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Impact of Forest Stewardship Council (FSC) forest certification on the provisioning of ecosystem services in forest landscapes of south-central Chile: a case study in the Nahuelbuta landscape

Impact van Forest Stewardship Council (FSC) certificering op de levering van ecosysteemdiensten in boslandschappen van zuid-centraal Chili: een case study in het Nahuelbuta landschap

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Dissertation presented in
Fulfillment of the requirements
for the degree of Master of Bioscience Engineering:
Agro- and Ecosystems Engineering

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June 2019

Acknowledgements

First, I would like to thank my promotors, professor Ben Somers and professor Adison Altamirano, for giving me this very interesting research opportunity, for giving advice and for always helping me out with my questions and doubts. Special thanks go to Priscila Molina Pérez, Carlos Vergara Aqueveque, Irina Montenegro Paredes and the whole team of the World Wide Fund for Nature (WWF) Chile for this collaboration. Working together with WWF was a dream coming true.

Secondly, my thanks go out to all Ph.D. students, both in Chile and Belgium, for making time to help me out with technical problems and questions, and to all the participants of the questionnaire, making this research possible.

I am also grateful for the support of my dear friends, with special thanks to my Chilean friends, for making my experience in Chile unforgettable!

Last, but not least, thanks to my parents, sister and the rest of my family, for always being there, no matter what.

Scientific summary

Sustainable forest management (SFM) is gaining more and more importance. Forestry companies increasingly implement forest certification programs as a market mechanism for this SFM. The two most important players of the more than 50 certification schemes are the Program for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC). The first being the largest and the latter being the first and fastest growing forest certification scheme, based on certified area. Forest certification originated in the context of concerns on deforestation and biodiversity loss. There is however a lack of scientific empirical evidence on the environmental effects of forest certification and more specifically on its effects on the supply of ecosystem services (ES). Chile's importance for the global forest industry, as one of the 10 most important countries dedicated to exotic forest plantations, makes it suitable for evaluating these effects. This study aimed to investigate the impacts of FSC certification on the supply of ES in forest landscapes of south-central Chile, using the Nahuelbuta landscape as a case study area, located in one of the 26 global priority areas for biodiversity. This was done by first identifying ES, related to the national FSC standards and then selecting the most relevant ES with a questionnaire for stakeholders associated to FSC: partners of the FSC network, companies owning FSC certified forests, academic people and FSC certification bodies. The effects were then assessed on most relevant ES: water regulation, fresh water supply, biodiversity conservation, habitats for plants and animals and soil conservation. ES were quantified biophysically by using the InVEST (Integrated Valuation of Ecosystem Services and Trade-offs) Annual Water Yield, Habitat Quality and Sediment Delivery Ratio models. The landscape was stratified in five sublandscapes (SLs), after which obtained model results were extracted for FSC certified and uncertified forest properties in each SL and statistically compared between a pre-certification baseline period (2008-2010) and a post-certification period (2016-2018). Effects of FSC were found to be positive for water yield (for 3 SLs), habitat quality, sediment export decrease (3 SLs) and sediment retention (for 2 SL), while negative with increased habitat degradation (4 SLs). Obtained insights, together with the used methodology, can contribute to the better understanding of effects of FSC certification on ES supply.

List of abbreviations

ArcGIS: Arc Geographic Information System

AET: Actual evapotranspiration

ASI: Accreditation Services International

ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer

AWY: Annual Water Yield

BMP: Best Management Practices

CAN/CSA-Z809: Sustainable Forest Management standard of the Canadian Standards Association

CAR: Corrective Action Request

CAT: Certification Assessment Tool

CB: Certification Body

CBD: Convention on Biological Diversity

CCBA: Climate, Community and Biodiversity Alliance

CERFOR: the Chilean System of Forest Certification (‘Sistema Chileno de Certificación Forestal’)

CHIRPS: Climate Hazards Group InfraRed Precipitation with Station data

CIREN: Natural Resources Information Centre (‘Centro de Información de Recursos Naturales’)

CL: conventionally-logged

CoC certification: Chain of Custody certification

CONAF: National Forest Corporation of Chile (‘Corporación Nacional Forestal’)

CPET: Central Point of Expertise on Timber

CWD: Coarse woody debris

DEM: Digital Elevation Model

ES: Ecosystem service(s)

ESA: European Space Agency

ESRI: Environmental Systems Research Institute

ETFRN: European Tropical Forest Research Network

FAMNK: Foundation Friends of the Noel Kempff Museum (‘Fundación Amigos del Museo Noel Kempff’)

FC: Forest certification

FCIS: Forest Certification Information System

FES: Forest ecosystem services

FLO: Fairtrade Labelling Organization

FMU: Forest Management Unit

ForCES: Forest certification for Ecosystem Services

FSC: Forest Stewardship Council

FSC P&C: FSC Principles & Criteria

GHG: Greenhouse gas

GIS: Geographic Information System

GMO: Genetically Modified Organism

GPS: Global Positioning System

HCV: High Conservation Value

HCVA: High Conservation Value Area

HD: Habitat Degradation

HQ: Habitat Quality

IC: Connectivity Index

ID: Identity

IFF: Intergovernmental Forum on Forests

IFL: Intact Forest Landscapes

IGI: International Generic Indicators

INFOR: Forest Institute of Chile (‘Instituto Forestal’)

INIA: Agricultural Research Institute of Chile (‘Instituto de Investigaciones Agropecuarias’)

InVEST: Integrated Valuation of Ecosystem Services and Trade-offs

IPF: Intergovernmental Panel on Forests

ITTO: International Tropical Timber Organization

IUCN: International Union for Conservation of Nature’s Red List of Threatened Species

JSP: Joint Solutions Project

KS: Kolmogorov-Smirnov

LULUCF: Land use and land-use change and forestry

m.a.s.l.: meters above sea level

MCPFE: Ministerial Conference on the Protection of Forests in Europe

MEA: Millennium Ecosystem Assessment

MHNNKM: Noel Kempff Mercado Natural History Museum (‘Museo de Historia Natural Noel Kempff Mercado’)

MPWG: Montréal Process Working Group

MSWEP: Multi-Source Weighted-Ensemble Precipitation

MTCS: Malaysian Timber Certification Scheme

MWW: Mann-Whitney-Wilcoxon

NASA: National Aeronautics and Space Administration

NGO: non-governmental organization

NSMD: non-state market-driven governance regimes

NTFP: Non-timber forest products

OECD: Organization for Economic Co-operation and Development

PAWC: plant available water content

PEFC: Pan-European Forest Certification; since 2003: Programme for the Endorsement of Forest Certification

QGIS: Quantum Geographic Information System

REDD+: Reducing Emissions from Deforestation and Forest Degradation

RF: Random Forest

RGB: Red-Green-Blue

RKLS: potential soil loss for each pixel if the land cover was bare soil

RIL: Reduced-Impact Logging

RS-GIS: Remote sensing-Geographical information system

RUSLE: Revised Universal Soil Loss Equation

SCP: Semi-Automatic Classification Plugin

SCR: Steering Committee Report of the State-of-Knowledge Assessment of Standards and Certification

SCS: Scientific Certification Systems

SDR: Sediment Delivery Ratio

SFM: Sustainable Forest Management

SFI: Sustainable Forestry Initiative

SL: Sublandscape

SMZ: streamside management zones

SNASPE: National System of Protected Areas (‘Sistema Nacional de Áreas Protegidas’)

SSW: Subsubwatershed

SVAP: Stream Visual Assessment Protocol

T: T-test

TNC: The Nature Conservancy

ToC: Theory of Change

TPAC: Timber Procurement Assessment Committee

UNCED: United Nations Conference on Environment and Development

UNFF: United Nations Forum on Forests

UNGA: United Nations General Assembly

U.S.: United States

VCS: Verified Carbon Standard

WWF: World Wide Fund for Nature

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1. Context and objectives

Forest certification is used more and more by forestry companies as a market mechanism to support and encourage of sustainable forest management (SFM) and advice consumers about forest product sustainability (Nussbaum & Simula, 2005; Clark & Kozar, 2011; FAO, 2018). This SFM is responsible management ensuring continuing forest ecosystem health, regeneration potential and production capacity to provide social, economic and environmental benefits, for generations of the present and future (Wang, 2004; MacDicken *et al*., 2015). Globally, there are more than 50 certification scheme, including the two largest players: the Program for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC) (Auld *et al*., 2008; Vogel, 2008; Walter, 2008; Clark & Kozar, 2011; FAO, 2018). Based on certified area, FSC is the fastest growing certification scheme (195,215,484 ha; including 84 countries) (FAO, 2018b; FSC, 2019) while the PEFC scheme is the largest (309,473,277 ha) (FAO, 2018b; PEFC, 2018). FSC, created in 1993, was also the first certification mechanism and originated from concerns on deforestation and biodiversity loss (Elliott & Schlaepfer, 2001; Kozak *et al.*, 2004; Nussbaum & Simula, 2005; Cashore *et al.*, 2006). It is an "independent, non-profit, non-governmental organization, established to promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests*"* (FSC, 2016d, p. 2).

Research on the environmental impacts of forest certification (FC), and more specific FSC certification, is however mostly based on literature studies, and shows both positive and negative effects (e.g. Cubbage *et al*., 2010; Elbakidze *et al*., 2011; Heilmayr & Lambin, 2016). So far, insufficient empirical proof exists on the effects of FC to obtain fully understanding of it at a global scale (e.g. Romero *et al*., 2013). There is thus a need for on-the-ground evidence for better understanding of these impacts. Specifically, there is a need to critically investigate for how long, when, how, where, why, at what cost and to what extent certification affects forest management and what the environmental effects of this management are (e.g. Romero *et al*., 2013). Moreover, since few evidence exists on effects on ecosystem service (ES) provisioning (e.g. Auld *et al*., 2008), there is an urgent need for studies investigating these effects.

Chile plays an important role in the global forestry sector, being on the fifth place for this sector in South America and one of the 10 most important countries devoted to exotic forest plantations (Cubbage *et al*., 2007), with more than 3 million ha plantations (3,084,354 ha in 2017) (National Forest Corporation of Chile (CONAF), 2017). In addition, it is country number 23 in the world, based on FSC certified area (2,331,595 ha) (FSC, 2019). Therefore, Chile's importance in the forestry context make it suitable for the investigation of environmental FC effects, including empirical evidence. This study evaluates FSC certification, hypothesizing there are effects on the supply of ES and focuses on the following:

General objective:

Evaluate the impact of FSC certification on ecosystem service supply in forest landscapes of south-central Chile, using as a case study the Nahuelbuta landscape in south-central Chile.

Specific objectives:

- Identify and select ecosystem services, associated with indicators of the national FSC standards.
- Assess the effect of FSC certified and non-certified forest properties on ecosystem service supply, using a pre-certification baseline period (2008-2010) and a post-certification period (2016-2018).

2. General literature study and background

2.1 Forest certification history, importance and concepts

2.1.1 Sustainable Forest Management and forest certification

Forest certification (FC) is a market mechanism to support and promote SFM and advice consumers about forest product sustainability (Nussbaum & Simula, 2005; Clark & Kozar, 2011; FAO, 2018). An hierarchical sustainability framework for land use (change) and forestry (LULUCF) projects was developed by Madlener *et al.* (2006) to support the programming, appliance and assessment of SFM (Figure 2.1). This framework gives potential guidelines and a structural example for toolkits for implementation as well as evaluation standards (Madlener *et al.*, 2006). This is in contrast to other standards and frameworks, for forest management evaluation alone making the direct connection from objectives to principles (Lammerts van Bueren & Blom, 1997; Holvoet & Muys, 2004; FSC, 2018[a]) or criteria (International Tropical Timber Organization (ITTO), 2005) (Figure 2.2). Principles, criteria and indicators were defined by as the following:

"A principle is a fundamental law or rule, serving as a basis for reasoning and action. Principles have the character of an objective or attitude concerning the function of the forest ecosystem or concerning a relevant aspect of the social system that interacts with the ecosystem. Principles are explicit elements of a goal, e.g. sustainable forest management or well managed forests.” (Lammerts van Bueren & Blom, 1997, p. 18)

“A criterion is a state or aspect of the dynamic process of the forest ecosystem, or a state of the interacting social system, which should be in place as a result of adherence to a principle of sustainable forest management (or well managed forest). The way criteria are formulated should give rise to a verdict on the degree of compliance in an actual situation.” (Lammerts van Bueren & Blom, 1997, p. 20)

“An indicator is a quantitative or qualitative parameter which can be assessed in relation to a criterion. It describes the features of the ecosystem or the related social system in an objectively verifiable and unambiguous way, or it describes elements of prevailing policy and management conditions and human driven processes indicative for the state of the eco- and social system.” (Lammerts van Bueren & Blom, 1997, p. 22)

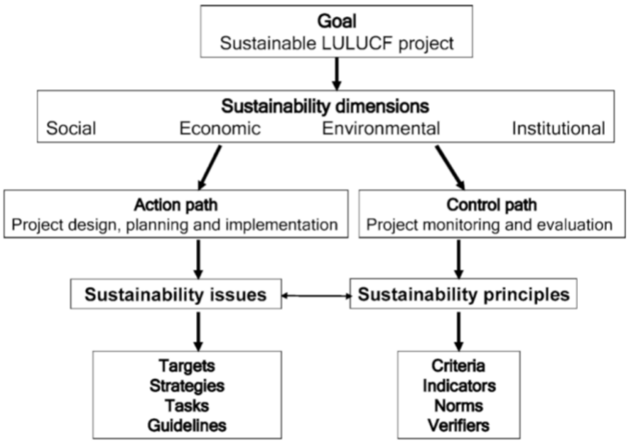

Figure 2.1: Hierarchical sustainability framework for LULUCF projects (Madlener *et al.*,2006, Figure 1, p. 245)

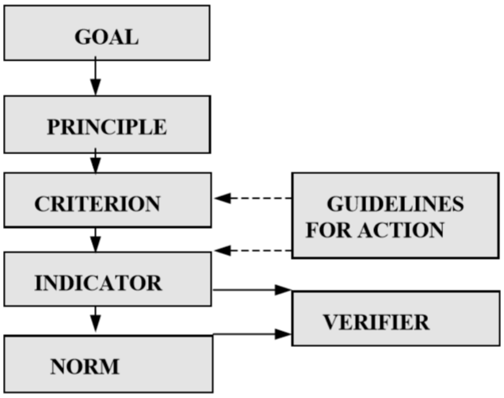

Figure 2.2: Hierarchical levels of the framework of Lammerts van Bueren & Blom (1997, p. 15) for the development of principles, criteria and indicators

Since there is no universal agreement about SFM definitions and it is dependent on local circumstances, the evaluation of global SFM is challenging (Wang, 2004; Nussbaum & Simula, 2005; MacDicken *et al*., 2015). It is also difficult to measure sustainability aspects directly, leading to the use of indicators in certification systems, as a proxy, e.g. for biodiversity (Den Ouden *et al.*, 2010). In the voluntary FC procedure, an independent third party (accredited certification body (CB)) judges about sustainability and quality the forest management and production, using standards, specific for every certification scheme (Rametsteiner & Simula, 2003; Nussbaum & Simula, 2005). Furthermore, the increasing certified forest area leads to a growing availability of certified wood and derived products (Den Ouden *et al.*, 2010). Therefore, two FC types exist: chain of custody (CoC) certification and forest management certification. The first assesses the production process from forest to consumer, and checks if certified material is separated from non-certified materials in this process, while the second evaluates the forest managements using specific standards or requirements (Nussbaum & Simula, 2005; FAO, 2018). End products are certified, when both certification types are present (Nussbaum & Simula, 2005; FAO, 2018). Despite of the increase in global certified area, there is a large difference between tropical and temperate forests: only 6 % of the total permanent forests (in 38 countries) are internationally certified as of 2014 in tropical domains, while 90% of the internationally certified forest area is situated in temperate and boreal domains (MacDicken *et al.*, 2015). Because deforestation is mostly linked to the southern hemisphere and tropical areas, there is an urgent need in increasing the portion of certified tropical forests (Siry *et al.*, 2005). Problems of developing countries to obtain certified producers are e.g. related to slow progress in markets (Eba'a Atyi & Simula, 2002) and phased approaches to certification could be a possible solution (Nussbaum & Simula, 2005). Finally, policies and regulations supporting SFM are globally present in 97% of the forest area (MacDicken *et al.*, 2015). The presence of SFM enabling tools and conditions (policy, legislation, stakeholder participation, forest inventories, forest management plans etc.) positively influences SFM, but is however no guarantee for effective SFM (Den Ouden *et al.*, 2010; MacDicken *et al.*, 2015). Hence, FC tries to support and simulate this effectivity (Den Ouden *et al.*, 2010; MacDicken *et al.*, 2015).

2.1.2 Forest certification history and standards

FC originated from concerns on deforestation and biodiversity loss in the 1980s with the creation of FSC as the first certification mechanism (Elliott & Schlaepfer, 2001; Kozak *et al.*, 2004; Nussbaum & Simula, 2005; Cashore *et al.*, 2006). An overview of the FC history can be found in Appendix A. FSC is an "independent, non-profit, non-governmental organization, established to promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests" (FSC, 2016d, p. 2). The forest management certification guarantees SFM, fulfilling the FSC Principles and Criteria (FSC, 2018d), while CoC certification latter is first needed for a company to obtain FSC labelled products (FSC, 2018f). In addition, there are three different FSC product labels: the FSC 100% label (products containing wood, completely originating from FSC certified forests), FSC Mix label (for products containing paper or wood from recycled materials, FSC-certified forests or FSC controlled wood, (for which i.a. controlled wood cannot be harvested illegally or in forests where High Conservation Values (HCVs) are under threat) and the FSC Recycled label (paper or wood in the products is derived from reused materials) (FSC, 2018f).

The FSC scheme is characterised by FSC Principles & Criteria (FSC P&C), guaranteeing SFM (FSC, 2018d). The International Generic Indicators (IGI) were created to increase the correspondence of global SFM standards and make it more efficient to approve national standards (FSC-International, 2015). In addition, national FSC standards have been developed in many countries to adapt the IGIs to the national situation (Evison, 1998; Nussbaum & Simula, 2005; FSC, 2018c).

The 10 FSC Principles are:

"**PRINCIPLE 1:** The Organization shall comply with all applicable laws, regulations and nationally-ratified international treaties, conventions and agreements.

PRINCIPLE 2: The Organization shall maintain or enhance the social and economic wellbeing of workers.

PRINCIPLE 3: The Organization shall identify and uphold Indigenous Peoples' legal and customary rights of ownership, use and management of land, territories and resources affected by management activities.

PRINCIPLE 4: The Organization shall contribute to maintaining or enhancing the social and economic wellbeing of local communities.

PRINCIPLE 5: The Organization shall efficiently manage the range of multiple products and services of the Management Unit to maintain or enhance long term economic viability and the range of environmental and social benefits.

PRINCIPLE 6: The Organization shall maintain, conserve and/or restore ecosystem services and environmental values of the Management Unit, and shall avoid, repair or mitigate negative environmental impacts.

PRINCIPLE 7: The Organization shall have a management plan consistent with its policies and objectives and proportionate to scale, intensity and risks of its management activities. The management plan shall be implemented and kept up to date based on monitoring information in order to promote adaptive management. The associated planning and procedural documentation shall be sufficient to guide staff, inform affected stakeholders and interested stakeholders and to justify management decisions.

PRINCIPLE 8: The Organization shall demonstrate that, progress towards achieving the management objectives, the impacts of management activities and the condition of the Management Unit, are monitored and evaluated proportionate to the scale, intensity and risk of management activities, in order to implement adaptive management.

PRINCIPLE 9: The Organization shall maintain and/or enhance the High Conservation Values in the Management Unit through applying the precautionary approach.

PRINCIPLE 10: Management activities conducted by or for The Organization for the Management Unit shall be selected and implemented consistent with The Organization's economic, environmental and social policies and objectives and in compliance with the Principles and Criteria collectively."

(cited from FSC, "The 10 FSC Principles", 2018, Available online: https://ic.fsc.org/en/what-is-fsc-certification/principles-criteria/fscs-10-principles).

