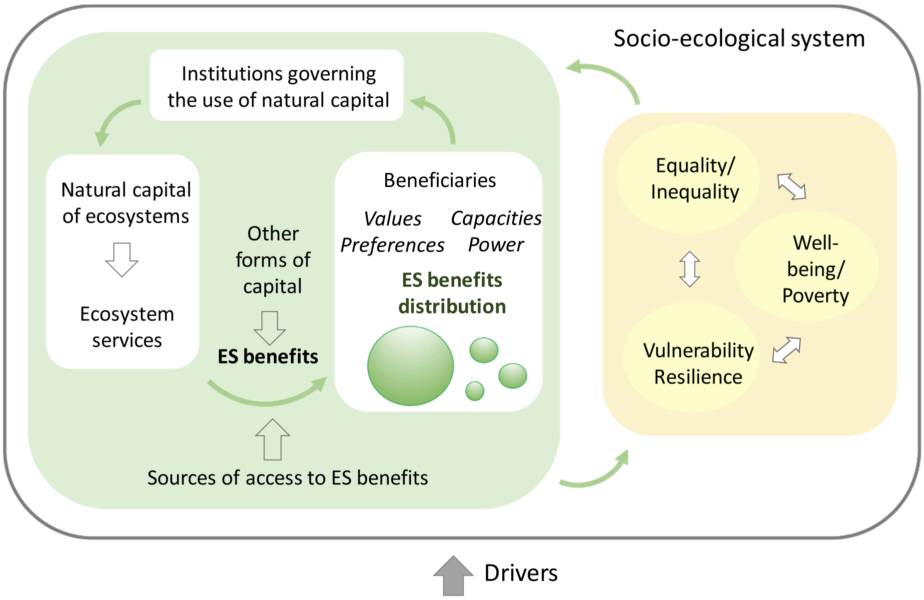

Fig. 1. Ecosystem services inequality (ESI) framework. The green box comprises the assumptions and links posed by the ES cascade model. The light yellow box represents the possible outcomes of the socio-ecological system given the dynamics in the green box. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

(Turner and Daily, 2008); (d) the socio-ecological vulnerability framework (Metzger et al., 2006; Turner et al., 2003), and (e) the theory of access to natural resources (Ribot and Peluso, 2003).

Socio-ecological systems are shaped by internal structures and processes (self-organization), facing external driving forces. Within a socio-ecological system, ES supply depends primarily on the natural capital of ecosystems, which in turn is affected by institutions that determine the access, management and use of natural resources, and on the effect of external drivers (e.g., climate). ES provide multiple benefits whose capture is also mediated by access sources, that are in turn determined by the institutional formal or informal context (Ribot and Peluso, 2003) (Appendix B, Supplementary material). These sources will determine how equal or unequal the distribution of ES benefits among beneficiaries is, hence the ESI level and will determine the ESI. Beneficiaries' decisions on use, consumption and enjoyment of ES feed back into institutions which should respond and adapt accordingly.

The interactions between the components of the ESI framework define the trajectory and outcomes of a socio-ecological system in terms of equality or inequality, vulnerability or resilience, and poverty or well-being. Several factors and interactions will determine that a socio-ecological system remains on a given trajectory, namely, the governance structures and practices that establish the rules, including access sources (e.g., legal property rights) and the capacity of the system to cope and adapt to the negative effects of given drivers of environmental change that influence the provision of ES (e.g., land use change).

The ESI framework was finally delineated as follows (Fig. 1): (a) Natural capital provides multiple ES, (b) whose capture and distribution is mediated by different sources of access, that in turn (c) are determined by the institutional context (formal or informal). Therefore, (d) beneficiaries' decisions on ES use, consumption and enjoyment, as well as their power, feed-back into institutions which should respond and adapt accordingly, and (e) the access sources and their institutional context interact with drivers of ES provision (e.g., climate change, land use change) and ecosystem and social vulnerabilities to determine ESI (i.e. how equal or unequal the distribution of ES benefits among beneficiaries is). On the other side, (f) ESI can further increase pressure on natural capital and ES supply, perpetuating poverty and vulnerability. The reciprocal relationships between poverty and natural capital degradation are a matter of a long lasting-controversy among those who see poverty as a cause of degradation and those who see poverty and nature loss as common consequences of development and economic policies (Duraiappah, 1998; Gerber et al., 2014).

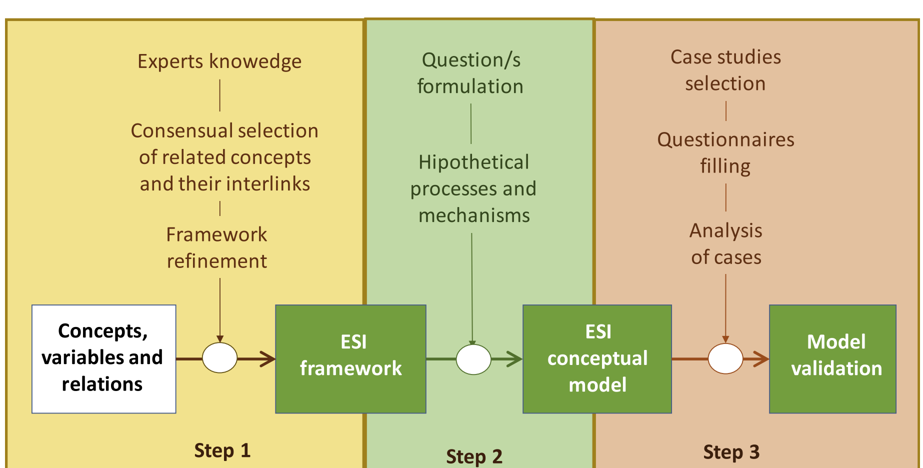

Fig. 2. Flow chart outlining main methodological steps applied for case analysis and conceptual modeling of ecosystem services inequality (ESI).

