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# Identifying Santiago's Natural Elements for Implementing an Ecological Planning Perspective. Have They Been Considered so far?

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**Abstract.** Santiago, the capital and biggest city of Chile, has experienced a rapid urban growth during the last decades. This has included a large increase in population, proliferation of suburbs, and the loss and degradation of thousands of hectares of natural and semi-natural areas, whose natural elements may play a key role for the city's sustainability. Taking into consideration the relevance of these natural elements for Santiago's future planning efforts, in this work we take an ecological planning approach, -where ecological and environmental considerations are set in the front, to identify Santiago's natural elements and assess how they are, and have been incorporated, in local and regional planning regulations. To achieve this goal, we first analyzed the city's geographical components using an ecological planning framework to identify the most relevant natural elements that could be considered worth to be included in planning regulations at the local and regional scales. The framework promotes the conservation and connectivity of natural, agricultural, peri-urban, and urban landscapes at the regional and local scale. Then, we analyzed past and present planning instruments to evaluate how they have incorporated the identified natural elements, and how these regulations (or the lack of them) may have driven the regional and local landscapes at its current state. Our results show that the identified natural elements have been rarely formally recognized in planning instruments, and therefore not taken in consideration for urban planning. Consequently, most of natural elements that are identified as relevant for ecological planning in Santiago are currently degraded. Nevertheless, these natural elements still provide valuable opportunities for increasing Santiago's sustainability if restored and conserved, and if they are better incorporated in planning regulations. The few regulations recognizing the natural elements do not indicate how to protect or conserve them, nor how they should be managed to provide benefits to the city. We conclude that in Santiago is imperative to modify current planning regulations, to effectively safeguard the conservation of these key natural elements, and to promote a better interconnection among natural, agricultural, peri-urban and urban landscapes at multiple scales.



## 1. Introduction

An ecological planning approach can be understood as the use of biophysical and sociocultural information to suggest opportunities and constraints for decision making about the use of the landscape. It is primarily a procedure that can reveal where specific land uses may be best implemented [1]. The ecological planning approach is based on understanding the mutual interactions between human activities and the natural environment, the value of natural processes, and the effects of these interactions on the structure of landscapes and ecosystems [2,3,4]. Nevertheless, ecological planning is defined in different ways depending on the discipline and on the scale or level at which the concept is applied. These definitions often rely on landscape ecology, regional planning, urban planning, and/or systemic-oriented perspectives. Thus, ecological planning is an integrative, transdisciplinary and holistic process [4], aimed to coordinate planning based on ecological principles and theories. It is applied in a comprehensive way at a large scale [5], constituting the environmental contribution to regional and urban planning [6]. It helps determining the capacities and limitations of natural resources available on a given region, provides general guidelines to evaluate the environmental impacts of planning initiatives, and acts as the basis for all planning decisions, ensuring harmony between development and quality of life at multiple scales [3,6].

In this study we use an ecological planning conceptual framework, based on identifying key natural elements at multiple scales, to evaluate if and how these elements have been integrated in the rapid urbanization process experienced by the metropolitan areas of Santiago (Chile) since the 90's. Particularly, we aim to: (1) Identify the most relevant natural elements and natural boundaries of this metropolitan region from the macroregional to the intra-urban scale. (2) Assess current spatial planning instruments to determine the extent at which they incorporate the natural elements and boundaries in their strategies. (3) Evaluate what have been the impacts of current planning instruments on the conservation of major natural elements identified as relevant for an ecological planning of Santiago.

## 2. Methodology

### 2.1. Area of Study

Chile is among the most urbanized countries in the world, with almost 90% of its population living in urban areas [7]. The capital city of Santiago (33°26'S; 70°39'W), is by far the largest city of the country, harbouring around 6.5 million people, and representing more than 40% of the total Chilean urban population [8,9]. Santiago has experienced a large urbanization growth during the last three decades, which has included an exponential population increase and the expansion of the city into natural and rural areas of high environmental value [8]. Unfortunately, this rapid urbanization process has not been coupled with urban planning policies considering the fundamental role that natural and agricultural areas play for urban sustainability [9]. This has resulted in the loss and degradation of ecosystem services, which has reduced Santiago's environmental quality, and is severely threatening the capacity of the city to cope with the new challenges imposed by climate change.