FSC was the only operational certification mechanism until 1997 and its important international role ascribes to four elements: 1) strong supporting non-governmental organizations (NGOs) 2) external funding possibility, 3) absence of viable alternatives and 4) the organization's crew engagement and quality (Baharuddin & Simula, 1998; Nussbaum & Simula, 2005). The people and industries not included in FSC (private forest owners, governments, a part of the global forest industry players…), saw it as a threat (Nussbaum & Simula, 2005). For example, smallholder private forests owners feared a reduction of their rights in control of forest management and would increase their costs, forest product industries were concerned about the strong influence of environmental NGOs if the FSC scheme would have a monopoly and tropical timber producers worried about certification being a new boundary to markets (Nussbaum & Simula, 2005; Auld *et al.*, 2008). In addition producers disagreed with the stringency of the FSC standards (Cashore *et al.*, 2004; Gulbrandsen, 2004) and thought that the one's applying the standards for SFM (forest owners and companies) should be creating these (Cashore, 2002; Cashore *et al.*, 2004). Although the acceptance of independent certification as a part of global economy gradually increased, several national certification schemes, competing with the FSC program were created (Elliott, 2000; Gulbrandsen, 2004; Nussbaum & Simula, 2005), for example the Sustainable Forest Initiative (SFI) (United States (U.S.)) and the Sustainable Forest Management standard of the Canadian Standards Association (CAN/CSA Z809) (Cashore *et al.*, 2004; Overdevest, 2004). However, these national schemes were confronted with acceptance problems in global export markets (Nussbaum & Simula, 2005). Therefore, there was a raising awareness of three things: NGO support is important for brand protection, using global schemes is easier for global trade as consumers easily understand the certification label and it is crucial to have sufficient supply if companies commit to only certified products (Nussbaum & Simula, 2005). This leaded to the European Pan-European FC (PEFC) scheme (1999) for common acceptance of national certification schemes (Nussbaum & Simula, 2005; PEFC International, 2018). The PEFC replaced its name in 2003 to Programme for the Endorsement of FC, becoming a global structure for acceptance and assessment of national and regional FC schemes (Nussbaum & Simula, 2005; PEFC International, 2018).

2.1.3 FSC certification compared to other certification schemes

Various studies have compared FC schemes. There is however a significant amount of certification scheme evaluations and comparisons, which cannot be recognized as objective, because of two groups in FC (Visseren-Hamakers & Pattberg, 2013). One group is preferring the FSC scheme (most environmental and social NGOs and some industries), while another group favours the PEFC scheme (principally national governments, forest owners and industries) (Cashore, 2004; Visseren-Hamakers & Pattberg, 2013). It happens that certification schemes recommend themselves for their SFM (Visseren-Hamakers & Pattberg, 2013). Furthermore, different focuses are present in research: industries study more the shared scheme characteristics (Oliver, 2004), while NGOs focus more on the limitations and comparisons of certification programs with generally high scores for the FSC scheme (Liimatainen & Harkki, 2001; Ozinga & Krul, 2004; Hirschberger, 2005). An example of a comparison by NGOs is the Certification Assessment Tool (CAT), developed by the World Wide Fund for Nature (WWF), which compares certification programs and their standards, based on the standard strength and the system strength (WWF, 2015). Even this is not based on empirical results, but uses document studies, the evaluation of the strengths uses indicators, being proxies for the probability of the implementations of the program's requirements on ground level (WWF, 2018e). Until now the CAT compared the FSC international system (version 4 and 5 and Malaysian certification standards), the Malaysian Timber Certification Scheme (MTCS) (with PEFC supporting its Standard for Natural Forests) and the PEFC system (WWF, 2018e). WWF (2018b) concluded that the FSC scheme has the highest credibility and system strength stronger than the other programs. Furthermore, stronger criteria on producer communication and emissions of greenhouse gases could improve the FSC program (WWF, 2018e). Additionally, the SFM requirements of governments are used as target when evaluating certification standards (Central Point of Expertise on Timber (CPET), 2010; Timber Procurement Assessment Committee (TPAC), 2010). The many certification schemes vary in their requirement broadness, the degree of these requirements surpassing the national requirements and the stakeholders defining their standards (Romero *et al.*, 2013). Moreover, a lot of studies made the comparison based on the strictness of their operation methods, constituencies and standards (Cashore, 2002; Holvoet & Muys, 2004; Fischer *et al.*, 2005; Terrell & Almeida, 2006; Auld *et al.*, 2008; McDermott *et al.*, 2008; Tikina & Innes, 2008; Overdevest, 2010; Clark & Kozar, 2011; Johansson & Lidestav, 2011). Holvoet & Muys (2004) studied 164 of the world's SFM standards (including PEFC and FSC) through multivariate statistics with a reference standard, created for this comparison. They found that the considerable difference between the standards generally come from a different geographical origin and application level: standards from developed countries prioritize ecologic functions of the forest and stress the necessity for information of investigations, whereas standards from developing countries mostly accentuate economic and social sustainability elements and focus less on research-based information (Holvoet & Muys, 2004). Furthermore, national standards generally contain monitoring aspects and less details, while Forest Management Unit (FMU) level standards incorporate monitoring elements and many concrete operational management aspects (Holvoet & Muys, 2004). They recommend harmonisation of standards of SFM through international collaboration when differences exist (Holvoet & Muys, 2004).

Although it is unlikely only harmonization can give a solution to the obstacles to certification in developing countries (e.g. less able to pay certification costs), it can benefit both consumers and suppliers such as a common certification framework and a common CoC standard (Fischer *et al*., 2005). Furthermore, Overdevest (2005) concluded differences remain present between standards endorsed by the PEFC and FSC schemes. Moreover, differences in 'prescriptiveness' (related to trust and power issues) among standards are present (McDermott, 2003; McDermott *et al*., 2008). Prescriptive standards have preference among non-producers to control over producers, while more flexibility and ability to decide about their own rules present among producers (Auld & Bull, 2003). Specifically, McDermott & Cashore (2008) conclude that in Canada and the U.S., FSC standards are more normative than the standards endorsed by the PEFC scheme. In addition, internal differences in prescriptiveness are present in the PEFC and FSC schemes, such as differences present among regional FSC standards in the US and Canada related to differences in governmental control (McDermott *et al*., 2008). Furthermore, Washburn & Block, (2001), compared the Montreal Process with the North American-based SFI standards and the FSC standards. The certification standards and Montreal Process both encourage SFM, but have different focuses: FSC standards are linked to FMUs and require outcomes, while the Montreal Process is more descriptive and focuses on national levels (Washburn and Block, 2001). Additionally, a meta-analysis by Clark & Kozar (2011) concluded FSC scheme performed the best for social and ecological health SFM criteria, compared to programs endorsed by the PEFC, like the SFI and the CAN/CSA-Z809, which performed the best for the economic firm endurance, and forest productivity SFM criteria. Besides, most certification schemes (excluding FSC) focus on individual parts of the chain of production (Clark & Kozar, 2011). This meta-analysis however included only one comparison study (of Sverdrup-Thygeson *et al.*, 2008) based on empirical information (Clark & Kozar, 2011).

In general, most of the mentioned comparative studies related to strictness conclude FSC is the most complete and strict certification scheme, in relation to social, economic, political and environmental problems (Romero *et al*., 2013). In this context more stringent standards, are assumedly linked to a larger change in behaviour of certified producers (Auld *et al*., 2008), but the preferred self-control and flexibility among producers may cause a faster adoption of less strict certification systems (Gulbrandsen, 2004; Auld *et al.*, 2007). Evaluation and comparison of certification program effectivity mostly focuses on the correspondence and application of standards (e.g. Mattli & Büthe, 2003), and therefore possibly not captures unapparent effects (Visseren-Hamakers & Pattberg, 2013). As a result, future investigation should concentrate on measurement of standards effectivity at different scales (local, national, landscape), the issue of the isolation of standard effects from other impacts and (sub)national legislation in the certification effectiveness evaluation (Visseren-Hamakers & Pattberg, 2013). Finally, this future research should also focus on the (in)direct impacts of FC, comparison of standards effectivity in and across geographical zones and the indefinite impacts in relation to economic, social and environmental indicators (Pattberg, 2012). Although these three mentioned components of SFM are important in the assessment of the effects of FC, the next sections focus on the environmental impacts.

2.2 Forest certification environmental effects and effects on ecosystem services

2.2.1 Forest related ecosystem services

Ecosystem services (ES), defined as: "the benefits people obtain from ecosystems" are more and more crucial in sustainable decision making (Corvalan *et al.*, 2005, p. 27). These services are divided in several categories: 'supporting services' (services "that are necessary for the production of all other ecosystem services, such as primary production, production of oxygen, and soil formation" (Corvalan *et al.*, 2005, p. 29)), 'provisioning services' ("the products people obtain from ecosystems, such as food, fuel, fibre, fresh water, genetic resources" (Corvalan *et al.*, 2005, p. 29)), 'regulating services' ("the benefits people obtain from the regulation of ecosystem processes, including air quality maintenance, climate regulation, erosion control, regulation of human diseases, and water purification" (Corvalan *et al.*, 2005, p. 29),), and 'cultural services' ("the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences" (Corvalan *et al.*, 2005, p. 29)). Biodiversity can be described as a structural ecosystem element and the "variability among living organisms from all sources, including terrestrial, marine, and other aquatic living ecosystems and the ecological complexes of which they are part" (Corvalan *et al.*, 2005, p. 29). Furthermore, biodiversity serves as a basis from which ES are created (Corvalan *et al.*, 2005).

ES from forests and plantations are crucial for human well-being: they provide ES, such as habitat provisioning, biodiversity conservation, soil conservation, carbon sequestration and climate regulation, provisioning services (e.g. timber, charcoal and fuel wood, NTFP), freshwater purification (3/4 of the global freshwater) and cultural services (from recreation to spiritual importance of forests and trees) (FAO, 2018e; Shvidenko et al., 2005). A forest plantation is defined as: "a forest area established by planting or sowing with using either alien or native species, often with one or few species, regular spacing and even ages, and which lacks most of the principal characteristics and key elements of natural forests" (FSC, 2014, p. 5). The global forest area was 3999133,622 $.10^3$ ha in 2015 of which 278539 $.10^3$ ha was the planted forest area in this year (FAO, 2015). Globally, forest plantations covered 187 ha in 2000, with most plantations in Asia (62%) (FAO, 2001; Shvidenko *et al*., 2005). Forest plantations (including rubber plantations and palm plantations) area was 77,973,000 ha in 2015, which is 13,657,000 ha more than in 2000 (FAO, 2015; Keenan *et al*., 2015) The most important genus for coniferous (31% of plantation cover) and deciduous species (40% of plantation cover) is respectively *Pinus* (pine) (20%) and *Eucalyptus* (eucalypts) (10%) (FAO, 2001; Shvidenko *et al*., 2005). Plantations are characterized by a short rotation length (5-10 to 30 years for most tropical species) potential high productivity (e.g. average annual increments of pine and eucalypt of 10 to 20 m3/ha/year, and extremely high potential values of 50-60 m3/ha/year for e.g. rose gum (*E. grandis*) and Caribbean pine (*P. caribaea*)) (FAO, 2001; Shvidenko *et al*., 2005). Furthermore, there are different plantation types: industrial plantations (48 % of plantations in 2000) (mainly with commercial goals (providing timber, fuelwood, construction wood, wood for paper and biomass etc. and some social benefits such as employment), non-industrial plantations (26 % of plantations in 2000) (for ES like carbon storage, water and soil conservation, biodiversity and habitat conservation) and plantations with unspecified uses (26 % of plantations in 2000) (FAO, 2001; FSC, 2014; Shvidenko *et al*., 2005). The important role to partially fulfil demands from natural forests is increasing more and more: plantations covered just 5 % of the global forest area in 2000, but were calculated to increase to 44 % by 2020 (FAO, 2001; Shvidenko *et al*., 2005). However, the total forest area on Earth reduced by 3% in the period of 1990 to 2015 (from 4128 Mha to 3999 Mha), with a loss in the tropics and gain of temperate forests (Keenan *et al*., 2015). In addition, competing interests and time frames of the forest and plantation related ES can result in conflicts, for example between local people and large companies (Shvidenko *et al*., 2005).

Next to the FSC IGIs and national FSC standards, FSC standards for forest plantations exist (FSC, 2014, 2015b; FSC CHILE, 2012). These standards include for example the requirement of minimizing fire creation, pests and diseases, impacts on water and soil, the introduction of invasive species and with prohibition of the use of genetically modified organisms (FSC CHILE, 2012; FSC, 2014). Furthermore, HCV Areas (HCVAs) were no interventions take place are identified for each operation and plantations under FSC certification need to conserve and restore natural forests, including the use of e.g. riparian buffer zones, corridors and a diversity in rotation periods and ages in stands forming a mosaic. (FSC CHILE, 2012; FSC, 2014).

2.2.2 Scientific evidence of forest certification effects: few empirical and local conclusions

Research about the evaluation of FC and its environmental impacts are most often based on literature studies, without empirical evidence and show both positive and negative effects (e.g. Gullison, 2003; Rametsteiner & Simula, 2003; Nussbaum, 2004; Gulbrandsen, 2005; Hagan *et al*., 2005; Newsom *et al*., 2005, 2006; WWF, 2005; Sverdrup-Thygeson *et al*., 2008; de Lima *et al*., 2009; Schlyter *et al*., 2009; Van Kuijk *et al*., 2009; Cubbage *et al*., 2010; Elbakidze *et al*., 2011; Gómez-Zamalloa *et al*., 2011; Johansson & Lidestav, 2011; Heilmayr & Lambin, 2016). Moreover, research on this topic generally concludes and stresses the need for extra research, including on-the-ground collected and empirical data, to understand the environmental effects of FC (Ozinga & Krul, 2004; Auld *et al*., 2008; Peña-Claros *et al.*, 2009; Blackman & Rivera, 2010; Sheil *et al.*, 2010; Clark & Kozar, 2011; Putz & Romero, 2012). For example, Auld *et al*. (2008) conclude that it is critical to study the empirical effects of certification linked to private and public attempts for decreasing pressure on HCVAs and reducing deforestation. Moreover, Clark & Kozar (2011) conclude it is probable that the certification effects show the highest manifestation in the first 17 years after the beginning of FSC certification. They also conclude there is little knowledge about the performance of FC systems to realize SFM goals and they state that ecological data assessment (e.g. biodiversity) will show whether all competing certification programs show equal effects. Romero *et al*. (2013) proposed a framework for effective FC evaluation and its empirical impacts. In addition, they use the impacts definition of the Organization for Economic Co-operation and Development (OECD): “the positive and negative, primary and secondary long-term effects produced by a development intervention, directly or indirectly, intended or unintended” (OECD, 2015, p. 3).

Furthermore, various studies state impacts depend on the local situation. For example Gullison (2003) and Rametsteiner & Simula (2003) concluded that FSC certification improved biodiversity related forest management, but with impacts varying with local conditions. The high spatial variability in forests and their management over the world, contribute to the various plant and animal responses on certification with differences between and within species (Van Kuijk *et al*., 2009).

In this section, an overview is given of the existing scientific literature on the environmental FC impacts.

Various studies examine general environmental impacts. For example, the assessment of the effectiveness of non-state FC programs in Sweden (FSC) and Norway (scheme based on the Living Forest standards and the ISO 14001 EMS standard) showed that the changed practices resulted in less environmental destruction (Gulbrandsen, 2005). Uncertainty however remained about the FC environmental effect and effectivity (Gulbrandsen, 2005). Furthermore, Cubbage *et al*. (2010) studied the certification effects on economic, management, environmental and social aspects. This study combined secondary data from audit reports with personal interviews of individuals of ten forestry companies in Argentina (FSC) and Chile (FSC and the Chilean System of Forest Certification ('Sistema Chileno de Certificación Forestal', CERTFOR)). Many practices improved in all firms (on average 27 changes per certified firm)., e.g. in environmental protection (like increased threatened species protection, planning of biological diversity, control of invasive species, and maintaining special sites and old growth/high conservation forest reserves). Since the study does not obtain estimations of the magnitude and relative impact of changes on the ground, Cubbage *et al*. (2010) mention the need of field studies to investigate such outcomes. In addition, the social and ecological effects (e.g. biodiversity conservation, forest structure improvements) of certification (FSC and PEFC) in Europe were shown to be positive-negative (over a 15 year period) using the Delphi method to obtain expert knowledge with questionnaire rounds (Gómez-Zamalloa *et al*., 2011). Changes needed for certification are small, and relatively good starting levels leaded to limited positive effects (Gómez-Zamalloa *et al*., 2011). They affirmed that FC in Europe should continue with a potential increase of the positive impact by i.a. informing people of FC (Gómez-Zamalloa *et al*., 2011). Moreover, Heilmayr & Lambin (2016) compare non state market-driven governance regimes (NSMD) in Chile using quasi experimental methods (FSC, CERTFOR endorsed by PEFC and the Joint Solutions Project ((JSP), with a commitment of Chilean timber companies for no natural forest clearance). This study showed higher environmental performance of FSC standards than CERTFOR standards and the JSP suspension (Heilmayr & Lambin, 2016). In addition, even though they are voluntary, NSMD policies were able to improve environmental performance and more likely take effective care of high deforestation, than traditional governmental policies (Heilmayr & Lambin, 2016). Miteva *et* *al.* (2015) investigated environmental and social impacts of FSC certification in Kalimantan, an Indonesian biodiversity hotspot, using quasi-experimental methods. In contrast to uncertified logging concessions, FSC had positive impacts on aggregate deforestation (5 % decrease) and air pollution (31% decrease), firewood dependence (33% decrease), malnutrition (average reduction of 1 person) and respiratory infections (32% decrease) (Miteva *et al.*, 2015). Furthermore, Hughell & Butterfield (2008) concluded that FSC certified forests are good alternatives for protected forests with wildfires, gold exploitation and illegal hunting and logging. In addition, Kukkonen *et al.*, (2008) found a lower neotropical forest regeneration in certified forests, compared to uncertified forests; although FSC certified forest are linked to more environmentally friendly management, there was a greater logging disturbance than before the certification in these forests. This regression analysis on a 46 forest tree fall gaps sample however didn't develop a credible counterfactual (Blackman & Rivera, 2010). Frost *et al.* (2003) report FC stimulated improvement of operational practices linked to riparian zones, water monitoring, clonal material and Genetically Modified Organisms (GMOs), road construction and maintenance in South Africa. Besides, qualitative results of semi-structured interviews by Ebeling & Yasué (2009) show that in many developing countries (e.g. Ecuador) with a limited control capacity in forestry, certification unlikely has significant environmental effects and unlikely stops deforestation in these countries. The study does however not include a counterfactual (Blackman & Rivera, 2010). In addition, de Lima *et al*. (2009) studied the FSC certification effects in highland natural forests in the Brazilian Amazon region, analysing empirical survey data. They found the presence of small positive environmental impacts (e.g. natural resources conservation) of certification, compared to close uncertified community forest and reported that many of the potential positive effects of certification were already being accomplished with community forest management. Furthermore, Newsom *et al.* (2012) unbundled sustainability standards to individual Best Management Practices (BMP) to use as investigation unit instead of certification programs. Examples of studied BMPs are the creation of riparian buffer zones and the creation and restoration of set aside natural ecosystems. They examined 111 scientific studies directly linked to core BMPs. 59 % and 58 % of these studies showed positive effects of BMP application and variables dependent on the environment, and on community/species dependent variables respectively. Results show that studies about the BMP effect on soil and water quality only use local measurements and often do not include downstream effects. They also conclude more research is needed to check if the positive effect are linked to BMP implementation of time passed after disturbance. Ranius *et al.* (2003) developed a simulation program to predict the coarse woody debris (CWD) amount in homogenous Norway spruce stands in central Scandinavia. Comparison with field data of the National Forest Inventory of Sweden showed the model predicts average CWD quantities in managed forests. They conclude i.a. that the CWD was predicted to be three times higher in FSC certified forests than in conventional forests. Additionally, Auld *et al.* (2008) studied (in)direct impacts of certification programs on forests and forestry. They conclude i.a. that CARs studies require to improve HCVF management, but that no clear conclusion of actual research exists of certification potential for decreasing deforestation pressure or contributing to forest conservation at landscape levels. Furthermore, Nebel *et al.* (2005) analysed secondary data of FSC certification (certified by SmartWood) in the eastern Bolivian lowlands. They showed that certification only limitly improved forest management and didn't stop deforestation. A survey of certified and uncertified Finnish wood product companies (25 each) by Owari *et al.* (2006) about general perceptions of certification concluded among others that is important for communicating environmental responsibility. Nebel *et al.* (2005) and Owari *et al.* (2006) however did not develop a counterfactual (Blackman & Rivera, 2010).

Many studies exist on the FC impacts on nature conservation, habitat, biodiversity linked themes. Since FC and biodiversity are both complex concepts, it is difficult to determine and measure their correlation (Van Kuijk *et al.*, 2009; Sheil *et al.*, 2010). Different hierarchical biodiversity components and various biodiversity metrics exist (Noss, 1990; Heywood & Watson, 1995). Proxies for biodiversity can also be used. For example, Vantomme (2010) proposes using non-timber forest products (NTFP) as a biodiversity proxy in monitoring of certified harvested forests. NTFP certification requirements include sustainable use, but are also a method to evaluate abundance of species linked to NTFP (Vantomme, 2010). Various certification programs include forest management for NTFPs in the certification requirements, for example FSC (FSC, 2009). Furthermore, there is no complete understanding of biodiversity (Van Kuijk *et al.*, 2009). In addition, different studies investigate different biodiversity aspects, using different field protocols and biodiversity metrics and different temporal and spatial scales, making it difficult to compare these studies and make general conclusions (Sheil *et al.*, 2010; Van Kuijk *et al.*, 2009). Different methods exist to evaluate certification effects, discussed below.