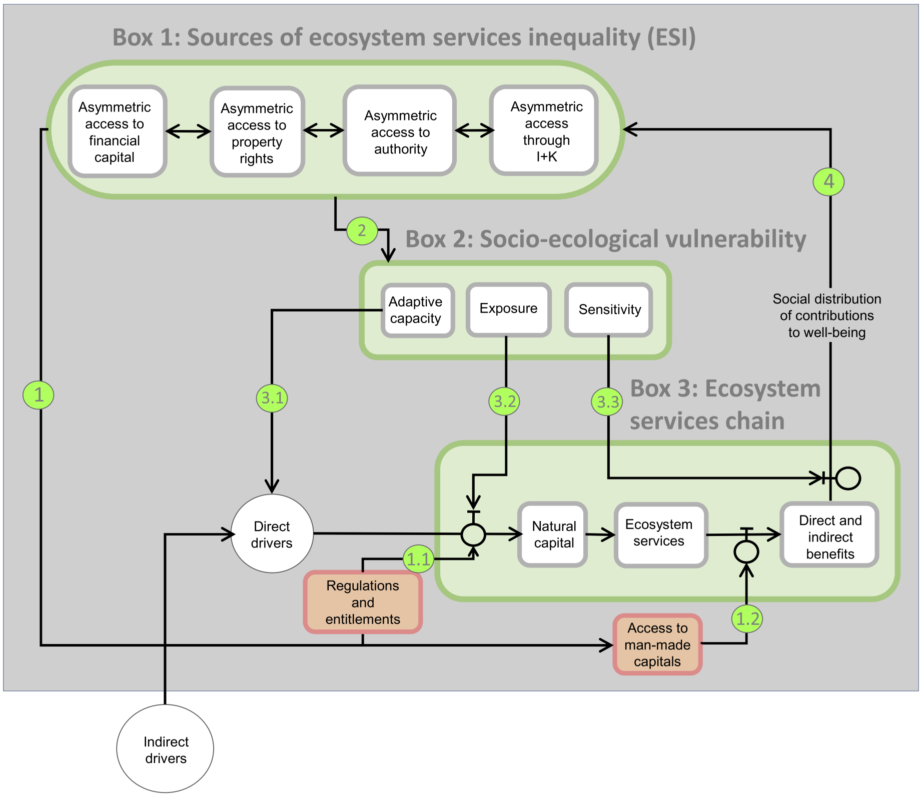

Fig. 3. Three main layers of the Ecosystem Services Inequality (ESI) model: sources of ecosystem services inequality (ESI) (Box 1), components of socio-ecological vulnerability (Box 2), the ecosystem services (ES) chain (Box 3), and a set of interactions among them (black arrows). Pink boxes represent the access to different forms of man-made capital (social, human, financial, and built capitals). I + K: information and knowledge. Arrows numbers represent the following links between boxes: 1. direct mechanisms of ESI impacts on the ES cascade; 2. indirect mechanisms of ESI impacts on the ES cascade; 3. socio-ecological vulnerability influences on ES cascade; 4. Feed-back between social distribution of ES benefits and ESI (ESI trap). Additional explanations to arrow numbers are explained in the body text. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3. Methods

Following the ESI conceptual framework, methods consisted in two additional sequential steps (a) development of a general ESI conceptual model; and (b) qualitative case analysis and validation of the ESI model in the Latin America geographical context (Fig. 2).

3.1. The ESI conceptual model

A conceptual model was developed following a deductive procedure to identify the role of ESI in socio-ecological systems and the main supporting mechanisms (Fig. 3). For this purpose, the ESI framework was disaggregated into different *components* and *relationships*. Then, *processes* and *mechanisms* were identified and, finally, *consequences* on system functioning were deduced.

The ESI conceptual model was focused on three main components of the ESI framework: (a) inequality in access to ES, (b) socio-ecological vulnerability, and (c) the ES chain (a simplification of the ES cascade) (Fig. 3). In order to gain focus, other components of the ESI framework (e.g., institutions for the governance of natural capital) were not neglected, but intentionally omitted.

Rather than showing a homogeneous influence of different sources of access on the capture of ES benefits, the literature suggests the dominance of some sources over others (Hicks and Cinner, 2014; Mullin et al., 2018; Villamagna et al., 2017). Therefore, the ESI model (Fig. 3) poses that the role of inequality on system dynamics is mostly mediated by four out the ten sources of access to natural resources posed by Ribot and Peluso (2003): asymmetric access to financial capital, to property rights (e.g., land, water, timber rights), to information and knowledge (I + K, including technological availability), and to individuals and institutions with authority to implement public policies on land/ocean use (Fig. 3, box 1).

Evidence in the literature supports the hypothesis that the mechanisms mentioned above are frequently associated, reflecting responses to other common factors or reproducing cause-effect relationships. For example, landowners and companies have shown to be more influential on policy makers and authorities than small farmers, peasants and/or indigenous communities in Latin America and other developing regions of the world (Cáceres et al., 2016; Nahuelhual et al., 2018b). Also, asymmetry is usually a necessary condition for the concentration of land entitlements and land use decisions in few social actors. Winners of that entitlement concentration processes obtain large benefits from replacing native ecosystems by cash crops, leading to the loss of traditional livelihoods, and the displacement of farmers and other settlers with precarious property rights (Cáceres et al., 2015; Dorn, 2015; Goldfarb and van der Haar, 2016; Reboratti, 2010). Although migration is one of the most common strategy of the displaced and ES dependent people, inequality is exported to other contexts (e.g., cities) where it is causally related to different psychological and social dysfunctions (Kumar and Yashiro, 2014).

In accordance to the ESI framework, this model envisages two routes through which the asymmetries in access to ES are related to the natural capital loss. The asymmetric distribution of entitlements and the access to financial and man-made capital may deepen the unequal access to ES benefits in the short term through direct mechanisms of ESI impacts (Adger, 1999) (Fig. 3, arrows 1.1 and 1.2), or it can also be projected into future scenarios, through indirect mechanisms of ESI impacts, consisting of the components of the vulnerability model component (Adger and Kelly, 1999; Laurent, 2011) (Fig. 3, arrow 2, box 2). Therefore. ESI-ES supply interactions (Fig. 3, arrow 2) may be mediated by increasing exposure of natural capital to different pressures (by increasing the sensitivity and/or by reducing the adaptive capacity to ES loss) (Fig. 4).

While a particular indirect driver (e.g., international trade or climate change) may potentially affect the natural capital of an entire region, actual local change depends on different interactions among associated direct drivers (e.g., deforestation pressure) with conditioning and random factors that define the local exposure (Fig. 3, box 2, arrow 3.1).

