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Assessment of quality of input data used to classify ecosystems according to the IUCN Red List methodology: The case of the central Chile hotspot

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ABSTRACT

During the last decade, the IUCN has developed criteria analogous to the Red List of Threatened Species to perform similar risk assessment on ecosystems, creating the Red List of Ecosystems methodology. One of the most significant challenges for the construction of these lists is the gathering and availability of the information needed to apply the criteria. We present a complement to the IUCN's methodology to assess the threat level to ecosystems, estimating the spatial and temporal quality of the information available in scientific publications. We did this by applying the IUCN criteria to determine the threat level to the sclerophyll ecosystems of central Chile. Spatially explicit studies that identify disturbances in the structure of the vegetation were selected, making it possible to quantify effectively the reduction in the ecosystems' distribution. The spatial and temporal quality of the assessment were estimated as the percentage of the potential ecosystem distribution and the time frame recommended by the IUCN (50 years), that the studies represented for each ecosystem. The application of the methodology allowed the assessment of a high percentage of the ecosystems (85%), which were classified based on the studies with ranges of temporal quality from 30 to 100% and spatial quality from 12 to 100%. If only the assessments with more than medium spatio-temporal quality are considered (>50%), eight of the 17 evaluated ecosystems are classified in threat categories, which represents 22.9% of the study area.

1. Introduction

The impact of human activities on natural ecosystems has been globally recognized, with the rates of decline of their distribution increasing towards the end of the 20th century (Keith et al., 2013). The scientific community has expressed its concern over the state of natural ecosystems, which has motivated the creation of a methodology to generate Red Lists of Ecosystems (RLE), which evaluates the risk to which they are subject, proposing robust criteria based on ecological theory (IUCN, 2016). Nevertheless, one of the difficulties that the analysis presents at the theoretical and practical levels is the identification of the final phase of an ecosystem's degradation (Rodríguez et al., 2011), therefore the concept of ecosystem collapse emerged, which is equivalent to species extinction (Newton and Tejedor, 2011).

Ecosystems have attributes of structure, function and composition, which act synergically (Noss, 1996) and which are considered open systems, since the energy flows freely through them (Leuschner, 2005). Ecosystems are sustained based on their primary productivity and amount of biomass; therefore, if it is lost or its amount is reduced, the resources on which the populations and communities rely will also be limited (Chapin et al., 2000). The mechanisms through which an ecosystem collapses are unclear, in particular when it comes to identifying the attribute that is modified (Keith et al., 2013). The problem lies in that the disturbance often not only affects a specific attribute; it also affects all of them simultaneously. Identifying these mechanisms demands complex studies that require field information and detailed data, at least in the case of the attributes of function and composition (Porter and Savignano, 1990; Keith et al., 2013). The loss of plant cover has been considered one of the main triggers of degradation at the global level, since the structure of the ecosystem is directly involved (Vitousek et al., 1997; Crespin and Simonetti, 2015). These changes in the structure can be easily identified by means of remote sensing technologies, which make it possible to know the land cover, defined as the appropriation and use of the geographic space in a way that is different from the natural one (Brown et al., 2014). Remote sensing has been able to retrieve the land cover, and indirectly the soil use, in Chile (Zhao et al., 2016) and worldwide (Gong et al., 2013) and can also evaluate the changes in soil use in vast expanses of territory, and this has been widely documented (Yu et al., 2015).

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The main challenge for the assessment of the criteria of the RLE is the unavailability of detailed ecological information for a large number of countries (Rodríguez et al., 2011). In Chile's case, knowledge of the ecosystems is incomplete, as this is one of the least studied levels of organization in the scientific literature (Simonetti, 2011). Therefore, it is vitally important to determine the effects that human activities have on them, focusing on those areas of greatest sensitivity, within which the Mediterranean ecoregion is key (Pliscoff and Fuentes-Castillo, 2011; Squeo et al., 2012). This ecoregion is considered one of the areas subjected to the greatest anthropic pressures nationally (Schulz et al., 2010), which puts the ecosystems at risk of degradation and collapse. From an ecological point of view, it has a high level of endemism that makes it fundamental in terms of conservation, and together with the Valdivian temperate forest it is a *hotspot* of the biodiversity recognized by the International Union for Conservation of Nature (IUCN) (Mittermeier et al., 2004; Myers et al., 2000). The sclerophyll forest is part of it and has been classified according to Luebert and Pliscoff (2006) as having a total of 10 vegetation belts, among which are the sclerophyll forests and woody scrub that extend from 31°S to 37°S, being located mainly in the Coastal Mountain Range and pre-Cordillera of the Andes.

The present study is an exercise in applying the IUCN criteria to evaluate RLE, based exclusively on information available in publications, assessing the spatio-temporal quality of the input data used in the assessment. Accordingly, the aim is to complement the protocol set out by Rodríguez et al. (2015) so as to facilitate the application of the IUCN's RLE criteria. This analysis was conducted in the biodiversity hotspot of the Chilean central zone.