Some studies use surveys and other data sources to assess certification impact. A case study in the U.S. by Hagan *et al.* (2005) used personal interviews and various other data sources to quantify changes in timberland ownership (between 1980 and 2005), especially focusing on effects on biodiversity. They found that landowners with SFI or FSC certification showed significantly robuster biodiversity practice than uncertified landowners. However, no significant difference between overall biodiversity practices scores between SFI and FSC were found, because of the small sample in the study. In addition, Moore *et al.* (2012) studied the effects of the FSC and SFI FC in North America using e-mail surveys of all certified organizations, following Dillman (2000) Tailored Design Method. Firms included 13 to 14 changes on average in (social, economic, forestry, system and environmental) practices to get certified. They found no statistical differences in the total number of changes, but results showed i.a. differences in particular forest practices: SFI certified companies needed to make more system/economic changes, while FSC certified firms generally required more forest management and environmental changes, with old-growth reserves, forest inventory programs and new forest inventory programs being the most frequently implemented. Sheil *et al.* (2010) used an open call on the European Tropical Forest Research Network (ETFRN) Forum for scientific articles (33 in total) complemented with an online survey (88 % response rate, research as largest stakeholder group). 30 % of the stakeholders stated certification should have as target to virtually conserve all species at pre-harvesting abundance levels, indicating logging should not change anything in the forest. The majority (81 %) of the participants agreed on the need for improvement of the quality of monitoring of fauna and flora programs.

Improvement strategies are discussed in several studies (e.g. Clark *et al.*, 2009; Peña-Claros *et al.*, 2009). Nevertheless, many respondents (36%) in the survey of Sheil *et al.* (2010) stated certification did not contribute to reduce deforestation rates, a topic also discussed by Auld *et al.* (2008) and Sheil *et al.* (2010). 62 % of the respondents found biodiversity friendly management and monitoring improvement costly. Subsidies and Payment for ES can be used to finance these requirements, although attention needs to be paid this doesn’t increase areas under schemes, with lower biodiversity conservation standards (Sheil *et al.*, 2010). Most respondents and articles agree certification contributes to biodiversity conservation in certified forests (Peña-Claros *et al.*, 2009; Van Kuijk *et al.*, 2009; Sheil *et al.*, 2010). Although FC contributed more to improving tropical forestry than any other measures with similar objectives (e.g. the Montreal Process, the Tropical Forestry Action Plan), there is a need to increase the certified tropical forests, with certification dealing with the actual landscape mosaic of intensively managed forests, still containing considerable biodiversity (Sheil *et al.*, 2010). There is also a need for better quantification and understanding of FC effects (Sheil *et al*., 2010). Moreover, HCVFs is often named as a key mechanism for biodiversity conservation (Sheil *et al*., 2010). Furthermore, Schulze *et al.* (2010) mention the need for a simple standard to motivate for BMP application (e.g. Reduced-Impact Logging (RIL)), with relatively large forest management and biodiversity benefits instead of complex standards. Jaung *et al.* (2016) characterise FSC stakeholder adaptability to a certification scheme. They created surveys with the Tailored Design Method of Dillman (2011) to rate eleven Forest ES (FES) using nine indicators linked to their self-assessed adaptability. Stakeholder groups were: FSC certification bodies, FSC certificate holders and FSC enabling partners. Their results showed a relatively high adaptability for carbon storage, NTFP provision and biodiversity conservation, while it was intermediate for watershed conserving services and low for agricultural products provision and ecotourism values.

Several studies used audit reports to evaluate FC effects. For example, WWF (2005) analysed 2817 CARs (in total linked to 18 million ha forest cover) of Latvia, Estonia, Sweden, Germany, the United Kingdom and Russia, including individual country reports. They concluded that FSC consistently improved social, economic and ecological issues in all six countries, linked to increased biodiversity levels and improvements of the conservation status. Most significant improvements were: deadwood level increase, threatened forest type restoration, identification, management and conservation of key habitats, reserves and biotopes and benefitting species diversity by natural regeneration, thinning and care etc. (WWF, 2005). In addition, Newsom *et al*. (2005) use FSC plans and audit reports to study the required changes of 129 operations linked to FSC (certified by SmartWood) in 21 countries to identify FC impacts. They conclude that required changes were affecting 15 forestry issues, with the three environmental issues required to improve being HCVAs and sensitive sites, riparian and aquatic areas and endangered and threatened species. Moreover, legal, economic, environmental, systems and forest management effects were approximately equal. Newsom *et al*. (2006) studied FSC certification effects (only FSC audited by SmartWood) with an on-the-ground examination of 90 FSC-certified forestry operations. They showed that FSC FC has quantifiable empirical effects when all requirements are implemented: certification demands changes of important forest practices, with ecological elements like Threatened and Endangered species (63 % of the operations) and HCVAs (71 % of the operations). They also conclude there is a need for more research on the FC effects on forest ecosystems and biodiversity. Ioras *et al*. (2009) assessed conservation gains in Romania and Bosnia-Herzegovina by reviewing National FSC standard drafts, HCVF Manuals, certification public summary reports and selected management certificates of seven FMUs. They found that most certified FMUs worked on identifying HCVFs, resulting in conservation gains, particularly related to ES, endangered, threatened and endemic species prevention and soil erosion prevention. Masters *et al.* (2010) analysed 130 audit reports of the FSC, SFI and CSA certification schemes to identify areas requiring operational improvements for certification and investigated four themes: economic, environmental, social and a management system theme. Although the requirements are not guaranteed to be implemented, audit conditions indicate the potential effects of each standard on forest management, with quantity and quality difference between the audit reports. FSC audits included the highest amount of requirements of conditions and recommendations to incorporate compared to SFI and CSA standards. In addition, the FSC standard requirements included more changes in all themes with FSC audits having the most conditions and requirements for HCVFs and Protected Forests. Furthermore, Peña-Claros *et al*. (2009) studied CARs of 123 FSC certified FMUs of managed tropical forests considering the 47 criteria to evaluate FMU performance. They found 20 FMUs related to biodiversity: some directly linked to biodiversity conservation, others applying best management practices with believed positive impacts on biodiversity; certification promoted RIL techniques were the most mentioned (Putz *et al.*, 2008; Peña-Claros *et al*., 2009). Few research however has studied actual RIL impacts on biodiversity (Van Kuijk *et al*., 2009). Peña-Claros *et al*. (2009) also showed that the amount of biodiversity linked issues decreased from the first to the second evaluation (98% to 82 %), implying that the initial identified problems were included in the biodiversity management of the FMUs and they believe that researchers and companies' collaboration and including all scientific knowledge in certification programs can benefit forest management. They found that there is a likely large effect of forest FSC certification on the long-term sustainability of forest management, primarily since the FMUs are required to make improvement, included in the CARs.

According to a review by Van Kuijk *et al*. (2009), BMP linked to FC positively affect biodiversity in managed forests. There is however little quantitative proof about long-term certification effects on biodiversity and few empirical data to support the evidence that certified forest management is sustainable, concerning biodiversity conservation at population and community levels (Van Kuijk *et al.*, 2009). In addition, well-managed certified forests do not equal undisturbed forests when considering biodiversity (Van Kuijk *et al*., 2009). The challenge and cost of large-scale credible research will probably make it remain scarce, leading to the need for additional studies to provide practical understanding of biodiversity parameters and management practices required by certification (Sheil *et al*., 2010). In addition, using a participatory approach for local standards and biodiversity goals reflecting local perceptions and needs can help (Sheil *et al*., 2010; Wiersum and Shretha, 2010). Moreover, human activity impacts on biodiversity are unpredictable and many threatening processes require more understanding, for which a conceptual framework of an integrated biodiversity monitoring program is proposed (Gardner, 2010).

Some studies show concern about FSC certified plantations. Menne (2010) states that the history of land use conversion of native vegetation to plantations results in doubts about the possibility to create responsibly managed forests and reverse bad plantation management once the damage of the latter is done. Furthermore, a literature analysis by Mielikäinen & Hynynen (2003) about the effects of PEFC certification in Finland concluded that the implementation of certain management practices are likely to positively affect biodiversity in boreal forests, although there is no empirical evidence with practices being e.g. leaving standing and lying retention trees in all rotation phases, protection of small valuable habitats in stands with commercial management and mixed stands. For tropical forests, Lagan *et al.* (2007) studied the Deramakot Forest Reserve in Sabah (Borneo, Malaysia), FSC certified since 1997, with implementation such as RIL management and HCVA protection. Their results showed higher population densities of endangered large animals (e.g. umbrella species like elephants and orang-utans) in certified forests compared to other areas in Sabah, however without empirical results. For the same forest, a comparison of biodiversity and carbon stocking by Mannan *et al*. (2008) concluded canopy tree species mostly keeping composition and richness levels similar to pristine forests nearby. They showed higher probability of soil fauna protection and more large mammals than in nearby protected areas, linked to FSC management. Furthermore, FSC requirements of conservation of dead trunks, high trees and fruit trees was linked to maintaining a relatively intact biodiversity. A significantly higher carbon stock in the Deramakot forests, compared to the conventionally logged forests was also obtained. Gullison (2003) and Rametsteiner & Simula (2003) showed that FSC certification improved biodiversity related forest management (e.g. by creating significant protected set-aside reserve areas within certified forests), but with impacts varying with local conditions. Moreover, Rametsteiner & Simula (2003) reasoned it is obvious FC not yet accomplished its original aim to save tropical diversity, since most certified areas are situated temperate and boreal forests (section 2.1.1). In addition, Gullison (2003) stated FC benefits biodiversity conservation in minimum three ways: decreased logging pressure on HCVAs, the improvement of ecological value for biodiversity and prevention of forest land conversion into agricultural land. Van Kreveld & Roerhorst (2009) investigated the effectiveness of FSC to protect gorillas, bonobos, chimpanzees and orang-utans in the Congo Basin and South East Asia. They concluded that logging under FSC certification guarantees more maintenance of the great ape habitats, compared to other forms of logging, because of e.g. decreased illegal logging, hunting, guarding and closing roads and conserving selected fruit trees. They conclude FSC concessions are potential suitable habitats for great apes, supplementing existing national parks and protected areas. In well managed FSC certified concessions, there is a high-density presence of Bornean organs-utans and western gorillas, while Sumatran orang-utans and chimpanzees, more sensitive to human activities, survive in FSC certified concessions with selective logging and low hunting pressure. Finally, great apes survival on the long term is only assured with the presence of suitable habitat networks of i.a. certified logging concessions and protected areas. Mekembom (2010) found that FC in Cameroon can contribute to biodiversity conservation in the country's production forests and that the pressure of CARs is needed to stimulate biodiversity-friendly management.

Few studies include empirical results. First, Sverdrup-Thygeson *et al*. (2008) studied effects of PEFC certification on empirical biodiversity values in 236 boreal forest regeneration zones. They conclude on-the-ground improvements of management by certification (e.g. higher retention tree number and buffer zone width in riparian habitat). However, it was difficult to separate the effects of the higher SFM consciousness and the FC effects. Furthermore, Elbakidze *et al*. (2011) investigated how FSC certification promotes boreal biodiversity conservation in Russia and Sweden. This biodiversity conservation was evaluated in terms of habitat network functionality and set-aside area. This study stressed that understanding standards and their on-the-ground appliance are needed for understanding the FSC potential for biodiversity conservation. Furthermore, FSC certified forest concessions in Bolivia showed no significant negative effects on species composition or abundance of terrestrial amphibians, understory birds and reptiles (Flores & Martínez, 2007; Maldonado, 2007). Results of other studies in Bolivia showed lower deforestation rates in FSC certified forests than in uncertified forest concessions and some national protection areas (Noel Kempff Mercado Natural History Museum (MHNNKM) and Foundation Friends of the Noel Kempff Museum (FAMNK), 2006; Killeen *et al.*, 2007). The Nature Conservancy (TNC) also found that FSC certified forests in the Brazilian Atlantic Forest region maintain more natural areas than other watershed parts, mostly because of the standards requiring legislation conformity (Touval *et al*., 2009). Although remaining research is required, they found FSC certification led to positive changes in land management, related to biodiversity conservation (e.g. HCVA conservation and riparian protection) (MHNNKM and FAMNK, 2006; Flores & Martínez, 2007; Killeen *et al*., 2007; Maldonado, 2007; Touval *et al*., 2009). Mostacedo & Quevedo (2010) provide empirical proof that HCVAs are effective in biodiversity conservation in Bolivia, and positive effects can be maximised by cooperation of researchers and managers. Various other studies also found the importance of HCVAs for biodiversity conservation (e.g. Bleaney, (2010)). Entenmann (2010) combines results of fieldwork and Geographic Information System (GIS) analysis to conclude that the non-carbon benefits of Reducing Emissions from Deforestation and Forest Degradation (REDD+) pilot projects support biodiversity conservation by incorporating this target in the project design. Finally, biodiversity conservation had a positive relation with FSC certification standards and their processes in Kilwa, Tanzania (Kalonga *et al.*, 2016). Adult tree species diversity, density and richness were considerably higher in FSC certified community forests than in uncertified (open entrance or reserves) forests. Certification of NTFP is included in the FSC program and already exists in some places in the world. Examples are natural rubber (0.1 % as FSC's global market share) and cork (4.6 % as FSC's global market share) (FSC, 2016a), dried fruits and medicinal herbs and rattan brazil nut (Pierce *et al.*, 2008; Hodgdon & Martínez, 2015). Although FSC NTFP standards aim at supporting producers and biodiversity protection, various studies mention the challenges, for example competition with Fairtrade or organic certification schemes (Pierce *et al.*, 2008; Schmitt *et al.*, 2008; Duchelle *et al.*, 2014).

Riparian areas have diverse critical roles, such as critical habitat provision for native fauna and flora, fertile soil provision for timber production and quality and quantity regulation of domestic water supply (e.g. Moore & Richardson, 2003; Pusey & Arthington, 2003; Semlitsch & Bodie, 2003; Lee *et al.*, 2004; Van Sickle *et al*., 2004). Certification schemes had different ways to include riparian buffer zones for riparian area protection and prevent forest management activity in these zones (included in FSC principle 6) (McDermott *et al*., 2008; FSC-International, 2015). Few studies evaluated the FC effects on hydrologically linked ES. For example, Dias *et al.* (2015) studied Mediterranean streams in cork oak landscapes in Portugal, by comparing ecological conditions of streams in certified areas with those in uncertified areas and little disturbed areas using the Stream Visual Assessment Protocol (SVAP) and linear mixed effects modelling. Significant positive impacts of FSC management standards on ecological conditions of riparian stream vegetations were found, however only quantifiable after five years of certification (versus three years certification): the ecological conditions of streams in certified areas were then similar to those in conserved sites with few disturbances.

It is expected that carbon storage and sequestration and biodiversity conservation are higher in certified forests, compared to uncertified forests (Putz & Nasi, 2009). Currently, carbon storage has not yet been identified to result from FSC certification (Foster *et al.*, 2008; Merger *et al.*, 2011; Gan & Cashore, 2013). However, Gan & Cashore (2013) showed SFM certification schemes (FSC, and schemes endorsed by PEFC) to be compatible with bioenergy certification programs, except for air quality, food security and greenhouse gas (GHG) emissions requirements. Coupling of certifications would benefit both, by reducing costs, enhancing development and adoption and improving forest management and efficiency of energy and land-use. Besides, it will help to balance biomass removal and soil productivity on the long term and help carbon sequestration in wood-based products and forest growing stock to offset bioenergy GHG emission. Furthermore, Merger *et al.* (2011) compared and evaluated REDD+ practical applicability of ten standards including FSC and PEFC standards and created a framework for this evaluation using six criteria: biodiversity protection, SFM, poverty mitigation and assessment, measurement of net GHG benefits, certification procedures and monitoring and reporting. Only the Verified Carbon Standards (VCS) certification program includes assessment, monitoring, reporting and certification of GHG benefits and none of the evaluated standards covered all criteria, implying the need for combining minimum two certification schemes to assure environmental and social completeness in REDD+ activities, however increasing the costs. They recommended taking into account the practical experiences of certification standards to improves REDD+ standards design, economic efficiency and social and environmental security guarantee, by partnerships between the certification schemes. Foster *et al.* (2008) assessed stand-level management impacts by measuring forest structure in 12 forest stands in the U.S., mainly containing sugar maple (*Acer saccharum*). No significant differences in living tree carbon storage, sugar maple tree value and living tree structure were found between FSC certified and uncertified harvests. In addition, both (un)certified harvests decreased total tree biomass by one-third, relative to reconstructed pre-harvest circumstances. Besides, both had similar harvesting impacts and showed significantly lower densities of several medium size trees and samplings, relative to reconstructed pre-harvest conditions. Nevertheless, the total residual CWD volume was significantly higher in certified forest stands, compared to uncertified stands, but smaller than in unmanaged mature forests. According to Pettenella & Brotto (2012), FSC certification seems to be an important precondition for a successful

REDD+ and Putz & Romero (2012) mention the potential use of FSC certification for REDD+ management. Moreover, FSC certification is a potential tool to obtain carbon payments, which can be used for subsidizing certification to increase its accessibility (Brotto *et al.*, 2010; Sheil *et al.*, 2010; Putz *et al.*, 2012). Medjibe *et al.* (2013) results of a field-study in Gabon showed wider logging roads in the conventionally-logged (CL) concessions than in the FSC sites and contributed to 4.7 % higher disturbance than in CL concessions. They also concluded logging resulted in less declines in above-ground-biomass in the FSC sites (7.1%) than in the CL sites (13.4%). Larger tree species composition changes were also present in the CL concessions. In the FSC certified concessions, with RIL methods, damage was reduced, causing carbon emission reduction and climate change mitigation, relative to uncertified forests. Medjibe *et al.* (2013) estimated carbon emissions, assuming immediate emissions, survival of all damaged trees, not including carbon residence time in products from harvested wood. Emissions were then calculated as the total of the destroyed (standing), harvested and damaged trees. They found carbon losses being double as large in CL forest sites (24.6 Mg/ha necromass, committed as emissions) compared to the FSC site (11.2 Mg/ha necromass, committed as emissions). Because of the pseudo-replicated study design (considering the sample plots in the FSC and CL concessions as replicates) and no perfect counterfactual, they carefully conclude certification has positive environmental effects, even after including logging intensity differences. Furthermore, the FSC scheme already uses traded intangible ES, with the market share of FSC in sold forest carbon offsets (6.0%, 0.9 MtCO2e of the total 14.9 MtCO2e of forest and land use projects) and the share of FSC forest management certificate holders, having earned money from ES (12.5 %) (FSC, 2016b). In 2012, FSC already had 33 projects, in 16 countries (spread over the five continents), with certification of forest carbon projects (1,494,000 ha) (FSC, 2012). More recently, pilot sites of the FSC ForCES project (see further) also included certification of carbon sequestration and storage, e.g. in Huong Son (Vietnam) (FSC, 2016c) and East Kalimantan (Indonesia) (FSC, 2017a).

No actual scientific studies, measuring effects of FSC certification on improving soil characteristics were found. There are however some studies identifying the role of soil characteristics, relative to (the potential of) certification programs (e.g. FSC) for improving soil management, mainly focusing on the standards (Cline *et al.*, 2006; Newsom *et al.*, 2006; van Dam *et al.*, 2010; Stupak *et al.*, 2011). Cline *et al.* (2006) provide practices and policies for soil productivity protection and describe how the U.S. and Canadian forest product industries, the Canadian Forest Service and the U.S. Department of Agriculture

Forest Service include soil productivity in their SFM principles. In addition, Stupak *et al.* (2011) and FSC (2015b) mention FSC standards include different aspects of soil characteristics, e.g. principles 6, 9 and 10 international standards require soil conservation with measures of e.g. soil fertility restoration, erosion and compaction reduction, no waste or chemical release into soil and minimization of fertilizer and pesticide use.