Different studies suggest that not just poverty, but land

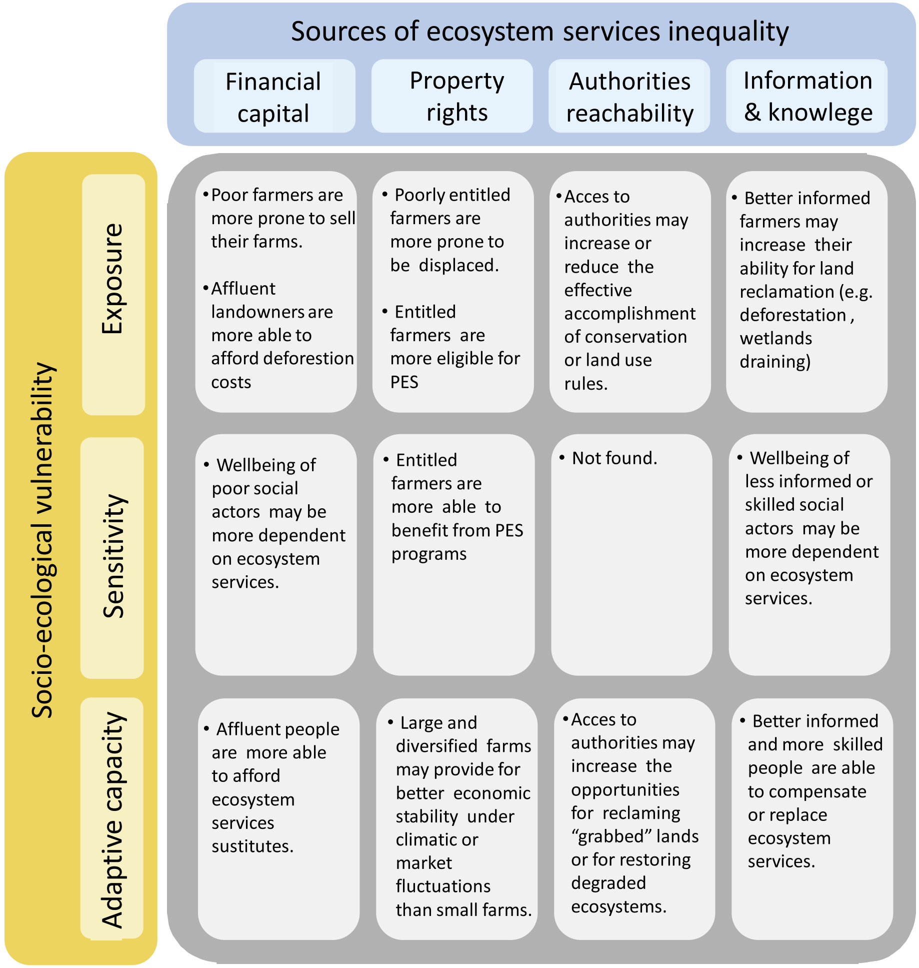

Fig. 4. Examples of interactions between sources of inequality in access to ecosystem services (ES) (columns) and the different components of vulnerability to loss of ES (files). PES: payment for ecosystem services.

concentration and high-input production systems (Manuel-Navarrete et al., 2009; Mastrangelo and Laterra, 2015), external investments and inequality in the access to authorities (Boillat et al., 2015; Seghezzo et al., 2011), and inequality in the distribution of costs and benefits of development (Robbins, 2011), are able to increase the exposure of natural capital to transformation or replacement of less modified ecosystems.

Socio-economic inequality and environmental inequality (of which ESI is a form, see Appendix A in the Supplementary material) are inextricably linked and mutually influenced (Adger, 1999). While poverty is related to individual vulnerability through resources dependence, income sources, and social status, socio-economic inequality is related to collective (or social) vulnerability, through institutions, markets, social security and insurance structures, and the relative distribution of income and access to diversity of economic assets. Therefore, inequality may increase the individual and collective vulnerability to ES loss due to external pressures (drivers), by increasing the sensitivity (resource dependence) and/or reducing the adaptive capacity to cope with and adapt to ES loss (Berrouet et al., 2018; Fisher et al., 2014).

Both sensitivity and adaptive capacity, the other two components of socio-ecological vulnerability can be impaired by ESI when income inequality leads to significant reductions of well-being for the most ES dependent social groups on ecosystem degradation or transformation scenarios (Daw et al., 2011; MEA, 2005), and unequal access to technology and credits reduce their adaptive capacity. Low adaptive capacity can intensify the impact of drivers through non-sustainable capture of ES to satisfy rural and/or urban population demand (green and red traps, respectively, Cumming et al., 2014).

Socio-ecological vulnerability may be also increased indirectly by positive feed-backs between asymmetric distribution of ES benefits to social and cultural capital of peasants, small farmers and indigenous communities (Fig. 3, arrow 3.1). The impact of joint drivers on already vulnerable systems can lead to further decline in well-being, particularly for most ES dependent actors. Loss of bonding relationships and traditional knowledge which support hunting, fishing, harvesting and collaborative agricultural practices, increases the sensitivity (Fig. 3, arrow 3.3) and reduces the adaptive capacity (Fig. 4, arrows 2.1 and 2.2) in face of different pressures like the expansion of industrial agriculture over working landscapes (Plummer and Armitage, 2010).

Economically disadvantaged social actors, whose' well-being strongly relies on ES supply and use, have fewer alternatives to cope with ES loss than wealthier people, which can perpetuate unfairness and take the system into an unsustainable trajectory or maladaptive situations. Therefore, differential vulnerability to ES loss due to ESI may lead to a feed-back effect on inequalities (Fig. 3, arrow 4) and then on ES loss, conducting to a ESI trap (see Glossary in Appendix A, Supplementary material). Ultimately, this socio-ecological conditions may lead to dispossession, displacement, and emigration processes, pushing the system to alternate states characterized by reduced stocks of natural capital (Cáceres et al., 2015; Meyfroidt et al., 2014). Notwithstanding, emigrations in the absence of competing actors may sometimes lead to recovery of natural capital (Izquierdo et al., 2011, 2008) as predicted by the forest transition theory (Mather, 1992).

Fig. 5. Geographical distribution of the study cases in five Latin American countries. HOPEL: Hopelchen, Campeche, Mexico; CHONTA: Chontalpa, Tabasco, Mexico; GUATE: Guatemala city, Guatemala; COMI: Marqués de Comillas, Chiapas, Mexico; OROT; Orotoy River Watershed, Meta, Colombia; CHACOS: Chaco salteño, Salta, Argentina; MBARA: Mbaracayú Biosphere Reserve, Canindeyú, Paraguay; CHACOC: Chaco cordobés, Argentina; PANGUI: Panguipulli, Chile; MAGA: Magallanes and Chilean Antarctic Region, Chile.

3.2. Model validation

In order to validate the model, we selected ten study cases from five countries along Latin America (Fig. 5, Table 1, Appendix D- Supplementary material) during two workshops organized by the VESPLAN Network (Vulnerability, Ecosystem Services and Rural Territorial Planning Network, Ibero-American Programme on Science and Technology for Development, CYTED), one of them held in Mbaracayú, Paraguay (October 2016) and the other held during the V International Congress of Ecosystem Services in the Neotropics (CISEN5), held in Oaxaca, México (November 2017). Researchers associated to selected cases were asked as experts to respond questionnaires oriented to obtain specific information about past or ongoing research from their study cases. Questionnaires were sent and analyzed between November 2017 and January 2018. Validation of the model was aided by specific information obtained from 10 selected case studies from five countries (Fig. 5; Table 1), which corresponded to past or ongoing investigations on socio-ecological systems and ES (See Appendix D, Supplementary material, for a description of each case).

The first questionnaire was intended to address information about: (a) contextual aspects of each case (e.g., area, location); (b) ES involved and threats to its provision; (c) main sources of vulnerability of ES and ecosystems; (d) trends in access to ES; (e) potential conflicts arising from unequal access; (f) sources of access influencing the capture of ES; and (g) relations between ES, natural capital and socio-economic inequalities. A second questionnaire was intended to collect answers on the relative importance of sources of access on ESI, according to a predefined list adjusted from Ribot and Peluso (2003) (Appendix B, Supplementary material). This questionnaire consulted about wide effects of ESI such as for example landscape (and seascape) transformations, rural exodus, legal and illegal overuse of natural capital, ecosystems degradation, biodiversity loss, and land grabbing, among others. Potential effects of ESI were defined a priory based on literature and author's own experience (see Appendix C, Supplementary material).

