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INTEGRACIÓN DE SERVICIOS ECOSISTÉMICOS HÍDRICOS EN LA PLANIFICACIÓN DEL PAISAJE: ANALISIS CIENCIOMÉTRICO Y CASO DE ESTUDIO EN LA ZONA CENTRO-SUR DE CHILE PARA LA PRIORIZACIÓN DE ÁREAS PROTEGIDAS.

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RESUMEN GENERAL

Los servicios ecosistémicos hídricos (WES) hacen referencia a los diferentes beneficios que el ser humano obtiene de los procesos hidrológicos que ocurren en los ecosistemas. Actualmente, la capacidad de provisión de servicios hídricos es vulnerable a diferentes amenazas como el cambio climático y el cambio de uso de suelo, generando incertidumbre en el bienestar a largo plazo de las personas que dependen de estos servicios. Debido a ello, este grupo de servicios ha ganado relevancia dentro de las discusiones sobre sustentabilidad tanto por tomadores de decisiones como investigadores.

La planificación del paisaje examina los diferentes usos que se pueden encontrar un paisaje determinado y sugiere medidas que garanticen la multifuncionalidad del territorio, siendo un proceso fundamental para la sustentabilidad del paisaje. Existen múltiples estudios sobre el vinculo entre planificación del paisaje y servicios ecosistémicos, sin embargo, el rol específico de los WES en la planificación territorial ha sido menos explorado en la literatura científica.

La presente investigación tiene como objetivo mejorar el grado de conocimiento teórico y práctico respecto a WES y la planificación del paisaje. Para esto en el primer capitulo se presenta un análisis cienciométrico donde se identifican las principales tendencias de este campo de investigación, investigación sobre las consecuencias del cambio de uso de suelo en la provisión de servicios, evaluación económica de servicios e investigación centrada en áreas urbanas.

Mientras que en el capítulo II se realiza un ejercicio de priorización espacial como insumo para la planificación del paisaje utilizando como objeto de conservación tres WES: suministro de agua, calidad de agua y regulación hídrica. Se evaluó el desempeño de las áreas protegidas de la zona centro-sur de Chile en la protección de áreas prioritarias de provisión de WES y se

determinó que la protección de áreas prioritarias es baja para todas las regiones.

Este trabajo aporta antecedentes fundamentales para comprender de mejor manera la relación entre WES y planificación del paisaje, y contribuye con información utilizable en procesos de planificación de paisajes para la zona centro-sur de Chile.

INTRODUCCIÓN GENERAL

Los sistemas socio-ecológicos corresponden un modelo conceptual que se define como un sistema acoplado compuestos por las esferas social y ambiental, integrando las diversas interacciones que existen entre ambas (Opdam 2009). Ambas esferas influyen y moldean las acciones de la otra, el ambiente moldea la actividad humana y esta a la vez tiene repercusiones en las condiciones biofísicas del ambiente. El concepto de servicios ecosistémicos (ES) es ocupado como un componente nexo que une a ambas esferas dentro de estos sistemas conceptuales (Reyers et al 2013; Castillo-Eguskitza et al 2019).

Los ES corresponden a los beneficios que las personas obtienen de los procesos biofísicos que ocurren en el ambiente (MEA 2005). La biodiversidad realiza diferentes funciones en los diferentes niveles de jerarquía ecológicos, por lo que cumple un rol fundamental en la provisión de ES, ya sea como un regulador de los procesos ecológicos o en ciertas ocasiones como un servicio final (Mace et al 2013). Este concepto representa de forma explicita las formas en las que el bienestar humano se relaciona con el medio biofísico, también ilustra cómo la acción humana puede generar cambios en el ambiente que impactan su propio bienestar (Abson et al 2014).

Los ES son múltiples y ha medida que han sido estudiados han sido definidos y clasificados bajo diferentes criterios (MEA 2005, Fisher, CICES, etc). Dentro de los ES de mayor importancia para el bienestar humano se encuentran aquellos relacionados con la disponibilidad de agua en un sistema, Braumman (2007) define a este grupo como Servicios Ecosistémicos Hídricos (WES en inglés).

Existen múltiples ejemplos que demuestran el vínculo entre los recursos hídricos con el bienestar humano. El agua es fundamental para la producción de alimentos y su disponibilidad tiene fuertes repercusiones en el estado de nutrición de las personas (Young at el 2021). También se ha reportado que el acceso a cuerpos de agua tiene influencias en el bienestar físico, psicológico y emocional de las personas (Volker & Kristemann

2011). Por otro lado, la calidad del agua también es un factor que influye en el bienestar de las personas, sobre todo la calidad del agua para consumo directo, riego y sanitización (Li y Wu 2019). En general los WES se pueden agrupan a grandes rasgos en cinco grupos: suministro de agua desviada, suministro de agua in situ, mitigación de daños hídricos, cultural y de soporte (Braumman 2015).

La actividad antrópica ha modificado profundamente los ecosistemas, afectando el funcionamiento hidrológico y por ende el bienestar humano e integridad ecológica de los ecosistemas. El cambio de uso de suelo, por ejemplo, altera las características físicas de la superficie terrestre y por lo tanto termina comprometiendo la capacidad de un paisaje de proveer ES (Jin et al. 2015) existiendo evidencia tanto para WES de provisión (Rodríguez-Echeverry et al. 2018) regulación (Deng et al. 2015) y soporte (Dimitriou y Zacharias 2010).

Además del cambio de uso de suelo existen otras amenazas al flujo de WES, tales como la contaminación ambiental y desviación de cursos de agua, las cuales también alteran el funcionamiento óptimo del ciclo hidrológico y afectan el flujo de WES (Arroita et al 2015, Fantin-Cruz et al 2016). Por otro lado, el cambio climático supone cambios en los parámetros climáticos que influyen directamente en la disponibilidad de agua de un sistema (Konopala et al. 2020, Martinez-Retureta et al. 2021).

Actualmente, muchas zonas del mundo enfrentan algún tipo de crisis hidrológica, que abarcan desde la escasez de agua, el riesgo de inundaciones, la pérdida de aguas subterráneas, la degradación ecológica, los riesgos sanitarios y la contaminación del agua, entre otras~~.~~ (Srinivasan et al. 2012). Esto ha provocado un gran interés en integrar estos desafíos en procesos vinculados a la sustentabilidad (Orlove y Caton 2010). Muchos estados han suscrito compromisos e iniciativas globales vinculadas a la conservación y manejo de los ecosistemas de agua dulce, sus especies y los servicios que proveen (Harrison et al 2016). Algunos ejemplos son las metas AICHI (Metas 6. Gestión sostenible de recursos acuáticos y 14. Servicios de los ecosistemas) y los ODS.

Planificación del paisaje para la sustentabilidad de WES

La disponibilidad de agua está determinada a gran escala por dinámicas que se dan dentro de la esfera biofísica, mientras que el acceso y uso de este recurso se encuentran determinado por las dinámicas de la esfera social que operan a escalas mucho más finas (Madrid et al 2013). La ciencia de la sustentabilidad del paisaje señala que la escala de paisaje ha llegado a ser la más adecuada para tratar con estas problemáticas, puesto que el paisaje abarca mosaicos de ecosistemas que incluyen tanto la esfera social como biofísica (Forman 1995, Wu 2012, Fisher 2018).

Esta ciencia investiga cómo potenciar la capacidad que tienen los paisajes de proveer de ES con el fin de obtener paisajes multifuncionales, que logren satisfacer las necesidades humanas sin comprometer la capacidad de provisión futura (Wu, 2013). La sustentabilidad del paisaje reconoce la importancia que tiene el patrón espacial del paisaje en su capacidad de proveer servicios, y también, el rol que cumple la planificación y gobernanza del paisaje en determinar este patrón espacial (Wu, 2021).

La planificación del paisaje examina los usos de suelos actuales y se encarga de proponer un uso del paisaje de acuerdo con sus características y condiciones ambientales. Es un proceso que desarrolla límites y oportunidades para la organización de sistemas con un énfasis en el contexto espacial que posee el paisaje (Von Haaren 2002). La información sobre flujo de ES ayuda a nivel estratégico a tomar decisiones sobre usos sustentables de suelo (Posner et al 2016).

La planificación del paisaje debe resolver diferentes conflictos debido a los múltiples intereses de uso que pueden existir dentro de un paisaje (Trees et al 2006). La información sobre ES ayuda a la resolución de diferentes procesos de tomas de decisiones, ya sea a nivel conceptual, generando conciencia en actores involucrados o a nivel estratégico e instrumental, proveyendo de apoyo para planes y políticas (Mckenzie et al 2014).

En el caso de los WES tanto la composición como la configuración espacial del paisaje determinan los flujos y variaciones hidrológicas de una cuenca

(Liu et al 2020) por lo que la integración del ciclo hidrológico en la planificación del paisaje es fundamental para asegurar la funcionalidad ecológica de los ecosistemas (Pimentel et al 2021).

Complementar la información sobre ES con indicadores de biodiversidad permite generar una planificación del paisaje que se centre en mantener la integridad ecológica del ambiente (Pan et al. 2021). Esta información puede ser utilizada en procesos de planificación espacial estratégicos proveyendo de un marco de trabajo para la incorporación sistemática del funcionamiento ecológico en la planificación territorial (Wilkinson et al. 2013)

La planificación sistemática para la conservación de biodiversidad se ha apoyado en el concepto de ES para argumentar sobre la importancia de mantener en condiciones óptimas los ecosistemas. Existen diferentes estudios que demuestran que la planificación del paisaje debiera considerar la complementación de objetivos de conservación de la biodiversidad con la protección de servicios ecosistémicos hídricos (Geist y Hawkins, 2016). En (Bai et al. 2013) muestran que escenarios en donde se prioriza la protección de ecosistemas ribereños aumenta la provisión de servicios ecosistémicos beneficiando a la población que depende de la cuenca mientras se asegura la conservación de la biodiversidad presente.

Contexto en Chile

La distribución espacial de la disponibilidad de agua en Chile es extremadamente variable dada la diversidad latitudinal y altitudinal que tiene el país (Fernandez y Gironas, 2021). Específicamente la zona centro y centro sur de Chile (30°- 41°S), durante los últimos años ha registrado una reducción importante en los niveles de precipitación y consecuentemente en los caudales en ríos (Garreaud, et. al. 2020; DGA 2021).

Además de estas condiciones, la zona también ha pasado por grandes procesos de cambio de uso suelo en las últimas décadas, en gran parte sustitución de bosque nativo por plantaciones forestales con especies exóticas (Echeverría et al. 2006). Estos cambios afectan directamente la disponibilidad de agua como la calidad de esta misma (Alvarez-Garreton et al. 2019).

En cuanto a la investigación sobre temas vinculados al agua en Chile en gran parte se enfoca en el análisis de la política hídrica del país, específicamente el código de Aguas y en los mercados de agua (Cantillana 2020). También existe una alta relevancia en la investigación referida al extractivismo minero y de la industria forestal y a los conflictos socio-territoriales por el agua. La mayoría de los estudios se concentran en la zona norte del país (Cantillana 2020).

A nivel de estudio sobre ES en Chile la investigación no se distribuye homogéneamente a lo largo del país, existe una concentración de estudios en las regiones de Valparaíso, Metropolitana, Los Lagos y Magallanes y Aysén (De la Barrera et al. 2015). En cuanto a la escala espacial, estos estudios han sido emplazados a escala local y muy pocos de ellos abarcan escalas de paisaje y/o región. Además, los estudios se centran en servicios culturales asociados a actividades turísticas y la caracterización de servicios hídricos es escasa (De la Barrera et al. 2015).

Estudios que vinculen la protección de servicios ecosistémicos con el Sistema Nacional de Áreas Protegidas (SNASPE) son escasos en Chile. Durán et al. (2013) evalúan la representación de tres servicios ecosistémicos: productividad primaria, almacenamiento de carbón y producción agrícola a lo largo de toda la red SNASPE concluyendo que la representación de estos servicios es baja afectando su protección en el largo plazo. No existen estudios que evalúen la representación de WES en áreas protegidas en el país.

Debido a estos antecedentes es posible señalar que existe una necesidad de profundizar el entendimiento con respecto a WES dentro del país y la zona centro-sur supone un área de estudio relevante debido a las condiciones que amenazan la capacidad del ciclo hidrológico de proveer servicios a las poblaciones humanas.

La presente investigación tiene como objetivo aumentar el grado de conocimiento teórico y práctico respecto a la provisión de WES y la planificación del paisaje. Para ello en el primer capítulo de este trabajo se realizó un análisis cienciométrico que permite visualizar la estructura del campo científico de WES y planificación del paisaje, con el objetivo de identificar los principales tópicos de investigación y la evolución temporal del campo científico. En el segundo capítulo se presenta un estudio de caso de priorización espacial que aporta a la planificación del paisaje para la protección de WES, donde (1) se evaluó el desempeño actual de la red de áreas protegidas del SNASPE en la protección de WES y (2) se establecen sugerencias para mejorar este desempeño.

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CHAPTER I: A GLOBAL REVIEW OF TRENDS IN ECOSYSTEM WATER SERVICES RESEARCH APPLIED TO LANDSCAPE PLANNING.

Abstract:

Landscape planning is a key process to move towards sustainable landscapes and ensure the provision of a range of ecosystem services, despite the relevance of the hydrological cycle in determining the well-being of people and the ecological integrity of ecosystems, water ecosystem services (WES) are still little considered in landscape planning processes. The objective of this study is to characterize the existing scientific research on WES in the context of landscape planning. For this purpose, we conducted a scientometric analysis to visualize the structural configuration of this scientific field and identify research trends.

The scientific field on WES and landscape planning is still in early stage of development and three main research topics were identified: (1) land use change as the most studied field, (2) economic evaluation of services, and (3) urban areas as the most studied landscape.