2. Materials and methods

The proposed protocol considers the same steps as those proposed by the IUCN's Red List of Ecosystems, but estimates the assessment quality at the end. Here we only summarize the red listing methodology; for more details, see its guidelines (Bland et al., 2016) and the associated scientific papers (Keith et al., 2013, 2015; Rodríguez et al., 2015).

2.1. IUCN Red List of ecosystems methodology

There are five criteria in the risk assessment protocol (Keith et al., 2013; Rodríguez et al., 2015):

A) refers to the reduction in the distribution of the ecosystem over a certain period of time (50 years in the past, 50 years in the future, 50 years in any range and historical loss) (Fig. 1-A);
B) refers to ecosystems with a limited geographic distribution;
C) refers to the degradation of the ecosystem's abiotic or environmental components over a certain period of time (same as Criterion A);
D) refers to the disruption of biotic processes or interactions fundamental to the ecosystem in certain period of time (same as Criterion A);
E) refers to a quantitative analysis that estimates the likelihood of an ecosystem's collapse.

The ecosystems for which no studies have been done on their distribution pass to the category of Deficient Data (DD). Regarding the classification of ecosystem risk, the final category is the one of greatest risk among all the criteria and sub-criteria assessed for each ecosystem (Rodríguez et al., 2015), which can be Least Concern (LC), Near Threatened (NT), Vulnerable (VU), Endangered (EN), Critically Endangered (CR) or Collapsed (CO). Threatened ecosystems are those classified in categories VU, EN and CR.

2.2. Assessment quality

The spatio-temporal quality of the assessment is a way to analyze whether the studies are representative of the IUCN-RLE criteria, which make certain demands in terms of minimum area and time data to evaluate an ecosystem's state of conservation (Keith et al., 2013). Satisfying the 50 years that the IUCN establishes to analyze the change processes is difficult when one considers that the oldest satellite images are from 1972. Therefore, we propose to work with ranges of temporal assessment quality, relating the time required by the IUCN for the criterion and the time that the study considers, expressed as a percentage (Fig. 1-A):

$$\left(\frac{\textit{Study time range}}{\textit{IUCN time criterion}}\right) \times 100, \tag{1}$$

which implies that a study of 40 years will have a temporal assessment quality of 80%.

In the case of the spatial quality of the assessment, the quality of the assessment is determined by relating the study area with the total ecosystem distribution (Fig. 1-B):

$$\left(\frac{\textit{Study area}}{\textit{Ecosystem area}}\right) \times 100 \tag{2}$$

If one uses the national land use cover map to estimate criteria (e.g., A3 and B), spatial quality is considered as 100% because this map covers the total ecosystem distribution. The final classification is determined by the study that presents the highest level of assessment quality. The levels of spatial and temporal quality were divided into three ranges: low (<50%), medium (50–80%) and high (>80%).

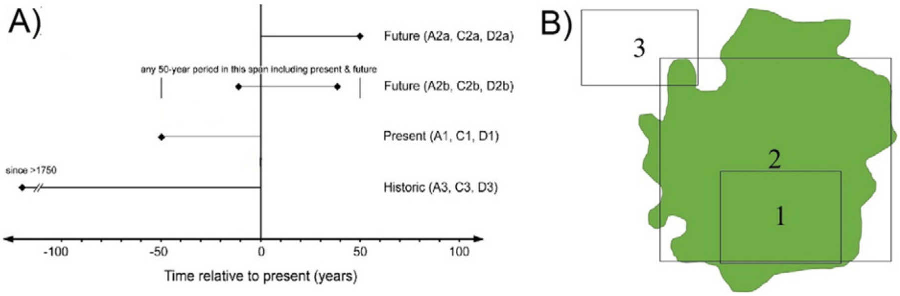

Fig. 1. Schemes of temporal (A, Keith et al., 2013) and spatial (B) scales that are used to estimate the assessment quality. In A) as an example, a study of 40 years has an 80% of temporal quality. In B) the area of three spatially explicit studies are represented (black boxes) in relation with an ecosystem distribution (green polygon): Studies 1, 2 and 3 represent 30%, 90% an 5% of the ecosystem and their information is 100%, 90% and 5% referred to the ecosystem.

2.3. Study area and systematization of the information

The study area was central Chile, specifically the ecosystems of sclerophyll forest and scrub located between 30°S and 40°S, between 0 and 1500 m a.s.l. (including a total of 20 vegetation belts). The ecosystem classification officially used in Chile is the one proposed by Luebert and Pliscoff (2006), who defined vegetation belts as groups of zonal vegetation communities with uniform structure and physiognomy, located under similar meso-climatic conditions that occupy a determined position along an elevation gradient, at a specific spatial-temporal scale. The digital representation of this classification was used to map the potential distribution of ecosystems.