### 2.2. Identification of natural elements through an ecological planning conceptual framework

Our conceptual framework is based on the identification of key natural elements that shape and compose the landscape at different scales, and on how these elements interact to promote the conservation and connectivity of natural, agricultural, peri-urban, and urban landscapes at multiple scales. We defined three spatial scales of interest: macroregional, regional, and urban. To identify these natural elements at the different scales we analysed a set of spatial layers, including geomorphology, land cover, hydrology, road network, and administrative boundaries.

### *2.3. Analysis of natural elements of Santiago in planning instruments*

We analyzed two main urban planning instruments that guide the urbanization process in Santiago. The first is the “Metropolitan Plan of Santiago” (PRMS for its acronym in Spanish), which is the main urban planning instrument for the entire metropolitan area. The second is the Metropolitan System of Green Spaces and Recreation (MSGSR), which is based on a metropolitan public policy to guide the implementation of public green spaces at the metropolitan scale. While the second does not regulate the urbanization process itself, it does provide a spatial layer on the typologies and areas that are defined as green spaces by the Metropolitan Government.

### *2.4. Analysis of the impact of planning instrument on natural elements of Santiago*

We categorized the land-uses types of the main metropolitan planning instrument of Santiago (i.e. PRMS) into three land-uses: (1) natural landscape conservation areas, (2) natural risk and recovery areas that facilitate the conservation of natural landscapes, and (3) productive areas. This land-use scheme was compared to the current extension of natural elements of Santiago (land cover data available from [9]) to evaluate if current planning instruments have been able to protect natural elements considered of high relevance.

## **3. Results and discussions**

### *3.1. Natural elements and boundaries of Santiago at different scales*

*3.1.1 Macroregional Scale.* Santiago faces the Coastal Mountain Range at its western edge and the Andes Mountain Range at its eastern edge, with altitudes up to 2,000 and 6,960 respectively, and an average width of 100 km. Both ranges enabled the formation of a fertile central valley produced by high fluvial, alluvial, fluvial-glacial, and glacial deposit accumulation coming from the erosion of the mountain relief that took place during the quaternary [10]. The Coastal range, the Andes mountains and the central valley conforms key topographic elements that generate a complex and heterogenous landscape that varies from north to south (Figure 1, Table 1). Towards the northern areas, both ranges build up latitudinal chains of mountains that produce the so-called “transverse valleys”, -i.e. narrow valleys crossed by one main water stream-, characterized by steep slopes facing either northern or southern sun exposure (Figure 1). Towards the south, both ranges meet in specific intersection points, forming enclosed flat valleys of larger surfaces. These valleys are defined by one main river that runs in an east-west direction. These are crystalline rivers originated in the Andes Mountains, but the steep descend to the valleys generates turbulences, therefore transferring important amounts of sediments downwards. When meeting the plain these rivers meander softly through the valley and cross the Coastal Mountains to deliver their waters into the Pacific Ocean, closing the watershed system (Figure 1). These sediment-originated plains exhibit soft slopes and a few isolated peaks locally known as Island Hills.

At a macroregional scale, boundaries are given by major watersheds or large valleys (Figure 1). Three watershed composed this level, being the Maipo Valley, named after the Maipo River, the main macroregional boundary of Santiago. This river originates in the Andes Mountains and limits with the current southern edge of the city. It gets fed by the Mapocho River, another important river that originates in the Andes. After the meeting point of these two streams, the Maipo River continues its way to the Pacific Ocean. Due to its large volume, waters of the Maipo river were canalized to irrigate agriculture lands located in the northern periphery of the old city. Currently, those canals still irrigate some remaining crops located in the northern part of the valley.