1. INTRODUCTION

Human well-being is closely linked to access to natural resources and the maintenance of optimal environmental conditions (Summers, Smith, Case, & Linthurst, 2012). It is also highly dependent on the availability of water resources to which people have access (Mehta, 2014). The concept of Ecosystem Services (ES) is used to refer to the benefits that people obtain from the different ecological processes that take place in the environment (MEa, 2005). These services are mediated by the biophysical components of the environment and the ecological functions performed by biodiversity. The hydrological cycle is one of the biophysical processes that largely determine the capacity of ecosystems to provide ES (Carpenter, Stanley, & Vander Zanden, 2011).

There are four hydrological attributes that regulate the supply of ES linked to water: (i) the quantity of water available in the system, (ii) the quality of this water, (iii) the spatial location of water flow, and (iv) the temporal fluctuations of the hydrological regime (Brauman, Daily, Duarte, & Mooney, 2007). The services derived from these attributes are diverse, since the uses that people make of water resources are multiple. However, these water ecosystem services (WES) can be grouped into five categories: (i) abstraction water supply, (ii) on-site water supply, (iii) hydrological damage mitigation, (iv) cultural water services, and (v) supporting water services (Brauman, 2015)

Due to the intrinsic complexity of the hydrological system, water resources management presents multiple challenges that require a careful planning process in order to implement appropriate management actions that ensure the sustainable flow of WES (Christ & Burritt, 2017). The planning of human activities affecting freshwater ecosystems must take into account certain hydrological factors, such as surface water flows and their temporal and spatial variations (Loucks, van Beek, Loucks, & van Beek, 2017)

On the other hand, landscape planning is a process that plays a key role in achieving sustainable landscapes that ensure the provision of ES (Wu, 2021). This process assesses the sustainability of current land uses and proposes changes that are in line with the characteristics of the landscape and its environment (Von Haaren & Albert, 2011)

Scientific research addressing landscape planning and ES has increased in recent decades (Babí Almenar, Rugani, Geneletti, & Brewer, 2018). Currently, several studies are available that present methodological aspects for evaluation and implementation of management measures linking these concepts (Cetas & Yasué, 2017; De Groot, Alkemade, Braat, Hein, & Willemen, 2010). As well as research for specific groups of ES, such as cultural ecosystem services and landscape planning (Plieninger, Dijks, Oteros-Rozas, & Bieling, 2013)Regarding research under a specific focus on WES, there are literature reviews regarding its conceptualization, main characteristics, assessment methodologies, and research challenges (Brauman, 2015; Brauman et al., 2007). As well as articles that have evaluated WES flow fluctuations (Duku, Rathjens, Zwart, & Hein, 2015; Terrado, Acuña, Ennaanay, Tallis, & Sabater, 2014).

However, despite the growing number of scientific publications, the impact of research on actual landscape planning processes and decision making remains limited (Albert, Aronson, Fürst, & Opdam, 2014)as in many cases the implications of research are not taken into account by policy and decision makers (Mascarenhas, Ramos, Haase, & Santos, 2015).

In recent years, there has been a significant increase in research on WES globally (Aznar-Sánchez, Velasco-Muñoz, Belmonte-Ureña, & Manzano-Agugliaro, 2019). At the same time, there has been an increase in the relevance of water issues in policies and agreements that focus water resources as a fundamental component for global sustainable development (Adeel, 2017). Despite this, WES in general remain to be fully incorporated within landscape planning processes (Wang, Zhang, & Cui, 2021).

This works presents a scientometric analysis of the WES and landscape planning scientific field. This method was chosen for its effectiveness in visualizing systematic patterns within extensive bodies of scientific literature(Cobo, López-Herrera, Herrera-Viedma, & Herrera, 2011) and enables to establish connections among literature concepts that may not be noticed through traditional manual review studies (Chen, 2017). This work seeks to (1) identify the main topics of research with the greatest impact on the scientific knowledge regarding WES applied to landscape planning and (2) analyze the temporal evolution of the scientific field.

METHODOLOGY

2.1 Co-citation analysis.

We performed a co-citation analysis to conduct the scientometric review. A co-citation analysis is a process of tracking pairs of articles that have been cited together by the source articles. When articles are cited by many authors, they can be grouped into thematic research clusters that reveal research trends within a specific knowledge domain (Suwase et al 2011).

This type of analysis can be represented as a knowledge network of interconnected nodes grouped in thematic groups "clusters". The nodes are the published articles while the lines connecting them represent the co-citations between articles. There are two types of references: *References that cite* and *References cited*, the first group correspond to the articles obtained from the bibliographic search. These works cite the nodes that make up the network and can be referred to as a *research front*. On the other hand, the references cited are the articles cited by the research front and are the nodes of the network, they constitute the intellectual basis of the discipline studied (Chicago, Echeverria, & Pizarro, 2022).

Nodes are grouped into knowledge clusters that can be visualized as polygons formed within the knowledge network. The ability to separate into multiple thematic clusters with a high level of differentiation implies greater scientific maturity.

Citespace is a software that allows the visualization of data through a bibliometric analysis. This tool was designed to study the structure and development of a scientific discipline and to establish research trends (Chen, 2014).

2.2 Bibliographic base

The bibliographic base was constructed based on the concepts of water ecosystem services and landscape planning using the following syntax: TS=("Ecosystem* Service*" OR "Environmental Service*") AND TS=(Landscape) AND TS=(Plann*) AND TS=(hydro* OR hydric* OR "water"). The search portal used was Web of Science

The search was limited only to articles written in English and published between 2005 and 2022. This time frame was defined by the publication of the Millennium Ecosystem Assessment in 2005 as the starting point, due to the boom in ES research it brought about (Deeksha & Shukla, 2022).

2.3 Metrics

There are metrics that allow characterizing the knowledge network, the clusters and the articles that compose them. The metrics used were:

- Modularity Q: Coefficient with values from 0 to 1 that indicates the capacity of the network to decompose into independent clusters. Values closer to 1 correspond to a network whose clusters have well defined boundaries.
- Mean silhouette S: Coefficient used to estimate the uncertainty of the thematic separation of the set of clusters. Values range from -1 to 1, higher values indicate that clusters have well defined thematic axis.
- Silhouette s: Coefficient used to estimate the uncertainty of the thematic separation of an individual cluster. Values range from -1 to 1, higher values indicate that a cluster has a well-defined thematic axis.
- Centrality c: A coefficient assigned to each item that indicates how connected the nodes are. Items with a high centrality value are known as pivotal and are able to connect different clusters to each other.

2.4 Stages of analysis

The bibliometric analysis was divided into three stages:

i. Analysis of the structure of the knowledge network:

In this stage, the shape of the resulting network is analyzed to visualize the maturity of the research field studied. The more elongated the shape of a network, the greater the scientific maturity (Chen, 2017).

Modularity (Q) and mean silhouette (S) metrics are also analyzed to describe the structural characteristics of the whole network. And articles with higher centrality are identified to understand how clusters are connected to each other.

ii. Cluster analysis

In this stage, the largest clusters of the network are analyzed to define their thematic axis. For this purpose, the articles with the highest frequency of co-citation within the cluster are reviewed.

iii. Time evolution analysis

Finally, using temporal mapping tools, the activity of each cluster between 2005 and 2022 can be viewed. This tool makes it possible to determine whether a research line remains active or not, as well as to characterize the temporal evolution of the scientific area studied.

The articles with the highest burst were also identified within this stage. Burst metric indicates when an article is highly cited in a short amount of time, these bursts can signal instances of heightened attention and pinpointing influential contributions within a specific field.

3. RESULTS

3.1 Knowledge network structure

The database, "Water Ecosystem Services and Landscape Planning", consists of 605 articles with 2091 references cited between 2005 and 2022. The co-citation analysis resulted in a knowledge network (figure 1) composed of 767 nodes, of which 455 (59%) are part of the main network. Its modularity value (Q) is 0.7579 and its mean silhouette value (S) is 0.8714, indicating that there are many clusters with well-differentiated topics

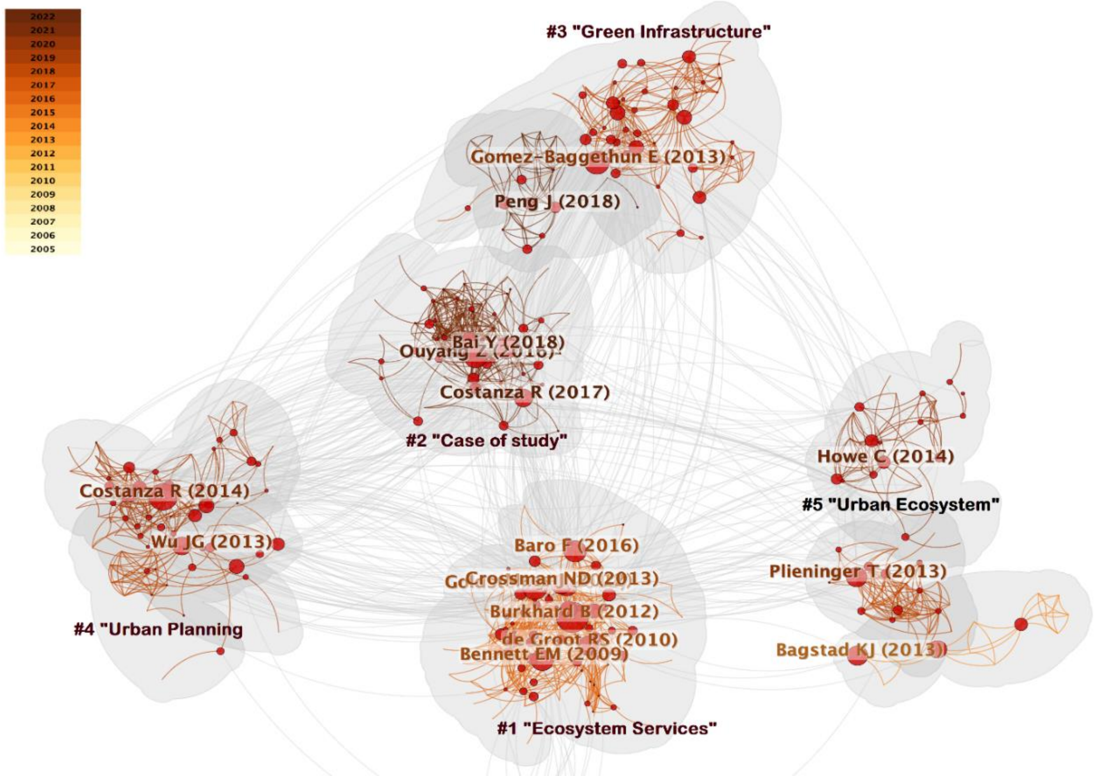


Figura 1. Knowledge Network formed with the concepts of Water Ecosystem Services and Landscape Planning.

Visually (Figure 1) this network is small, and its clusters are scattered and separated from each other, forming a network with an elongated shape. The centrality index (Table 1) is generally low within the network and no article exceeds 0.1. The article with the highest centrality index corresponds to Burkhard 2012 (0.09).

Tabla 1. Top 5 articles with the highest centrality

Author	Year	Title	Centrality

Burkhard et al.	2012	Mapping ecosystem service supply, demand and budgets	0.09
Constanza et al	2014	Changes in the global value of ecosystem services	0.07
Bai et al	2018	Developing China’s Ecological Redline Policy using ecosystem services assessments for land use planning	0.05
Ouyang et al	2016	Improvements in ecosystem services from investments in natural capital	0.05
Bennett et al	2009	Understanding relationships among multiple ecosystem services	0.05

3.2 Cluster analysis:

The main knowledge network (Figure 1) is composed of several thematic clusters. We analyzed the five biggest cluster to identify research trends within the scientific field.

Cluster #1 "Ecosystem Service" contains a total of 107 cited articles and is the largest in the network, representing 13.95% of the total number of nodes. Its silhouette value is 0.856. The articles contained mostly deal with the applicability of the ES concept in spatial planning instruments. The articles with the highest citation within the cluster correspond to (i) De Groot 2010, review on the challenges of integrating ES in planning processes, establishing that there is still no coherent and integrated approach for the practical applicability of the concept of ES neither in landscape planning processes nor in decision making and management strategies. (ii) Burkhard 2012, where a matrix is presented as a method for mapping ES. This matrix estimates the capacity of different land covers and land uses to provide different services, evaluated with values from 1 to 5 assigned by experts. Finally, (iii) Nelson 2009, performs a spatially explicit analysis of trade-offs between ES, biodiversity conservation and commodity production, to support decision making.

Cluster #2 "Case of study" contains a total of 74 cited articles and represents 9.65% of the total nodes in the network. Its silhouette value is 0.816. The articles focus on evaluating the role of landscape pattern and its changes in the provision of ES. The articles with the highest citation correspond to (i) Constanza 2017, Conducts a review on the evolution in ES research and points out the need for further research on economic evaluation of ES. (ii) Ouyang 2016, which evaluates the provision of ES and results of China's "Natural Forest Conservation Forest" policy, which seeks to increase the capacity of ecosystems to provide ES. Finally, (iii) Song 2017 which evaluates the effects of land use change on the value of ES.

Cluster #3 "Green Infrastructure" contains a total of 64 cited articles representing 8.34% of the total number of nodes in the network. Its silhouette value is 0.861. The articles contained within this cluster focus on urban areas and the ES that can be found within them. The articles with the highest number of citations correspond to (i) Gomez-Baggetthun 2013, where an analysis of urban ES is carried out, concluding that good urban planning that enhances the capacity of cities to provide ES is fundamental to mitigate the ecological footprint produced by urban areas. (ii) Wolch 2014, an article that focuses on access to urban green areas and their relationship with environmental justice and public health. Finally, (iii) Fletcher 2015, conducts research on urban water management focusing on the different terminology used for urban drainage.