Several studies assess the impact of FC on landscape characteristics (e.g. Azevedo *et al.*, 2005a; Azevedo *et al.*, 2005b; Lopatin *et al.*, 2016; Kleinschroth *et al.*, 2018; Reyes & Altamirano, 2018). Azevedo *et al*. (2005a; 2005b) developed a methodology for the analysis of management practices impacts on landscape function and structure, in relation to sustainability evaluations in intensively managed forest landscapes. With simulations and models of physical and biological landscape level processes, including habitat, landscape structure and hydrologic models, illustrated with pine warbler (*Dendroica pinus)* habitat in Texas (Azevedo *et al*., 2005a; Azevedo *et al*., 2005b). Habitat fragmentation was found under SFI, because of narrow forested management zones (streamside management zones (SMZ)) along streams, crossing pine stands, likely to have little negative effects on the habitat of pine warbler (Azevedo *et al*., 2005a; Azevedo *et al*., 2005b). In the SFI scenario, landscape level sediment yield was lower, mainly by reducing channel degradation in SMZ and leaving riparian buffers, relative to the non SFI scenario (Azevedo *et al*., 2005a; Azevedo *et al*., 2005b). In addition, sediment yield and runoff were higher in pine watersheds without disturbance, compared to managed pine watersheds (Azevedo *et al*., 2005b). Water yield and surface runoff at subarea scales were the same for the SFI and non-SFI scenarios, while at SFI scenario had relatively lower sediment yield at watershed scale (Azevedo *et al*., 2005b). Furthermore, Kleinschroth *et al*. (2018) examined intact forest landscapes (IFLs): a criterion of the FSC principles: extensive forest areas without human activity signs such as roads, detected with remote sensing. They found a higher absolute IFL loss in certified concessions, compared to uncertified concessions. Informal logging in uncertified forests uses small, narrow and sub-canopy paths, mostly invisible with remote sensing giving the result of intactness (Peres *et al*., 2006; Kleinschroth *et al*., 2018). In contrast, strict controls lead to decreased post-logging in certified areas with positive effects on e.g. elephant and great ape populations (Stokes *et al*., 2010; Kleinschroth *et al.*, 2015). Certified concessions also have wider roads for efficient and planned harvesting for one of two years, after which they remain visible with RS unto 20 years (Stokes *et al*., 2010; Kleinschroth *et al.*, 2015). Furthermore, road networks in FSC certified forest concessions are re-used for several rotations (Kleinschroth *et al.*, 2016). The road networks may be more extensively detectable in certified concessions, compared to uncertified concessions, but certified estates have a higher probability for maintaining long-term forest quality (Kleinschroth *et al.*, 2018). Finally, the IFL concept of FSC needs to include a recovery period of intactness after controlled forestry interventions (Kleinschroth *et al.*, 2018). Finally, Reyes & Altamirano (2018) and Montenegro *et al.* (2018) assessed the FSC certification effects on landscape indicators in the Valdivian Ecoregion of Chile (2008-2016), considering three sub landscapes for each of the two studied landscapes (landscape Nahuelbuta and the Valdivian River Basin landscapes). They combined satellite image analyses with field verifications and found the largest natural regeneration in uncertified areas (compared to certified areas), a significant decrease of the patches' proximity index in certified areas and increase in uncertified areas. The aggregation index increased slightly in the entire study area (certified and uncertified areas). They experienced various challenges, such as the limited availability and access to information, because of the existence of few similar studies. Therefore, their results served as baseline information in this study area, contributing to monitoring data and as a methodological example. It was also difficult to link the identified changes with FSC certification effects only, since FSC certified logging firms in the study area, also adopted other voluntary tools and procedures.

Although FSC IGIs include cultural value conservation and some FSC national standards take care of outdoor recreation and scenic beauty, they don't associate these aspects with tourism, don't explicitly address these ES and FC studies have not yet covered ecotourism linked ES (Sheppard *et al.*, 2004; Harshaw *et al.*, 2007; Jaung *et al.*, 2016).

The FSC scheme has some recent projects, including the TransparantForests project (started in 2013) to integrate Remote sensing-Geographical information system (RS-GIS) techniques in the scheme and investigate the Forest Certification Information System (FCIS) practical potential in providing independent geo-spatial data improving FC (European Space Agency (ESA), 2016). Moreover, the Forest Certification for ES (ForCES) six-year project (created in 2011 by FSC and the United Nations Environment Programme) to promote conservation of critical ES in SFM forests, to create standards for ES and to create market access tools to facilitate recognition of ES (linked to Payment for Environmental Services (PES)) (FSC, 2018c). Pilot sites of the project are situated in Nepal, Indonesia, Vietnam and Chile (Parque Pumalín, Carahue and Mechaico) (FSC, 2018c).

So far, insufficient empirical proof exists on the effects of FC to obtain fully understanding of it at a global scale (e.g. Romero *et al*., 2013). There is a demand for critical research of the on-the-ground effects of FC, including impacts in situ in the forest and ex situ, in the neighbouring areas (e.g. Romero *et al*., 2013). Romero *et al*. (2013) give some possible explanations for the lack of critical investigation. First, there are intrinsic challenges in logistic and methodology for the evaluation of potential (in)direct effects of complex interference, in a high diversity of forests, under various political, socio-economic and ecological situations. Second, certification just recently gained importance for forest management decisions in some regions, such as the Congo Basin. Third, there is an assumption that ecological, social, economic and political benefits are inherent to FC. Missing appropriate certification effect evaluation leads to higher risk to both decreasing and increasing responsibility of the certification process as such (Rogers, 2012). Additionally, certification effectiveness could be increased by linking interventions of conservation and forest management certification, with paying for ES (Hyde, 2012). Finally, since few evidence exists on effects on ES supply, there is an urgent need for investigating these effects.

3. Material and Methods

3.1 Study Area

3.1.1 The Valdivian Ecoregion

The study area is situated in the Valdivian Ecoregion1, in the south of Chile (Southern America) (Figure 3.3). This ecoregion (Scientific Code: NT0404) is one of the 867 terrestrial ecoregions and is located in ‘the temperate broadleaf and mixed forests’ habitat, defined by WWF (Olson et al., 2000; WWF, 2019a, 2019b, available online https://www.worldwildlife.org/ecoregions/nt0404). Several geological events leaded to the current situation: the formation of the Coastal and Andes Mountain Ranges and the Intermediate Depression (Villagrán & Hinojosa, 1997). The climate in the ecoregion has a large longitudinal, altitudinal and latitudinal variability and is influenced by orographic, atmospheric, oceanographic and latitudinal factors, which is related to the vegetational variation (Appendix B.1; Romero, 1985; Santibañez, 1990; Arroyo *et al*., 1996, 1995; Conti, 1998; Leubert & Pliscoff, 2004). Moreover, the ecoregion has a long isolation history, which resulted in a biogeographic island, separated from other biotas by the Andes, the Pacific Ocean and the Atacama desert, and related to a high biodiversity and endemism

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[1] An ecoregion is defined as a “large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions” (WWF, 2019, available online: https://www.worldwildlife.org/biomes). These ecoregions represent the distribution pattern of biodiversity on Earth, driven by evolution and geologic, climatic conditions (Olson et al., 2000; WWF, 2018a).

(Wolodarsky-Franke & Herrera, 2011; Appendix B.1) . The large variability in climate, geography, geology etc. also leaded to different forest ecosystem types (Veblen, 1983; Gajardo, 1994) and vegetational floors, classified by Luebert & Pliscoff (2006) (Appendix B.1). The ecoregion and its ecosystems are currently threatened (status: critical/endangered), for which actions for habitat preservation and restoration of what remains are urgent (WWF, 2019). Unsustainable forest management (for firewood, commercial ends), native forest conversion to exotic plantations or agriculture and human caused forest fires are mainly threatening the Valdivian temperate forests (Wolodarsky-Franke & Herrera, 2011; WWF, 2019b). According to Labarías & Wilken (2006) and Wolodarsky-Franke & Herrera (2011), these threats can further increase under climate change. In fact, the named hazards leaded to a decrease in native forest cover in the ecoregion, estimated by 40 %, with a native forest conversion (Lara *et al.*, 1999; Lara *et al.*, 2003; Wolodarsky-Franke & Herrera, 2011; Appendix B.1).

There are some remaining relatively large areas in the Coastal Valdivian Range with virgin native forests, but in general, fragmentation and degradation are present (WWF Chile, 2008). Deforestation leaded to a significant fragmentation and reduction of the native forest area between 1975 and 2007 (Echeverría *et al*., 2006; Jiménez, 2011). Furthermore, the areas with the highest species richness coincide with highest human density characterised areas, with large threats and pressure from plantation forestry and agriculture (Armesto & Rozzi, 1989). In addition, 99 % of the protected areas in southern South America are present in the Argentinean of Chilean Andes, and not in the coastal ranges of these latitudes; Andean forests have more imposive landscape elements, than coastal forests: large lakes, views on impressive volcanoes and small lagoons (Smith-Ramirez, 1993; Smith-Ramirez & Armesto, 1994; WWF, 2019). 11 vegetational floors are not represented in the system of national protected areas ('Sistema Nacional de Áreas Protegidas' (SNASPE)) (Luebert & Pliscoff, 2006) and 30 are represented in this system by less than 10 % of its remaining area (Wolodarsky-Franke & Herrera, 2011). There are besides very few areas protected in the Intermediate depression (WWF, 2019). Hence, even without considering climate change scenarios, this system of protected areas is not fitting the biodiversity protection need over time in the whole ecoregion (Wolodarsky-Franke & Herrera, 2011).

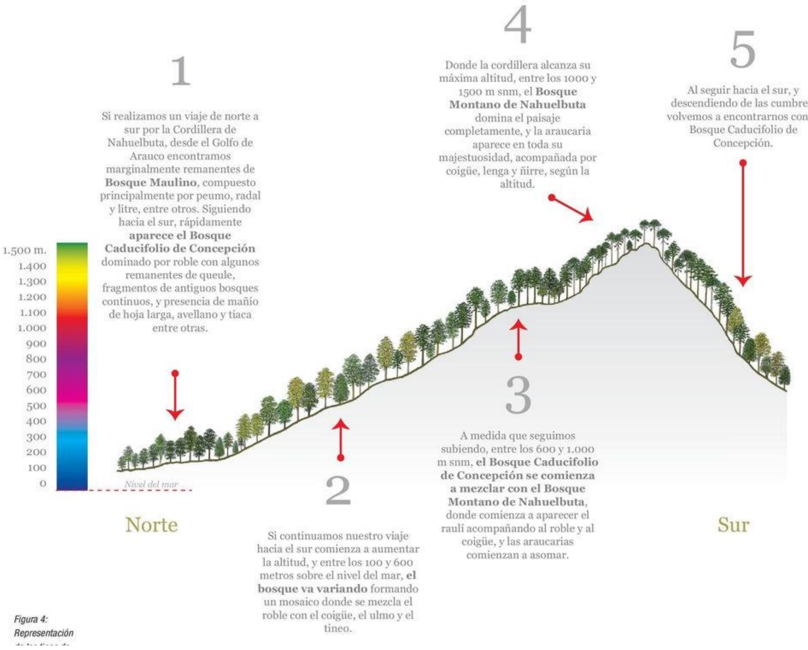
More recently, WWF Chile identified 12 priority areas to focus on, in terms of biodiversity conservation (WWF Chile, 2008). In addition, WWF Chile (2011) created a strategic plan of the ecoregion to contribute to sustainable conservation and use of its natural resources, where all stakeholders are participating. However, the majority of the areas needed to accomplish the proposed conservation measures are privately owned, leading to necessary public-private collaborations (Wolodarsky-Franke & Herrera, 2011). The strategic plan includes four priority strategies: management of private areas under protection, promoting environmental alliances in the private financial sector, empowering sustainable livelihoods and governance models and promoting FSC certification in forest plantations for nature conservation in the ecoregion (Wolodarsky-Franke & Herrera, 2011). Part of this last strategy is voluntary FSC certification of forestry companies, in relation to markets demanding this certification (Wolodarsky-Franke & Herrera, 2011). The current monitoring of this certification impacts on social and environmental levels by WWF Chile has to evaluate the meaning of this strategy (WWF Chile, 2008).

3.1.2 The Nahuelbuta Coastal Mountain Range

The Nahuelbuta mountain range is the part of the Coastal range between the Bío Bío river (northern limit, 37°11' S) and the Imperial river (southern limit, 38°45'S), having a longitude of 190 km and width of 50 km (Wolodarsky-Franke & Herrera, 2011). Furthermore, it was entitled as a World Biodiversity reserve (Wolodarsky-Franke & Herrera, 2011). The Nahuelbuta range is one of the Coastal range parts with the highest endemism and biodiversity levels, while it is also has very scarce ecosystem conservation and is suffering from the greatest environmental modifications and a high fragmented native forest landscape (Wolodarsky-Franke & Herrera, 2011). The interaction of different ecosystems plays an important role in making it one of the 25 global biodiversity hotspots (Wolodarsky-Franke & Herrera, 2011). Furthermore, the topographic variation creates a climatic variation with a subhumid warm Mediterranean climate in the north and a temperate humid and rainy climate in the South, with a variability in ecological environments, for hosting the large biodiversity (Figure 3.1) (Wolodarsky-Franke & Herrera, 2011; Appendix B.2). Here, important species with conservation priorities include the Chilean pine (*Araucaria araucana*) (Wolodarsky-Franke & Herrera, 2011). The fauna and its distribution in the Nahuelbuta range depend on the variability in vegetation conditions and also on i.a. their diet and ability to move with many vertebrates being endemic and having conservation problems (Wolodarsky-Franke & Herrera, 2011).

Nowadays, the majority of remaining forests are owned by large forestry firms, including them in their protected areas and aiming for long-term conservation (Pauchard, 2011; Appendix B.2). During the last centuries, more than 70 % of the natural vegetation was lost in the Nahuelbuta Range (Wolodarsky-Franke & Herrera, 2011). Only 3.5 % (7.000

ha of the 200.000 ha) of the native forest in the Range are protected as SNASPEs, e.g. the Natural Contulmo Monument and the Nahuelbuta National Park, however not covering all the habitats and natural vegetation present in the mountain range (Wolodarsky-Franke & Herrera, 2011; Appendix B.2). Threatening human activities, such as forest exploitation and extensive agriculture, are partly responsible for i.a. water quality and soil degradation (Wolodarsky-Franke & Herrera, 2011). In addition, the Range is also threatened by the native forest fragmentation (with about 12.000 native forest fragments, only 3 having areas larger than 500 ha), land degradation and the interaction with exotic species of forest plantations (radiata pine (*Pinus radiata*) and eucalypt (*Eucaluptus* spp.)), all hindering natural regeneration (Wolodarsky-Franke & Herrera, 2011). The Mapuche communities, partly depending on native forests for their income and receiving ES (e.g. fresh water supply), are suffering from the exotic plantation expansion and some conflicts remain with forestry firms (Wolodarsky-Franke & Herrera, 2011). The actual FSC certification of some large forestry companies reduced the threat of native forest conversion into exotic plantations (Wolodarsky-Franke & Herrera, 2011).



1
Si realizamos un viaje de norte a sur por la Cordillera de Nahuelbuta, desde el Golfo de Arauco encontramos marginalmente remanentes de **Bosque Maulino**, compuesto principalmente por peumo, radal y litre, entre otros. Siguiendo hacia el sur, rápidamente **aparece el Bosque Caducifolio de Concepción** dominado por roble con algunos remanentes de queule, fragmentos de antiguos bosques continuos, y presencia de mañío de hoja larga, avellano y tiaca entre otras.

2
Si continuamos nuestro viaje hacia el sur comienza a aumentar la altitud, y entre los 100 y 600 metros sobre el nivel del mar, **el bosque va variando** formando un mosaico donde se mezcla el roble con el coigüe, el ulmo y el tineo.

3
A medida que seguimos subiendo, entre los 600 y 1.000 m snm, **el Bosque Caducifolio de Concepción se comienza a mezclar con el Bosque Montano de Nahuelbuta**, donde comienza a aparecer el raulí acompañando al roble y al coigüe, y las araucarias comienzan a asomar.

4
Donde la cordillera alcanza su máxima altitud, entre los 1000 y 1500 m snm, el **Bosque Montano de Nahuelbuta** domina el paisaje completamente, y la araucaria aparece en toda su majestuosidad, acompañada por coigüe, lenga y ñirre, según la altitud.

5
Al seguir hacia el sur, y descendiendo de las cumbres, volvemos a encontrarnos con el Bosque Caducifolio de Concepción.

Figure 3.1: North-South transect (from left to right), through the Nahuelbuta Range, representing the forest variability (Wolodarsky-Franke & Herrera, 2011, p. 17). 1) A Maulino forest is present starting from the Gulf of Arauco, containing mainly i.a. radal (*Lomatia hirsuta*), litre tree (*Lithraea caustica*) and peumo (*Crypotocarya alba*). The deciduous forest of Concepción emerges more to the south, with a dominating role of Patagonian oak (*Nothofagus obliqua*), but also the appearance of i.a. Chilean hazelnut (*Gevuina avellana*) and the presence of ancient continuous forest fragments. 2) The forest changes in a forest mosaic with a mix of Patagonian oak with ulmo (*Eucryphia cordifolia*), tineo (*Weinmannia trichosperma*) and coigüe (*Nothofagus dombeyi*) (100 to 600 meters above sea level (m.a.s.l.)) more to the south. 3) A mix of the deciduous forest of

Concepción with the Montane Nahuelbuta forest is found between 600 and 1.000 m.a.s.l., where rauli (*Nothofagus alpina*) starts to occur, together with Patagonian oak and coigüe and with starting appearance of the Chilean pine. 4) The Montane Nahuelbuta forest is dominating between 1.000 and 1.500 m.a.s.l. altitude with the presence of the Araucaria, with lenga (*Nothofagus pumilio*), Antarctic beech (*Nothofagus antartica*) and coigüe, depending on the altitude. 5) In the south the deciduous forest of Concepción appears again. (Text adapted and translated from Figure 4 of Wolodarsky-Franke & Herrera (2011, p. 17).

Moreover, there has been a transformation of the forest management with time with remaining tolerant native species in the understory and a lower planting density in the 1970, in contrast with current more frequent harvests and higher densities, preventing native seed germination and causing soil erosion, increasing sedimentation in rivers and fertility loss (Wolodarsky-Franke & Herrera, 2011). Illegal extraction of timber and NTFP from native forests, an important income for farmer and indigenous families (with traditional knowledge of the use and applications of these products), is currently contributing to native forest degradation with difficult regeneration (Wolodarsky-Franke & Herrera, 2011). The creation of markets for these NTFP benefits both native forest revaluation and local family income, with nutritional and medicinal products, such as the araucaria seeds, tree bark and mushrooms, being the most demanded products (Wolodarsky-Franke & Herrera, 2011). Furthermore, several seeds have ornamental value and various plant species are used as natural dye-material (Wolodarsky-Franke & Herrera, 2011).

Other threats for native forests and their biodiversity are forest fires, mostly caused by human actions, also emitting large CO_2 amounts (Wolodarsky-Franke & Herrera, 2011). Moreover, the Nahuelbuta Range biodiversity and habitat value was mostly unknown by people, taking few actions for conserving this area, but recently ecotourism increased (doubled in 2000-2011) (Wolodarsky-Franke & Herrera, 2011; Appendix B.2).

Recently, ES are being more included in research with attempts to also incorporate their value in economic analysis, with one of the most appreciated ES being the scenic beauty of the SNASPEs in the area, benefitting tourism (Wolodarsky-Franke & Herrera, 2011). In contrast, the fresh water supply of the native forest ecosystem to cities, such as Contulmo (approx. 7.000 habitants) and Angol (approx. 48.996 habitants), is largely undervalued by local people (Wolodarsky-Franke & Herrera, 2011). Streams and rivers from native forest covered watersheds have a summer water flow of three to six times higher than watersheds covered with other vegetation (e.g. exotic forest plantations or meadows); protection of this ES should be obtained by encouraging sustainable water use and degraded watershed recovery (Wolodarsky-Franke & Herrera, 2011).

In conclusion, the Nahuelbuta Range is a unique zone, being part of an important biodiversity hotspot, needing urgent conservation because of the current threats, decreasing ES supply and negatively influencing the life of people living there (Wolodarsky-Franke & Herrera, 2011). In order to do this, a participatory approach between all stakeholders is important with clear objectives, including priority areas for conservation with efficient management and conservation, ecotourism, educational programs to increase valuation of this conservation and research about ES in the area (Wolodarsky-Franke & Herrera, 2011).

3.1.3 The Nahuelbuta landscape

The Nahuelbuta landscape is the case study area to investigate impacts of FSC certification on forest landscape of south-central Chile. Situated in the Nahuelbuta Coastal Range (Figure 3.3), and in the zone where transition takes place between the Valdivian temperate rainforests and sclerophyllous forests, it is part of one of the 25 global priority areas for biodiversity (Wolodarsky-Franke & Herrera, 2011; Montenegro *et al*., 2018). It is also one of the priority landscapes in the Valdivian Ecoregion, delineated by WWF Chile to apply its strategic conservation actions (Bosshard *et al.*, 2015). By 2020, WWF Chile expects to guarantee engagement of forestry firms to FSC certification, which involves efficacious conservation of 100.000 ha forest ecosystems in HCVAs and is linked to 10.000 ha restoration in priority forest landscapes (Bosshard *et al.*, 2015). One of their conservation strategies is making the production and use of natural resources (e.g. timber, pulp and paper) sustainable in these priority areas, by decreasing negative social and environmental effects, using i.a. certification systems, like FSC (Bosshard *et al.*, 2015). Because of its important location in the Nahuelbuta Range, with extremely high biodiversity and endemism and a scarce ES conservation, suffering from several threats, the Nahuelbuta landscape is a critical area with the need for urgent conservation (Wolodarsky-Franke & Herrera, 2011; Montenegro *et al*., 2018). In addition, it’s large cover of forest plantations, of which already a considerable part being FSC certified (Figure 3.2; 278,259 ha in 2018) makes the landscape suited for this case study. The forest plantations contain mainly radiata pine and Eucalyptus spp. (e.g. Tasmanian bluegum (*Eucalyptus globulus*) and shining Gum (*Eucalyptus nitens*)) and are primarily owned by two large forestry companies: Arauco S.A. and Forestal Mininco S.A (Montenegro *et al*., 2018). This in contrast to other areas, where certified plantations are owned by several small firms, complicating information access and communication. In addition, Forestal Mininco S.A., Masisa S.A. and Arauco S.A. own about 55 % of the forest plantations in the Valdivian Ecoregion, with the other 45 % is in the hands of medium- and small sized companies and landowners (Montenegro *et al*., 2018).