A qualitative analysis of the cases for the validation of the model was carried out according to different criteria, in order to examine the occurrence of the components of the model in the set of cases, as well as the relevance of each case to examine the adjustment of the model. Ten validation criteria were selected, intending to capture the main components and relationships included in the ESI model. Validation was performed criteria by criteria (horizontal analysis) for examining the occurrence of model components across the cases array, as well as case by case (vertical analysis), for examining model fitting within each case. Since the ESI conceptual model aims to provide explanations of the mechanisms rather than ex post interpretations, the case studies were categorized by researchers other than those who formulated the model.

4. Results

The occurrence of the components of the model in the set of cases, as well as the relevance of each case to examine the adjustment of the model, are summarized in Table 2. The horizontal validation analysis allows evaluating the different parameters of the model and the vertical validation analysis allows evaluating the adjustment levels of the cases in the different validation criteria.

4.1. Horizontal analysis of validation criteria of the ESI model

Criterion 1: ESI sources were identified and evaluated. Whereas all ESI sources included in the ESI model (Fig. 4, box 1) are depicted by the cases, additional ESI sources like negotiation ability, participation in governance processes and, market reachability, were also well weighted (Table 3). Financial capacity ranks as the most prominent access source driving ESI (median value of 5), followed by asymmetric property rights, negotiation ability, participation in governance processes, market reachability, and technology availability (I + K in the ESI model) (median value of 4). On the other side, illegal access, loss of cultural identity and asymmetric labor capacity are, in general, ranked with low values.

Criterion 2: Most important ESI sources were included by the model. The criterion was verified for all the cases (Table 3). Yet, some ESI sources emerging from the cases, were not well accounted by the model. This can be clearly observed for Chontalpa, Marqués de Comillas, Chaco Salteño and Chaco Cordobés (Appendix C). For example, different ESI sources were triggered in the Marqués de Comillas municipality, after former communal land use systems (ejidos) and collective control of natural resources were undermined by the National Constitution reform in 1992 (art. 27), allowing the sale of ejidal lands. This allowed for inequalities in land location and extent, due to privileged access to authorities, which interacted with other sources of inequality.

Criterion 3: Negative influences of ESI on the ES chain are identified. That is, natural capital and/or ES losses are at least partly due to mechanisms involving ESI. According to respondents (Question 10 in Questionnaire 1, Appendix C, Supplementary material), and in agreement with ESI conceptual model (see 1, 3.1–3.3 arrows in Fig. 4), this criterion was verified for nine cases (Table 2).

Three kinds of ESI impacts were rated as high to very high for most cases: (a) market and socially driven landscape and seascape transformations and rural exodus, (b) legal overuse of natural capital,

Table 1
List of study cases selected for the validation of the ESI conceptual model.

Case	Acronym	Location	Biome	Main involved ecosystem services[1]
1. Chaco Salteño	CHACOS	Eastern Salta province, Argentina	Deciduous Dry Forest (Chaco)	Wild plants and animals for nutrition; Wild plants for fibers and energy source; Cultural heritage, symbolic, sacred or religious meaning
2. Chaco Cordobés	CHACOC	Pocho Department, Córdoba province, Argentina	Deciduous Dry Forest (Chaco)	Wild plants for fibers; Wild plants for nutrition; Wild plants as source of energy; Cultivated plants for nutrition; Water regulation
3. Chontalpa	CHONTA	Chontalpa subregion, Tabasco State, México	Tropical Perennial Forest	Wild plants for fibers; Water flow regulation; Cultivated plants for nutrition; Surface water for drinking; Carbon sequestration; Pest control; Aesthetic experiences
4. Marqués de Comillas	COMI	Marqués de Comillas, Chiapas, México	Tropical Perennial Forest	Cultivated plants for nutrition; Water regulation; Surface water for drinking; Water flow regulation; Control of erosion and sediment retention; Regulation of atmospheric conditions
5. Guatemala	GUATE	Cayalá Ecological and Sports Park, Guatemala City, Guatemala	Tropical Perennial Forest	Control of erosion; Regulation of atmospheric conditions; Health, recuperation or enjoyment; Aesthetic experiences; Education and training
6. Hopelchén	HOPEL	Hopelchen municipality, Campeche, México	Tropical Perennial Forest	Wild animals for nutrition; Wild plants for fibers; Cultivated plants for nutrition; Reared animals for nutrition (beekeeping); Surface water for drinking; Water flow regulation; Decomposition and fixing processes for soil quality; Cultural heritage
7. Magallanes	MAGA	Magallanes region, Chile	Coastal and Open Sub-Antarctic Ocean	Wild animals for nutrition (king crab fishery)
8. Mbaracayú	MBARA	Mbaracayú Biosphere Reserve, Canindeyú, Paraguay	Subtropical Semi-deciduous Forest	Wild plants for nutrition; Wild plants for health; Wild animals for nutrition; Animals reared for nutritional purposes (cattle); Genetic material; Cultural heritage
9. Orotoy	OROT	Orotoy River Basin, Meta, Colombia	Tropical Perennial Forest	Wild plants for nutrition and health; Cultivated plants for nutrition; Surface water for drinking; Regulation of water quality; Soil quality; Pest control; Health, recuperation or enjoyment
10. Panguipulli	PANGUI	Panguipulli county, Chile	Temperate Rainforest	Wild animals for nutrition; Wild plants for fibers; Cultivated plants for nutrition; Surface water for drinking; Regulation of temperature and humidity; Health, recuperation or enjoyment; Cultural heritage

[1] Ecosystem services were categorized by following the CICES 5.1 classification (Haines-Young and Potschin, 2018). Main categories of ecosystem services for each case were extracted from bibliography and experts descriptions provided in the Appendix D (Supplementary material). Since different methods of ecosystem services assessment may be involved, comparisons of ecosystem services among cases may be misleading.

Table 2
Fit levels of the study cases to the ecosystem services inequality (ESI) model. Crossed cells identify the validation criteria that fit to each study case according to questionnaires responses and case descriptions. Overall fit levels were calculated for each case and for each validation criteria as the total number of fits (crosses) along columns and rows, respectively. Rows and columns were arranged according to their fit levels.

Validation criteria	Study case name										Fit level
	HOPEL[4]	CHACOS	CHACOC	GUATE	MBARA	OROT	CHONTA	PANGUI	MAGA	COMI	
ESI sources were identified and evaluated	X	X	X	X	X	X	X	X	X	X	10
Most important ESI sources identified in the case were included by the model	X	X	X	X	X	X	X	X	X	X	10
Negative influences of ESI on the ES chain were inferred	X	X	X	X	X	X	X	X	X		9
Indirect mechanism of ESI impacts on NC[1] and ES[2] were identified	X	X	X	X	X		X	X	X	X	9
ESI is not a stable attribute across time; it is increasing or has recently increased	X	X	X	X	X	X		X		X	8
Influences of SEV[3] components on drivers were identified	X	X	X		X		X		X		6
Direct mechanisms of ESI impacts on natural capital and ES were recognized	X	X	X	X		X					5
Positive feed-backs between ESI and ES supply (ESI traps), were deduced	X	X	X	X	X						5
Reciprocal influences between ESI sources were recognized	X	X		X							3
Overall fit level	9	9	8	8	7	5	5	5	5	4	

[1] NC: natural capital.
[2] ES: ecosystem services.
[3] SEV: socio-ecological vulnerability.
[4] HOPEL: Hopelchen, CHACOS: Chaco Salteño, CHACOC: Chaco Cordobés, GUATE: Guatemala, MBARA: Mbaracayú, OROT: Orotoy, CHONTA: Chontalapa, PANGUI: Panguipulli, MAGA: Magallanes, COMI: Marqués de Comillas.

ecosystems degradation, or biodiversity loss, and (c) illegal use and overuse of natural capital in private and protected areas and oceans (Table 4). According to cases' descriptions (Appendix C, Supplementary material), those ESI impacts were related to direct and indirect mechanisms (through different components of socio-ecological vulnerability) (see the next item for examples).