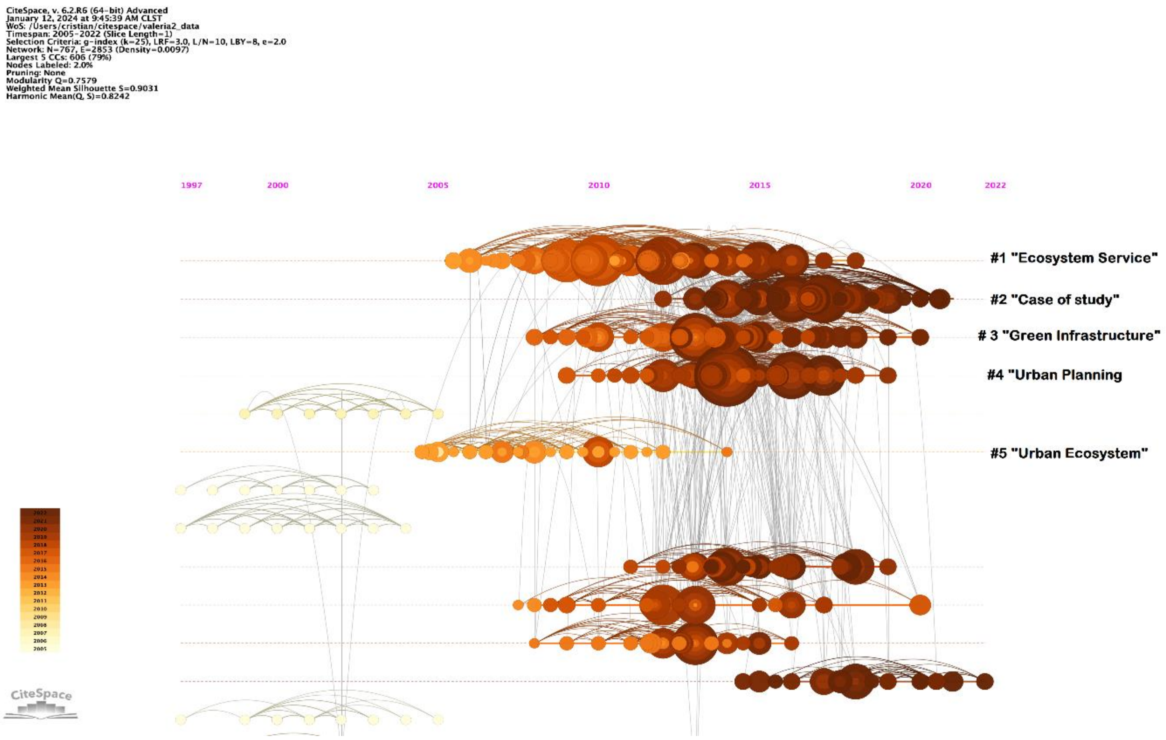
Cluster #4 “Urban planning” contains a total of 56 items representing 7.3% of the total nodes in the network. Its silhouette value is 0.799. The articles focus on the economic evaluation of HE loss. The articles with the highest citation correspond to (i) Constanza 2014, where a monetary evaluation of ES is made at a global level considering land use changes that have occurred from 1997 to 2011. (ii) Kindu 2016 makes an economic assessment of ES loss due to land use change between the years 1973-2012 in Ethiopia. It estimated a loss of 19.3 US million, where climate regulation and water treatment contribute the most to the monetary loss. Finally, (iii) Tolessa 2017 also conducts an assessment of the economic loss of ES caused by land use change.

The cluster #5 Urban Ecosystem contains 42 cited articles representing 5.48% of the total number of nodes in the network. Its silhouette value is

0.934. Its articles focus on ecosystems present in urban areas. The articles with the highest citation are (i) Grimm 2008, a review on the ecology of urban areas and how it differs from more "natural" ecosystems and (ii) Tzoulas et al 2007, a review on the use of green infrastructure in cities and how it is linked to the health of both people and ecosystems.

3.3 Temporal analysis

Clusters #1 and #5 are the oldest clusters formed in the knowledge network (Fig 2). The articles contained in cluster #1 have the highest burst rates (Table 2), this indicates a high citation within a short timeframe, particularly 2010 corresponds to the year with the highest cluster activity recorded.



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CiteSpace, v. 6.2.R6 (64-bit) Advanced
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WoS: /Users/cristian/citespace/valeria2_data
Timespan: 2005-2022 (Slice Length=1)
Selection Criteria: g-index (k=25), LRF=3.0, L/N=10, LBY=8, e=2.0
Network: N=767, E=2853 (Density=0.0097)
Largest 5 CCs: 606 (79%)
Nodes Labeled: 2.0%
Pruning: None
Modularity Q=0.7579
Weighted Mean Silhouette S=0.9031
Harmonic Mean(Q, S)=0.8242
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Figura 2. Timeline of cluster activity.

Cluster #2 is the most recent cluster formed among the analyzed clusters, emerging after 2010 with the theorical and methodological foundations set by the older clusters. This cluster maintain its activity in recent years, closely followed by Cluster #3.

Tabla 2. Top 5 items with the highest burst index

Author	Year	Title	Burst
De Groot et al.	2010	Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making	8.68
Nelson et al.	2009	Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales	8.55
Seto et al.	2012	Global forecasts of urban expansion to 2030 and direct impacts on biodiversity and carbon pools	6.58
Bennett et al.	2009	Understanding relationships among multiple ecosystem services	6.56
Fisher et al.	2009	Defining and classifying ecosystem services for decision making	5.38

4. DISCUSSION

4.1 Research trends

Although research on landscape planning and WES is at an early stage of development, this scientometric analysis identified three research trends that characterize the knowledge network for this scientific field.

Land use change as the main threat studied.

Land use change is the most studied threat within the knowledge network. Articles within Cluster #2 focus on assessing land use change processes aiming to evaluate the consequences of historical alterations in services availability, and model prospective scenarios for guiding landscape spatial planning.

Changes in the spatial pattern of landscapes at the regional scale directly impacts ES flow, as changes in landscape structure influence ecological processes taking place (Hao et al., 2017). This impact extends to the hydrological cycle, affecting WES provision by modifying the physical properties of the soil that influence water flow (Aboelnour, Engel, Frisbee, Gitau, & Flanagan, 2021).

Integrating water cycle information into studies of land use change provides valuable insights into how land-use decision may impact vital WES and enhances a better spatial planning decision making, especially when considering trade-offs between land uses (Pimentel, Rogéliz Prada, & Walschburger, 2021). The incorporation of finding from these studies into landscape planning facilitates the recognition of sustainable land use practices that optimize water resources management.

Relevance of the economic valuation of WES

A large portion of articles focus on economic evaluation of WES, specifically grouped in Cluster #4, these articles have a high centrality value indicating their role in linking different thematic clusters to each other. Providing information on economic costs is fundamental for good planning and subsequent management and management of resources and services, particularly water (Christ & Burritt, 2017).

This type of assessment allows highlighting the contributions of the environment and exposing the consequences of its preservation, loss, or restoration in terms comparable to other relevant aspects of land use decision making(Hanley & Shogren, 2002). Incorporating WES monetization into landscape planning provides a quantifiable framework for evaluating the contributions of WES, enabling planners to weigh the economic benefits against potential environmental and societal costs.

However, there exists significant criticisms regarding the monetization of WES supported by the argument that access to these services is a fundamental human right that should be guaranteed for the entire population. Moreover, evidence suggest that monetization may have adverse effects on pro-environmental actions by diminishing the intrinsic value of nature (Goff, Waring, & Noblet, 2017). While there are instances where monetization can be effective under certain circumstances, this is not the case when additional measures to protect threatened ecosystems are lacking (Temel, Jones, Jones, & Balint, 2018)

Urban landscape as the main landscape studied.

Another trend in WES and landscape planning research is urban areas being the predominant type of landscape used in study cases. Within cluster #2 and #5 articles focus on defining and assessing urban ecosystem services, the most studied services are surface runoff water management and climate regulation. Water resources management is a key component for city sustainability, given the multiple challenges that can arise due to an inadequate water planning, such as flooding, water pollution, inefficient waste management and water scarcity (Capodaglio, Ghilardi, & Boguniewicz-Zablocka, 2016).

Numerous articles within these clusters focus on the implementation of blue-green infrastructure as a dual-purpose solution, both addressing damages while enhancing the capacity of cities to provide WES and achieve sustainability commitments. Provision of urban ES depends on the accessibility and spatial arrangement of green and blue areas, and therefore on land use decisions made during spatial planning processes (Cortinovis & Geneletti, 2018).

Cities sustainability is a subject that has risen its relevance in recent (Kong, Liu, & Wu, 2020), which can be noted in the activity of clusters dealing with these topics (Fig. 2 Cluster #2). This research increase has the potential to facilitate well-informed decision making by policymakers and urban planners as they gain understanding of the multifaceted benefits that WES can provide.

4.2 Challenges for scientific research.

The predominant focus on the three identified research trends leaves multiple information gaps concerning critical aspects related to the provision and flow of WES.

One crucial but relatively underexplored aspect is the impact of climate change on WES provision. While research on land use change is extensive, the scope of climate chance as a threat remains comparatively limited. Recognizing spatial planning as an essential process for adaptation to new climatic conditions that will affect the flow of WES is imperative. For this, it is necessary that the methodologies used to model future water behavior consider future climate scenarios and their respective levels of uncertainty so that information provided by researchers is of relevance in planning processes (Runting et al., 2017).

Another gap is researching biodiversity indicators alongside WES for an effective landscape planning and the protection of ecosystems. Understanding the intricate relationship between biodiversity and WES is key for ensuring the resilience and sustainability of aquatic ecosystems (Teixeira et al., 2019). Integrating this information provides a holistic view of aquatic ecosystems that when used in landscape planning ensures both the supply of WES and the protection of the biodiversity that supports these services.

Furthermore, it is critical to broaden the scope of research beyond urban landscapes. Focusing mainly on urban areas may lead to information gaps regarding wilder ecosystems, which often play a key role in the provision of WES. Assessing and protecting diverse types of ecosystems such as forests and wetlands is crucial as they contribute significantly to maintaining water quality, regulating water flow, and supporting biodiversity (Esquivel, Echeverría, Saldaña, & Fuentes, 2020; Janse et al., 2019). Acknowledging the importance of these ecosystems in research and planning processes is fundamental for achieving landscape management strategies that safeguard WES.

5. CONCLUSION

The scientific field on WES applied to landscape planning is still in early development stages. Research is predominantly centered on urban planning and assessment of consequences derived from land-use changes. There is a need to broaden this scope by undertaking comprehensive case studies that extend beyond urban contexts. Specifically, research should delve into diverse types of landscapes and ecosystems, as well as the impacts of climate change on WES.

To establish WES as an integral component of planning instruments it is important to generate robust scientific evidence through diverse case studies. These should not only expand the spatial focus but also aim to solve water conflicts through landscape planning and management strategies. By doing so, researchers can provide the necessary empirical foundation for policymakers, facilitating the inclusion of WES in planning activities.

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CHAPTER II: WATER ECOSYSTEM SERVICES HOTSPOTS IDENTIFICATION AND MAPPING FOR PROTECTED AREAS SYSTEMATIC CONSERVATION PLANNING IN SOUTH-CENTRAL CHILE

Abstract:

WES encompass the various benefits people obtained from hydrological processes within ecosystems. Currently, the ecosystems that provide water services are vulnerable to diverse threats like climate and land use changes. Hence, examining the potential role of protected areas as a conservation policy in safeguarding WES becomes crucial for holistic conservation planning that caters to both human and biodiversity needs.

In this study we identified priority conservation hotspots for WES supply and assessed if they are adequately protected within a protected areas network in South-Central Chile. WES priority areas distribution change when different threats are considered in the assessment and in general protected areas don’t cover priority areas. Incrementing protected areas expanse is fundamental to safeguard the ecosystems that provide WES.

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1. INTRODUCTION

Conservation science focus has evolved in recent decades, shifting from the protection of individual taxa to embracing a holistic approach to the "human and nature" relationship, where concepts such as "human well-being" and "ecosystem services" (ES) have gained increasing relevance within this scientific discipline (Mace 2014).

ES refers to the array of benefits that people obtain from multiple ecological functions (MEA 2005). This conceptual framework enables to link biological conservation with human development through environmental integrity (Kandziora et al. 2013; Dong et al. 2015). This approach to conservation science has the potential to develop strategies that protect both ecosystems and the services they provide (Pahl et al 2013). Thus, conservation measures, such as protected areas (PAs) no longer refer exclusively to endangered taxa, but also to the ES that these areas provide (Watson et al. 2014).

PAs encompass regions shielded against human interference; these areas can be national parks, reserves, national monuments, and a various other designation (Brockington et al. 2012). Their primary goal is to establish optimal environments for biodiversity conservation by reducing threats that jeopardize its optimal development. To achieve effective conservation, the three attributes of biodiversity -composition, structure, and function- must be considered ensuring the ecological integrity of the ecosystems protected and the services they provide (Parrish et al. 2003).

PA establishment competes with other human activities within the same territory (Smith et al. 2010). Heightened land-use competition places PAs under pressure to justify their presence within the landscape (Bragagnolo et al. 2016). Consequently, modern approaches to protected areas transcend their original focus on biodiversity conservation, now integrating the concepts of ES and human well-being (Ingram et al. 2012, Watson et al. 2014).

Although the integration of these concepts in PA planning has increased, efforts remain scattered and there exists diverse criteria to designate conservation sites (Cimon-Morin et al. 2013). Thus, a systematic prioritization approach has been proposed to craft efficient PA networks with strategic spatial distribution where priority sites are determined according to criteria such as species richness and abundance as well as level of threat (McIntosh et al. 2017).