Key concepts were sought in the ISI Web of Knowledge database related to the modification of the ecosystem properties (Pickett and Cadenasso, 1995; Bland et al., 2016) of the sclerophyll forest and scrub ecosystems in Chile: deforestation, land use, land cover, Mediterranean, Chile, change, modification, loss and degradation. These concepts were linked in several combinations, which revealed a total of 23 works related to the topic. To be able to estimate the spatial and temporal quality of the assessment, only the spatially explicit studies were included, since the other study types do not contribute an assessable spatial dimension using the RLE criteria. Each of the works was classified according to methodology, identifying the main dynamics or pressures described on the ecosystem being studied and the level of classification accuracy (see Supplementary material, Table A1).

In order to use the maps from the publications to identify the losses per ecosystem, georeferencing and supervised classification were used. To generate the supervised classifications, maximum likelihood estimation was used with training polygons in each of the covers on the maps, using the symbols that appeared in the publications to classify them. The classifications were calibrated by photointerpretation, manually delineating some polygons to enhance the classification. To apply Criterion A3, the potential distribution of ecosystems proposed by Luebert and Pliscoff (2006) was considered to be the initial area and all the reported anthropic land uses in the Chilean Native Forest Registry (Official registry of land uses in Chile) (CONAF et al., 2013), were considered to be losses. To apply Criterion B, the map of current vegetation was used (CONAF et al., 2013), identifying those ecosystems with a limited distribution (Rodríguez et al., 2015).

3. Results

The literature on changes in the central zone of Chile is limited but quite varied, including studies into the changes of use and cover, forest fires, invasion of exotic plants and animals, desertification and deforestation in general. The great majority of studies is mensurative and spatially explicit; second are experimental studies, and finally bibliographical analyses (see Supplementary material, Table A1).

The selected studies were based methodologically on the use of satellite images as the source of information for different objectives (see Supplementary material, Table A1), being 14 in total. The studies on change of use and soil cover calculate different loss rates for each area of a particular study. Then there are the studies focused on fragmentation patterns of the habitat, which apply landscape metrics to interpret the changes. Studies about forest fires mainly focus on their spatial patterns and the propagation of these patterns over time, associated with the ecological dynamics such as vegetation succession after fires in the sclerophyll forest. The smallest number of studies focuses on bioclimatic or ecosystem processes, such as the estimation of evapotranspiration or hydrological regimes in sectors affected by change of land use and soil cover. Most of the studies selected used medium-resolution multispectral remote sensing, in particular information from the Landsat program, to identify mainly change of land use and soil cover patterns. Nine out of fourteen studies report the level of accuracy of the classifications, which are in general >70% (see Supplementary material, Table A1).

The most frequently studied zones are located in the coastal zone at 34°S latitude, whereas there are areas like the northern part of the sclerophyll ecosystems that have not been studied (Supplementary material Fig. A1). Some ecosystems have up to 10 published studies, whereas others have few studies in their distribution area (Supplementary material Fig. A1). The study periods of the works go from the 1970s to the current decade and most works have been published since 2009 (Supplementary material, Table A1).

3.1. Classification of ecosystems

Table 1 presents the classification of the threat level of the evaluated ecosystems in the Chilean central zone *hotspot*. Next are some examples of the details of the assessment.

3.1.1. Coastal Mediterranean sclerophyll forest of *C. alba* and *P. boldus*

Luebert and Pliscoff (2006) classified it as an ecosystem of laurifolious-sclerophyll forest. The study by Schulz et al. (2010) indicates that this ecosystem has lost only 5% of its area, and is in the category of Least Concern (LC) according to Criterion A1 (Table 1, Supplementary material Fig. A2). Its historical loss in the same area in the study by Schulz et al. (2010) corresponds to 16%, which reaffirms the category assigned in the previous sub-criterion. On the other hand, the study by Castillo et al. (2009), which covers 23.6% of the ecosystem's total area and is located in the coastal zone near the city of Valparaiso, shows that there has been a 38.3% loss resulting from forest fires in that sector. These fires saw a 60% increase in recurrence between 1986 and 2007. Therefore, it is classified as VU according to Criterion C1. Considering the study of greatest quality, the ecosystem is classified as LC according to Criteria A1 and A3 (Table 1, Supplementary material Fig. A2).

Interior Mediterranean sclerophyll forest of *L. caustica* and *P. boldus*. This ecosystem is dominated by a tree stratum, where bush individuals of *Q. saponaria* and *C. alba* appear, which although they are typically arboreal, here are present as scrub due to extraction conditions over many years (Luebert and Pliscoff, 2006). The study by Olivera-Guerra et al. (2014) determined the change in evapotranspiration of the original forest cover when replaced by other soil uses. Evapotranspiration of the remaining forest cover was considered original or potential evapotranspiration of the ecosystem. The authors determined that the average of the historical or potential summer evapotranspiration of the forest was reduced by 33% (relative severity). On the other hand, it was quantified that the extension of the ecosystem at historical level has been reduced by 61.9% (from 8024 km^2 to 3054 km^2). Therefore, it was classified as Near Threatened (NT) under Criterion C3 (61.94% extension and 33% relative severity). Nevertheless, under Criterion A3 it is VU (Fig. 2, Table 1).