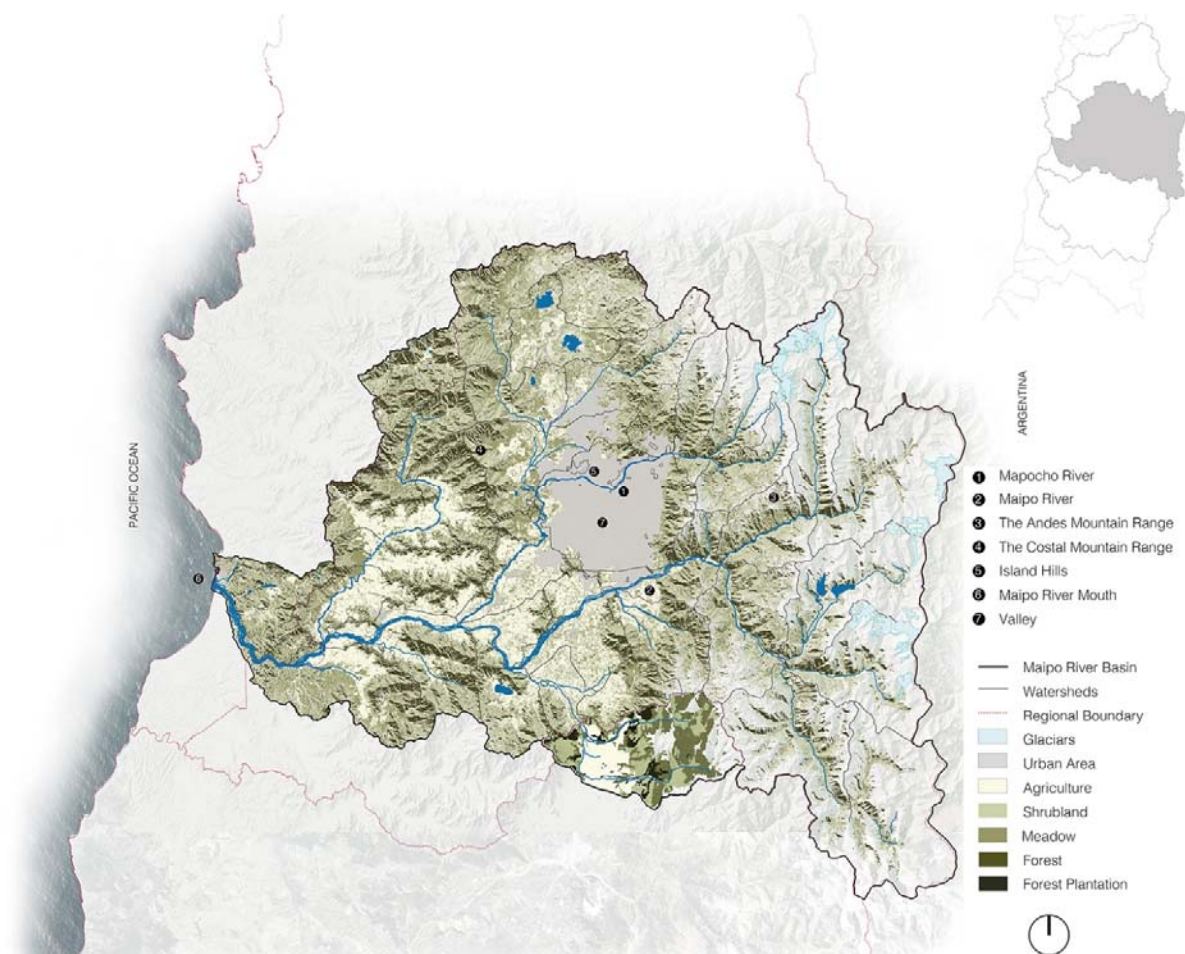


**Figure 1.** Natural elements and boundaries of Santiago at the macro regional scale

**3.1.2 Regional Scale.** At this scale, the rivers that cross the valley are essential elements of the landscape, constituting natural corridors between the mountain ranges and the ocean, but also between the mountain ranges themselves (Figure 2, Table 1). Several solids, air masses, and organisms flow through these rivers. With high precipitations, the rivers performance is altered, by carrying a large volume of water and sediments. Most of water streams within the urban limits have been canalized and/or walled, modifying their original dynamic configuration. This impede them to naturally flood the plains in the event of large rain events. Consequently, in Santiago, the regional scale is defined by the Maipo River's watershed. Within this watershed is possible to identify the presence of natural (i.e. forests, shrublands, grasslands) and cultural (i.e. urban areas, agricultural fields) ecosystems.