Pinpointing areas capable of delivering multiple ES allows identifying priority sites for implementing measures that ensures their sustained provision (Goldstein et al. 2017, Fan et al. 2018). Additionally, concepts such as threats and vulnerability are also used to identify biodiversity hotspots, however, their application in ES hotspots identification remains limited, despite their relevance in determining ecosystems capacity to provide ES (Schröter and Remme 2016).

Regarding Water Ecosystem Services (WES), numerous threats compromise the integrity of the hydrological cycle, thereby jeopardizing its capacity to provide essential services (Tang 2020). For instance, due to the consequences of climate change there's a global anticipation of shifts in precipitation regimes, impacting water availability affecting both societies and ecosystems (Konopala et al. 2020). Simultaneously, rising temperatures directly impact the hydrological cycle through processes such as evaporation and evapotranspiration affecting water regulation and availability (Martinez-Retureta et al. 2021). Wildfires, also have the capacity to impact the hydrological cycle affecting the flow of WES (Hohner et al. 2019, Vukomanovic and Steelman 2019).

Regarding the inclusion of WES in PAs design there is a global bias in their establishment, with most PAs located in terrestrial ecosystems that may not inherently contain key freshwater components such as rivers, compromising WES preservation (Harrison et al. 2016).

Several studies highlight the benefits of implementing conservation measures associated with the protection of WES. Bai et al. 2013 evidence that prioritizing the protection of riparian ecosystems significantly enhance the provision of ES, benefiting watershed-dependent populations while ensuring biodiversity conservation. Moreover, there is extensive evidence that corroborates the impact of maintaining native forests and wetlands on the optimal water yield of watersheds (Lara et al. 2009, Little et al. 2009, Martínez-Retureta et al. 2020).

In Chile, there is significant gaps in ES research, particularly concerning in its spatial distribution. Studies concentrate in the central zone using predominantly a local scale in the assessments. Furthermore, most of the services studied tend to be cultural services linked to tourism activities (De la Barrera et al. 2015). As for WES studies, most of them concentrate in the norther area and they focus on water extraction for mining activities (Cantillana 2020). Building upon this context, it becomes evident that there is a deficit regarding WES knowledge.

Simultaneously, PAs distribution across Chile is markedly uneven, most of PAs are concentrated in the southern territory, affecting the protection of biodiversity across its various attributes and levels throughout the rest of the country (Duran et al. 2013). Assessing the performance of PAs in terms of ES representation not only gauges the protection level of these services but also measures the success of the spatial design of PAs (Xu et al. 2017).

Additionally, it allows to identify new sites worthy of consideration for legal protection frameworks (Manhães et al. 2016, Zarandian et al. 2017, Li et al. 2020). This information can be used in strategic spatial planning processes providing a framework for the systematic incorporation of ecological functioning into territorial planning (Wilkinson et al. 2013).

However, studies that link the conservation of ES to the PAs network are scares in Chile. Duran et al. 2013 evaluate the representation of three ES – primary productivity carbon storage and agricultural production- within the national PAs network, revealing a low representation of the three services. For this representation to increase, it is necessary to explicitly integrate the flow of ecosystem services into protected area prioritization, both when choosing which sites will be integrated into the network and when designating objectives and strategies.

This study aims to evaluate the current protection of WES in Chile’s PAs. Specifically, a systematic spatial prioritization analysis was conducted to identify WES hotspots in south-central Chile. This assessment considered both the capacity of the watersheds to provide WES, as well as its vulnerability to threats. Subsequently, we evaluated the effectiveness of the existing PAs system in protecting the identified WES hotspots, aiming to propose new sites for their protection.

2. METHODS

- 2.1 Study Area

The study area (Figure 3) is situated within the central-southern region of Chile specifically between 35° and 30° latitude, encompassing the administrative regions of Maule, Ñuble, Biobio and Araucanía. The combined area of these regions totals approximately 92225,77 km2. The macro-geomorphology of this zone its characterized by the presence of two mountainous formations: the Andes Mountain range to the east and the Coastal Mountain range to the west, with and intermediary depression known as the central valley.

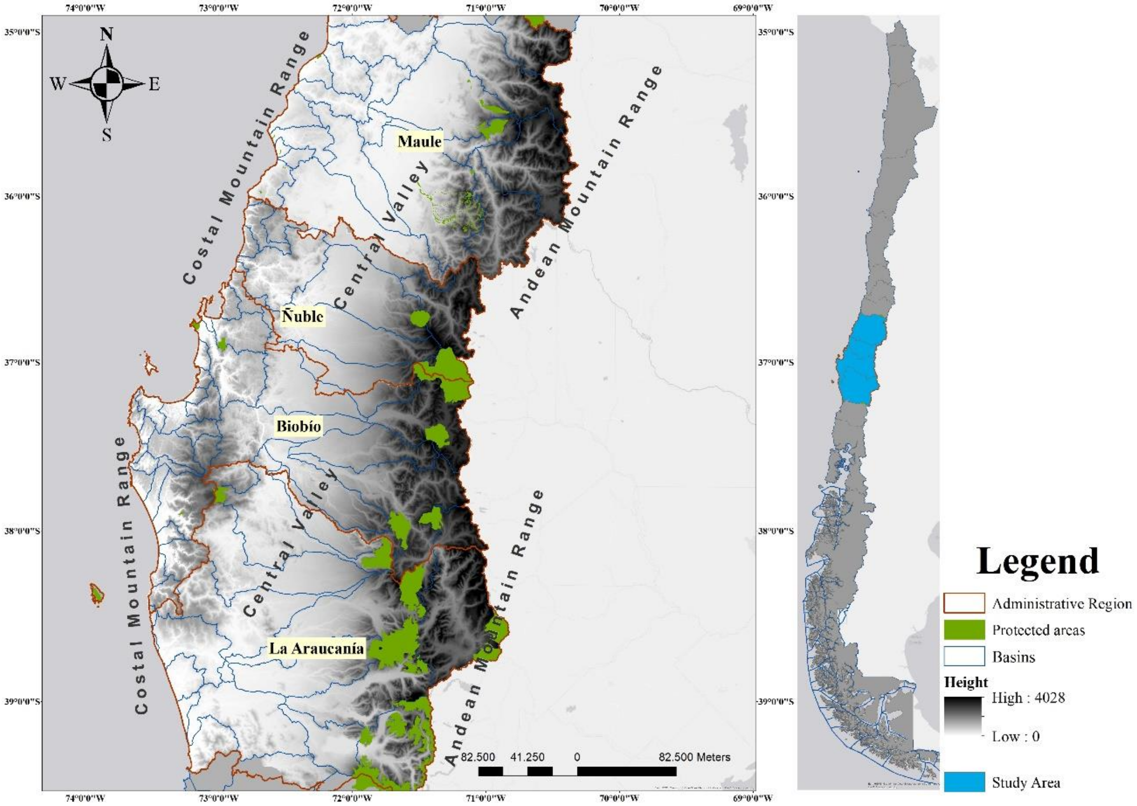

Figura 3. Study area corresponding to the four administrative regions and PAs spatial distribution. Mountain ranges are shown in darker colors.

The study area holds significant importance for the conservation of WES due to process that threats their provision. For instance, land-use changes have occurred across expansive geographic regions in the past decades, resulting in a great loss of native forest to exotic forest plantations (Echeverría et al., 2006; Rodríguez-Echeverry et al., 2018). Moreover, there has been a continual decline in average precipitation levels since 2007. In 2020 there was a 26% deficit in average annual precipitation compared to the 1961-1990 average (DMC, 2021). Thee shifting climate patterns contribute to the prevailing mega-drought conditions, severely limiting the access to various WES, particularly impacting rural and indigenous communities within the area (Torres-Salinas et al 2016).

This region included 308 sub-basins. Currently, the northern area has been declared as a water scarcity and depletion area by the State (DGA). Climate change projections indicate an anticipated rise in average temperatures coupled with reduced precipitation. These forecasts position the Central-Southern area as highly susceptible to water scarcity, further exacerbating the impacts of the ongoing mega-drought (Araya-Osses et al., 2020).

2.2 Water Ecosystem Services modeling

Assessing ecosystems capacity to provide certain services requires indicators derived from measuring biophysical processes that derive these services (Grizzetti et al 2016). These indicators were constructed using topographic data, land use data, precipitation and soul erodibility data. These datasets were used in a N-SPECT model (Non-Point Source Pollution and Erosion Comparison Tools). This model

We selected three WES for this assessment, according to CICES classification they are: Surface water used for nutrition, materials, or energy, Dilution by freshwater and Hydrological cycle and water flow regulation. Pixel values for the 308 sub-basins were normalized within a range of 0 to 100 using the formula: $zi = (xi - \min(x))/(\max(x) - \min(x)) * 100$. This enables direct comparison among the indicators. Higher values near 100 signify a greater capacity to provide a specific service, whereas lower values indicate a limited capacity to provide the service.

Tabla 3. Summary of WES used for the assessment.

WES	Description	Indicator
Surface water used for nutrition, materials, or energy	Availability of surface water in ecosystems	m3/s
Dilution by freshwater	Sediment concentration of N and P in water	% N and P concentration normalized
Hydrological cycle and water flow regulation	Capacity of water bodies to maintain flow volume	Volumetric difference

2.3 Threats indicators

We selected threats encompassing climate change, land use change and wildfires as factors impacting the capacity of ecosystems to provide WES. Four indicators were mapped:

Land use change: We identified areas experiencing native forest and wetlands cover loss between 1986 and 2017, since these ecosystems have a key role in the integrity of the hydrological cycle (Bullock 2003). Pixel losses were extrapolated to the sub-basin level using ArcGIS zonal statistics and then values were normalized within a 0-100 range.

Precipitation decreases: Data on potential precipitation decrease to 2050 was obtained from the ArCLIM platform and reports from the IPCC were spatialized using a multivariate model. The values were normalized within a range of 0-100 to enable comparison with other indicators.

Temperature increases: We utilized the variance between the mean temperature of a recent historical period (1980-2010) and projected annual mean temperature for the near future (2035-2065) under the RC 8.5 climate model scenario. The data was obtained from the ArCLIM platform at the sub-basin level and values were normalized within a 0-100 range for comparison.

Wildfires: We identified wildfires occurrence point data for the years ()-2023. These occurrences were extrapolated to the sub-basin level via ArcGIS' zonal statics tool summing occurrence pixels. Subsequently, values were normalized within a 0-100 range.

2.4 Hotspots mapping

We conducted a spatial prioritization analysis at the administrative regional scale, aligning with the political and administrative boundaries of each region within the study area. We constructed five different scenarios (Table 4) to assess changes in hotspots distribution.

Tabla 4. List of scenarios and the spatial information used to construct them.

Scenarios	Water supply	Water quality	Water regulation	Land-use change	Temperature increase	Precipitation decrease	Wildfire occurrence
S1	x	x	x				
S2	x	x	x	x			
S3	x	x	x		x	x	
S4	x	x	x				x
S5	x	x	x	x	x	x	x

We used ZONATION v.4 software to generate a spatially explicit hierarchical prioritization of the study area using the WES and threats indicators previously mentioned. This software zones the landscape establishing priority areas for conservation using indicators of interest. These are loaded in a raster format to establish the conservation value of each cell (pixel) within the study area (Minin 2014). Then, through the additive benefit function (ABF) rule, the cells with the lowest value are eliminated in an iterative process. (Moilanen 2007).

The result is a map where pixels are organized in a ranking of values that fluctuates between 0 (low priority) and 100 (high priority). The cells with the highest value correspond to the places with the greatest coincidence of the characteristics of interest, which in this assessment are 1. Greater capacity of provide WES and 2. Greater threats processes.

The resulting maps were classified into ten ranks (deciles) where higher deciles have a higher conservation priority using the Reclassify tool in ArcGIS. This study considered the top fraction of the landscape (10%) as the hotspots.

2.5 PAs performance assessment

We identified PAs affiliated with the National Services of State Protected Areas (SNASPE) to assess their effectiveness in protecting WES hotspots.

PAs encompassing national monuments, national reserves, and national parks were identified within the study area.

We constructed a prioritization scenario restricted to the current distribution of PAs “S6 PAs” using the indicators of WES (water supply, water quality, water regulation), threats (land use change, temperature increase, precipitation decrease, wildfire occurrence) and the protected area distribution map.~~:~~ Then, we compared the performance curves provided by Zonation of the scenarios previously mentioned with the restricted scenario. Additionally, we calculated the spatial congruence between the spatial distribution of the hotspot’s areas and the distribution of PAs using ArcGIS.

3. **RESULTS**

3.1 Spatial distribution of WES and threats

Each WES exhibits a distinct spatial distribution (Figure 4). Basins with high capacity for water regulation are mainly grouped in the Andes Range across the four study regions. Conversely, water quality also has highest values in the Andean Mountain range across the four regions with some high-quality basins located in the Coastal Mountain range of Biobío and Araucanía regions.

The basins with the highest capacity to provide water supply in Maule, Ñuble and Biobio regions are dispersed along the biggest rivers of each region. However, in Araucanía, this service is concentrated in few basins within the Andean mountain range.