In contrast, three kinds of ESI impacts were rated as null or low for most cases: (a) conservation due to displacement of rural people, land and ocean concentration, (b) environmental vandalism (e.g., intentional fires) due to social dysfunctions, (c) waste production, pollution, environmental diseases.

Criterion 4: Indirect mechanisms of ESI impacts on natural capital and ES were identified in accordance with the model. As suggested by the ESI model, most of the cases show that ESI affects the exposure to drivers of land/ocean use change, and/or the sensitivity to ES loss, and/or the adaptive capacities (Fig. 4, arrows 2.1–2.5), which in turn, are able to enhance the loss of natural capital and ES (Fig. 4, arrows 3.1–3.3). The four study cases illustrating expansion of the agriculture frontier and

Table 3
Relative importance of access sources leading to ESI as identified by expert's answers to semi-structured interviews (from Questionnaire 1, Appendix C). Numbers (from 1 to 5) within the cells indicate the relative importance (from null to very high) of each access sources for each case. Rows and columns were arranged according to their cell median values. Cell tones were selected according to cell values, from dark blue (very high importance) to white (null importance).

ESI sources	Study case name[1]										Median values
	CHONTA[1]	CHACOS	GUATE	MAGA	PANGUI	CHACOC	MBARA	OROT	HOPEL	COMI	
1 Asymmetric financial capacity	5	5	5	5	5	5	3	4	5	4	5
2 Asymmetric property rights	5	5	4	5	5	4	3	3	3	1	4
3 Asymmetric negotiation ability	5	4	4	4	4	2	5	5	1	4	4
4 Asymmetric participation in governance processes	5	3	5	3	4	3	5	5	2	2	4
5 Asymmetric markets reachability	3	5	5	4	5	2	5	3	4	2	4
6 Asymmetric technological availability	4	5	3	4	3	3	3	2	5	4	4
7 Asymmetric knowledge level	5	3	3	3	5	4	3	4	2	3	3
8 Asymmetric authority reachability	5	5	5	3	3	4	4	2	3	2	3
9 Asymmetric labor capacity	3	4	2	4	3	4	3	2	4	3	3
10 Illegal access	5	4	2	4	1	3	2	2	3	2	2
Median values	5	4.5	4	4	4	3.5	3	3	3	2.5	

[1]CHONTA: Chontalapa, CHACOS: Chaco Salteño, GUATE: Guatemala, MAGA: Magallanes, PANGUI: Panguipulli, CHACOC: Chaco Cordobés, MBARA: Mbaracayú, OROT: Orotoy, HOPEL: Hopelchen, COMI: Marqués de Comillas.

Table 4
Impacts of ecosystem services inequality (ESI) on natural capital and ecosystem services. Numbers within the cells indicate the relative importance (1: null, 2: low, 3: medium, 4: high, 5: very high) of each access sources for each case according to experts' answers to Questionnaire 2. Rows and columns follow the same order as in Table 3. Cell tones were selected according to cell values, from dark green (very high importance) to white (null importance).

Impacts	Study case name[1]										Median values
	CHONTA	CHACOS	GUATE	MAGA	PANGUI	CHACOC	MBARA	OROT	HOPEL	COMI	
1. Market and socially driven landscape and seascape transformations and rural exodus [2]	5	5	5	4	4	4	5	4	5	4	4,5
2. Legal overuse of natural capital, ecosystems degradation, or biodiversity loss	5	5	5	3	5	4	4	4	5	4	4,5
3. Illegal use and overuse of natural capital in private and protected areas and oceans	5	5	1	3	5	4	4	4	4	3	3,0
4. Displacement of rural people, land concentration, land and ocean grabbing [3]	2	3	4	5	2	4	3	3	4	2	3,0
5. Waste production, pollution, environmental diseases	3	3	1	2	3	1	2	2	5	2	2,5
6. Conservation due to displacement of rural people, land and ocean concentration [3]	3	4	5	1	1	1	2	4	1	2	2,0
7. Environmental vandalism (e.g. intentional fires) due to social dysfunctions [4]	4	1	1	3	5	1	1	3	1	3	2,0
Median values	4,0	4,0	4,0	3,0	4,0	4,0	3,0	4,0	5,0	3,0	

1CHONTA: Chontalapa, CHACOS: Chaco Salteño, GUATE: Guatemala, MAGA: Magallanes, PANGUI: Panguipulli, CHACOC: Chaco Cordobés, MBARA: Mbaracayú, OROT: Orotoy, HOPEL: Hopelchen, COMI: Marqués de Comillas. [2]deforestation, afforestation, overfishing; legal, [3]illegal, armed conflicts, green and blue grabbing, [4]social conflicts, delinquency.

land property accumulation driven by international trade of commodities (Chaco Salteño, Chaco Cordobés, Hopelchen, Orotey River Basin), are not only losing natural capital and ES because of direct ESI impacts (as explained above), but also, because past ESI conditions made them vulnerable to the forthcoming scenarios. For example, past inequality in the access to property rights by small farmers, peasants and native communities determined the exposure of their territories to land clearance for the expansion of the agricultural frontier over the Chaco dry forests (Chaco Salteño and Chaco Cordobés). In turn, their low adaptive capacity to the loss of different ES (e.g., forage for domestic animals, non-timber provision ES by forests), determined the overuse and degradation of natural capital in their remaining territories.

High asymmetry in access to financial assets (including incomes), in the access to the authorities and law protection, as well as in financial and technological sources of access to ES capture as cash crops, make Guaraní communities around the Mbaracayú Natural Reserve and other remaining forests of Paraguay, highly vulnerable to legal and illegal deforestation, sometimes through illegal leasing of their lands to cash crop farmers.

In Marqués de Comillas municipality, the vulnerability increases as a result of inequality in location and property sizes, hence in the exposure to ES loss and finally, in the amount of compensations for lack or loss of ES. Therefore, ESI influences on natural capital are mediated by socio-ecological vulnerability because the allocation of Payments for Ecosystem Services (PES), and consequent conservation practices, were concentrated in large properties. Historical inequality in the access to land, added to the dependence of small land owners on the extraction of timber and the use of forage, has promoted the degradation of their forests and pastures, and a growing pressure over their remaining forests and pastures.