**3.1.3 Urban Scale.** The urban scale comprises a continuous, including the urban fabric, and the natural and cultural ecosystems in close contact with it, such as natural and agricultural lands (Figure 3). Therefore, at the urban scale, boundaries could be defined by the group of micro-watersheds that conform the major

watershed of the Maipo river. Dissecting the Maipo River watershed into a set of urbanized micro-watersheds allows to distinguish several landscape singularities, such as differences between the structure and composition of the prevailing flora found in natural ecosystems, and the detection of degraded areas within them. Within natural landscapes it is possible to distinguish between a diversity of vegetated-based natural elements, including sclerophyll, xerophyte and thorny shrublands; sclerophyll and deciduous forests; and grasslands. Within cultural landscapes, natural elements are represented by croplands, forest plantations, and vegetated and impervious urban soils (Table 1, Figure 3).

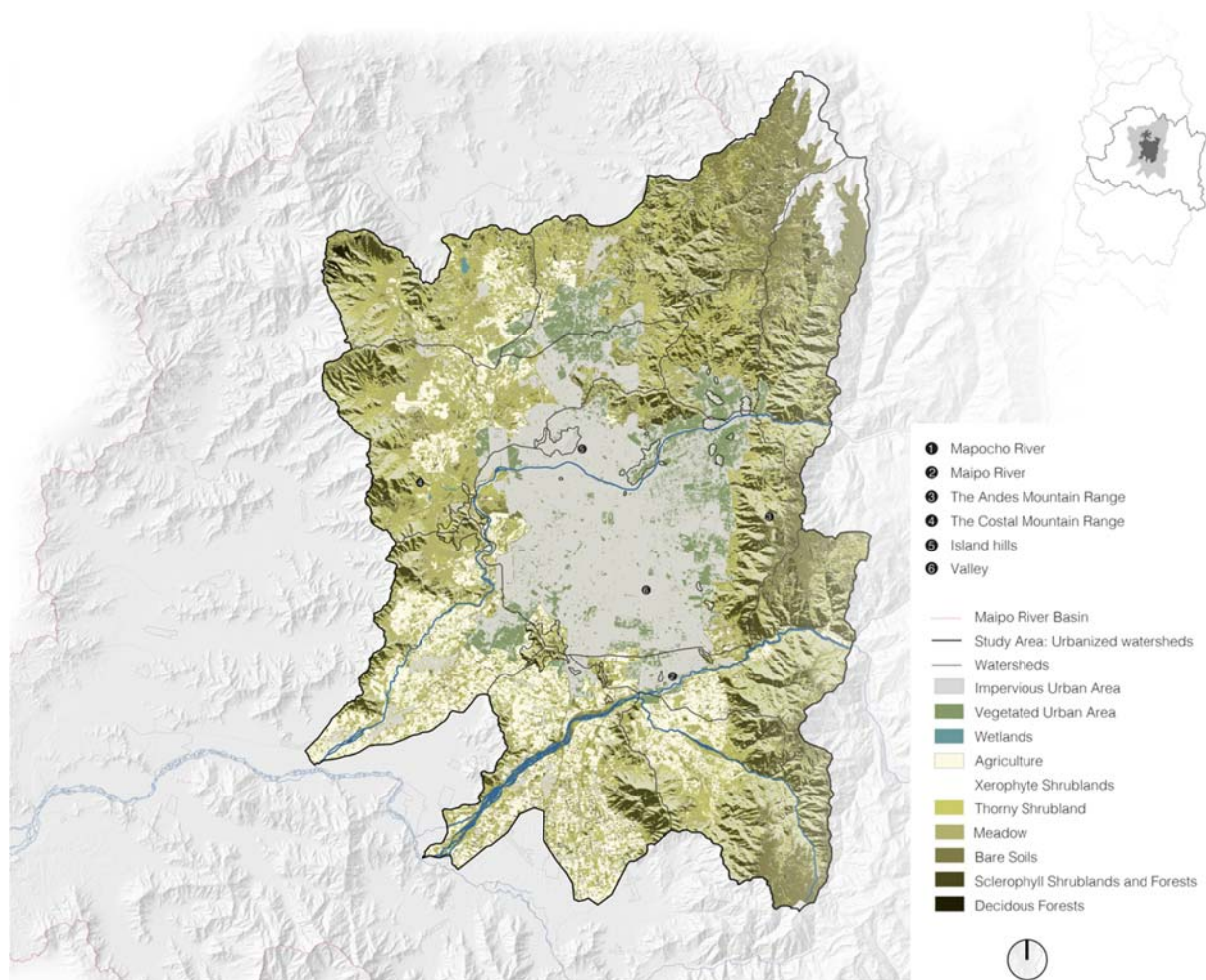


**Figure 2.** Natural elements and boundaries of Santiago at a regional scale



**Table 1.** Main natural and cultural elements of Santiago to consider in an ecological planning at the three spatial scales analyzed in this work.