The former obtained FSC forest management certification in September 2013, while the latter obtained this certification in December 2012 (WWF Chile, 2014). In 2014, Forestal Mininco S.A. owned 656,000 ha certified areas, of which 478,333 ha being plantations of radiata pine and eucalypts in the Valdivian Ecoregion (WWF Chile, 2014), which is 30.15 % of the total FSC certified area of plantations in Chile in 2014 (1,585,410 ha) (FSC Chile, 2018). In this year, Arauco S.A. was already the largest FSC certified Chilean forestry company, based on forest management certified area (1.1 million ha in 2014, of which 735,000 ha are plantations and 200,000 ha are forests) (WWF Chile, 2014). Therefore, 45,33 % of the FSC certified plantations in Chile and 46.70 % of the total FSC certified area were in hands of this company in 2014 (FSC Chile, 2018). In addition this company agreed to manage and monitor 63,000 ha of HCVAs (WWF Chile, 2014). The landscape is partly located in the Araucanía region and partly in the Bío Bío region. Finally, is characterized by a spatial variation in climate, topographic and vegetation conditions: the landscape has three different climate zones (Figure 3.4), seven vegetational floors (Appendix B.3; Luebert & Pliscoff, 2006) and several geomorphological units (Figure 3.4).

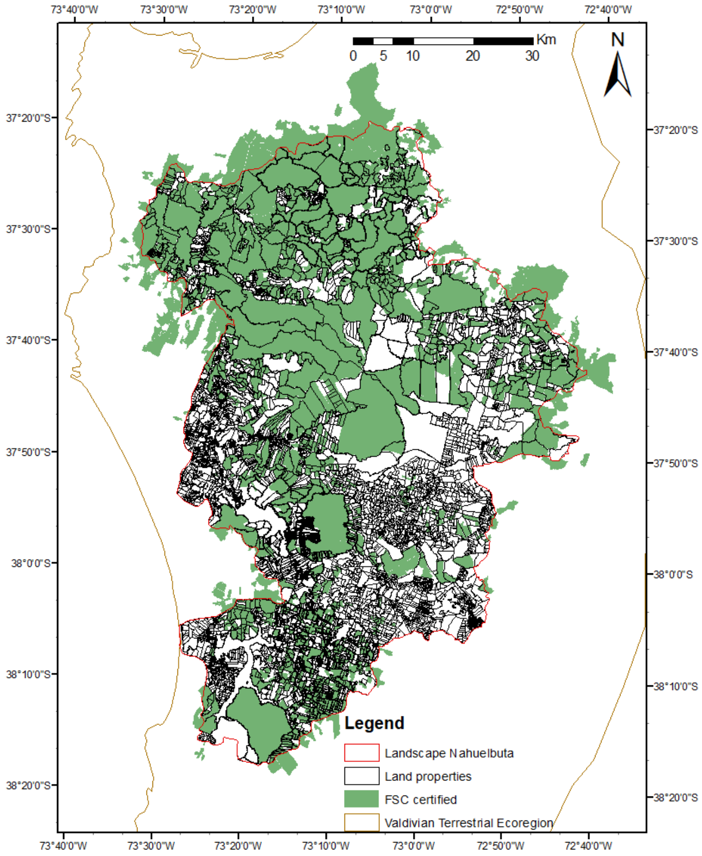


Figure 3.2: Location of the Nahuelbuta landscape (WWF Chile, 2018b), representing the landscape properties and the most actual distribution of FSC certified areas (2018) (WWF Chile, 2018b), map by author

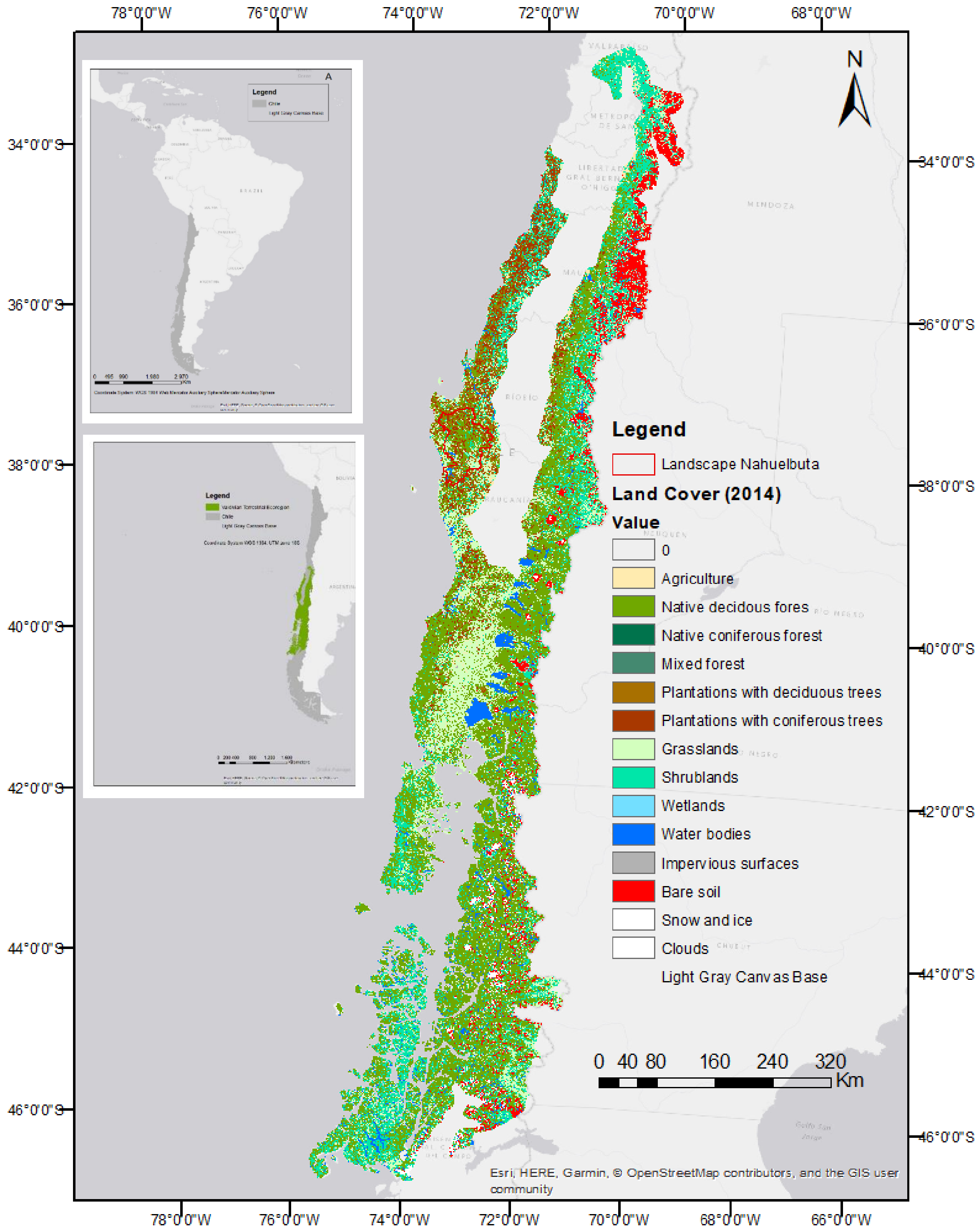


Figure 3.3: Location of the study area: Chile in South America, Valdivian ecoregion in Chile (Olson *et al.*, 2001) and Land cover (2014) of Valdivian ecoregion (Hernández *et al.*, 2016; Zhao *et al.*, 2016), with the Nahuelbuta landscape (WWF Chile, 2018b) in red, map by author

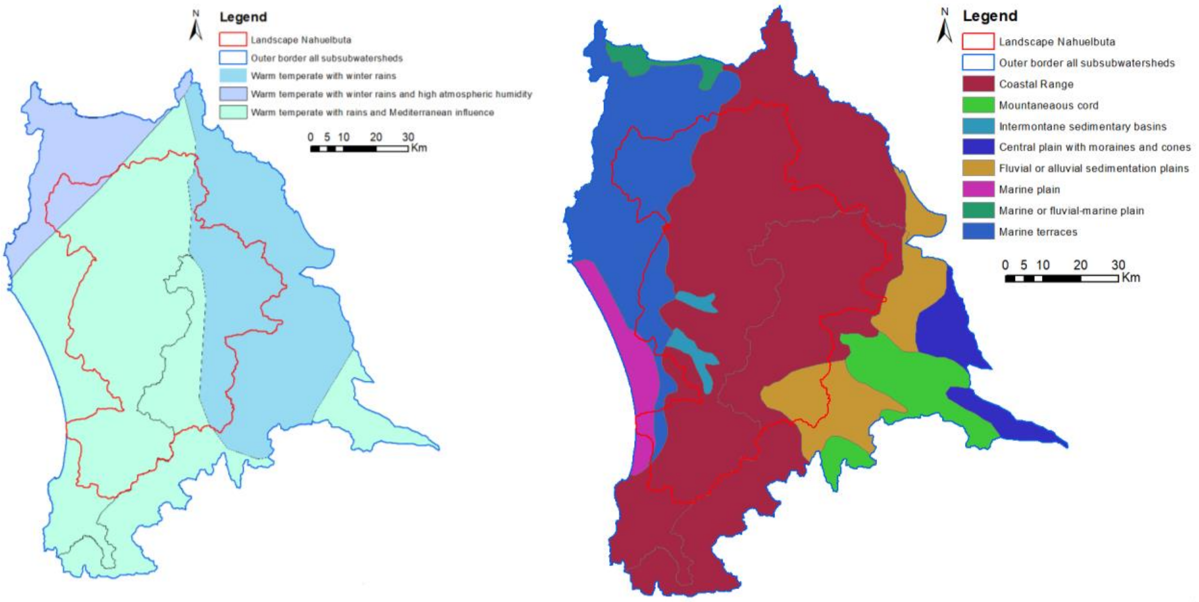


Figure 3.4: Climate zones (Albers, 2018b) (left) and geomorphological units (Albers, 2018b) (right) in the landscape (WWF Chile, 2018b), showing the region border (black), translated to English, map by author

3.2 Literature study

Search engines Google Scholar, Limo and ResearchGate were used to collect literature, inserting keyword combinations. Scientific publications were chosen using the criteria of citation number and publication date, giving preference to highly cited and/or recent studies. Second, a selection of publications was made by reading titles, abstracts and conclusions. Furthermore, relevant papers, found in the reference list of the already selected publications were included in the selection. Google was used to complete information when websites were cited in the selected publications. By fully reading papers of this selection, a final selection of publications was made, which was analysed and discussed in the literature study. For each paragraph of the literature study different combinations of key words were used (Table 3.1). The search for publications happened both in English and Spanish, but in Table 3.1 only the English words are shown. For each reference in this study, the primary source was cited.

Table 3.1: Combinations of key words used in search for literature

Paragraph 2.1.1	Forest certification, forest management, SFM, sustainability, sustainable forest management, standards, principles, criteria, indicators, certification body
Paragraph 2.1.2	Forest certification, sustainability, forest management, SFM, history, origin, forest principles, criteria, certification scheme, FSC, Forest Stewardship Council, certification process, accreditation, General Assembly, members, PEFC.

Table 3.1 continued: Combinations of key words used in search for literature

Paragraph 2.1.3	Forest certification, FSC, Forest Stewardship Council, PEFC, certification scheme, SFM, sustainable, certification standards, evaluation, difference compare, comparison.
Paragraph 2.2.1	Ecosystem services, Millennium Ecosystem Assessment, forest, plantation, land cover, percentage, forest cover, global, natural forest, FSC standards, FSC, international, national.
Paragraph 2.2.2	Forest certification, standards, certification schemes, environmental, effect, impact, empirical, on-the-ground, literature, FSC, biodiversity, soil, landscape, ecosystem services, habitat, survey, questionnaire, water, watershed, riparian, river, stream, carbon, sequestration, storage, monitor, tourism, valuation, payment.
Paragraph 3.1	Ecoregion, terrestrial, WWF, Chile, Valdivian ecoregion, ecosystem service, mountain range, Coastal range, Nahuelbuta, landscape, history, forest, management, threats, climate, topography, vegetational floor, vegetation, biodiversity, conservation, species, priority, variation, fragmentation, endemic, land cover, nature, FSC.

3.3 Communication with WWF Chile and forestry companies

To obtain all necessary information and data needed for this study, the ‘Universidad de La Frontera’ and WWF Chile were the starting contacts, coordinating the communication with forestry companies, FSC Chile and other stakeholders. A seminary was attended about recent monitoring results of FSC and its environmental and social effects in southern Chile, where also personal contact with people of FSC and WWF Chile was made, making further communication via email and skype easier. Furthermore, the research plan was presented for both WWF Chile and representatives of Arauco S.A. and Forestal Mininco S.A. to inform them about the study and facilitate further communication to obtain necessary data.

3.4 Selection of ecosystem services to evaluate

A first selection of ES was made based on ES (groups) of the Millennium Ecosystem Assessment (MEA) of Corvalan *et al*. (2005). Second, these ES were related to ‘the indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012) to make a final first selection. Third, ES associated to FSC were included in a questionnaire for stakeholder groups to obtain a ranking of relevance of evaluation of ES in the context of environmental FSC impacts. The questionnaire was created with the online survey software

QuestionPro (2019) following the Tailored Design Method of Dillman (2011). Stakeholders were identified following similar stakeholder groups as used by Jaung *et al*. (2016): partners of the FSC network (e.g. WWF), companies owning FSC certified forests and FSC CBs, but in this study also academic people related to FSC were included. WWF Chile was the central contact to obtain information of all stakeholders, which were then invited by email to answer survey. After 3 weeks, reminders were sent to stakeholders who didn't reply yet and this was repeated with a second reminder 6 weeks after the online survey activation. The questionnaire was created in Spanish and consisted of several questions to obtain practical information about the stakeholder, followed by the questions related to FSC. Invited stakeholders could obtain further information about questions and doubts about the survey by email or phone call, in addition to giving further comments. Related to this, the practical questions included: e-mail address, to which stakeholder group the respondent belongs and what its relation to FSC was. Furthermore, the main question asked to make ranking of ES from most to least relevant to evaluate in the context of environmental impacts of FSC certification. Finally, the participants needed to answer for each ES if the evaluation is relevant on the short (≤ 10 years) or long term (> 10 years) and which potential synergies and trade-offs exist with other ES. Answers were analysed both as overall results and results for each stakeholder group. In addition, the response rate of the questionnaire was calculated by dividing the number of respondents by the amount the persons invited by email. Finally, ES in the top 10 of relevance were considered for evaluation.

3.5 Collecting and preparing inputs for the ecosystem service models

InVEST (Integrated Valuation of Ecosystem Services and Trade-offs; Sharp *et al*., 2018b) models were considered for the quantification and mapping of the ES, selected with the questionnaire. InVEST is a toolset of models for the quantification and mapping of ES conditions, in biophysical and/or economic outputs and to support decision making related to the management of natural resources (Sharp *et al*., 2018b). It allows for the comparison of different scenarios and supports the discovery of trade-offs and synergies between ES (Sharp *et al*., 2018b). The stand-alone spatially explicit software is based on the structure of "supply, service, and value" scheme, making the connection with benefits for the human beings (Sharp *et al*., 2018b, p.10). Here, 'supply' is defined by "what is potentially available from the ecosystem (i.e. what the ecosystem structure and function can provide)" (Sharp *et al*., 2018b, p. 10), 'service' represents the "demand and thus uses information about beneficiaries of that service” (Sharp *et al*., 2018b, p. 11) and ‘value’ involves “social preference and allows for the calculation of economic and social metrics” (Sharp *et al*., 2018b, p. 11). The models were created as an element of the Natural Capital Project to link ES with their value and stimulate investment in natural resources. This project is a collaboration between Stanford University, the Nature Conservancy, the Chinese Academy of Science, the Stockholm Resilience Centre, the University of Minnesota, and WWF (Stanford University, 2018). The InVEST models were preferred above other ES models because of the following characteristics: spatially explicit, freely available, presence of links with land cover in the models and the possibility of scenario analysis (Sharp *et al*., 2018b).

First, an overview table was created of all selected models (Table 3.2), together with a summary of necessary inputs and resulting outputs (Appendix D and H). Second, inputs where searched making use of different sources: open access databases, expert consultation and scientific publications. For the latter, publications using InVEST models and/or investigating ES in Chile or other countries in the world were the starting point (search engines Google Scholar, Limo and ResearchGate; key words combinations: InVEST, models, ecosystem service, habitat quality, water yield, sediment delivery ratio). Second, already collected inputs were processed for input preparation, using QGIS (Quantum GIS) (QGIS Development Team, 2018) and ArcGIS (Environmental Systems Research Institute (ESRI), 2017), e.g. involving calculations of averages of time. Calculated results were subsequently checked with values found in literature. For each input, the source and processing method are given in Appendix D. Finally, models were selected corresponding to the three most relevant ES for evaluation, because of unavailability of certain inputs of the other first selected models in Table 3.2: the Annual Water Yield (AWY) model, the Habitat Quality (HQ) model and the Sediment Delivery Ratio (SDR) model.

Table 3.2: Selected InVEST models with corresponding ES

InVEST model	**ES**
Annual Water Yield: Reservoir Hydropower model	Water cycle and watershed protection, fresh water supply
Seasonal Water Yield model	
Habitat Quality model	Biodiversity conservation (habitat quality as proxy for biodiversity), habitats for plants and animals
Habitat Risk Assessment model	Habitats for plants and animals
Sediment Delivery Ratio model	Soil conservation and erosion regulation, regulation of natural risks
Carbon Storage and Sequestration model	Carbon capture and storage, climate regulation
Nutrient Delivery Ratio model	Nutrient cycle

Each of the selected InVEST models requires input of a landcover raster, which was created with a supervised classification of Google Earth images. This is a collection of different image sources, from i.a. Street View and aerial images to satellite images, with availability of present and historical images (Google, 2019). It can be either single images associated with a certain moment in time or mosaic images from several dates (Google, 2019). First, the availability of images was explored for days in the baseline period (2008-2010) and post-certification period (2016-2018), using Google Earth Pro (Mountain View CA: Google Inc., 2019). This availability was also explored over different scale levels. The selection of days for which to download images was made, based on the following: availability for the same day in the whole study area and as much as possible similar source of images and similar spatial resolution. This leaded to selection of Red-Green-Blue (RGB) images for 15/02/2008 and 15/02/2016, with a spatial resolution of 8.68 m. These images were downloaded and combined with the software Google Earth Image Downloader 6.24 (Allmapsoft, 2019), using a zoom level of 15 (Appendix E). Sentinel 1 and 2 satellite image were no option because they are not available for the baseline period (available since 2014) (European Space Agency (ESA), 2018, 2019). In addition, main available satellite images in the studied periods are Landsat 7 (launched in 1999, spatial resolution: 15 m for thermal infrared radiation, 7,60 m for panchromatic band 6 and 30 m for bands 1 to 5) (National Aeronautics and Space Administration (NASA), 2018a) and Landsat 8 (launch in 2013, spatial resolution: 100 m for thermal infrared radiation, 15 m for band 8 and 30 m for shortwave, near and visible infrared radiation) (NASA, 2018b) and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) images (spatial resolution: 15 m for visible and near infrared radiation, 30 for shortwave infrared radiation and 90 m for thermal infrared radiation) (NASA, 2004). However, the study by Reyes & Altamirano (2018) and Montenegro *et al.* (2018) mentioned in section 2.3.2 concluded that the used ASTER images resolution limited the identification of certain land cover types, such as native forests or protection zones smaller than 30 m, further limiting the accuracy of conclusions about FSC impact. These publications thus recommended the use of higher spatial resolution satellite images in future research (Montenegro *et al.*, 2018; Reyes & Altamirano, 2018), being the main reason for the choice for Google Earth images for this study.