Different inequality sources made the settlers and natural capital of Tabasco vulnerable to the impact of the Chontalpa development plan, which consisted in the replacement of more than 90.000 ha of tropical forests and wetlands by croplands and moving local communities to small villages. Despite of settlers intends of resistance, their access to authorities and public decisions was not enough to avoid their relocation and the application of unsustainable agricultural transformation of former ecosystems. The king crab fishery in the Magallanes region of Chile clearly illustrates how the inequality in the access to this ES, because of limited number of fishing licenses instead of limited capture rates, may give place to illegal access that increases socio-ecological vulnerability, and at the end, the loss of natural capital, benefits and well-being of an important portion of the region inhabitants (Appendix D, Supplementary material).

Criterion 5: ESI is not a stable attribute; it is increasing or has recently increased. This criterion was defined in order to explore whether ESI levels were raising within systems as posed by the model when initial ESI levels and ES loss reinforce each other (Fig. 4, arrows 1, 2.1–2.5, 3.1–3.3 and 4).

Common to all cases is the fact that ESI increases rather than decreases over time, despite the fact that most countries involved have experienced improvements in economic indicators. For example, in the Chaco Salteño of Argentina, ESI increases as access to land of small farmers, peasants and aboriginal communities (belonging to Guaraní, Wichí, Kolla, Chané, Chorote, Chulupí, Diaguita, Ocloya, Tapiete and Qom etnias) is progressively being reduced.

Small farmers and peasants in the Chaco Cordobés of Argentina, whose land tenure mechanisms have been precarious through generations, are also affected by a continuous reduction in their access to ES like forage for livestock and food and raw materials by new social actors with the capacity to invest in clearing, fencing and irrigating the land. This leads to overgrazing and degradation of the peasant's remaining lands and, consequently, to the loss of a variety of ES derived from the natural system (water retention, fruit and wood production). In some cases, inequality have led to dispossession as in Hopelchen, México, depriving Mayan "ejidatarios" from relevant ES.

The expansion of oil palm production along the Orotoy River Basin, Colombia has triggered a complex spiral of ecological and social disturbances, leading to growing asymmetries in the access to local ES. Native communities of the Guaraní etnia near the Mbaracayú Natural Reserve in Paraguay are exposed to inequality sources similar to those of faced by native and small farmer communities of Argentinian Chaco.

Other causes of active ESI rising consist on the historic inequality in land distribution, as represented by Marqués de Comillas in México and

Panguipulli municipality in Chile, which has led to extreme land concentration on few large properties. Small properties at the expense of other ESs for which PES mechanisms provide an incentive.

All these cases share a common past of inequalities that go back to imprint of colonization on land tenure in terms of access and size. The neoliberal model has deepened these inequalities and generated new ones, such as the case of Guatemala City, where asymmetries in the participation in governance processes and in authority's reachability (among other access sources) have led to inequalities in environmental quality. Urban development pressures have prompted local governments to authorize construction of condominiums over previously forested areas that served as recreational spaces for all, with the consequent loss of ES benefits to previous beneficiaries and disappearance of biodiversity.

There are two cases that do not offer clear evidences of a continuing amplification of asymmetries in the access to ES. That is the case of Chontalapa, México, where unsuccessful agricultural and development policies determined the irreversible degradation of significant portions of the natural capital and the displacement of farmers to towns. On the other hand, the only case depicting a marine ecosystem (Magallanes, Chile) provides an example where fishing effort control policies (vessel exclusion), intended to regulate access to the king crab (*Lithodes santolla*) artisanal fishery, which in interplay with high market prices are suspected to promote illegal fishing.

Criterion 6: Influences of socio-ecological vulnerability components on drivers were identified in accordance with the model. Some study cases illustrated how ESI, through its influence on adaptive capacity to ES loss, may support or enhance different drivers of change in natural capital (Fig. 4, arrow 3.1). For example, emigration process due to poor adaptation to ES decline, and/or because forced dispossessions, weaken social resistances to ecosystem transformation. This is the case of Chaco Salteño, Chaco Cordobés, and Orotoy River Basin, where the voluntary or forced emigration of smallholders has preceded land concentration, deforestation, and the cultivation of cash crops by large farmers. In Hopelchen case, the government supports mechanized agriculture in the region by providing subsidies and issuing permissions for commercial production of genetically modified soybean. The expansion of mechanized agriculture is mainly practiced by the Mennonites migrants, who obtain legal access to increasing amounts of land previously owned by Maya communities (lease or purchase), but carry on illegal forest clearing to establish soybean.

Changes in land property regimens in Mexico, have been associated in Marqués de Comillas to land selling and accumulation by large farmers from outside and with higher economic capital, leading to a new deforestation period in the region. People perceive that deforestation has affected the local climate, and the availability and regulation of water resources. But this deforestation has increased at least in the last period due to land accumulation of farmers from outside who do not have sense of place and have a low dependence on local ES.

In several cases interactions between ESI and vulnerability have led to displacement and migration with a concomitant transformation of the original systems. Nonetheless, such transformations may entitle significant loses in livelihoods and indigenous acknowledge such as the case of ejidal communities in Mexico.

Criterion 7: Direct mechanisms of ESI impacts on natural capital and ES were recognized. Direct influences of ESI on the ES chain (Fig. 4, arrow 1.1) were suggested for Chaco Salteño and Chaco Cordobés in Argentina, Hopelchen in México, and Orotoy River Basin in Colombia, where the inequality in the different access sources (for example, the concentration of financial capacity and property rights, technological availability) made possible the deforestation and overuse of aquifers by large landholders, and exclusion of peasant and native communities from different ES benefits. Analogously, the remaining natural areas with recreation value within urban zones (Guatemala City case), formerly opened to public recreation, are later vanished due to the construction of private condominiums.

Criterion 8: Positive (non-regulatory) feed-backs between ESI and ES supply (ESI traps) are deduced. Since this criterion is not an observable fact, but a consequence of model integration to be deduced, it was not included in the questionnaires. Therefore, this criterion was validated by considering whether the case study comprised both negative influences of ESI on the ES chain and positive influences of ES loss on ESI (Fig. 4, arrows 1 - and/or 2 and 3 - and 4).

The occurrence of this type of feed-back could be deduced for those cases describing accelerated expansion of the agriculture frontier (Chaco Salteño, Chaco Cordobés, Hopelchen, Mbaracayú). Over time, the crops occupy new areas and natural capital is lost, while remaining areas possible to be cleared increase their real estate value. In this way, the economically disadvantaged actors lose their access to ES and ESI deepens. This loss of access can be voluntary (due to the sale of rights), or compulsive (due to legal or illegal evictions, sometimes highly conflictive and violent), but its consequences in terms of depopulation and loss of resistance to the replacement of ecosystems, are similar. An analogous reasoning can also be applied to cases of remaining natural areas of recreational value within urban zones, here represented by the Guatemala City case.