Macro-Regional scale	Regional Scale	Urban Scale
Coastal Range	Natural ecosystems: forests, shrublands, grasslands	Sclerophyll shrublands and forests
The Andes		Deciduous forests
Valley (including island hills)	Cultural ecosystems: urban areas, agricultural fields	Xerophyte shrublands
Rivers		Thorny shrublands
		Grasslands
		Sealed urban soils
		Vegetated urban soils
		Croplands
		Forestry plantations



**Figure 3.** Natural elements and boundaries of Santiago at an urban scale

### 3.2. *Assessment of identified natural elements in Santiago's urban planning regulation*

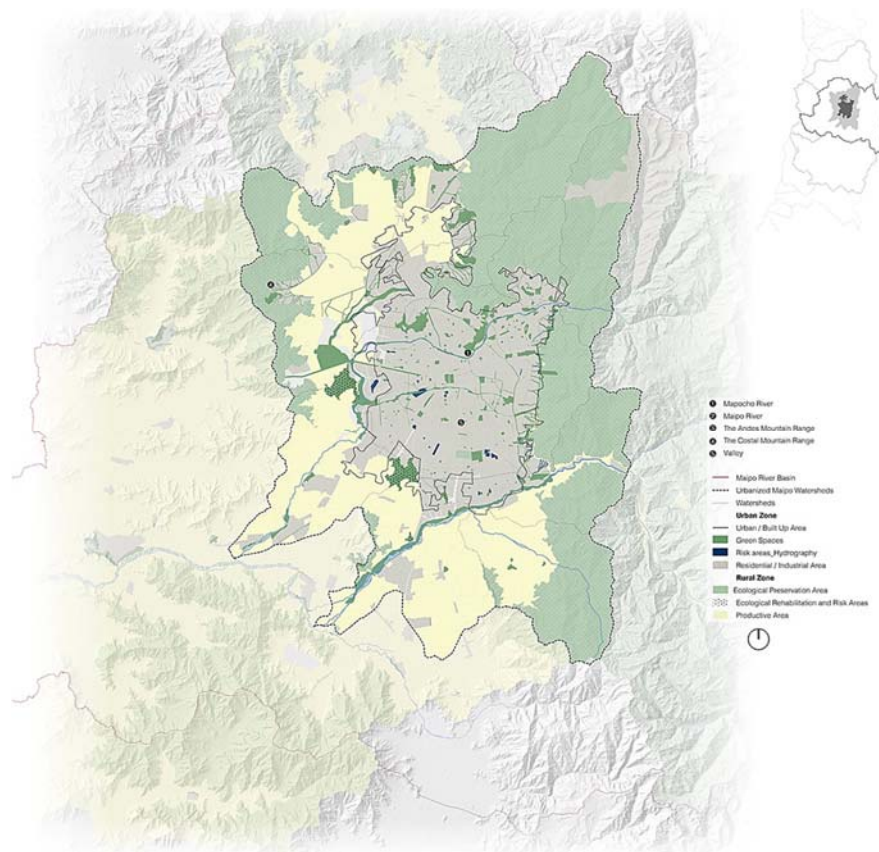
The main land-use planning instrument of Santiago is the “1994 Plan Regulador Metropolitano de Santiago (PRMS)”, which defines zoning regulations that either allow or prohibit activities to be developed on different areas. This instrument guides the urbanization process in Santiago as local (municipal) plans need to follow these zoning regulations in their design processes. The main objective of the PRMS was to “improve the relationship between the city and its surroundings, protecting the environment and natural resources of the intercommunal system to ensure better conditions of habitability, rationally and conveniently targeting urban growth to preserve the natural heritage”. The most relevant ecological criteria in this instrument are related to two main aspects: 1) a zoning that protects natural ecosystems (including biodiversity and landscape heritage) and agricultural fields outside the urban boundary, and 2) a zoning of green spaces within the developable land or the urban area.