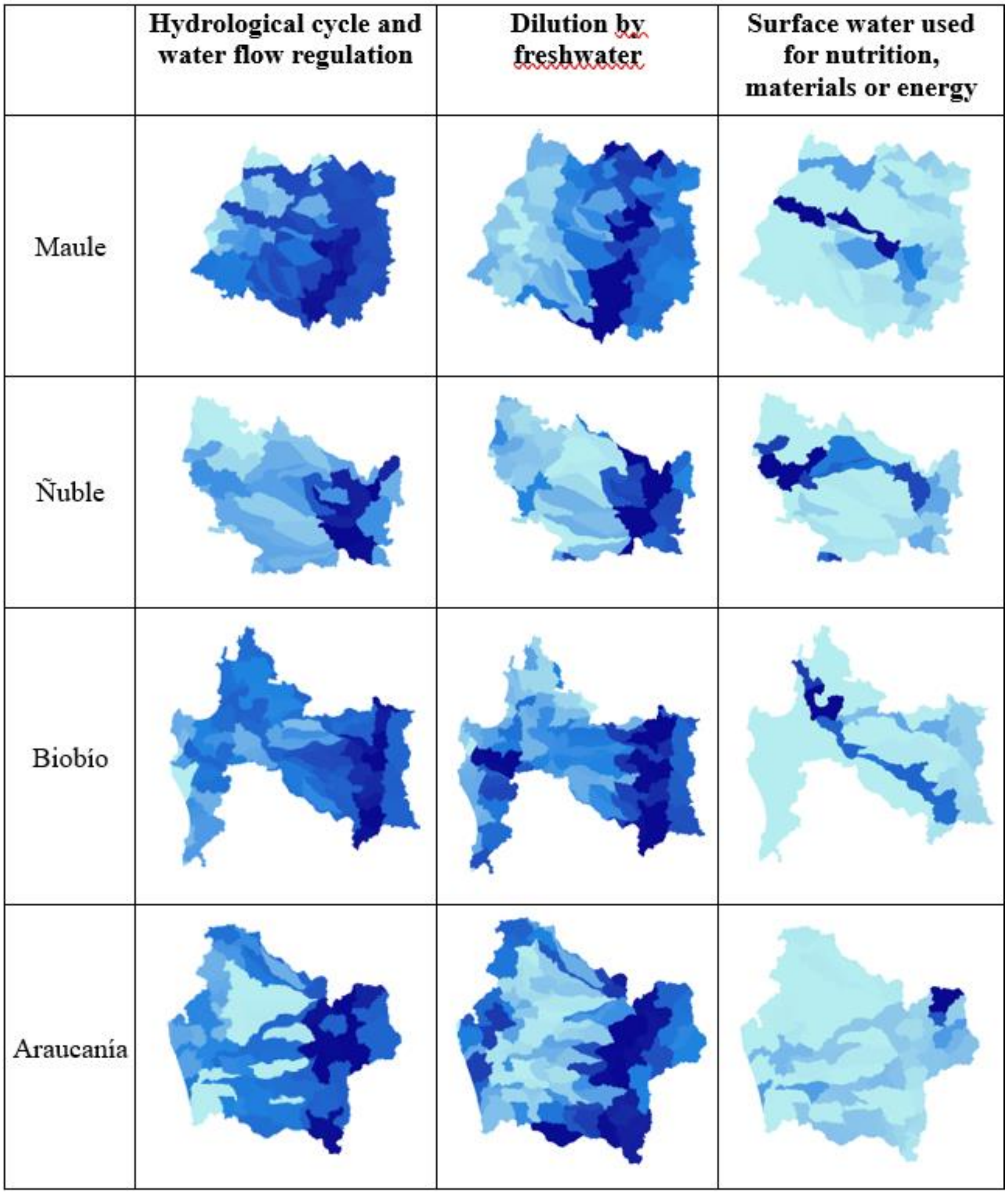

Figura 4. WES spatial distribution.

As for the spatial distribution of the selected threats (Figure 5), LUC is the only threat that does not follow a defined spatial pattern throughout the four regions. High levels of LUC are mostly concentrated in the Coastal mountain range though there are some basins with high values at the Andean mountain range in Ñuble and Biobio regions. While in Maule and Araucanía there are high threatened basins in the central valley area.

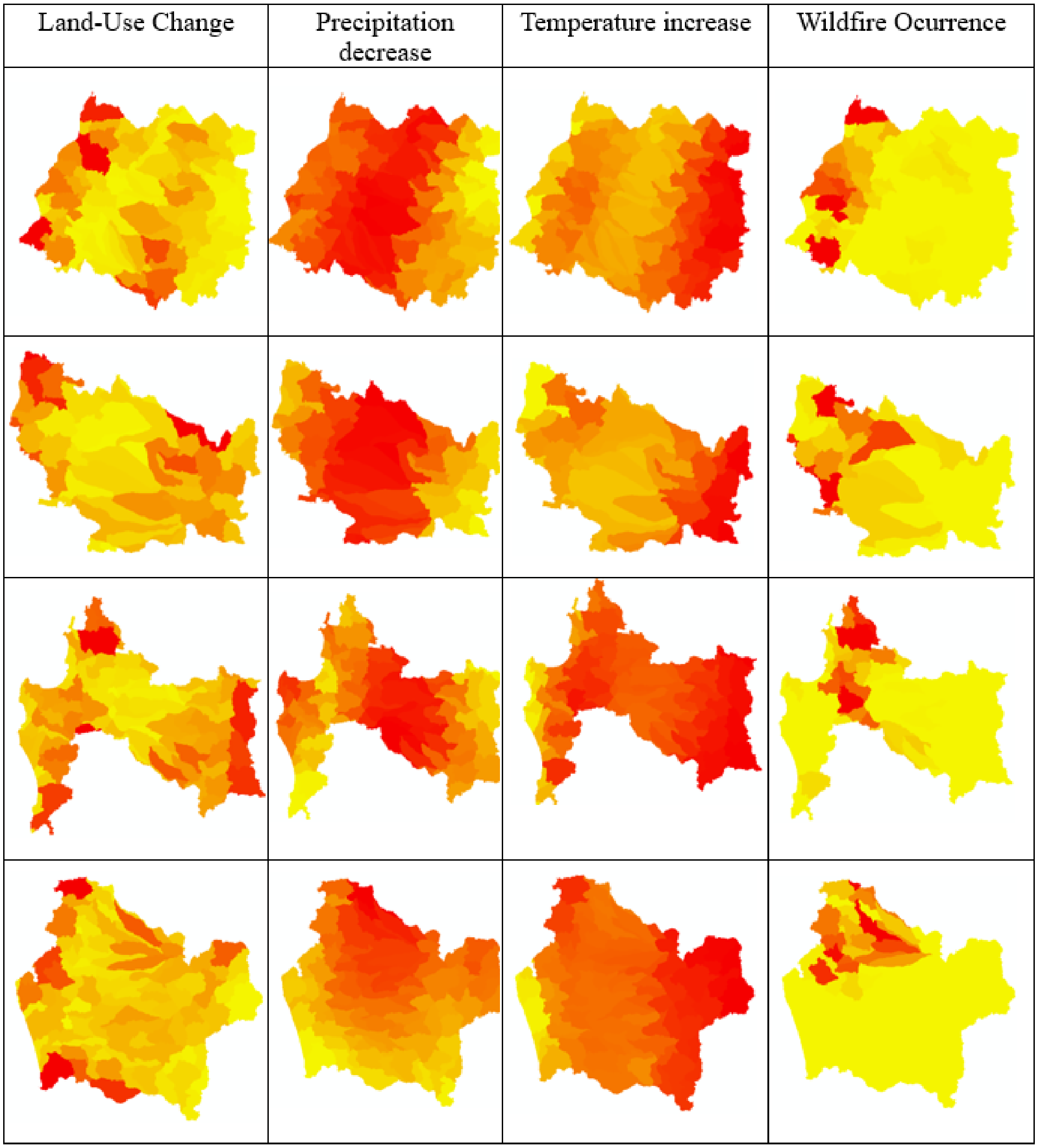

Figura 5. Threats spatial distribution, land use change; precipitation decrease; temperature increase; wildfire occurrence. Red represents higher threat values and yellow lower threat values.

The other three threats exhibited consistent patterns across the four regions. Precipitation decreases concentrates within the central valley area, although with decreasing values towards the southern extent of the study area. Temperature increase predominantly occurs in the Andean mountain range across all four regions, however, there are basins with high threat values in some of the Coastal mountain range in Biobio region. Lastly, wildfires display a consistent spatial pattern throughout the four regions, primarily concentrating in the Coastal Mountain range.

3.2 Spatial prioritization scenarios and hotspots identification

The spatial pattern of hotspots varies in every scenario. In Maule region (Figure 6), when threats are not considered WES hotspots are distributed along the basins of the biggest river and some basins located in the Andean mountain range. When threats are incorporated in the assessment this spatial pattern changes. For instance, in the S2 basins in the southern Andean gained priority presenting new hotspots. As for S3 the hotspots observed in the WES scenario mostly maintain its distribution with only two small new hotspots at the northwest and southwest. And in S4, hotspots are incorporated in the Coastal Mountain range.

Lastly, in S5, when WES supply and threats are jointly considered, hotspots distribution concentrates both within the Coastal Mountain range and basins in the southwest area of the region.

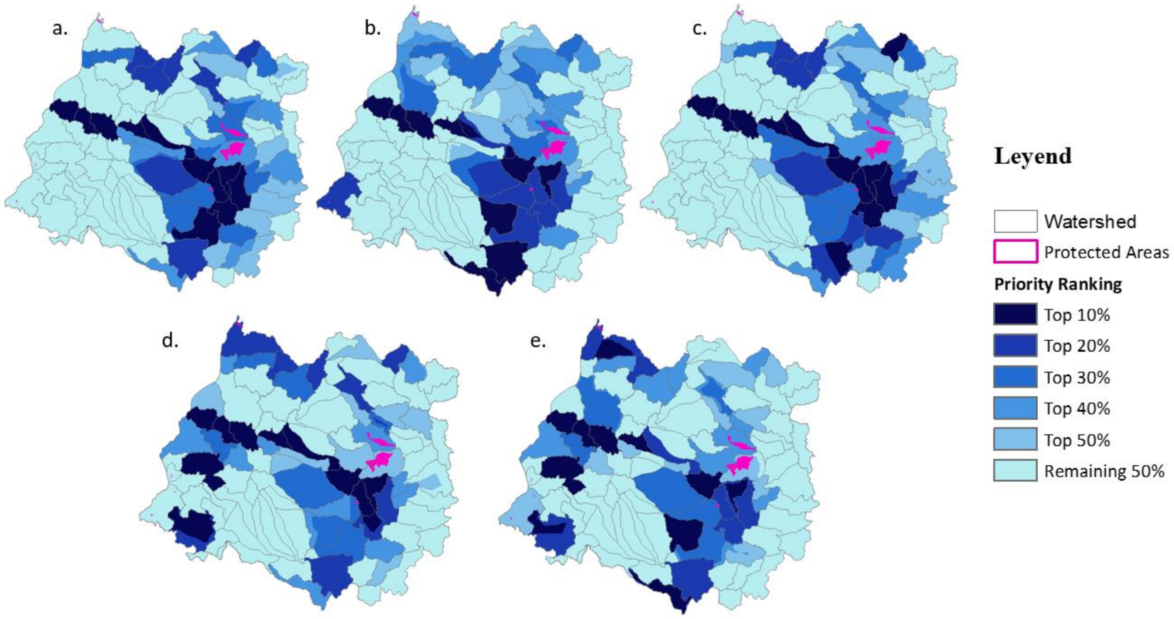

Figura 6. Figura 8. Spatial prioritization maps of Maule region: a) S1; b) S2 c) S3; d) S4; e) S5. The priority level decreases as the colors become lighter; hotspots equal the top 10%.

In Ñuble region (Figure 7) hotspots in S1 are primarily concentrated within the Andean Mountain range in two big clusters with an additional hotspot in the Coastal area. In S2 the northern hotspot gained priority level incrementing its surface area, while reducing the size of hotspots in the southeast and coastal area. S3 presents a new hotspot in the Coastal Mountain range while those in the Andean Mountain range remain mostly consistent. In S4, two new hotspots appeared in the Coastal Mountain range while the northern Andean hotspots remain.

Lastly, in S5, the hotspots in the northern Andean Mountain range expanded its surface area while two new hotspots appeared in the Coastal Mountain range, mirroring the spatial distribution observed in the WILDFIRE scenario.

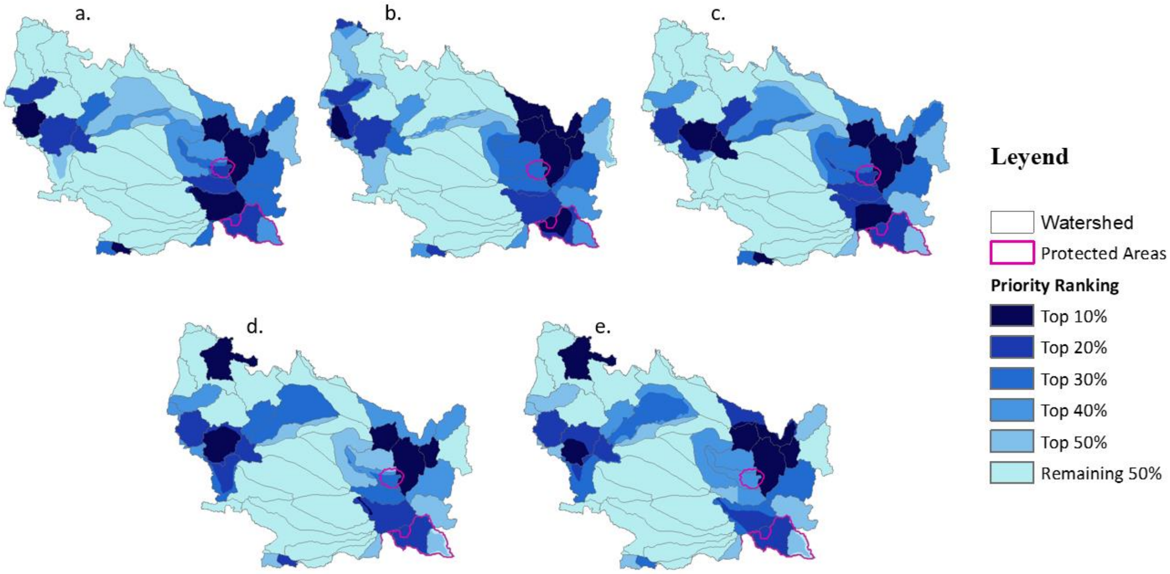

Figura 7. Spatial prioritization maps of Ñuble region: a) S1; b) S2 c) S3; d) S4; e) S5. The priority level decreases as the colors become lighter; hotspots equal the top 10%.