Criterion 9: reciprocal influences between ESI sources are recognized. Occurrence of interrelated ESI sources, as described by the ESI model (Fig. 4, box 1), was identified in three of the study cases (Table 3). The emergence of new social actors and forms of territorial control (extra-regional agricultural enterprises) in the Chaco cases, illustrates how, in a context of land use regulations but legal insecurity and weak enforcement, the inequality in financial capacity and property rights are finally translated in loss of social capital, and emigration or displacement of peasants and native communities Displacement of rural people as consequence of ESI inequalities received a high rate for the Chaco Cordobés and it was only rated as medium for the Chaco Salteño case, perhaps because the last case was focused on indigenous communities and they are absent in the former.

In Hopelchen case, migration of financially more capable Mennonites in the Maya indigenous people territories lead to concentration of land (through rent or purchase) within the first group. Such inequality in the access to capital is closely related to an unequal access to technology, resulting in Mayas' dependence of technical services provided by Mennonites in land cultivation process. The expansion of mechanized agriculture together with the modification of land tenure and contamination by the glyphosate applications required by genetically modified soybean, have reduced the space and condition for traditional Mayan agriculture and beekeeping, causing deep conflicts between these two local groups (Appendix C, Supplementary Material).

In Marqués de Comillas, inequality in property rights (including asymmetric landholding sizes) and other factors determined privileged legal access to some individuals and institutions with the authority to influence public decisions on land use and conservation, influencing who benefits from ES.

4.2. Vertical analysis of validation criteria of the ESI model

The level of adjustment to the ESI model varied among cases, revealing that model may provide a useful interpretation of the role of inequality in socio-ecological systems in some contexts, but that it omitted or misinterpret relevant reality features in other contexts.

Half of the selected cases showed a good fit to the model, with seven, eight or nine validation criteria accepted out of a total of nine (Table 2). For simplicity we adopted an unweighted validation procedure, but evidences on feed-backs between ESI and ES supply (ESI trap) deserves a special attention, since this criterion is discriminating the highest scored cases from the rest. Cases that fitted the ESI trap criterion (criterion 8), corresponded to contexts of active exclusion of disadvantaged beneficiaries of ES that in turn leads to increasing ESI levels, as it occurs in the expansion of cash crops over native forests or the appropriation of remaining natural areas in urban landscapes.

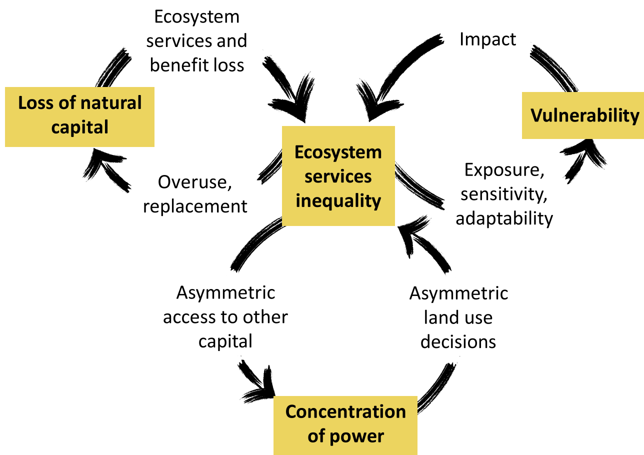

Fig. 6. The ecosystem services inequality (ESI) trap (simplified from Fig. 4), consisting of three reinforcing feed-backs: ESI-concentration loop (1), ESI-NC loss loop (2), and ESI-vulnerability loop (3).

On the other side, the ESI model showed a low performance for a portion of selected cases (score = 6 or less), revealing that ESI does not necessarily lead to ESI traps. It is worth noting that these cases not only share a lack of deductible positive feed-backs between ESI and ES supply, but also, a lack of evidence about other two validation criteria, which are the reciprocal influences between ESI sources and direct influences of ESI on natural capital and ES.

5. Discussion

5.1. The ecosystem services inequality (ESI) model

While several studies describe the underpinnings of the unequal access to ES benefits (Villamagna et al., 2017), few provide sufficient context to enable a thorough understanding of ESI sources and effects within socio-ecological systems (positive or negative), if any. Such studies contribute to the accumulating evidence that ES support well-being particularly of the most deprived people, but offer little evidence on the different sources of ESI, their interactions, and further effects of ESI on vulnerability and poverty. A considerable gap remains in understanding these links, how they change over time, and how pathways out of inequality may be achieved based on the sustainable use of ES. In contrast to previous and static correlative studies at large spatial scales, we carried out a comprehensive local level analysis of the role of inequality on natural capital changes, using a socio-ecological system approach. We tested a conceptual model representing the mechanisms linking access sources, distribution of ES benefits and vulnerability (ESI model) in a Latin American context, and also provided a methodological procedure for case based analysis of ESI role.

The ESI conceptual model and the examined study cases revealed that: (a) ESI sources are not only defined by asymmetric financial capacity but also, by several economic, social, political and technological mechanisms that constrain access to ES benefits, (b) ESI influences on natural capital are not only expressed as biodiversity loss, but are also associated to the loss of ES supply and their benefits, (c) which in turn, may promote the loss of natural capital by overuse from the most dependent ES beneficiaries, and principally, by (d) increased vulnerability to the impact of concentrated power of internal and external actors, (e) ESI driven vulnerability may beget higher ESI, driving the socio-ecological system within an unsustainable trajectory, and pushing the system to usually undesirable alternative states, but (f) that positive feed-back loops do not take place in all cases, and ESI damping mechanisms remain to be identified.

5.2. Different contributions of access sources to ESI

The evidence from this study corroborates the importance of financial asymmetries as a source of ESI (see Table 3), but it also recognizes reciprocal influences between access sources which together perpetuate ESI and marginality. Thus for example, inequality in land property rights is one of the crucial underpinnings of long-run persistent financial and asset (technology) inequality. In addition to the fundamental role of land distribution on ESI pre-modern rural economies and indigenous territories, a growing concentration of private land promotes several other asymmetries such as market and authority reachability, and consequently rising of vulnerability and ES loss (e.g., Chaco Salteño, Hopelchen. Marqués de Comillas, and Panguipulli cases).

The evidence also contests the role of secure property rights as the panacea to effective environmental management and good governance. Some cases show that private property rights structures may be enhancing private agents' legal claims to land and forests and the profitability of their activities, but the result may be more rather than less natural capital loss, such as the case of Chaco Salteño. In other cases, a new structure of formal rights has come to replace informal institutions over communal lands with disastrous results for local communities (case of Chontalpa).

5.3. Navigating ESI traps

In several case studies, the links included in the ESI model represent to socio-ecological traps, or more narrowly defined an ESI trap (see Glossary in Appendix A, Supplementary material), where asymmetries in access (sources of ESI) lead to social inequalities that in turn cause environmental inequalities. Environmental inequalities in turn increase vulnerability which lead to further social and environmental inequalities (Fig. 6).

Poverty and inequality traps have been identified as causes of environmental degradation but the subject is highly contested (Barrett et al., 2011; Dasgupta, 2010; Duraiappah, 1998). On the empirical level, the social-ecological approach reveals the existence of a strong, reciprocal, and complex relationship between them. For example, social inequalities caused for example by asymmetric access to financial mechanisms and technology, leads to ecological crises (e.g., land degradation).