In the next the step the combined Google Earth images were georeferenced in QGIS, using control points created in Google Earth Pro with maximum zoom levels. Coordinates were given in the coordinate reference system WGS 84 (EPSG:4326) and the nearest neighbour resampling method was used, together with a linear transformation type. In addition, control points were added to minimize residuals. The latter represent the difference in the coordinates of the control points and those predicted by the georeferencing model (ESRI Inc., 2016). Further, the supervised land cover classification, using spectral signatures (Sanhouse-García *et al.*, 2016) was executed. This classification consists of a three subsequent phases: a training stage, classification stage and output stage (Lillesand *et al.*, 2014). The training stage involves the creation of training polygons representative for each land cover class (Lillesand *et al.*, 2014). For 2008, these polygons were created in QGIS using land cover cadastre shapefile of 2008 for the Bío Bío region (CONAF, 2008) and maximum zoom levels in Google Earth Pro. For 2016, these polygons were created in QGIS using maximum zoom levels in Google Earth Pro for visual interpretation, a detailed land cover raster of Chile of 2014 (30 m spatial resolution) (Hernández *et al*., 2016; Zhao *et al*., 2016), cadastre shapefiles of 2016 for the Bío Bío region and Aracaunía region respectively (CONAF, 2016) and terrain Global Positioning System (GPS) coordinates, collected during field work. For the latter, minimum 20 reference points were taken for each land cover class, noting down the current land cover and taking pictures of the situation. For each land cover class (Table 3.3), 210 polygons were created, which were further split using the 80:20 ratio for training and validation polygons respectively, following the Pareto Principle or the 80/20 rule. This rule expresses that 20 % of the causes explain 80 % of the impacts and 80 % of the causes explain 20 % of the consequences (de Koch, 2001; Brynjolfsson *et al.*, 2011). In the subsequent classification stage, the most similar land cover class is assigned to each image pixel, after which the output phase results in a classified image (Lillesand *et al*., 2014). Two textural features, calculated in QGIS (sum average, information measures of correlation, described by GRASS Development Team (2019) were included in the classification as extra bands to improve classification. Different classification tools were tested all using the Random Forest (RF) machine learning method, with the QGIS Dzetzaka plugin (Karasiak & Perbet, 2018; Karasiak, 2019).

The RF algorithm is recently proven to be successful for efficient, reliable and robust land cover classification of high resolution (Hayes *et al.*, 2014), multispectral (Akar & Güngör, 2012), multisource (Belgiu & Drăguţ, 2016; Gislason *et al.*, 2006) data with large scales (Belgiu & Drăguţ, 2016; Deng & Wu, 2013; Rogan *et al*., 2003), being insensitive to overfitting (Breiman, 2001). This non-parametric RF classifier has obtained successful results for classifications with a relatively high number of classes (e.g. Rodriguez-Galiano *et al.*, 2012) and classes with similar spectral traits (Akar & Güngör, 2012). Furthermore, it can process ancillary data, such as Digital Elevation Model (DEM) data (Breiman, 2001; Corcoran *et al.*, 2013; Hayes *et al.*, 2014). The RF algorithm is an ensemble tree-type learning algorithm handling a potential large amount of variables, and estimating the importance for each in the classification (Breiman, 2001). The RF is defined as: “a classifier consisting of a collection of tree-structured classifiers $\{h(x, \theta_k), k = 1,\ldots\}$, where the $\{\theta_k\}$ are independent identically distributed random vectors and each tree casts a unit vote for the most popular class at input x” (Breiman, 2001, p. 2). During the training stage, trees are created and train each an original data sample, making random subsets of variables for data splitting at the nodes (Akar & Güngör, 2012; Breiman, 2001; Gislason *et al.*, 2006). Trees are thus grown by randomly selecting between all best splits (Akar & Güngör, 2012; Breiman, 2001; Gislason *et al.*, 2006). Every tree of the RF represents a vote for the most successful class and the majority vote all trees then decides about the output (Breiman, 2001; Gislason *et al.*, 2006). Next, the classified raster was post-processed with the use of a dilation filter in QGIS to smooth the data. Furthermore, masks of existing water (Albers, 2018a, 2018b), urban areas (Ministerio de Vivienda Y Urbanismo, 2016), beaches and dunes (CONAF, 2008; CONAF, 2017) and wetland (Ministry of Environment Chile (Ministerio del Medio Ambiente), 2015) shapefiles were applied as filter: land cover classes of pixels overlapping with these shapefiles were modified to the water and wetland classes respectively. Furthermore, land cover and land cover change were analysed in QGIS using the Semi-Automatic Classification Plugin (SCP). Finally, accuracy analysis was executed with this SCP, creating a confusion matrix with associated metrics: kappa, overall accuracy, producer’s and user’s accuracy, described by Lillesand *et al.* (2014).

Table 3.3: Classified land cover classes with identity number and descriptions, inspired by descriptions of Montenegro *et al.* (2018)

Identity (ID)	**Land cover class**	**Description**
1	Adult plantation	Adult plantations of radiata pine and eucalypt
2	Young plantation	Young plantations of radiata pine and eucalypt
3	Native forest	Adult and young forest with native species of heights > 2 m and crown covers > 25 %
7	Agriculture	All agricultural land under cultivation, including i.a. grain and vegetable crops
8	Grassland	Annual and perennial pastures
9	Water	Water bodies and large rivers

Table 3.3 continued: Classified land cover classes with identity number and descriptions, inspired by descriptions of Montenegro *et al.* (2018)

Identity (ID)	**Land cover class**	**Description**
10	Shrubland	Native shrub vegetation with heights < 2 m and crown covers < 25 %
11	Wetland	Wetlands
12	Built/urban/industry areas	Areas of human use, including urban and industry areas
13	Bare soil	Clear-cut areas and soils without vegetation cover
14	Beaches and dunes	Beaches and areas with dune vegetation

Most inputs for the HQ model were obtained with a second questionnaire. Here, the same software and method (QuestionPro (2019) and the Tailored Design Method of Dillman (2011) were used as for the first questionnaire. A limited number of experts of each stakeholder group of the first questionnaire (in total 10) was invited to answer this survey. Again, the survey was in Spanish and reminders were sent every 3 weeks. In addition, practical questions included e-mail address, to which stakeholder group the respondent belongs, followed by questions about the model inputs. Response rates were also calculated, and results were analysed by calculation of average values over all experts. Average weights were normalised to obtain values between 0 and 1.

3.6 Ecosystem service models and scenarios

Based on available information and selected relevant ES from the survey, this study focuses on three ES models: the Annual Water Yield (AWY) model, Sediment Delivery Ratio (SDR) model and the Habitat Quality (HQ) model.

3.6.1 Annual Water Yield model

The AWY model quantifies and maps how each landscape zone contributes to annual average water yield for consumption and hydropower production, linked to mainly land use patterns, soil and climate characteristics (Sharp et al., 2018b). The most important outputs are annual average water yield (m3) and annual average water supply (m3) (including consumption), for each (sub)watershed (Sharp et al., 2018b). A detailed overview of inputs and their references with pre-processing methods and all obtained outputs is given in Appendices D and H. The model is based on a water balance to calculate annual average water yield Y(x) for every pixel x: $Y(x) = (1 - \frac{AET(x)}{P(x)}).P(x)$ with P(x) the annual precipitation (mm) and AET(x) the annual actual evapotranspiration (mm) of pixel x (Sharp et al., 2018b). The Budyko curve of Fu (1981) and Zhang et al. (2004) is used to calculate $\frac{\mathrm{AET(x)}}{\mathrm{P(x)}}$ for vegetated land cover classes, including a catchment parameter ω(x): $\frac{\mathrm{AET(x)}}{\mathrm{P(x)}}=1+\frac{\mathrm{PET(x)}}{\mathrm{P(x)}}-(1+(\frac{\mathrm{PET(x)}}{\mathrm{P(x)}})^{\omega})^{1/\omega}$. Here, the potential evapotranspiration PET(x) is given by Kc(lx). ET0(x) with Kc(lx) being the crop evapotranspiration coefficient of the land cover lx and ET0(x) the reference evapotranspiration for pixel x, calculated from climate parameters for a reference vegetation (e.g. grass) (Allen et al.,1998; Sharp et al., 2018). The empirical catchment parameter ω(x) reflects climate and soil characteristics, not given by annual average precipitation P(x) and volumetric plant available water content AWC(x) and is given by $\omega(x)= Z \cdot \frac{\mathrm{AWC(x)}}{\mathrm{P(x)}}+1.25$ (Donohue et al., 2012). Here, the seasonality parameter Z, include local hydrological patterns (e.g. of precipitation), with 1.25 referring to the minimum $\omega(x)$ value (for bare soil) (Donohue et al., 2012). In addition, AWC(x) is defined as: Mininum (root restricting layer depth, vegetation root depth). PAWC with PAWC the plant available water content (PAWC) (ranging from 0 to 1) (Sharp et al., 2018b). The model first calculates all parameters on pixel scale after which they are summed and averaged to (sub)watershed levels (Sharp et al., 2018b). Consumptive demands can be used as input to determine annual average water supply volume as the difference of average annual water yield and consumption volume (Sharp et al., 2018b).

This InVEST model has several limits. First, it does not separate subsurface, surface and baseflow (Sharp et al., 2018b). Second, maxima and minima in water supply flows and flow rates for consumption and hydropower production are not captured, since the models calculates results on a year basis (Sharp et al., 2018b). Third, the model is created for areas larger than pixel scale, and may not capture complicated landscape patterns (Sharp et al., 2018b). Fourth, irrigation water transport between subwatersheds or moments in the year is not well captured in this approach (Sharp et al., 2018b). Fifth, consumptive demand is simplified, as the average water use for consumption per landcover class is used as input, there can be a large variation in this use within each land cover class (Sharp et al., 2018b). In addition, supply input is e.g. probably upstream of urban areas, with a high water demand, resulting in a spatial discrepancy of modelled versus real demand points (Sharp et al., 2018b).

3.6.2 Sediment Delivery Ratio model

The SDR model calculates and maps sediment retention and delivery in landscapes, using topographic, soil, climate, management practice parameters and land cover patterns (Sharp et al., 2018b). Important inputs are a DEM and a land cover raster. Main outputs are annual averages of total potential soil loss (tons/(sub)watershed), exported sediment to the stream (tons/(sub)watershed), and sediment retention (tons/pixel), relative to bare soil cover (Sharp et al., 2018b). The model is based on the hydrological connectivity concept with parameters defined by Borselli et al. (2008) (Sharp et al., 2018b). A detailed overview of inputs, pre-processing methods, corresponding references and all outputs is given in Appendix D and H respectively.

First, the model calculates the annual soil loss from each pixel x using the Revised Universal Soil Loss Equation (RUSLE) of Renard et al. (1997): $usle(x) = R(x).\ K(x).\ LS(x).\ C(x).\ P(x)$, with for pixel x, R(x) the rainfall erosivity (MJ.mm (ha.hr)-1), K(x) the soil erodibility (ton.ha.hr (MJ.ha.mm)-1), LS(x) the slope length gradient factor (-), C(x) the crop management factor (-) and P(x) the support practice factor (Sharp et al., 2018b). The model calculates LS(x) from the DEM using the algorithm proposed by Desmet & Govers (1996). Second, the model calculates the connectivity index IC for every pixel, associated with the hydrological connection of sediment sources and sinks (e.g. rivers) (Borselli et al., 2008; Sharp et al., 2018). This index links sediment sources with sediment sinks (e.g. rivers), with higher connectivity values reflecting a higher probable connection and thus transport of source erosion to the sink (e.g. in locations of steep slopes or with few vegetation)) (Borselli et al., 2008; Sharp et al., 2018). The index is given by: $IC = \log_{10}(\frac{Dup}{Ddn})$, with Ddn being the flow path between the nearest stream and every pixel and Dup equalling the upslope area of every pixel and defined as $Dup = \overline{C}\overline{S}\sqrt{A}$ with A the upslope contributing area (m2), $\overline{S}$ the average slope gradient of this area (m/m) and $\overline{C}$ the average C factor for this area (-) (Borselli et al., 2008; Sharp et al., 2018). In addition, Ddn is defined as $\sum_x \frac{d(x)}{C(x)\ S(x)}$ with S(x) and C(x) the slope gradient and C factor for the xth pixel respectively and d(x) the flow path length along the xth pixel, following the steepest downslope direction (m) (Borselli et al., 2008; Sharp et al., 2018). The model computes A and the downslope flow path with the D-infinity flow algorithm of Tarboton (1997) (Sharp et al., 2018b). In the next step, the SDR is calculated with the formula of Vigiak et al. (2012): $SDR(x) = \frac{SDRmax}{1 + \exp(\frac{IC0-IC(x)}{k})}$ with k and IC0 the calibration parameters linked to the shape of the SDR-IC increasing curve and SDRmax the theoretical maximum SDR with an average of 0.8 (Vigiak et al., 2012) used in the model (Sharp et al., 2018b). Finally, the model computes the sediment export E, defined as $E(x) = usle(x) \,.\, SDR(x)$ for pixel x, and $E = \sum_x E(x)$ for the total watershed (ton/(ha.yr)), with E(x) the sediment export of pixel x, really reaching the stream (Borselli et al., 2008; Sharp et al., 2018). In addition, it is possible to use extra artificial drainage layers as input to capture the element of artificial connectivity (Sharp et al., 2018b). The model calculates the sediment retention index for pixel x as $R(x).\,K(x).\,LS(x).\,\big(1\text{-}C(x).P(x)\big).SDR(x)$, being the soil loss avoided by the current land cover relative to bare soil, with the SDR as a weight factor (Sharp et al., 2018b). It gives an underestimation, for not including upstream sediment flowing related retention through pixel x (Sharp et al., 2018b). The SDR model also has several limitations. First, the RUSLE equation includes inter-rill and rill erosion, but no other sediment sources or erosion such as landslides, streambank or gully erosion (Renard et al., 1997; Sharp et al., 2018b). This equation was also created in the U.S., resulting in potential limits in successful results for other areas erosion (Renard et al., 1997; Sharp et al., 2018b). However, adjusting the C, P, K and R inputs to local conditions can decrease the risk of this limitation and successfully generate realistic values (Sougnez et al., 2011; Sharp et al., 2018). Finally, the sensivity of the model to most input parameter is potentially high with errors in the empirical input parameters and calibration parameters giving potentially large effects on output results (Sharp et al., 2018b).

3.6.3 Habitat Quality model

The HQ model uses land cover information and threats to biodiversity to quantify and map habitat quality, calculating temporal changes and relative degradation and area of the different habitat types in a landscape (Sharp et al., 2018b). The model uses habitat quality as indicator or proxy for biodiversity and assumes higher habitat quality and extent mean higher support for all biodiversity levels (Sharp et al., 2018b). Habitat quality is defined as the ecosystem capability for supply of suitable conditions for population and individual persistence (Hall et al., 1997), included as a continuous variable (Sharp et al., 2018b). The intensity and distance of human land uses to habitats influence this quality with high intensity and small distances decreasing the quality (McKinney, 2002; Forman et al., 2003; Sharp et al., 2018). Main inputs are a current land cover raster (optional for baseline and future moment), habitat suitability scores H(j) for each land cover type j (0 to 1), threats to biodiversity and habitats and impacts of these threats on the habitats (Sharp et al., 2018b).

These impacts are included with four factors: the distance between the source of the threat and the habitat with an exponential or linear function reflecting the decay of threat impacts with increasing distance, the threat's relative impacts and the relative sensitivity of every habitat type to every threat (0 to 1) (Sharp et al., 2018b). For linear decay, the impact of threat r coming from pixel y on habitat in pixel x is given by $i(rxy)= 1-(\frac{d(xy)}{d(r)max})$, while for exponential decay the following formula is valid: $i(rxy)=\exp(-\left(\frac{2.99}{d(r)max}\right) d(xy))$, with d(r)max the maximum distance over which threat r is effective and d(xy) the linear distance between pixels y and x (Sharp et al., 2018b). The relative sensitivity S(jr) of habitat type j to threat r with higher values indicating higher sensitivity, is an element of the total threat level in pixel x with habitat type j $D(xj)= \sum_{r=1}^{R} \sum_{y=1}^{Y(r)} (\frac{w(r)}{\sum_{r=1}^{R} w(r)}).r(y).i(rxy).\beta(x).S(jr)$ with Y(r) the total number of pixels of the threat raster, R the total amount of threats, β(x) the accessibility of pixel x (0 to 1) and w(r) the relative weight of the threat source (Sharp et al., 2018b). Furthermore, the habitat quality in parcel x of land cover j is defined as $Q(xj)=H(j).\ (1-\left(\frac{D^z(xj)}{D^z(xj)+k^z}\right))$, with k and z (2.5 in model) constant scaling parameters and k the half-saturation constant (Sharp et al., 2018b). Finally, habitat rarity of habitat j, relative to other habitats of a landscape, for a current or future landscape is calculated using a baseline land cover raster: $R(j) = 1-\frac{N(j)}{N(j)\text{baseline}}$ with N(j) the pixel amount in land cover type j for the current of future landscape and N(j)baseline the pixel number in land cover type j for the baseline landscape (Sharp et al., 2018b). The overall rarity of habitat type j in pixel x is given by: $R(x)= \sum_{x=1}^{X} \sigma(xj).R(j)$ with X the total number of pixels in the landscape and $\sigma(xj) =1$ when pixel x is in land cover j for the current or future landscape and 0 if this is not the case (Sharp et al., 2018b). A detailed overview of inputs, pre-processing methods, corresponding references and all outputs is given in Appendices D and H. Habitat rarity was not calculated for this study, given the lack of a baseline land cover map. The model limitations include the additiveness for all threats in the landscape, while in reality the impact of several threats may be higher than reflected by their sum (Sharp et al., 2018b). In addition, if a buffer around the landscape of width d(r)max is not considered, results will show less threat intensity at the landscape edges (Sharp et al., 2018b).

3.6.4 Overall results

Resulting maps from the models were visualized in QGIS and ArcGIS, including calculation of changes. The difference was used for the outputs of the HQ Model (output 2016 – output

2008), while the change for the other two models was calculated as: ((output 2016 – output 2008)/output 2008).100, a formula also used by Bhagabati et al. (2014).

3.7 Extraction of model results with sampling

It is important to understand which effects can be expected before assessing the impacts of certification (Nussbaum & Simula, 2005). Therefore a Theory of Change (ToC) is needed: a model characterizing the change process of a certain certification intervention (Romero *et al.*, 2013). This theory can help a priori development of research questions in the assessment of the effects of certification (Romero *et al.*, 2013). Since it is a result of explaining expected effects and process of this change it also stimulates critical thinking (SCR, 2012; Stein & Valters, 2012). The development of a ToC needs to be participatory (Rogers, 2012; Vogel, 2008) and iterative (James, 2011). In addition, this theory helps to understand obstacles to successful certification implementation and how it encourages SFM interventions under various dynamic scenarios (Furman & Gland, 2009; White, 2010; Gertler *et al.*, 2011; Romero *et al.*, 2013). Moreover, the theory should include the inputs, activities, outputs, and outcomes of an intervention with SFM as goal (Jagger *et al.*, 2010; Romero *et al.*, 2013). Furthermore, the economic, social and ecological context of an intervention need to be considered, because they influence its effects (Romero *et al.*, 2013). Romero *et al*. (2013) propose a methodological framework for investigating the (in)direct intervention effects in the short and medium term and the contribution of processes to certification linked outcomes. The FSC program itself developed and ToC with description, pathways, intended impacts with linked indicators and supporting strategies (FSC, 2015a). Finally, Blackman & Rivera (2010) state that a counterfactual outcome must be developed when evaluating the certification effects: an estimation of the environmental outcomes in the case of no certification, to include influencing factors, unrelated to certification. The difference between actual and counterfactual outcomes then equals the certification effect (Blackman & Rivera, 2010). When using uncertified area outcomes as a control group, and it is assumed that certified areas would have had the same outcome when not certified, selection bias needs to be avoided (when areas characterized by factors influencing the outcomes (e.g. lower erosion rates) are selected for certification (Blackman & Rivera, 2010; Romero *et al.*, 2013). Several methods exist for building credible counterfactuals, such as the ‘quasi-experimental’ and the ‘randomized’ certification design (Blackman & Rivera, 2010; Romero *et al.*, 2013).

In this study, an expert knowledge method was combined with a 'before-after' sampling design. The former involving stakeholder consultation with a survey and the latter implying the data comparison of pre-certification and post-certification periods (Romero *et al.*, 2013). A quasi-experimental approach, a comparison between FSC certified (Figure 3.5) and uncertified areas (Romero *et al.*, 2013) is partly used by comparing temporal changes between both areas.

A stratified random sampling method was used for the comparison between the pre- and post-certification periods (also used by Reyes & Altamirano (2018)). First, the landscape was divided in five sublandscapes (SLs), being as homogenous and representative for the landscape conditions (mainly geomorphological units and climate zones (Figure 3.4) and subwatersheds (Figure G.2, Appendix G) as possible. In addition, these sublandscapes needed to cover FSC certified areas (Figure 3.2). Next, all forest properties containing minimum 20 ha FSC certified areas in 2018 were selected. Finally, forest properties were randomly selected out of the total selection of certified properties (30-40 after removing outliers; sometimes including HCVAs in their limits) (Figure 3.5). Uncertified forest properties were selected similarly, using properties larger than 20 ha under forest cover (plantation or native forest) outside of the certified areas in Figure 3.2 and selecting the same number as for the certified properties, in each SL. Model outputs of the InVEST model maps were then extracted for these forest properties for further statistical analysis. InVEST models were first run for the whole landscape, instead of only for the forest properties, because of the models including landscape connectivity (Sharp *et al.*, 2018b).