3.1.2. Interior Mediterranean sclerophyll psammophytic forest of *Q. saponaria* and *Fabiana imbricata*

This is a sclerophyll forest with a dominance in the tree stratum of *Q. saponaria* and *L. caustica* and in the shrub stratum an abundance of *F. imbricata*. It is the southernmost sclerophyll ecosystem in Chile, contiguous to the south of its distribution directly with the rainy temperate forests (Luebert and Pliscoff, 2006). If the potential distribution is compared to the current area, it shows that the ecosystem has lost almost all of its original distribution, being relegated to small patches of forest in ravines and hills (Table 1, Supplementary material Fig. A3). A historical loss of 81.2% is estimated, thus under Criterion A3 this ecosystem is Endangered (EN) (Table 1). On the other hand, using the study by Aguayo et al. (2009), the ecosystem shows a loss of 59% of the distribution it had in 1979 until 2000; therefore, according to Criterion A1, it is classified as Critically Endangered (CR) (Table 1, Supplementary material Fig. A3).

Table 1
Number of criteria used and quality of the risk status assessment of 20 terrestrial ecosystems of central Chile. ID corresponds to the identifier for vegetation and geographical coverage as can be seen in Fig. 3. Spatial and temporal quality or studies that support the highest risk classification are shown. In some ecosystems, two IUCN status appears, because they represent the result of the assessment of the two criteria with more quality and risk. In these cases, the highest risk status should be considered.

ID	Ecosystem	# Criteria assessed	# Sub-criteria assessed	# Sub-criteria supporting overall status	Spatial criteria assessed	Functional criteria assessed	Criteria determining overall status	Spatial quality (%)	Temporal quality (%) (years of study)	IUCN status
1	Interior mediterranean thorn forest of *A. caven and Prosopis chilensis*	3	4	2	+	+	A1, D1	48.5	40 (20 yr)	NT
2	Andean mediterranean thorn forest of *A. caven and Baccharis paniculata*	3	4	3	+	+	A1; D1, A3	96.5	40 (20 yr) 100 (historical)	CR; VU
3	Coastal Mediterranean thorn forest of *A. caven* and *Maytenus boaria*	1	2	1	+		A3	87.7	100 (historical)	VU
4	Interior mediterranean thorn forest of *A. caven and Lithraea caustica*	0					–	–	–	DD
5	Coastal mediterranean sclerophyll arborescent scrub of *Peumus boldus and Schinus latifolius*	1	1	1	+		A3	100	100 (historical)	LC
6	Interior mediterranean sclerophyll arborescent scrub of *Quillaja saponaria and Porlieria chilesis*	1	1	1	+		A3	100	100 (historical)	LC
7	Andean Mediterranean sclerophyll forest of *Kageneckia angustifolia and Guindilia trinervis*	1	1	1	+		A3	100	100 (historical)	LC
8	Coastal Mediterranean sclerophyll forest of *Cryptocarya alba and P. boldus*	2	2	2	+	+	A1, A3	74.3	80 (40 yr) 100 (historical)	LC
9	Coastal Mediterranean sclerophyll forest of *L. caustica and C. alba*	2	3	2	+	+	C1, A3	32.3 100	80 (40 yr) 100 (Historical)	CR
10	Andean Mediterranean sclerophyll forest of *Q. saponaria and L. caustica*	3	5	2	+	+	A1, D1	32.3	80 (40 yr)	VU
11	Coastal Mediterranean sclerophyll forest of *L. caustica and Azara integrifolia*	2	2	1	+	+	A1	21.1	80 (40 yr)	VU
12	Interior Mediterranean sclerophyll forest of *L. caustica and P. boldus*	2	3	1	+	+	C3; A3	12.1	100 (historical)	NT; VU
13	Andean Mediterranean sclerophyll forest of *L. caustica and Lomatia hirsuta*	1	1	1	+		A1	15	30 (15 yr)	LC
14	Interior Mediterranean sclerophyll psammophytic forest of *Q. saponaria and Fabiana imbricata*	1	1	1	+		A3	87	100 (historical)	CR
15	Coastal Mediterranean deciduous forest of *Nothofagus macrocarpa and Ribes punctatum*	3	5	2	+		B1, B2-c, B3	100	100 (current)	VU
16	Interior Mediterranean deciduous forest of *Nothofagus obliqua and C. alba*	0					–	–	–	DD
17	Andean Mediterranean deciduous forest of *N. obliqua and Austrocedrus chilensis*	0					–	–	–	DD
18	Coastal Mediterranean deciduous forest of *Nothofagus glauca and Azara petiolaris*	2	3	2	+	+	A1; C3	70.4 32	80 (40 yr)	EN; VU
19	Coastal Mediterranean deciduous forest of *N. glauca and Persea lingue*	2	3	2	+	+	A1, A3	74.8 100	80 (40 yr)	EN
20	Coastal Mediterranean short scrub of *Chuquiraga oppositifolia and Mulinum spinosum*	4	7	4	+	+	A1, B1, B2-c; B3	68 100	80 100 (current)	EN; VU