While some degree of inequality in the access to ES is expected for any socio-ecological system at any given time, not all the systems depicted by the cases are losing natural capital, and in not every case the loses in natural capital can be attributed to an ESI trap. When ESI promotes an ESI trap? In what extent this depends on ESI features (e.g., mechanisms involved, inequality degrees, ES dependence, and satisfaction of ES demands) and/or on ESI context (e.g., sources of vulnerability, types and impact intensity of drivers of ecosystems change, governance structures and institutions)? While our methodological approach does not allow for quantitative answers to these questions, the results suggest the importance of reciprocal influences between ESI sources, as well as the importance of direct influences of ESI on natural capital and ES, which are common to cases of active expansion of cash crops over native forests, or the appropriation of remaining natural recreation areas in urban landscapes (see 3.3.1 section, Table 3).

The decline in social and economic inequality indicators registered in many Latin American countries since the late 1990s coincides with the abandonment of strong market-based policies towards a political scenery in which the social problems of poverty and inequality play a prominent role. This "re-politicization" of inequality has expressed itself in the revival of mass protest manifestations and it has generated a diverse array of policy tools for tackling inequality and poverty (De Castro et al., 2015). Socio-ecological systems in this study are reflecting both past adjustment economic policies and the revival of distributive policies, institutions and mechanisms aimed to alleviate and compensate for socio-economic inequality, such as land reform policies (Lloyd-Sherlock, 2009).

Results also suggest that initial inequality levels scale up towards the depletion of human, social and economic capital of disadvantaged social actors which most depend on natural resources, leading to different forms of exclusion and transformation of their territories (direct influences of ESI on natural capital). Therefore, it is possible to discriminate two contrasting consequences or roles of inequality in socio-ecological systems, depending if inequality becomes marginality (see Glossary in Appendix A, Supplementary material) or it is dampened through public policies, before inequality creates a trap.

Although our study did not contemplate the explicit evaluation of processes capable of slowing or stopping trajectories of marginalization and loss of natural capital, some clues can be inferred from the information available for the case studies where ESI traps could not be inferred. For example, in Chontalapa, development policies determined the compulsive moving of small farmers into urbanizations, so the loss of natural capital was not mediated by their marginalization but, paradoxically, by attempts of agricultural modernization and social integration (Tudela, 1989). In Marqués de Comillas, an ESI trap was probably prevented by a series of participative governance initiatives not observed in the rest of the cases, which consisted in the implementation of PES schemes, and territorial planning initiatives (Castro and Ortiz, 2015). There was also an interest in developing a territorial planning, in order to optimize land use and conserve its natural resource base, advancing in the implementation of schemes that increase sustainability and the improvement of ES supply and livelihoods. In this context, the process for the development of the 'Community Ordinance of the Marqués de Comillas Microregion Territory' was initiated, as a product of a participatory inter-ejidal planning process (Castro et al., 2015).

On the other hand, Magallanes exemplifies a situation where due the lucrative value of a natural resource (king crab), stakeholders and managers overlook risks of unexpected sudden decline in stocks and associated social-ecological consequences (Steneck et al., 2011). The closing of entry to new fishers and the high prices of the products are causing several forms of illegal access: these short-term economic opportunities impede or prevent long-term commitments to reverse the socio-ecological degradation that illegal fishing can cause.

The expected feed-backs between ESI and loss of natural capital, were not always positive (non-regulatory), as expected. Interestingly, in some cases such as Panguipulli, inequality in access to land and financial capacity to acquire the land (Table 3, Appendix D), has led to conservation in large properties but at the social cost of green grabbing. As represented by Panguipulli case, the historic unequal distribution of land and successive forest policies in Chile, have led to concentration of wealth in large properties today dedicated to to nature conservation. Therefore, land inequality is ensuring conservation, but at the cost of benefits being seized by higher income groups (Nahuelhual et al., 2018a).

While the ESI model partly fits to socio-ecological systems where governance of natural capital and its institutions cannot make up for the loss of poor people access to ES, it should be expanded to account for the growing resistance of indigenous communities, small farmers and rural workers or peasants in several regions of Latin America to neoliberal exclusion processes (e.g., Brent, 2015; Carruthers, 2008a,b; Harris, 2003; Reed, 2003; Rice, 2012).

6. Conclusion

In this paper, the conceptual framework of ES was expanded to explore the links between inequality, socio-ecological vulnerability and natural capital concepts, and to support the construction of a conceptual model addressing the ESI role within socio-ecological systems. Testing this model using an heterogeneous array of study cases provides evidences suggesting that inequality in the access to ecosystem services may hinder the conservation and recovery of the existent natural capital constituting a perverse feed-back between inequality and ES loss in the territory (ESI traps). However, our analysis also shows that these ESI traps do not always operate (or are not always inescapable), and that the effective policy interventions can be fundamental to slow down further losses of natural capital and further inequalities in the distribution of ES benefits.

In the face of the multiple social traps that characterize the vulnerable socioecological systems of Latin America, the sustainable governance of natural capital cannot be reduced to the management and conservation of ecosystems, but rather requires the creation or the improvement of institutions and instruments aimed at reducing inequality in access to ES benefits. Given this context, ES research and emergent policies must acknowledge the sources and impacts of ESI within social-ecological system dynamics in order to avoid ES-based interventions that may sustain or even aggravate environmental injustices (Kronenberg and Hubacek, 2016).

Public awareness about the consequences of access inequality on natural capital is a necessary first step for the promotion, support and legitimization of different public policies aimed to inequality reduction (e.g., EJAtlas, 2018; SEV-project, 2018). ES assessments can take into account the influences of ESI on the vulnerability to ES loss through an inequality index, like is proposed in the ECOSER mapping tool (Laterra et al., 2016). Therefore, socio-ecological inequality could be mainstreamed into ES governance through monitoring relevant components of the ESI model, in a similar way as proposed by Zafra-Calvo et al. (2017) for assessing and monitoring of social equity in protected areas.

Acknowledgements

This article is a collaborative output of the VESPLAN (Vulnerability, Ecosystem Services, and Territorial Planning) network (www.vesplan.org), which was supported by the CYTED (Programa Iberoamericano de Ciencia y Tecnología para el Desarrollo), and partly funded by grants Fondo para la Investigación Científica y Tecnológica FONCYT (ANPCYT) PICT 15-0672, BEST-P Inter-American Institute for Global Change Research CRN3095 which is supported by the US National Science Foundation (Grant GEO-1128040), FONDECYT-Chile 1151187 and FONDAP-Chile 15150003. The formulation of the ESI framework was initiated during a workshop of the VESPLAN network, held in Mbaracayú Nature Reserve (Paraguay, October 2016) thanks to the CYTED and the Fundación Moisés Bertoni support, and refined during a second workshop held during the V International Congress of Ecosystem Services in the Neotropics (CISEN5), held in Oaxaca, México (November 2017). Hopelchen case was funded by the PAPIIT-UNAM IN302918 project. We are thankful to Daniel Cáceres and Natalia Pérez Harguindegy, the Editor, and three anonymous reviewers for valuable comments on an early draft of this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecoser.2018.12.001.

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