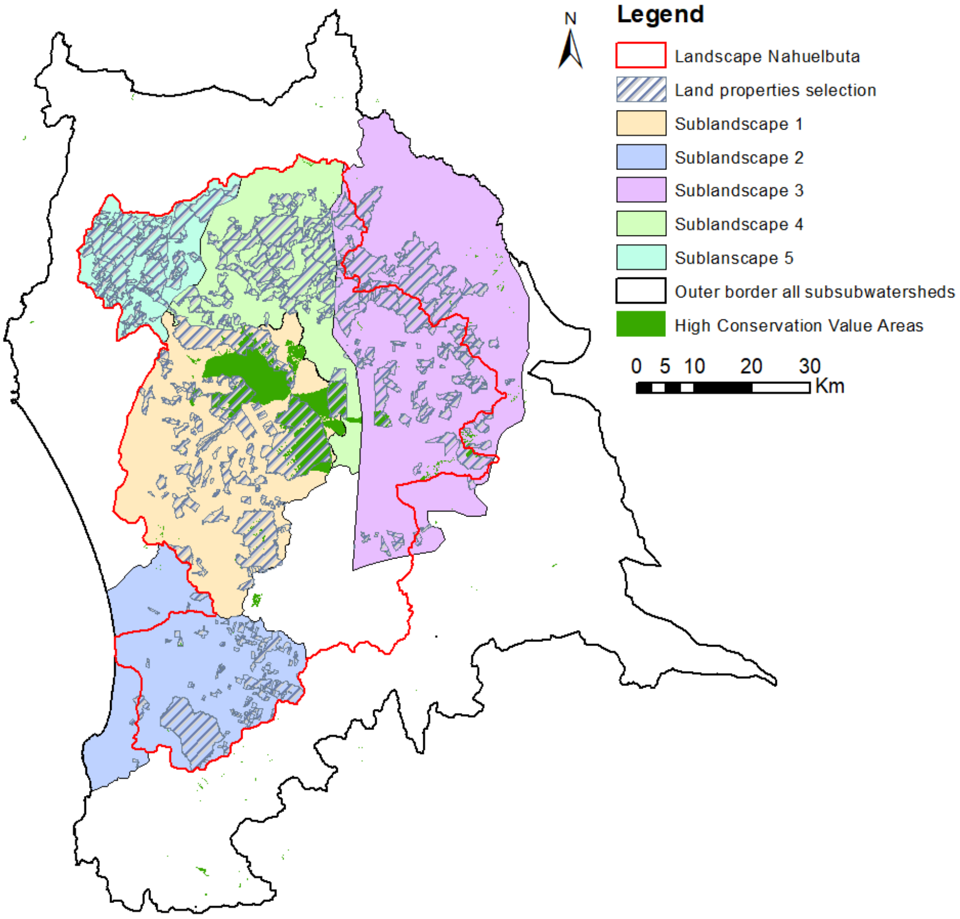


Figure 3.5: Landscape Nahuelbuta (WWF Chile, 2018b) with the 5 sublandscapes and selected FSC certified forest properties, sometimes including HCVAs (WWF Chile, 2018b) in their limits, map by author

3.8 Assessing effects of FSC certification on ecosystem service supply

First, results were extracted from the InVEST output maps for the selected forest properties, using QGIS. Second, ES biophysical values were summed to property scales. Next, these values were compared between 2008 and 2016, each for FSC and uncertified properties, using paired tests. Average changes from 2008 to 2016 were then compared between FSC and uncertified plots. Data were tested for normality with a Shapiro-Wilk (SW) test ($\alpha = 0.05$). When the normality assumption for two-sample t-test (T) was not true, the Mann-Whitney-Wilcoxon (MWW) and/or Kolmogorov-Smirnov (KS) tests were used ($\alpha = 0.05$). Hypotheses of these tests were however different (Table 3.4). Hypothesis definitions of the software R were used, after which data were analysed in this software (R Core Team, 2018).

Table 3.4: Null (H0) and alternative (Ha) hypotheses of the used tests between datasets A and B (CDF = Cumulative Distribution Function; µd = true mean difference, TLS = True Location Shift

	SW	**T two-tailed**	**T lower-tailed**	**T upper-tailed**	**MWW two-sided**	**MWW left sided**	**MWW right-sided**	**KS two-sided**	**KS left-sided**	**KS right-sided**
H0	Data are normally distributed	µd=0			Data from A and B follow the same distribution					
Ha	Data are not normally distributed	µd ≠0	µd <0	µd >0	TLS ≠0	TLS< 0	TLS >0	CDF A ≠ CDF B	CDF A < CDF B	CDF A > CDF B

4. Results

4.1 Selection of ecosystem services to evaluate

4.1.1 Relations between national FSC standards and ecosystem services

The relationships between national FSC standards and ES are shown in Appendix C. ES were grouped according to supporting, provisioning, regulating and cultural ES, associated with the standards and the corresponding description (example in Table 4.1).

Table 4.1: extract Appendix C: ES and related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P = Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Soil conservation and erosion regulation (Corvalan *et al*., 2005)	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	"CRITERION 6.5 Written guidelines shall be prepared and implemented to: control erosion; minimize forest damage during harvesting, road construction, and all other mechanical disturbances; and protect water resources." (FSC CHILE, 2012, p. 49)

4.1.2 FSC stakeholder survey

The overall response rate of the questionnaire results was 32.45 %, as 49 out of 151 invited stakeholders responded. These participants represent different stakeholder groups as graphically represented in Figures 4.1 and 4.2.

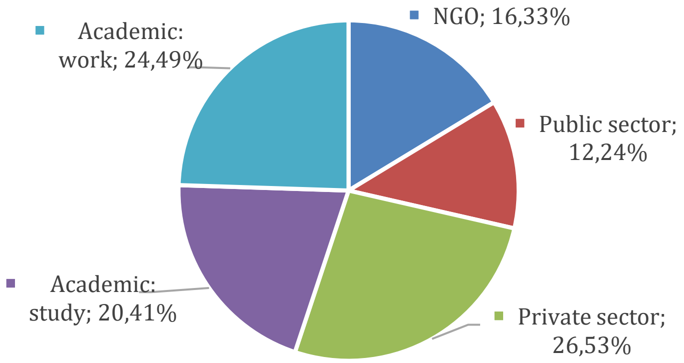


Figure 4.1: Shares in percentage (%) of participants of the five stakeholder groups

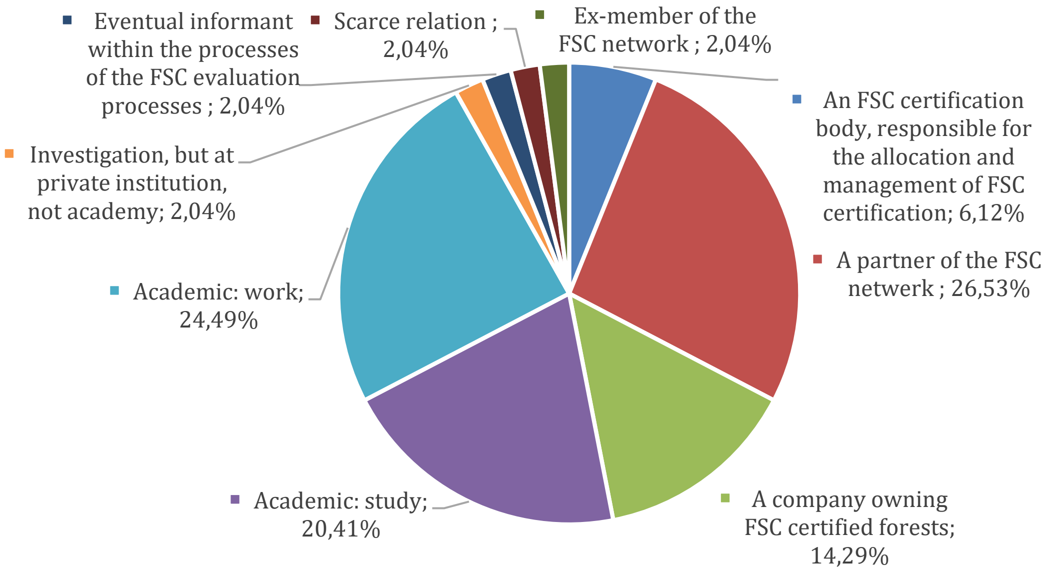


Figure 4.2: Shares in percentage (%) of participants of the detailed stakeholder groups

The overall ranking of relevance to evaluate certain ES, related to FSC certification impacts, shows ES related to water (3.78 and 4.43), biodiversity (4.82), habitats (5.35) and soil conservation (5.61) as highly relevant (Figure 4.3). Similar graphs, for each stakeholder group, show similar results with these ES in the top ten, except for the ‘private’ and ‘Investigation’ group (Appendix I).

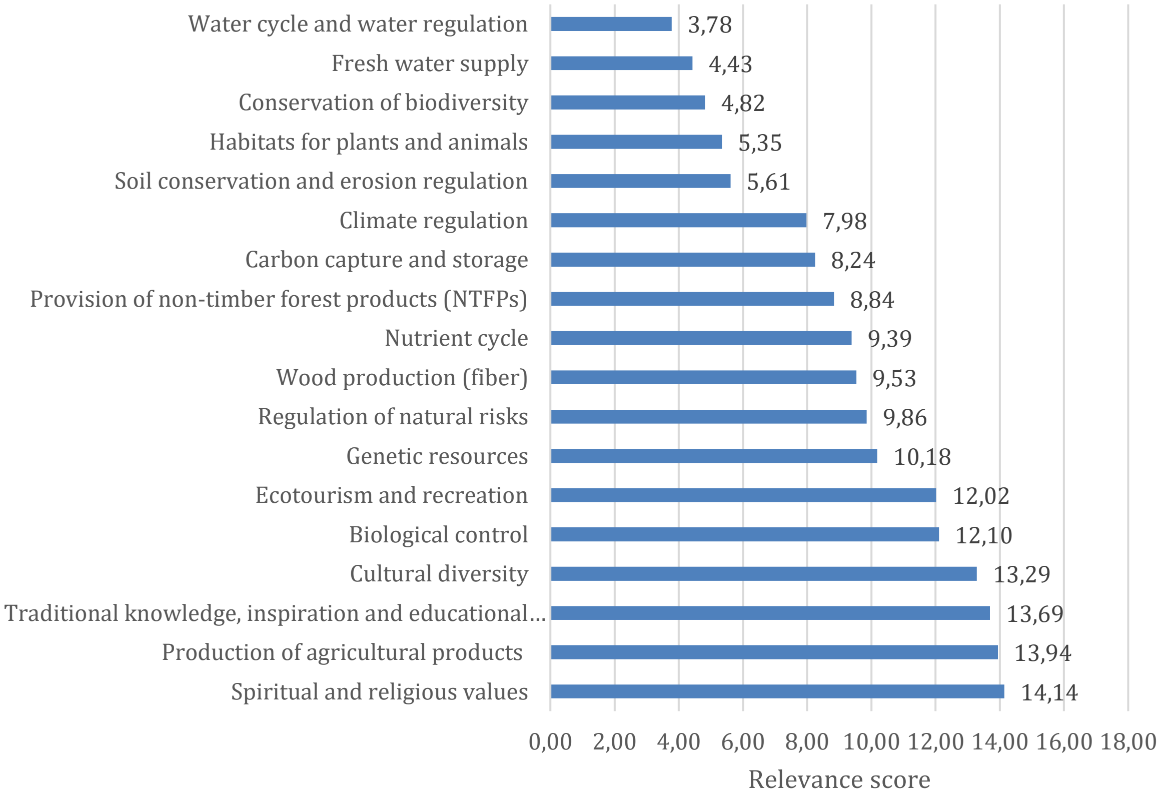


Figure 4.3: Overall relevance scores, including all stakeholder groups, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance, scale 1-18)

Stakeholders indicated the importance of long-term evaluation for climate regulation (0.88 score), biological pest control (0.59 score), carbon capture (0.62 score), water cycle (0.53 score), nutrient cycle (0.70 score), natural risk regulation (0.60 score), biodiversity conservation (0.51), wood production (0.52 score) and genetic resources (0.75 score) (Figure 4.4). Results suggest short-term evaluation for ecotourism (0.31 score), traditional knowledge systems (0.44 score) and spiritual values (0.43 score), habitats (0.40 score), fresh water supply (0.43 score) and NTFP supply (0.47 score) (Figure 4.4). Results for each stakeholder groups are given in Appendix I.

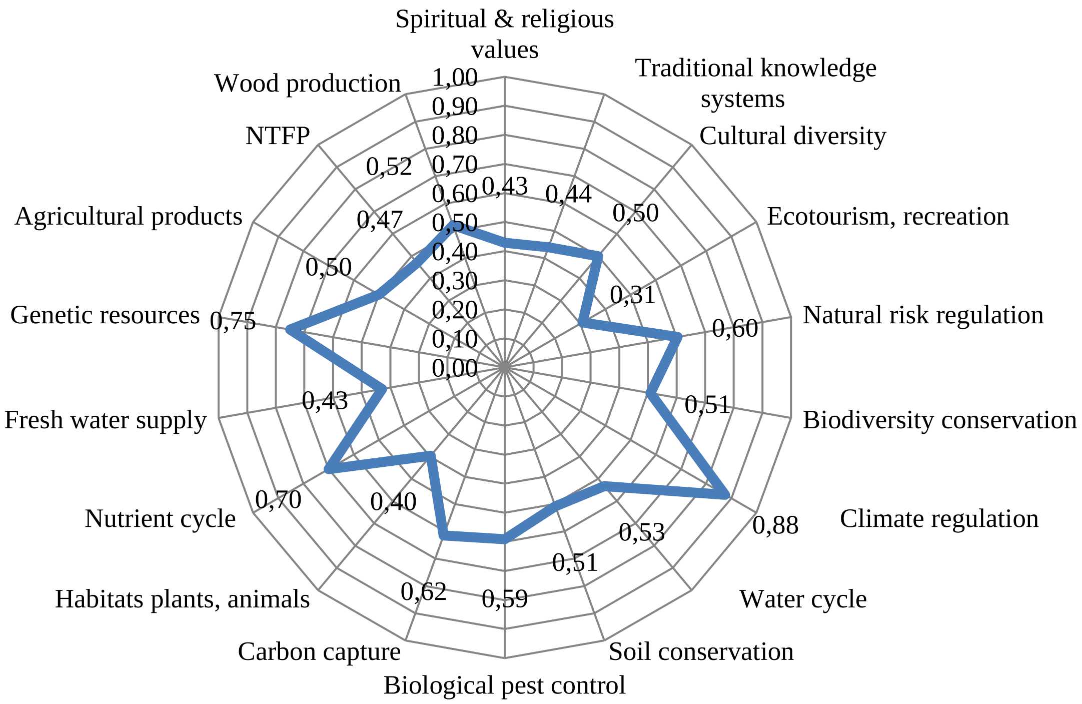


Figure 4.4: Overall normalized scores about the evaluation period of each ES, values range between 0 (short-term (≤ 10 years) and 1 (long-term > 10 years), scores below and above 0.5 suggest short-term and long-term evaluation respectively

For each of the ES in the survey, trade-offs and synergies with several other ES were suggested. The two most important trade-offs and synergies were listed for each ES (Table 4.2). More detailed representations are given in Appendix I, including analyses for the different stakeholder groups.

Table 4.2: Each of the 18 ES in the survey with the two most important trade-offs and synergies, and the number of votes for these correlations

ES	Trade-offs	Synergies
Wood production	Biodiversity conservation (18), habitats for plants and animals (17)	Carbon capture and storage (21), soil conservation and erosion regulation (7)
Supply of NTFPs	Wood production (16), biodiversity conservation (11)	Traditional knowledge, inspiration and educational values (17), genetic resources (8)
Production of agricultural products	Biodiversity conservation (13), habitats for plants and animals (11)	None of the other ES (9), ecotourism and recreation (8)
Genetic resources	Wood production (14), production of agricultural products (14)	Biodiversity conservation (27), habitats for plants and animals (11)

Table 4.2 continued: Each of the 18 ES in the survey with the two most important trade-offs and synergies, and the number of votes for these correlations

ES	Trade-offs	Synergies
Fresh water supply	Production of agricultural products (15), wood production (18)	Water cycle and water regulation (21), soil conservation and erosion regulation (8)
Nutrient cycle	Wood production (17), production of agricultural products (10)	Soil conservation and erosion regulation (14), biodiversity conservation (9)
Habitats for plants and animals	Wood production (26), production of agricultural products (18)	Biodiversity conservation (27), genetic resources (7)
Climate regulation	Wood production (17), production of agricultural products (13)	Water cycle and water regulation (12), regulation of natural risks (11)
Carbon capture and storage	Wood production (14), production of agricultural products (12)	Climate regulation (16), wood production (12)
Biological pest control	Wood production (11), production of agricultural products (11)	Biodiversity conservation (12), production of agricultural products (9), wood production (9)
Soil conservation and erosion regulation	Wood production (12), production of agricultural products (18)	Water cycle and water regulation (13), Fresh water supply (14)
Water cycle and water regulation	Wood production (19), production of agricultural products (16)	Fresh water supply (18), climate regulation (9)
Biodiversity conservation	Wood production (21), production of agricultural products (13)	Habitats for plants and animals (16), water cycle and water regulation (10)
Regulation of natural risks	Wood production (15), production of agricultural products (10)	Soil conservation and erosion regulation (13), water cycle and water regulation (10)
Ecotourism and recreation	Wood production (18), habitats for plants and animals (9)	Biodiversity conservation (15), cultural diversity (13)
Cultural diversity	Wood production (17), production of agricultural products (3)	Spiritual and religious values (15), traditional knowledge, inspiration and educational values (12)
Traditional knowledge, inspiration and educational values	Wood production (13), genetic resources (6)	Cultural diversity (17), spiritual and religious values (11)
Spiritual and religious values	Wood production (16), production of agricultural products (7)	Traditional knowledge, inspiration and educational values (18), cultural diversity (12)

4.2 Collecting and preparing inputs for the ecosystem service models

For each model, a detailed information of inputs with corresponding reference and processing method, and outputs is given in Appendices D, G and H. The land cover classification is described in this section. Land cover rasters of 2008 and 2016 (Figure 4.5) showed overall differences in the percentage of pixels classified for each land cover class. In general, clear differences were present for adult and young plantation (ID 1 and 2 respectively), native forest (ID 3) and shrubland (ID 10) (Table 4.3). For example, the adult and young plantation percentages for 2008 were 34.96 % and 1.47 % respectively (Table x), while 15.76 % and 24.71% for 2016 respectively (Table 4.3). In addition, native forest was represented by 9.53% of the pixels in 2008 and 36.37 % in 2016 (Table 4.3). Furthermore, shrubland had shares of the total pixel amount of 28.38 % and 2.44 % for 2008 and 2016 respectively (Table 4.3). The combined and georefenced Google Earth images on which this classification was based are given in Appendix E.

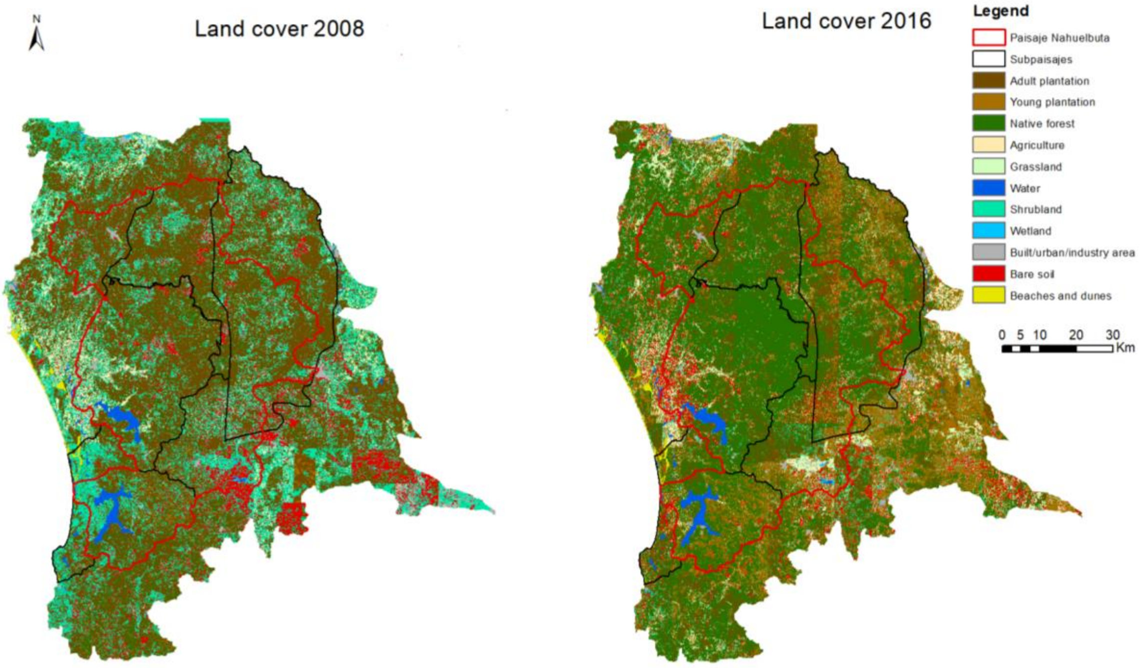


Figure 4.5: Classified land cover rasters of 2008 (left) and 2016 (right) with corresponding legend, map by author

Land cover changes from 2008 to 2016 mainly included changes from adult plantation (ID 1) to young plantations (ID 2) (8.44 %) and native forest (ID 3) (16.44 %) on the one hand and changes from shrubland (ID 10) to young plantations (7.28 %) and native forest (8.14 %) on the other hand (Figure 4.6; Figure E.3 in Appendix E).