3.1.3. *Coastal Mediterranean deciduous forest of Nothofagus macrocarpa and Ribes punctatum*

This is a forest dominated by *N. Macrocarpa*, with a tree stratum rich in *R. panctatum*, *Berberis actinacantha*, *Calceolaria meyeniana* and *Azara petiolaris*, also presenting sclerophyll elements. It has a highly reduced extension of 973 km^2 and is present on the hills of La Campana, El Roble and Altos de Cantillana. The analysis of the results reported by Schulz et al. (2010) revealed that it has had a decrease of 8.9% in the last 40 years and a historical decrease of 20.2%; thus, it can be classified as LC under Criterion A1. The limited distribution motivated the assessment through Criteria B1, B2 and B3 (Table 1, Supplementary material Fig. A4):

- *B*1: Convex minimum polygon of 5867 km^2, and is only present in six locations, which is why it is classified as VU.
- B2: 45 cells of 10 km occupied by the ecosystem, and it is therefore classified as VU.
- B3: Has only six locations; however, the closeness to Santiago, as well as the processes of cover loss of the contiguous ecosystems leads to it being classified as VU.

3.1.4. *Other ecosystems*

Some sclerophyll ecosystems that lack studies on their structural modifications include: coastal Mediterranean sclerophyll wood scrub of *P. boldus* and *Schinus latifolius*, interior Mediterranean sclerophyll wood scrub of *Q. saponaria* and *Porlieria chilensis* and Andean Mediterranean sclerophyll forest of *Kageneckia angustifolia* and *Guindilia trinervis*. Nevertheless, the historical loss was evaluated under Criterion A3, which showed that their historical losses have been very low (15%, 3% and 1%, respectively), and they were therefore classified as LC (Table 1).

Of all the ecosystems that have been proposed for assessment (20), it was possible to classify three ecosystems as CR, three as EN, five as VU and six as LC or NT, whereas three ecosystems had no records and were therefore classified as DD (Fig. 3-A, Table 1).

3.2. *Assessment quality*

When the degree of assessment quality is analyzed, it can be seen that seven of the 17 ecosystems that could be evaluated had spatial quality >50%. The ecosystems located between 34° and

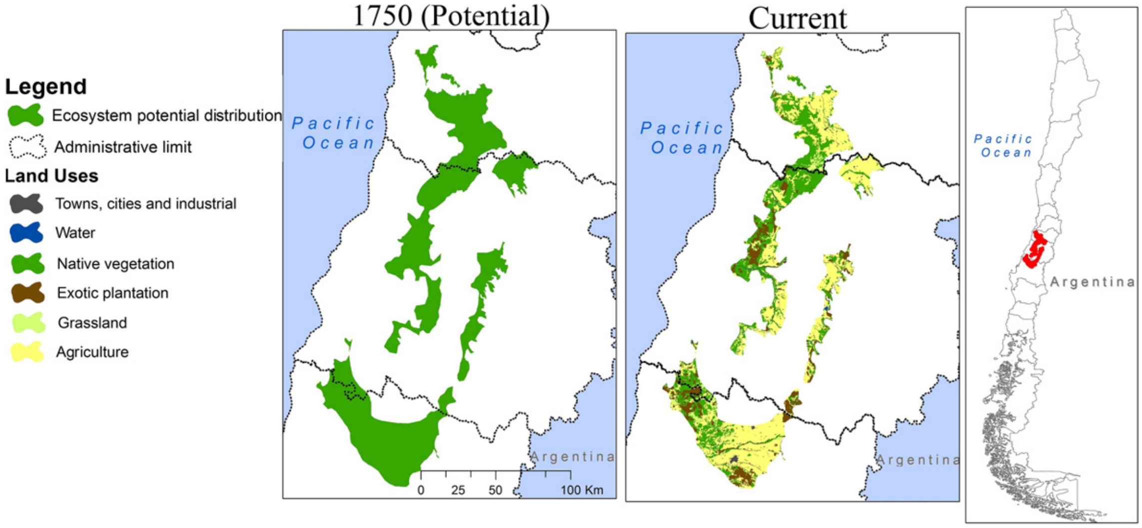

Fig. 2. Map of area loss of the Interior Mediterranean sclerophyll forest of *Lithraea caustica* and *Peumus boldus*, using the criteria of historical decline (A3).