In Biobio region (Figure 8), hotspots in S1 are distributed along the region’s main river with an additional hotspot at the northeastern Andean Mountain range. In S2, the northeast hotspot increased its surface area and a new hotspot appeared in the southwest area of the region. Under S3, hotspots maintained its spatial distribution along the main river, increasing its size in the eastern area compared to S1. S4 scenario, priority levels increased significantly within the Coastal Mountain range incorporating two big hotspots in the northwest area.

Lastly in S5, hotspots maintain its original spatial distribution along the main river, while an additional hotspot appeared in the northern area of the Coastal Mountain range.

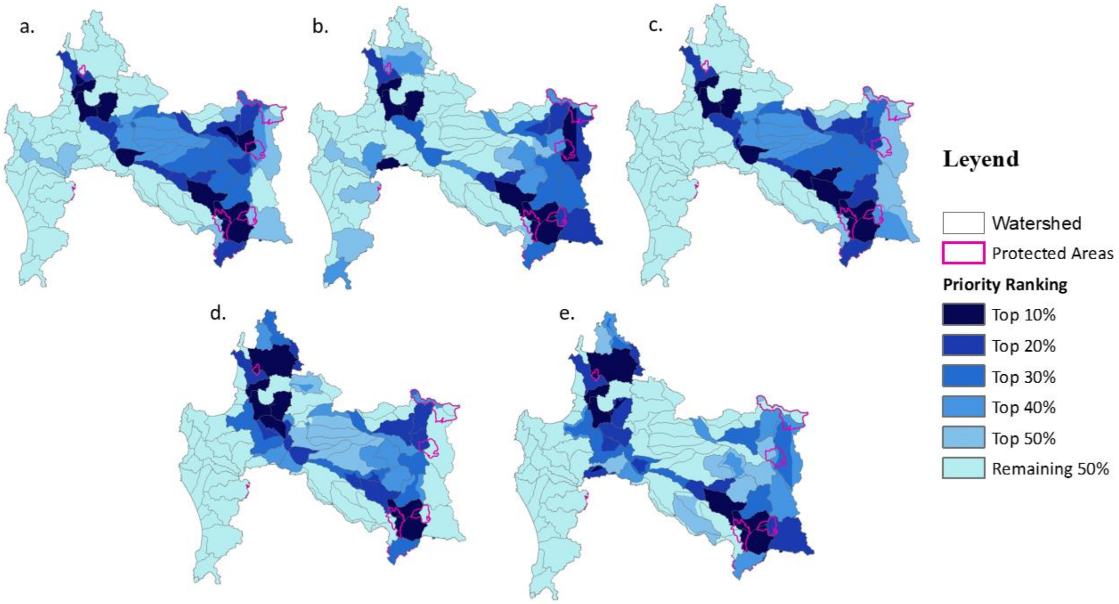

Figura 8. Spatial prioritization maps of Biobio region: a) S1; b) S2 c) S3; d) S4; e) S5. The priority level decreases as the colors become lighter; hotspots equal the top 10%.

In Araucanía region (Figure 9), in S1, hotspots are predominantly distributed in the Andean Mountain range, primarily concentrated in the northern area. Under S2, priority diminishes in the northwest area and two new hotspots appeared, one in the northwest in the Coastal Mountain range and the other in the southern area of the central valley. In S3, hotspots consolidate within the northern are of the Andean Mountain area similar to S1. While in S4 scenario, new hotspots appeared in the Coastal Mountain range, particularly in the northern area of the region.

Lastly in S5, the northern Andean Mountain range loses priority compared to the S1 with just one hotspots remaining in the area, while several hotspots are incorporated in the Coastal Mountain range.

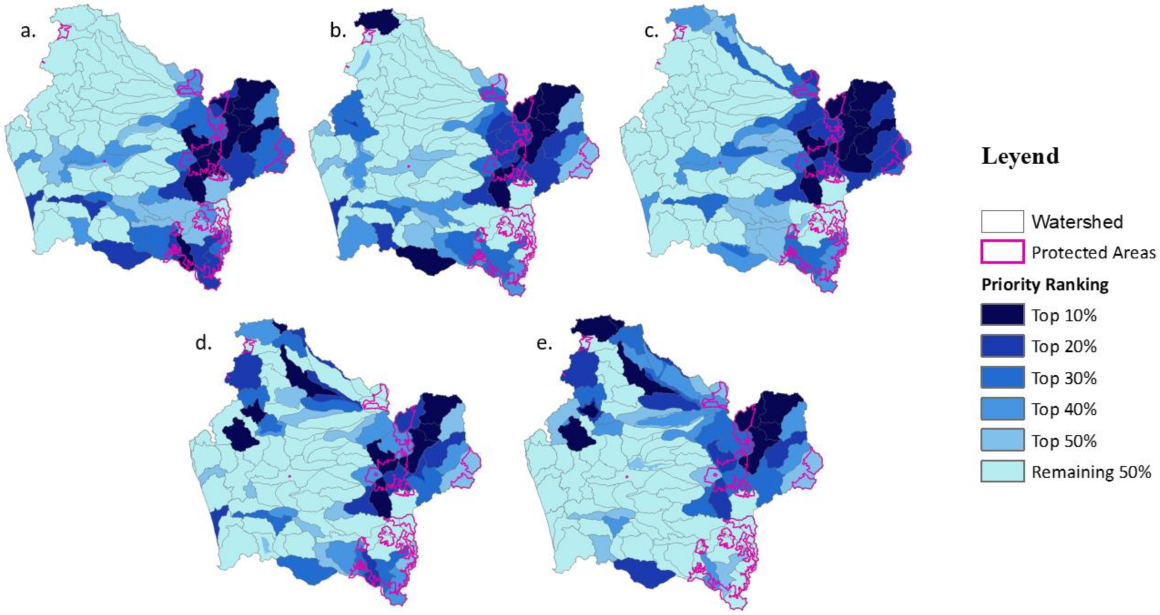

Figura 9. Spatial prioritization maps of Araucanía region: a) S1; b) S2 c) S3; d) S4; e) S5. The priority level decreases as the colors become lighter; hotspots equal the top 10%.

Across the four administrative regions threats influence the spatial distributions of WES hotspots, this can be noticed when comparing S1 and S5 (Table 5).

Tabla 5. Spatial coincidence between S1 and S5

Region	**Hotspot area km2**	S**1** – S5	
		Surface area km2	**%**
Maule	2976,89	1304,76	43,83
Ñuble	1309,79	667,21	50,94
Biobío	2390,07	1570,09	65,69
Araucanía	3134,62	1356,61	43,28

3.3 PAs network performance assessment

Twenty-six PAs spanning a total area of 4062,93 km2 were identified across the four administrative regions. The distribution of PAs is uneven, with a significant portion situated in Araucanía region 2531,99 km2, followed by Biobio 847,63 km2, Ñuble 502,48 km2 and finally Maule 180,83 km2.

The priority fraction protected under SNASPE varies across the scenarios within each administrative region. Maule region (Fig. 10) currently has the lowest level of WES protection in all scenarios with a representation of the top10% less than 1% in every scenario.

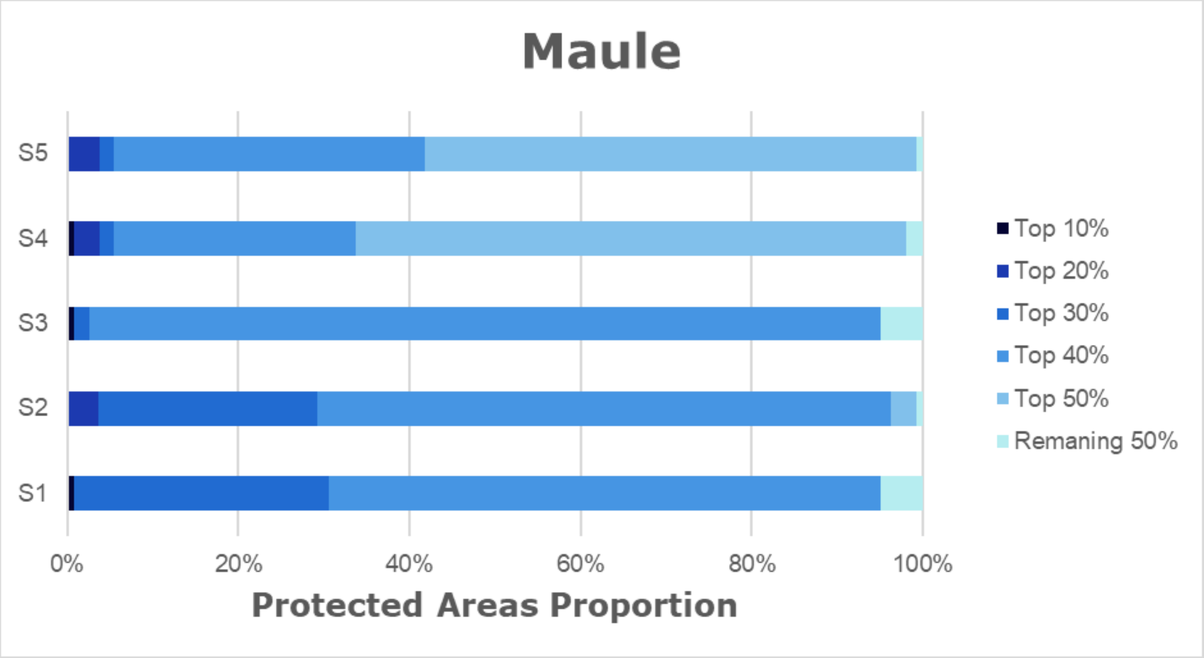

Figura 10. Proportion of priority decile found within the PAs in Maule region.

In Ñuble region (Fig. 11) scenario S2 has the biggest representation under SNASPE 31,58% however every other scenario has low representation (>5%).

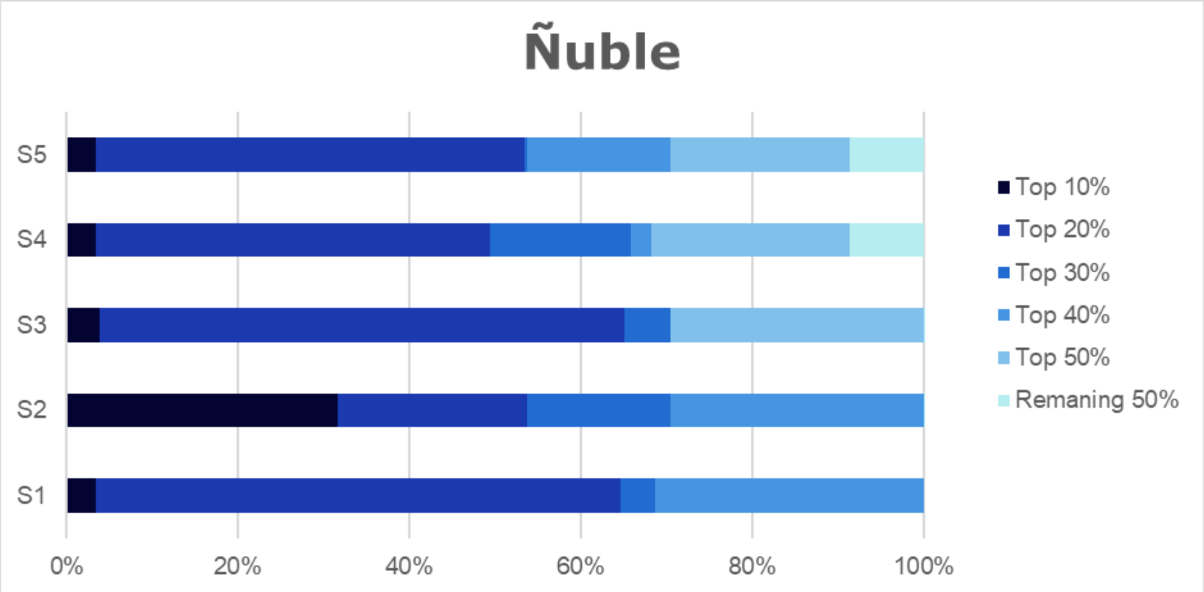

Figura 11.Proportion of priority decile found within the PAs in Ñuble region.

Biobío region (Fig 12) exhibits the higher protection to the Top 10% fraction consistently across scenarios, above 20%, making it the region with the most effective spatial distribution of SNASPE for WES protection.