In this regard, we highlight the division that this plan establishes between urban areas (urban or developable areas) and areas restricted to urban development (rural or non-developable areas). Urban areas include the so-called Metropolitan System of Green Spaces and Recreation (MSGSR) and risk areas (related to hydrological corridors and a residential/industrial area). While areas restricted to urban development are represented by areas of ecological preservation, ecological rehabilitation, and risk (rivers and creeks, mainly), and agriculture productive areas. The PRMS definition of the MSGSR integrates and associates metropolitan parks to mountain ranges, rivers, linear parks, and new rehabilitation areas. However, the two main aforementioned zoning categories are the only components of the PRMS directly recognizing the presence of natural elements within and beyond the urban limit. Furthermore, while this instrument defines major zoning areas, it does not make any difference for the urban-rural intersection, approaching this boundary as a sharp artificial limit.

*3.2.1 Urban planning instruments: natural elements at the macroregional-to-regional scale.* The PRMS and their several amendments establish land uses inside and outside the urban boundary. Outside the urban boundary, restricted and excluded areas (rural areas) could be grouped under three different categories: 1) “Natural landscape conservation areas”, which include areas for the conservation of wetlands, areas destined to ecological preservation and areas where the priority is given to natural preservation. 2) areas excluded from any productive activity due to their natural risk of natural disasters or because they were defined as restauration areas. 3) areas intended for productive uses, like agroindustry, intensive agricultural activity, forestry, and controlled real estate development. (Figure 4).

At the other hand, the zoning and regulations applied to urban areas in the PRMS are much richer in terms of the diversity of uses, but there are no specifications regarding the natural elements these areas should contain. For example, the PRMS has no zoning types for the conservation of natural landscapes within areas classified as urban. In this regard, except for the explicit recognition of urban, rural and natural ecosystems the PRMS does not consider the variety of natural elements we identified as relevant at the macroregional and regional scales.





**Figure 4.** Simplified map of the current urban and rural zoning according to the Metropolitan Region Planning Regulations.

*3.2.2 Urban planning instruments: natural elements at the regional-to-local scale.* We analyzed the planning instruments at these scales by evaluating the Metropolitan System of Green Spaces and Recreation (MSGSR), as this is the only instrument that considers natural elements at metropolitan and local scales. The four main green spaces typologies described in this plan are: 1) urban parks; 2) green spaces related to mobility; 3) green spaces related to water streams; and 4) vegetated urban facilities. A set of metropolitan and inter-municipal parks are included in the plan. Nevertheless, most of the parks included in this instrument have been planned as small parks or public squares. A notable exception is the Metropolitan Park of Santiago, the second largest park in Latin America (750 ha approximately), located on an Andean intromission in the valley of Santiago. While the MSGSR includes several large parks within the urban area, the large number of them have not been implemented yet. This includes a set of several “island hills” (more than 4500 ha) that if restored could largely increase the provision of green spaces of the city.

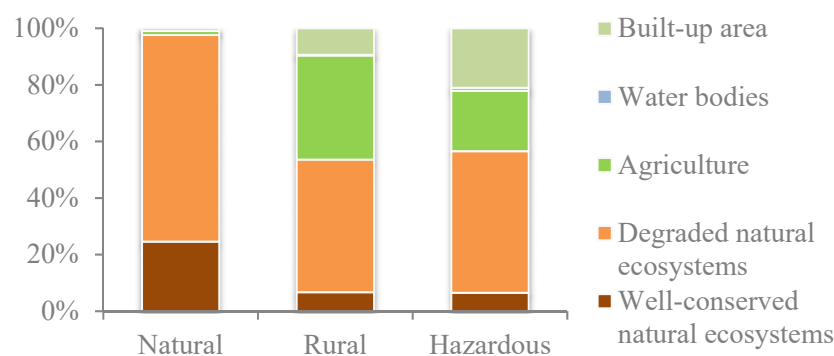
Although the current MSGSR instrument makes possible to imagine a network of interconnected green spaces (Figure 4), going from a local network of small parks to a system of regional parks able to connect the Andes with the Coastal Range, this planning instrument has not been designed for that, and therefore the potential linkages between green spaces are largely missing. This is highly contradictory with ecological planning criteria in terms of a regional scale perspective and the pursuit of interaction between urban and natural ecosystems. Furthermore, the MSGSR does not consider the variety of native ecosystems types

representative from Santiago, nor the potential relevance of particular areas for helping conserving biodiversity. In this sense, this instrument appears to be conceived under a static ecological view without taking in consideration the importance of ecological flows to sustain the biological processes within the different green areas. Nevertheless, the presence of green spaces related to mobility and green spaces related to water streams could provide the basic structures to generate an ecological connectivity between local natural elements, and between these and the natural areas beyond the urban boundary.