35° have the lowest ranges of geographic quality (Fig. 3-B). If the temporal quality is analyzed, 14 of the 17 ecosystems assessed have ranges greater than 50%, which corresponds to 82.5% of the evaluated ecosystems and represents 95% of the study area (Fig. 3-C). In general, the coastal ecosystems between 32°S and 34°S latitude have high values of spatial and temporal assessment quality because a large

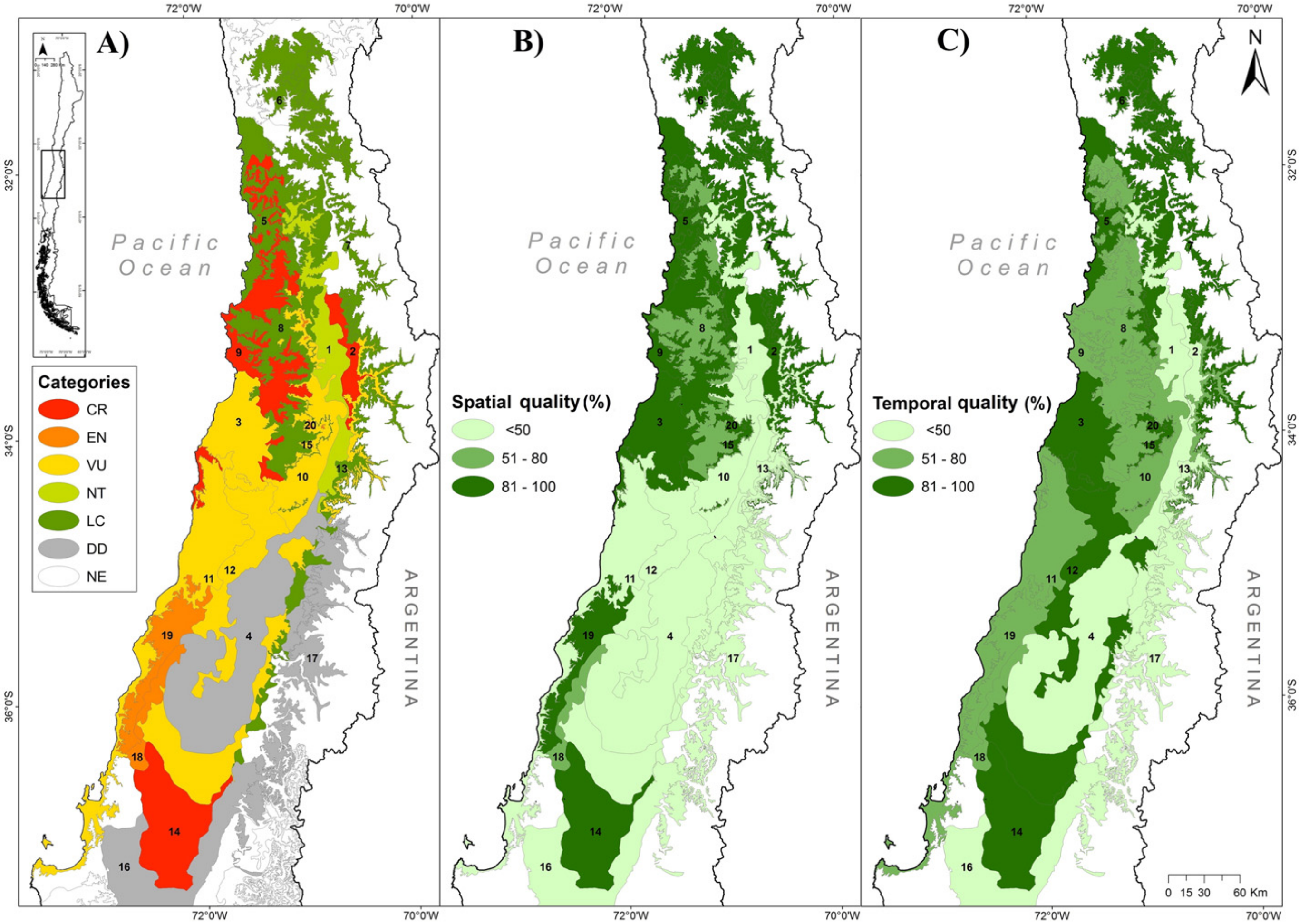

Fig. 3. Classification of ecosystems by: A) threat level according to the IUCN Red List of Ecosystems, B) spatial quality and C) temporal quality of the assessment according to the studies used. The identity of each ecosystem is represented by the numbers on the maps and the names are presented in Table 1.

number of studies have been carried out in this area (Supplementary material Fig. A1).