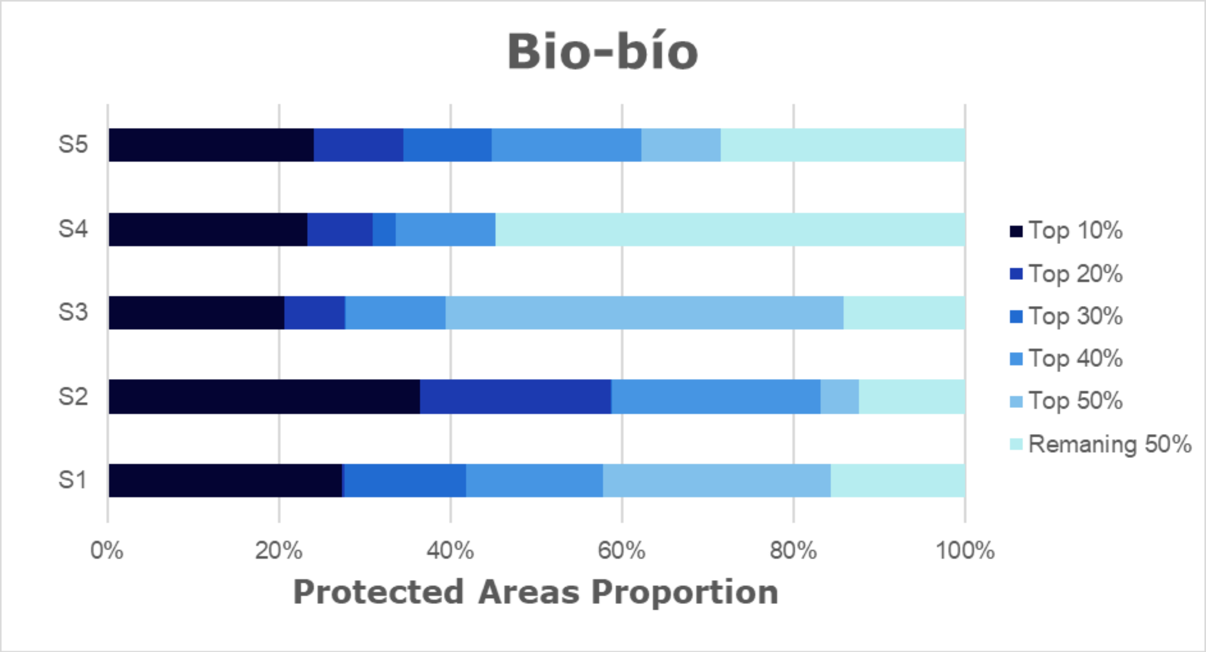

Figura 12. Proportion of priority decile found within the PAs in Biobío region.

Finally, in Araucanía region (Fig. 13) scenario S1 has the biggest representation under SNASPE 25,13%, the rest of the scenarios have lower representation. Both S4 and S5 have under 10%.

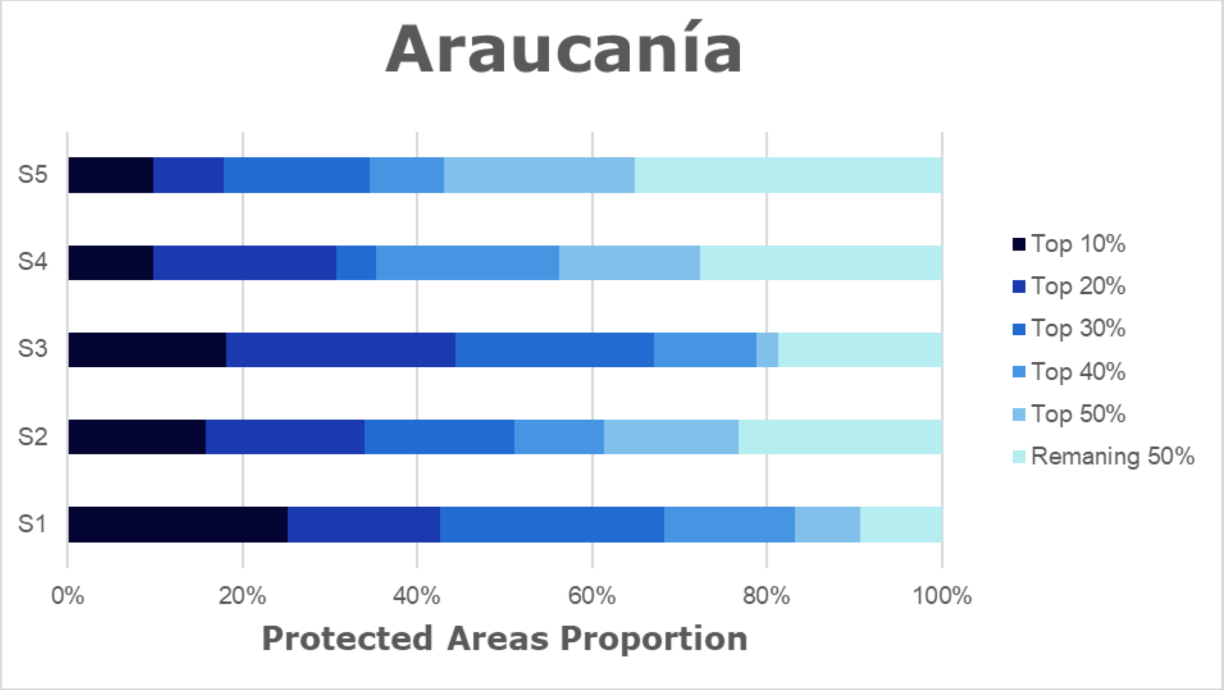

Figura 13. Proportion of priority decile found within the PAs in Araucanía region.

Regarding the assessment of SNASPE performance in ZONATION, (Figure 14). Maule has the smallest area protected by SNASPE, accounting for only 1% of the region, protecting just 1% of the priority basins. The replacement cost of the distribution of PAs with S5 is 0, while its 1% under S1.

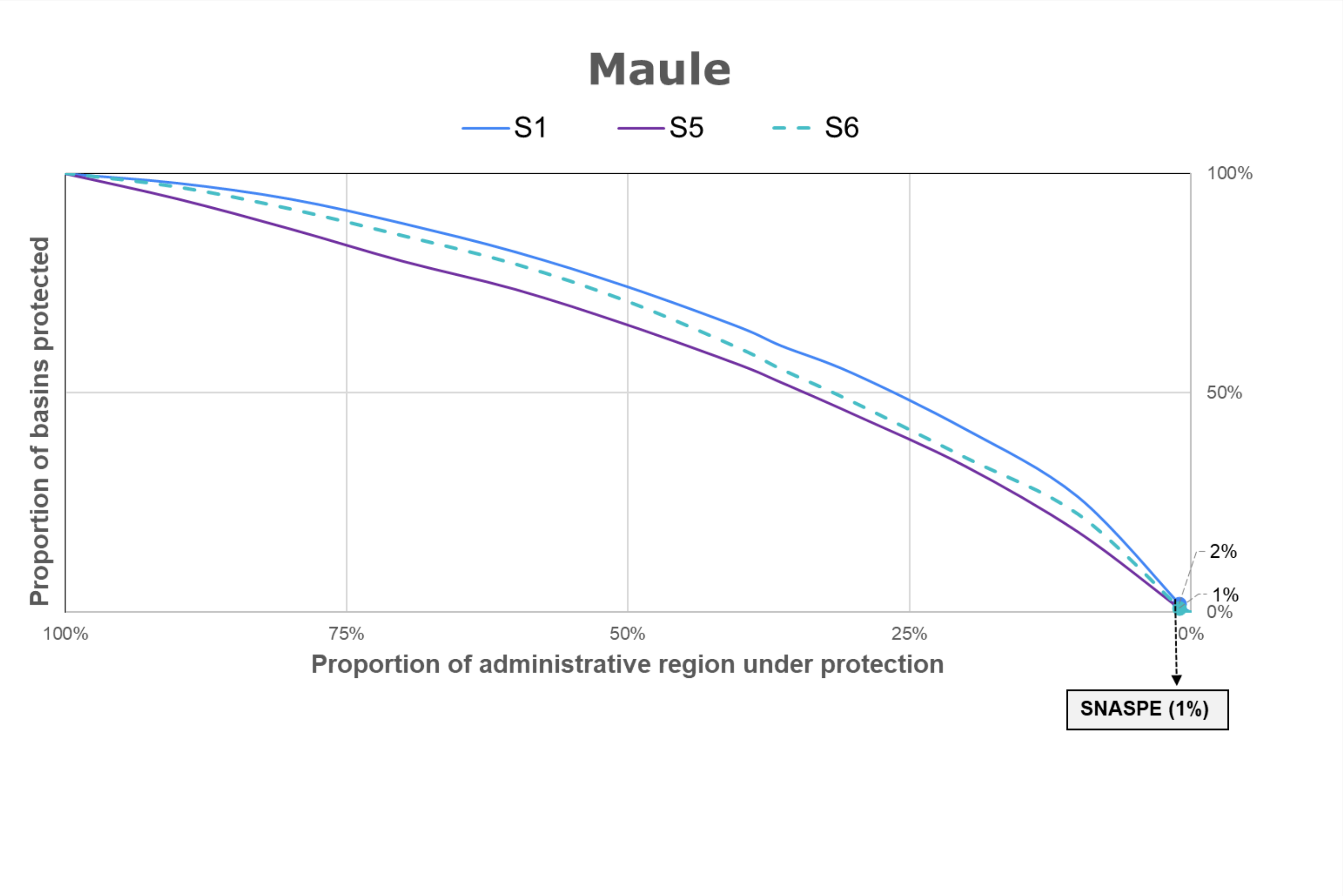

Figura 14. Proportion of hotspot basins included in Pas in Maule region for scenarios S1, S5 and S6.

Both in Ñuble and Biobio SNASPE (Fig. 15 and 16) area accounts for 4% of the total region area and the proportion of protected priority basins is similar, 5% and 4% respectively. The replacement cost with S1 is 6% in both regions while with S5 is 3% in Ñuble region and 4% in Biobio region.

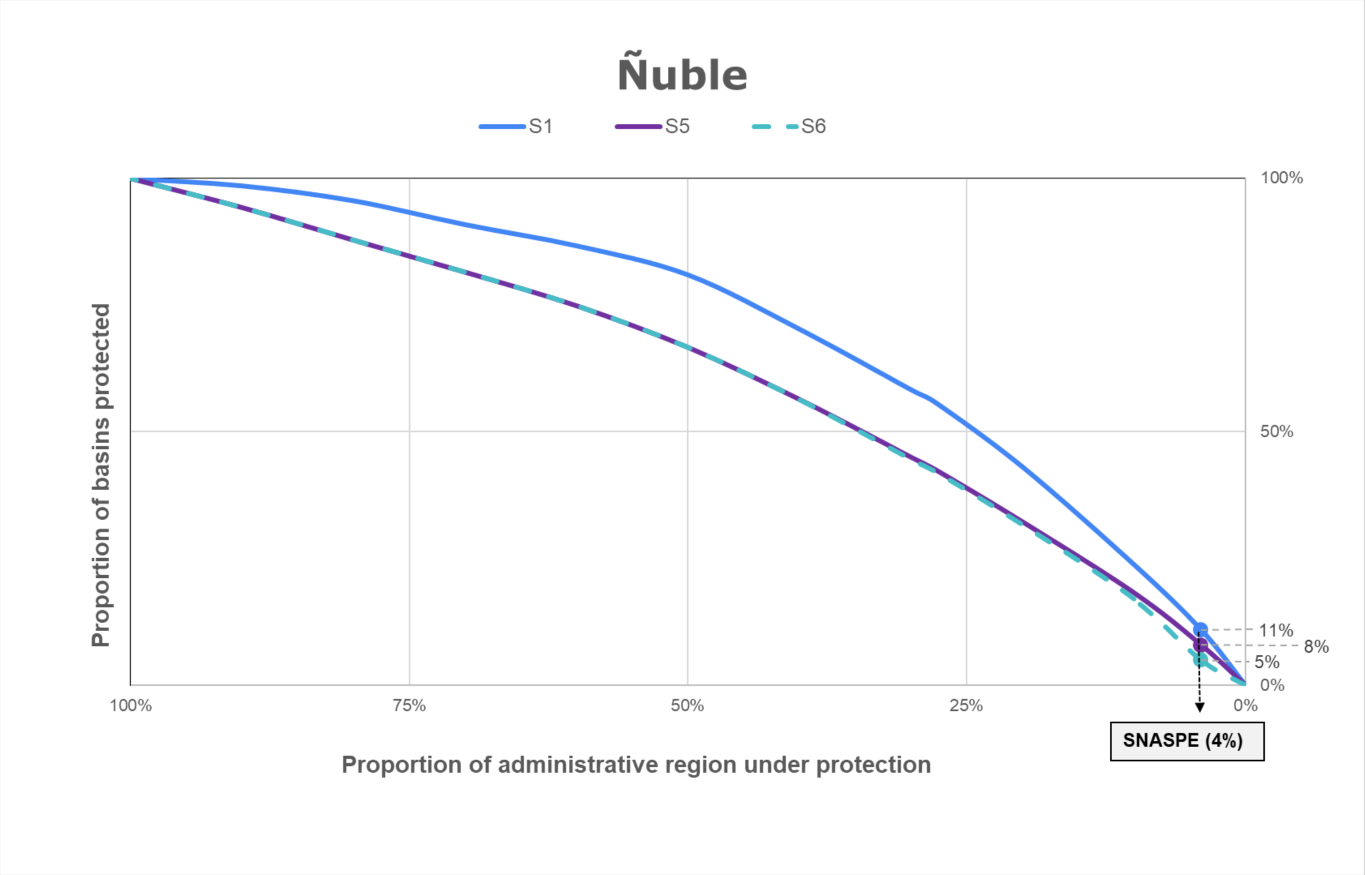

Figura 15. Proportion of hotspot basins included in PAs in Ñuble region for scenarios S1, S5 and S6.