### 3.3. Assessment of the impact of planning regulation on natural elements current status

**3.3.1 Regional scale.** Natural landscape conservation areas are effectively mostly covered by natural ecosystems in rural areas, so they have been currently excluded from residential and productive uses (Figure 5). Based on current land cover, these areas are strongly dominated by natural ecosystems (97.7%). However, most of them can be regarded as degraded natural ecosystems. Only 36.8% of the areas planned to be productive areas are currently covered by agricultural lands. This is a low percentage and shows that they are not been used for their planned purpose. In addition, most of the areas without crops are degraded ecosystems (Figure 5).

Natural risk and recovery land-use types areas are facilitating the conservation of natural landscapes. In fact, more than half of the natural risk and recovery areas (57.5%) are effectively contributing to the conservation of natural landscape, but most of these landscapes are composed by degraded natural ecosystems. However, this typology of zoning is destined to avoid urban (built-up) and agricultural development in areas where there are natural risk and there is an intention to help in their recovery. Nevertheless, 20% of these zones are occupied by built-up areas and agricultural lands, meaning that this recovery goal is far from being accomplished (Figure 5).



**Figure 5.** Share of current land cover by zoning according the planning regulations

**3.3.2 Urban scale.** An evaluation of the current land cover in areas designed as green spaces by the MSGSR show that only a small part of them have been consolidated as urban green spaces (12.5%), or effectively serves for conserving peri-urban remnants of well-conserved native vegetation (19.2%) (Table 2). A significant part of green spaces is currently covered by degraded natural ecosystems (49.7%) and land uses that avoid the establishment of vegetation, like rivers, unvegetated built-up areas, and bare soils (17.5%).

**Table 2.** Current land cover in areas designed as green spaces according the planning regulations.

Green spaces (GS)	Area [ha]	Share of MSGSR
Planned at urban scale (MSGSR)	20,502.3	100%
Actually consolidated as urban GS	3,384.0	16.5%
GS covered by well-conserved natural ecosystems (mature shrublands and forests) or urban vegetation	3,944.9	19.2%
GS covered by degraded natural ecosystems (grasslands and primary shrublands)	20,498.0	49.7%
GS covered by agriculture	1,249.6	6.1%
GS without vegetation cover (inland waterbodies, sealed urban soils and bare soils)	3,595.1	17.5%

#### 4. Conclusions

A proper characterization of Santiago's natural elements can be done by conceiving of the city's watersheds as natural boundaries, instead of paying attention to the administrative frontiers set by successive planning instruments. In this regard, the main rivers of Chilean central valleys are to be considered key elements for the natural delimitations that they provide. Seemingly, an urban scale analysis should not only consider the built-up area, but also consider the natural ecosystems and agricultural lands located in the peri-urban areas functionally connected to the city. This work proposed an urban scale boundary defined by the entire watershed hosting the river that is most connected to the urban fabric of Santiago. Consequently, the identification of the natural elements that should be included in the ecological planning of the city would require a multiscale approach.

After identifying and analysing Santiago's natural elements and their incorporation in the city's current regulatory plan (PRMS), we can conclude that natural elements are not formally recognized and that they are mostly excluded from development due to their topographical unsuitability for this purpose. Despite this exclusion—condition that could be thought as an opportunity for their preservation—this zoning does not indicate how to protect or preserve them, nor how to enhance the benefits that they can provide to citizens. Even though natural mountain areas are legally protected, they still are vulnerable to erosion, climate change, anthropic actions, and many other changes all quite hard, or even impossible, to revert. Given that most natural elements in Santiago, except the valley plain, have not been strongly modified so far, there is still an opportunity to integrate them into planning and development, and hence, to take advantage of their benefits.

In this sense, a preliminary proposal consists on integrating natural elements to planning instruments by incorporating urban-natural and urban-rural-natural gradients. Such gradients could diminish the strictness of the current urban boundary and therefore favour the interaction between human activities and the natural environment. By planning and designing these gradients, natural elements could be incorporated to the urban area which could still be protected from pervasive uses, generating a more symbiotic relation between cities and natural elements.

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