In terms of the assessment quality, in the case of the coastal Mediterranean thorn forest of *A. caven* and *Maytenus boaria*, the study conducted by Schulz et al. (2010) covers 87% of the distribution of this ecosystem and analyzed the last 40 years (1975), which means 87% geographic quality and 80% temporal quality for the criteria of recent loss (*A*1). The same study for the case of the coastal Mediterranean sclerophyll forest of *C. alba* and *P. boldus* (Supplementary material Fig. A2), covers 74% with the total distribution of this ecosystem (geographic quality) in the same time period. For this same ecosystem, the study by Castillo et al. (2009) only achieves 34.8% spatial quality and 40% temporal quality, which is considered low or insufficient. The study by Olivera-Guerra et al. (2014) covers 12.1% of the distribution of the interior Mediterranean sclerophyll forest of *L. caustica* and *P. boldus* (Fig. 2); however, it provides measurements that can be extrapolated to the entire ecosystem (change in evapotranspiration of the forest). The study by Aguayo et al. (2009) covers 87.6% of the distribution of the interior Mediterranean psammophytic sclerophyll forest of *Q. saponaria* and *Fabiana imbricata* (Supplementary material Fig. A3), which implies a high spatial quality; in addition, the study analyzes the last 40 years, which is why it has a temporal quality of 80% in Criterion A1. In the case of the criterion of historical reduction, since the potential distribution minus the anthropic covers is used, the spatial and temporal quality are 100%.

Other ecosystems have low spatial and temporal quality in the studies reviewed that make it possible to evaluate IUCN criteria. For example, interior Mediterranean thorn forest of *A. caven* and *Prosopis chilensis*, with a spatial quality of 48.5% and temporal quality of 40% (Vergara et al., 2013) and the interior Mediterranean sclerophyll forest of *L. caustica* and *P. boldus*, with a spatial quality of 12.1% (Olivera-Guerra et al., 2014).

4. Discussion

4.1. Potentialities of the method

Assessment of the sclerophyll ecosystems of the Chilean central zone reveals the applicability of the methodology for the development of RLE in each country. There is a considerable amount of information already published and methodologically validated, which can be adapted to the ecosystem assessment criteria stipulated by the IUCN (Rodríguez et al., 2015; Keith, 2015; Keith et al., 2013, 2015; Bland et al., 2016) using the present assessment protocol.

It is worth noting that assessment through this methodology must be undertaken individually, i.e., one ecosystem at a time. This is because each study will have results and conclusions relative to the study area; however, within the study area the representativeness of the different ecosystems will be highly variable. It is suggested that the study that best represents the ecosystem always be taken, as in the case of the interior Mediterranean psammophytic sclerophyll forest of *Q. saponaria* and *F. imbricata* (Supplementary material Fig. A4), which is represented as 87.6% in the study by Aguayo et al. (2009). Another advantage of working with already validated studies is that they have various goals, so not only a spatial quantification can be produced, but there are also references about which processes are involved in generating the risk, which pressures the study reveals and what effects on the ecosystem are occurring. Similarly, there are some studies focused on measuring change of use and cover, others on estimating biophysical variables like evapotranspiration, others on quantifying connectivity, and so forth.

The method is flexible and seeks to adapt to the local assessments of ecosystems in each country or region; however, it is necessary to justify correctly the selection of the studies that will be used to implement the protocol (Bland et al., 2016). Studies covering the ecosystem scale should be preferred because they allow a spatial compatibility to assess the processes that drive ecosystem functionality. One of the limitations of the method is that it is only applicable to those ecosystems where previous studies exist; but this method detects sites with information gaps, where it is necessary and urgent to direct research efforts. In the case presented, 15% of the ecosystems proposed for assessment did not have the sufficient amount of data to be able to develop the protocol, for which they had to be classified as DD. In turn, 30% of the ecosystems evaluated obtained a spatial and temporal quality less than 50%. This is a clear indicator of the need to improve the coverage of spatially explicit studies, with high levels of accuracy in their classifications that can make the most of the proposed protocol. These studies must also cover a considerable area of the ecosystem so they can contribute high levels of quality; this case study initially found 19 studies focused on the structural changes of the sclerophyll ecosystems in central Chile, yet only 14 of them were spatially explicit.

We did not find studies that applied criterion E (probability of collapse), likely because it requires a large amount of information (Keith et al., 2013); it has only recently been applied on the Coorong Lagoon in Australia (Collen et al., 2016).

4.2. Sources of uncertainty

The recognition of the range of spatial uncertainty is fundamental in the selection of the studies to use to implement the protocol laid out here, which is clearly stipulated in publications by Keith et al. (2013), Rodríguez et al. (2015) and Bland et al. (2016). The way to incorporate this uncertainty is by recognizing the representativeness of the studies of the ecosystems (Regan et al., 2002). Some studies have little spatial quality, and therefore producing assessments concerning the entire ecosystem is dangerous. With respect to the uncertainty or range of temporal effectiveness, Keith et al. (2013) established the assessments in a time window of 50 years (into the future, into the past or a window for any time) as a standardized protocol. The analyzed case studies show, however, that there are ecosystems that have reached sufficient ranges of loss to classify them as CR or EN. Therefore, working with time ranges of less than 50 years would not be a problem in the higher threat categories. In other cases there is a probable undervaluing of the real category, since many of the ecosystems that appear as VU in an assessment with time intervals less than 50 years, could in fact be in a higher threat category.