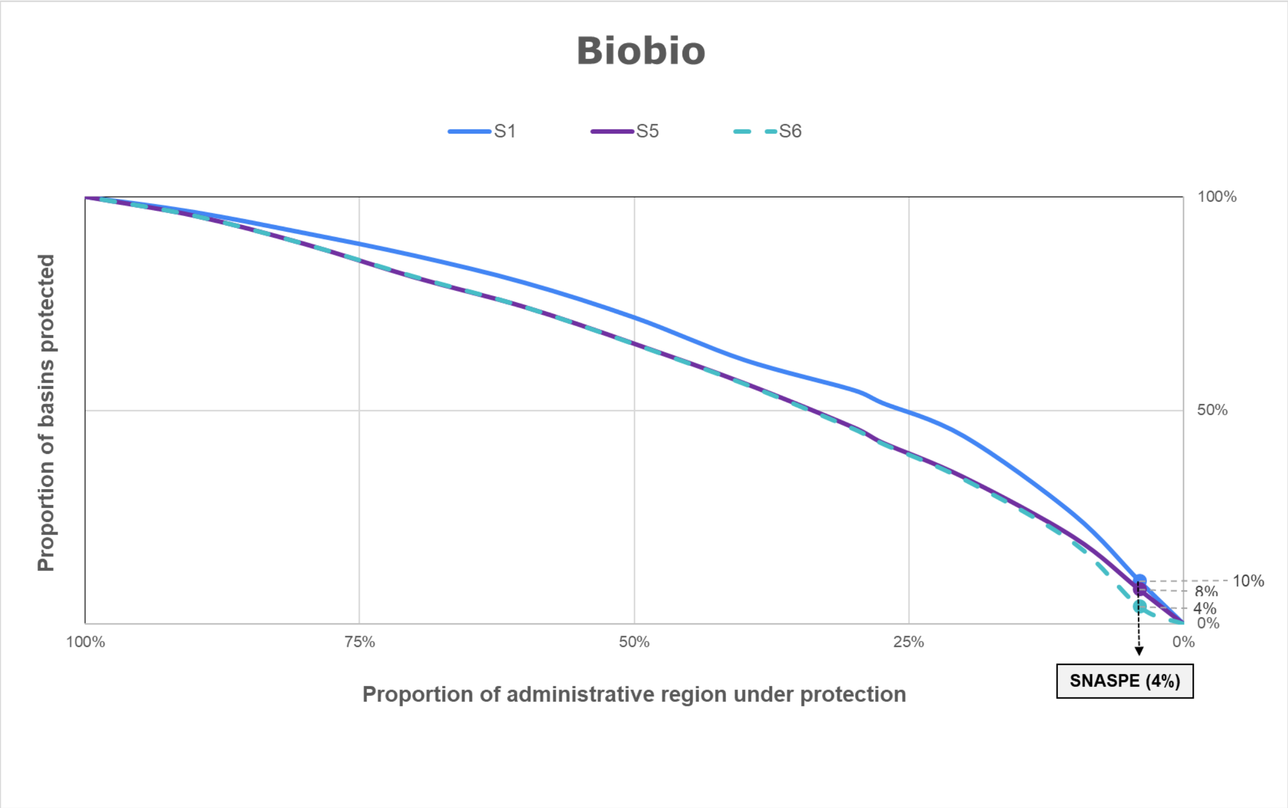

Figura 16. Proportion of hotspot basins included in PAs in Biobío region for scenarios S1, S5 and S6.

In Araucanía SNASPE (Fig. 17) area accounts for 8% of the total area of the region, protecting 8% of priority basins. Contrarily, the distribution of scenarios S1 and S5 protect 20% and 16% respectively. The replacement costs are 12% and 8% in the respective scenarios, this is the biggest replacement costs among the four regions.

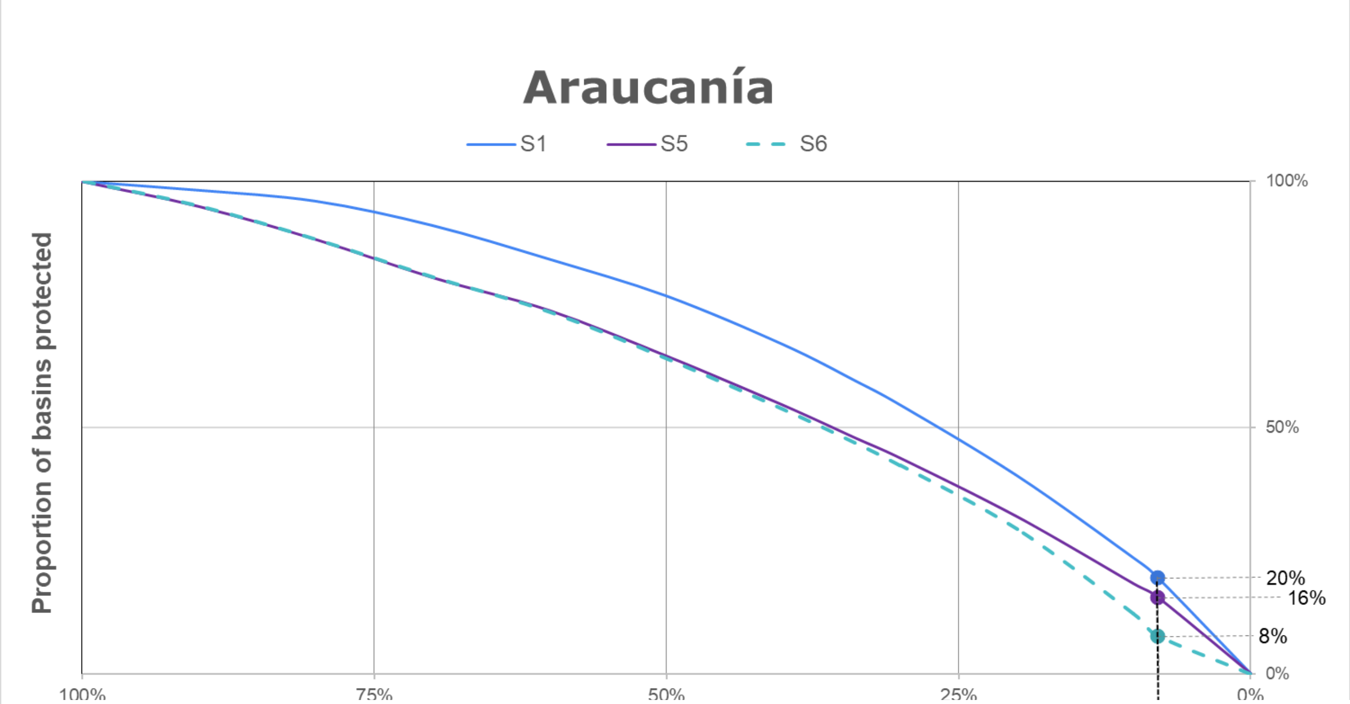

Figura 17. Proportion of hotspot basins included in PAs in Araucanía region for scenarios S1, S5 and S6.

4. DISCUSSION

4.1 Hotspots identification and protection

The identification of areas with a high capacity for providing WES serves as a key strategy in setting priority places where to implement conservation measures such as PAs, facilitating spatial planning processes (Cai et al. 2017, Li et al. 2017). As was observed, the spatial distribution of WES hotspots varies across the landscape upon the prioritization of specific variables. Basins within the eastern mountain range and those associated with major river courses tend to hold higher conservation priority in term of their capacity to provide WES.

However, when threat processes affecting WES provision are factored into the priority variable, the spatial pattern of hotspots undergoes significant alterations. Across the four administrative regions, new hotspots emerge, particularly within sector of the Coastal Mountain range. This new distribution mandates careful consideration in PAs implementation strategies.

The inclusion of threat indicators contributes to a more precise spatial prioritization, particularly when these indicators encompass variable directly impacting the integrity of the hydrological cycle, such as lower precipitation levels, temperature fluctuations (Fan et al. 2016), land use changes and forest fires (CITA)

In terms of the effectiveness of the SNASPE PAs network, there's a notable higher protection of hotspots observed at the headwater's basins, particularly within the Andean Mountain range area. The concentration of PAs in these areas aligns with the global trend of concentrating PAs at headwater basins. This strategy sustains ecological functionality of freshwater ecosystems and also it benefits from encountering less competition with alternative land uses (Harrison et al. 2016)

Across the four regions, the existing PAs network provides limited protection to WES hotspots, with Maule region exhibiting the least efficiency. Notably, in all regions, scenarios integrating threats have a lower hotspots representation in PAs, primarily due to a smaller coverage of PAs in the Coastal Mountain range. A strategic distribution of PAs along both headwaters and mouth basins could potentially enhance hotspot protection.

For instance, Biobio region showcases PAs distributed across both the Andean and Coastal Mountain range leading to the highest hotspots protection among the four regions. In contrast, Araucanía region features a higher surface area of PAs in the Andean Mountain range, however, its level of hotspot protection significantly decreases when threats are considered because the priority levels shift to the Coastal Mountain range.

Expanding the coverage of PAs within hotspots in the Coastal Mountain range across all regions could significantly contribute to the protection of WES. Specifically, in Maule region, which has the lower efficiency in PAs spatial pattern, augmenting PAs distribution along the main river holds potential to elevate effectiveness of WES protection. Establishing PAs along river systems stands a strategic conservation approach, preserving water flow, nutrients, and sediments flow, maintaining vegetation not represented in terrestrial PAs and also serving as biological corridors facilitating movement of both aquatic and terrestrial fauna (Pittock et al. 2015).

However, it’s crucial to note that the mere establishment of PAs does not guar the preservation of the hydrological cycle integrity that provide of WES. To ensure that PAs are successful there must be some crucial considerations such as ensure the representation of diverse aquatic habitats, monitoring spatio-temporal fluctuations in the hydrological regime, maintaining water quality and preservation of riparian vegetation (Acreman et al. 2020).

4.2 Landscape planning for WES protection

Due both the involvement of numerous stakeholders in water resources management and the vast beneficiaries of these services, complementing PAs establishment with an integrated watershed management becomes imperative (Juffe-Bignoli et al. 2016). This integrated approach enables the implementation of management strategies encompassing the entire hydrological cycle across watersheds, transcending PAs boundaries.

In landscape planning science, scale has a pivotal role. In the case of WES, assessing pertinent hydrological indicators at finer scales helps capture local variations within the same watershed (Sun et al. 2020). Nonetheless, the execution of management policies, strategies and actions should operate at a regional or landscape scale to ensure their efficacy and relevance within a given territory (Gomez-Baggethun et al. 2013).

In Chile, there are political instruments operating at the regional scale which objectives align with the maintenance of ES and PAs creation. For instance, Regional Development Strategies embody long-term, broad social initiatives, delineating major regional objectives and priorities for public and private actions (Soms 2004). Additionally, the Regional Land Use Plan (PROT) as defined by law 21074, it's a political instrument that guides the use of the region's territory to achieve its sustainable development through strategic guidelines and a macro zoning of said territory.

Each region of the study area confronts unique challenges in enhancing the effectiveness of SNASPE network for WES protection. The presented information facilitates the establishment of spatial priorities where to implement actions aimed at fulfilling the objectives outlined in mentioned political instruments.

4.3 Study limitations

To design an effective PAs network, is essential to assess the state of biodiversity using metrics such as representativeness, vulnerability, and irreplaceability. This assessment aids in establishing conservation priorities since the main objective of PAa is the preservation and integrity of biodiversity (Kukkala and Moilanen 2013).Considering that this study focuses on characterizing the protection status of WES indicators related to biodiversity were not included in the spatial prioritization process. However, supplementing WES flow with biodiversity indicators could enhance choosing areas with grater relevance in the maintenance of both biodiversity and WES, particularly for freshwater biodiversity (Domisch et al. 2019, Funk et al. 2019, Riis et al. 2020).

When suggesting new areas for future PAs, considering implementation feasibility is a key step. Factors determining objectives success such as spatial connectivity between PAs (Brennan et al. 2022), engagement and support from local communities (Cetas and Yasué, 2017) funding for PAs maintenance (Watson et al. 2014), among others, need to be considered. These aspects play an important role in determining the viability and efficacy of proposed conservation strategies.

5. CONCLUSION

Identifying areas with optimal capacity to provide WES allows for prioritizing the establishment of new PAs crucial for conserving ecosystems integral to the hydrological cycle’s functioning. Currently, the existing PAs under SNASPE does not protects WES hotspots sites, especially when threats to the hydrological cycle are considered. Consequently, a considerable portion of the areas with the highest priority remains unprotected.

Expanding the surface area of PAs in south-central Chile holds great importance in preserving the integrity of basins that supply essential WES to the population. Each region has it owns challenges and collaborative efforts among regions to effectively protect hotspots is required. While augmenting PAs coverage is crucial, this must be complemented with an integrated watershed management due to the involvement of numerous stakeholders and institutions responsible for managing and utilizing water resources. This integrated approach is imperative for a holistic conservation and sustainable resource management.

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CONCLUSIONES GENERALES

El presente trabajo presentó nuevos antecedentes que mejoran el grado de entendimiento respecto a WES aplicados para la planificación del paisaje. En primer lugar, se estableció que el estudio de los WES es una disciplina científica en continuo desarrollo. Se identificaron tres tendencias temáticas de investigación a nivel global, investigación sobre las consecuencias de cambio de uso de suelo en la provisión de servicios, evaluación económica de servicios ecosistémicos e investigación enfocada en áreas urbanas y sus necesidades.

A partir de lo concluido en el primer capítulo se justifica la pertinencia de desarrollar un caso de estudio en el segundo capítulo, con el fin de disminuir las brechas de conocimientos identificadas. El caso de estudio busca presentar un estudio sobre WES aplicado a la planificación sistemática del paisaje para la conservación dentro de la zona centro-sur de Chile. Se estableció que las áreas protegidas pertenecientes a SNASPE no son suficientes para asegurar protección de WES y que su distribución espacial dentro del territorio no es eficiente generando importantes costos de remplazo. Cada región dentro del área de estudio presenta sus propios desafíos en cuanto al aumento de la superficie espacial de áreas protegidas, siendo la región del Maule la más deficiente en este aspecto.

Utilizar información sobre WES es fundamental para una planificación del paisaje y toma de decisiones que aseguren la sustentabilidad de los ecosistemas. Trabajos futuros deberían enfocarse en complementar información sobre WES con información sobre biodiversidad para generar análisis más integrativos que aporten a proteger la integridad ecológica de los ecosistemas que proveen de servicios esenciales para el bienestar humano.