The main problem is that most of the studies do not cover 100% of the area of an ecosystem, as they were generally not undertaken with the aim of satisfying the methodology of IUCN Red Lists; they do, however, contribute valuable information to evaluate the degradation of the ecosystems. In this case, it was assumed that the maps from the publications did not contain errors, because they were validated in the publication process. Nevertheless, the processing of the image for georeferencing and supervised classification can have some errors, which is why it is recommended that the generated maps be meticulously reviewed, compared with those described in each publication, and corrected manually in the case of errors.

It must also be recognized that each study considered different parameters (see Supplementary material Table A1), and so it is recommended that the assessment be done ecosystem by ecosystem, since there are methodological differences in the construction of each cartography or classification of soil uses (e.g., satellites used, classification methodology, software used).

4.3. On ecosystem assessments

The subject of the assessment of ecosystems has been described by many studies on the topic of RLE (Keith, 2009; Keith et al., 2013; Keith, 2015); however, there is no overall assessment of ecosystems as each country or region has its own assessments (Keith, 2009). In the case of species, this subject is more resolved since under the taxonomic classification the objects of conservation, which are comparable or established at global level, can be determined directly (Noss, 1996; Keith et al., 2013).

In Chile there is also a great variability of classifications, which focus mainly on formations and vegetation belts, built with different methodologies and that have units with some spatial differences. In the present study we used the classification of vegetation belts proposed by Luebert and Pliscoff (2006), which is based on zonal vegetation communities. Considering what was proposed by Keith et al. (2013, 2015), the classifications must describe the characteristic native biota. Luebert and Pliscoff's (2006) classification is useful for this type of assessment since it details the plant communities and main ensembles of plant species associated with each vegetation belt, it describes the main dynamic of the belt in terms of anthropogenic functioning and impact, which makes it very complete. A deficiency in the assessment is that azonal ecosystems are not included, such as wetlands, peat bogs, vegetation determined by site conditions, bottoms of ravines, and others. This represents a significant information gap, since these ecosystems can be put under a great amount of pressure and are often quite vulnerable (Moller and Muñoz-Pedreros, 2014, RAMSAR, 2013; Murray et al., 2015).

4.4. On the situation of the ecosystems in the central Chilean hotspot

In the case of the ecosystems in central Chile, 47% of the 17 ecosystems evaluated showed high spatial quality, whereas 70.6% showed high temporal quality. If only the studies with high or medium spatial and temporal quality (>50%) are considered, eight of the 17 evaluated ecosystems, or 22.9% of the study area, are in threat categories (VU, EN, CR). The situation of the ecosystems in this zone is worrisome because their representativeness in the National System of Protected Areas in Chile is very low (Luebert and Pliscoff, 2006; Pliscoff and Fuentes-Castillo, 2011; Durán et al., 2013).

These ecosystems have, among others things, three great threat drivers: exotic plantations in the coastal zone, the expansion of the agricultural border in the central depression and the change to pasturelands and scrub in the mountain ecosystems for livestock farming. Examples of these changes are on the coastal Mediterranean thorn forest *A. caven* and *Maytenus boaria*, where the main cause of loss is the expansion of forestry plantations, as well as an increase in agricultural area (Schulz et al., 2010). This same study by Schulz et al. (2010) identifies that expansion of the agricultural border is the cause of losses in the coastal Mediterranean sclerophyll forest of *C. alba* y *P. boldus*. Finally, some ecosystems in the central zone *hotspot* have very limited distributions, as is the case of the coastal Mediterranean deciduous forest of *N. macrocarpa* and *Ribes punctatum*, which has been affected by the change of use and soil cover associated with the creation of pasturelands for livestock farming.

Other dynamics identified in Chile but which have barely been studied are the changes in abiotic or flow conditions in the ecosystem; Olivera-Guerra et al. (2014) determined that on average real evapotranspiration in summer periods in the interior Mediterranean sclerophyll forests of *L. caustica* and *P. boldus* is 7.745 mm day^{-1}, whereas for the other covers that have replaced this it is 5.190 mm day^{-1}, which represents a 33% reduction in the historical evapotranspiration of that ecosystem.

5. Conclusions

The methodology showed here shows that it is possible to evaluate the criteria proposed by the IUCN using information from existing scientific publications. The levels of spatial and temporal quality of the studies analyzed showed great variability, thereby reinforcing the notion that these concepts must be considered when ecosystems are classified according to their threat level.

We recommend that studies be conducted with an approach and methodology that evaluate the threat level. To do this, it is necessary to use a spatially explicit approach and define the study area based on the extension of the ecosystem(s) to be examined. In order to maximize the temporal quality, it is recommended that the oldest satellite images available are used. In the case of Chile, we recommend placing the emphasis on those ecosystems that have been classified here in a threat category.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.biocon.2016.10.038.

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