Table 4.3: Land cover classification results for 2008 and 2016, with percentage of classified pixels and the area (m^2) for each land cover class

Class ID	Percentage (%)	Percentage (%)	Class ID	Percentage (%)	Percentage (%)
	2008	2016		2008	2016
1	34.96	15.76	**10**	28.38	2.44
2	1.47	24.71	**11**	0.43	0.43
3	9.53	36.37	**12**	4.92	4.92
7	2.75	4.55	**13**	7.04	4.62
8	2.67	2.67	**14**	0.20	0.20
9	0.69	0.69			

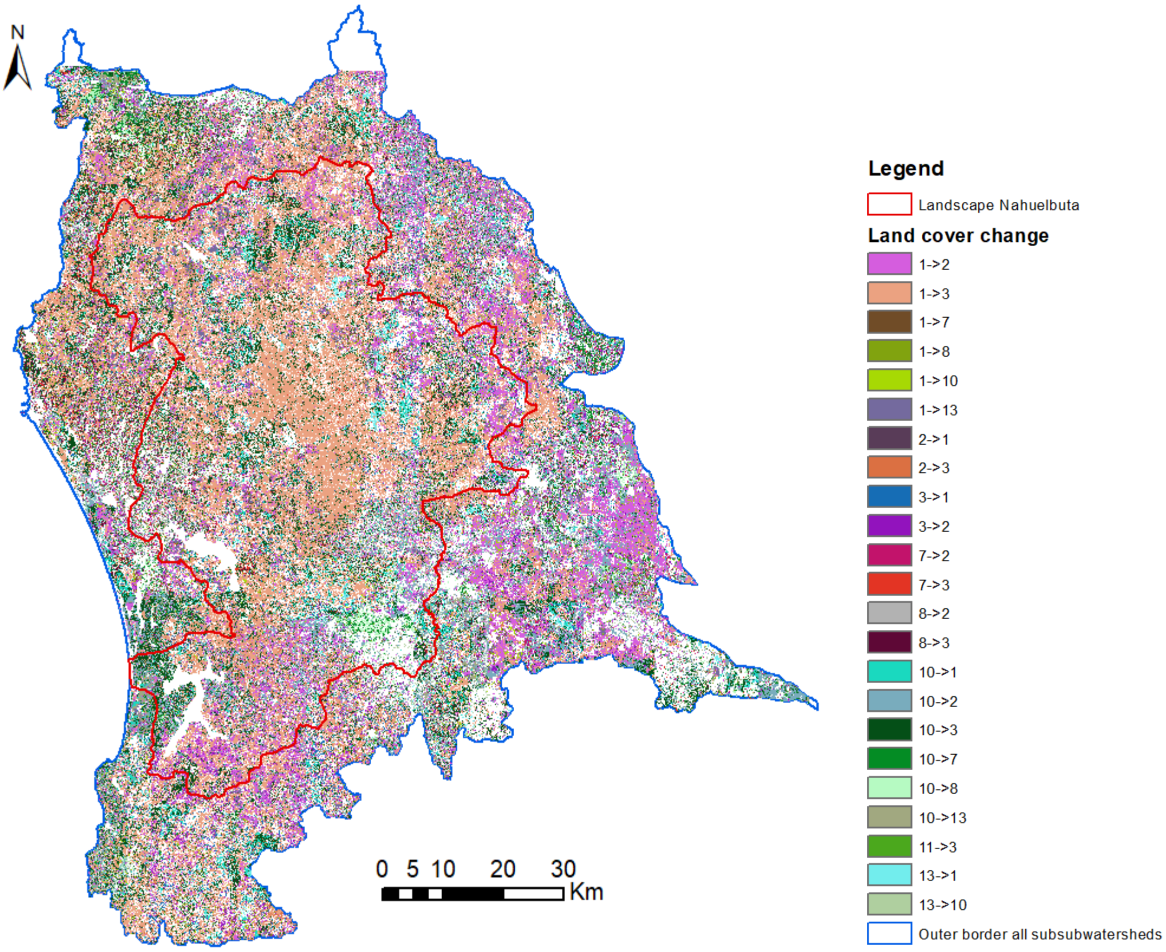


Figure 4.6: Land cover change from 2008 to 2016 within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018), with reference class ID → new class ID in legend, map by author

The overall accuracy of the classification for 2008 was 62.8844 % with a $\hat{\kappa}$ of 33.0980 %. In addition, the producer accuracies of land cover classes were higher than 60 %, except for young plantations (0.5956 %), native forest (26.0893 %), grassland (29.5562 %) and shrubland (36.3050 %) (Table 4.4). In addition, user accuracies were higher than 60 %, except for young plantations (15.7358 %), native forest (39.8222 %), grassland (38.1803 %) and shrubland (52.4663 %) (Table 4.4). Furthermore, $\hat{\kappa}$ values were larger than 70 % for agriculture (72.68 %) and bare soil (91.66 %), but smaller than 70 % for adult plantation (23.64 %), young plantation (0.78 %), native forest (30.38 %), grassland (37.11 %) and shrubland (47.74 %) (Table 4.4). Values for water, wetland, urban/industry/built areas and beaches and dunes were not included, because masks were used for areas with these land covers.

Table 4.4: Accuracy analysis results for 2008 (confusion matrix in Appendix E)

Land cover class	Producer accuracy (%)	User accuracy (%)	$\hat{\kappa}$
1	92.1437	65.6736	0.2364
2	0.5956	15.7358	0.0078
3	26.0893	39.8222	0.3038
7	73.0802	73.3940	0.7268
8	29.5562	38.1803	0.3711
10	36.3050	52.4663	0.4774
13	98.9690	91.8519	0.9166

The overall accuracy of the classification for 2016 was 80.8116 % with a $\hat{\kappa}$ of 65.9674 %. Furthermore, the producer accuracies of land cover classes were larger than 60 %, except for adult plantations (56.7370 %) and shrubland (6.7744 %) (Table 4.5). In addition, user accuracies were larger than 60 %, except for grassland (55.1202 %) and shrubland (14.3756 %). $\hat{\kappa}$ values were larger than 60 % for all classes, except for grassland (53.72 %) and shrubland (10.65 %) (Table 4.5).

Table 4.5: Accuracy analysis results for 2016 (confusion matrix in Appendix E)

Land cover class	Producer accuracy (%)	User accuracy (%)	$\hat{\kappa}$
1	56.7370	69.4676	0.6552
2	69.0241	85.4637	0.8346
3	94.4984	85.3410	0.6262
7	61.1554	73.6925	0.7231
8	64.2629	55.1202	0.5372
10	6.7744	14.3756	0.1065
13	95.3025	90.1885	0.8995

4.3 Ecosystems service models and scenarios

4.3.1 Annual Water Yield model

Overall changes in AWY model outputs were present in the landscape and within the sublandscape. First, SL 1 showed change patterns, differing between the different subsubwatersheds (SSW). The southern SSW showed decreases in AWY (both in mm/pixel as in m^3/SSW) (Figures 4.7, J.1) and water consumption (m^3/SSW and m^3/ha/SSW) (Figure J.2), with increasing water supply (m^3/SSW and m^3/ha/SSW) (Figures 4.8, J.3). This was also the case for the central SSW in SL 1, except for increasing total AWY volumes (m^3/SSW) (Figure 4.7) and decreasing mean water supply (m^3/ha/SSW) (Figure J.3). The northern SSWs of SL 1 had increasing AWY (mm/pixel and m^3/SSW) (Figures 4.7, J.1), decreasing total water consumption (Figure J.2) and supply (Figure 4.8) and increasing mean water consumption (Figure J.2) and supply (Figure J.3). Second, the northern and central SSWs of SL 2, were characterised by increasing mean AWY (mm/pixel) (Figure J.1) and mean water consumption (m^3/ha/SSW) (Figure J.2), but decreases in total volumes of AWY (Figure 4.7) and consumption (m^3/SSW) (Figure J.2), resulting in decreases in mean (Figure J.3) and total water supply (Figure 4.8) (m^3/ha/SSW and m^3/SSW respectively). The southern SSW of SL 2 was marked by similar changes, except for decreasing mean AWY (mm/pixel) (Figure J.1) and increasing total water consumption (m^3/SSW) (Figure J.2). Third, the northern SSW of SL 3 were represented by increasing mean (Figure J.1) and total AWY (Figure 4.7), decreasing mean and total water consumption (Figure J.2) and increasing mean (Figure J.3) and total water supply (Figure 4.8). Additionally, inputs for SSWs in the north-eastern areas of SL 3, produced decreases of mean (Figure J.1) and total AWY (Figure 4.7) and mean supplies (Figure J.3), with increases of mean and total water consumption (Figure J.2) and total water supply (Figure 4.8). The central and southern SSWs of SL 3, were characterized by decreases in both mean (Figure J.1) and total AWY (Figure 4.7) and consumption (Figure J.2), resulting in decreasing mean (Figure J.3) and total water supplies (Figure 4.8). Fourth, the northern SSW of SL 4, was represented by increasing mean AWY (Figure J.1), and total water supply (Figure 4.8), but decreasing total AWY (Figure 4.7), mean and total water consumption (Figure J.2) and mean water supply (Figure J.3). In addition, the SSW in the eastern part of SL 4, was marked by a similar pattern, except for increasing total consumption (Figures 4.7, 4.8, J.1, J.2, J.3). Finally, the SSWs of SL 5 were characterised by a general decrease in total and mean AWY and supply with almost no changes in mean and total water consumption (Figures 4.7, 4.8, J.1-J.3).

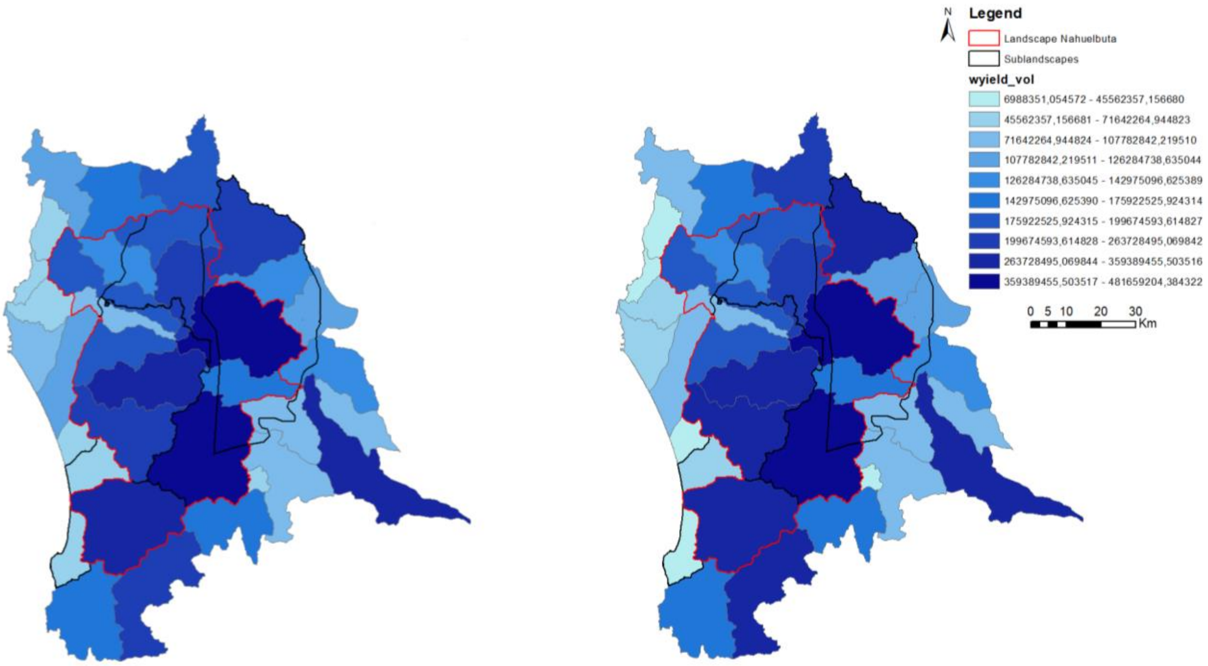


Figure 4.7: Outputs AWY model per SSW: AWY volume (m^3/SSW) for 2008 (left) and 2016 (right), maps by author

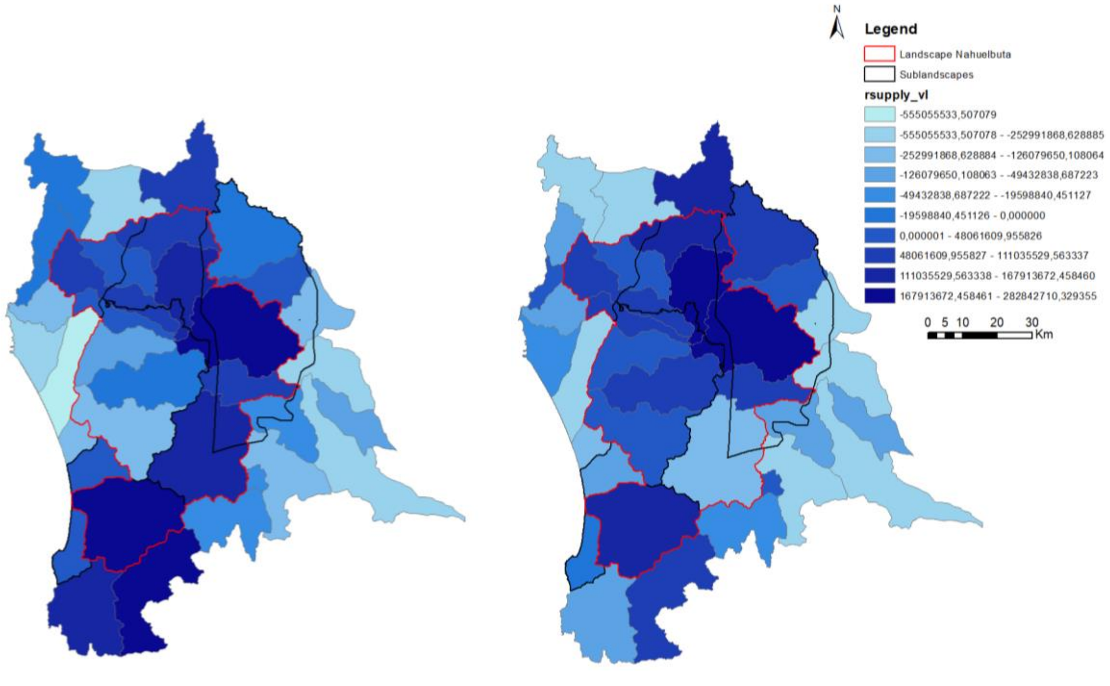


Figure 4.8: Outputs AWY model per SSW: total water supply (m^3/SSW) for 2008 (left) and 2016 (right), maps by author

Patterns in mean AWY, actual evapotranspiration (AET, mm/pixel) and the fraction of the latter and precipitation (-/pixel) reflected patterns in inputs of the AWY model (Figures G.1, J.4, J.5). In general, the AET and the fraction showed minima in the north-south oriented zone in the landscape, resulting there in maxima for the mean AWY (Figures J.1, J.4, J.5). The AET ranged from 0 to 1,237.8 mm/pixel with changes from -100 to 150 % (Figure J.4).

Values in the north-south zone were mainly between 0 and 709.3 mm/pixel, with changes between -44.7 and 38.9 % (Figure J.4). Furthermore, the ratio in Figure J.5 was characterized by values between 0 and 1 and differences between -1 and 1, with values in the north-south zone of the landscape ranging between 0 and 0.5 and differences ranging mainly from -0.12 to 0.14 (Figure J.5). Finally, AWY was situated between 0 and 1684.86 mm/pixel, with changes mainly ranging from -44.7 to 38.9 % (Figure 4.9).

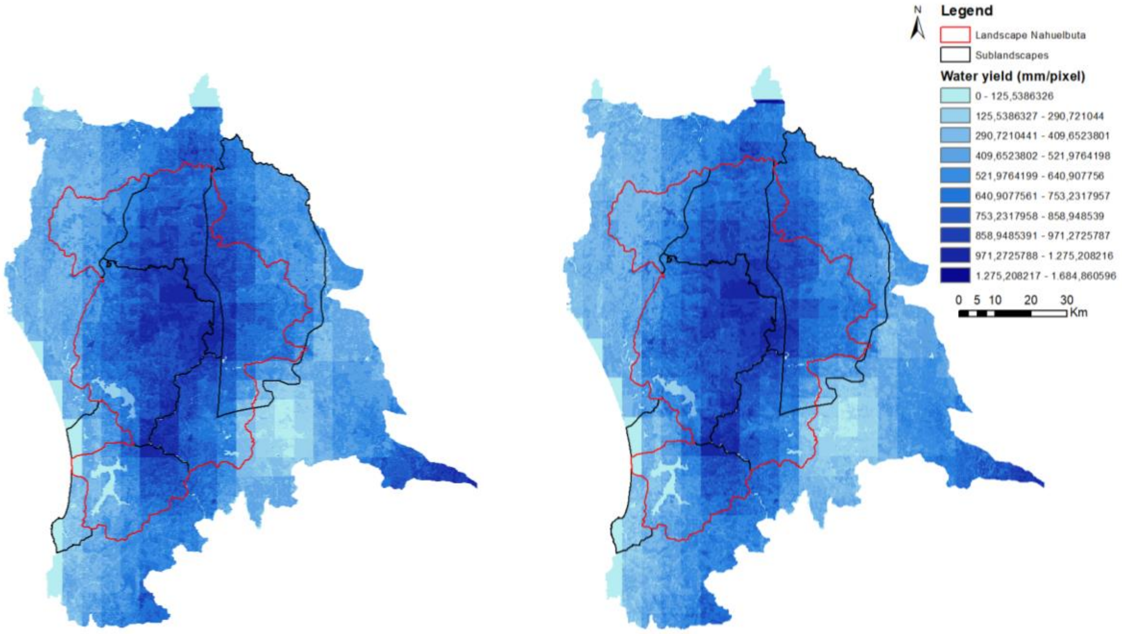


Figure 4.9: Outputs Annual Water Yield model: estimated water yield (mm/pixel) in 2008 (left), 2016 (right), maps by author

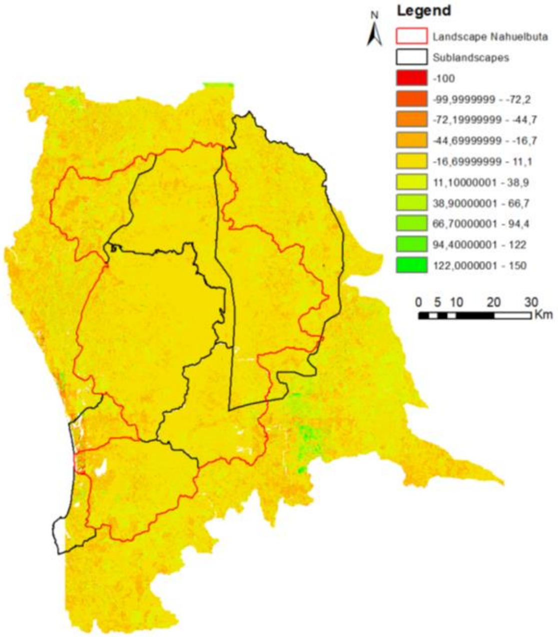


Figure 4.9 continued: Outputs Annual Water Yield model: percentage (%) change relative to 2008 (right), maps by author

4.3.2 Sediment Delivery Ratio model

For the SDR model, outputs also reflected the input conditions (Appendix G: Figure G.3). The output of the stream location (Figure J.6) resulted partly from the calibration with the threshold flow accumulation (Appendix D) comparing outputs with real stream locations (Figure G.4). There was similarity, but not all real streams were included (Figures G.4 and J.6). The potential soil loss for each pixel if the land cover was bare soil (RKLS; tons/pixel) ranged mainly between 0 and 100 with maxima reached in the same north-south zone as mentioned above (Figure J.7). Furthermore, the sediment retention in Figure 4.10 reflects the retention, relative to bare soil land cover (Sharp *et al.*, 2018b). These values mainly ranged from -2.03.10^{35} to 250 tons/pixel (Figure 4.10) with percentages changes between -100 % and 150 %, but mostly between -16.7 % and 11.1 % (Figure 4.12). No values for percentage (%) changes were obtained were sediment retention was zero. A small north-south zone with retention values larger than 83 tons/pixel was present for both years (Figure 4.10).

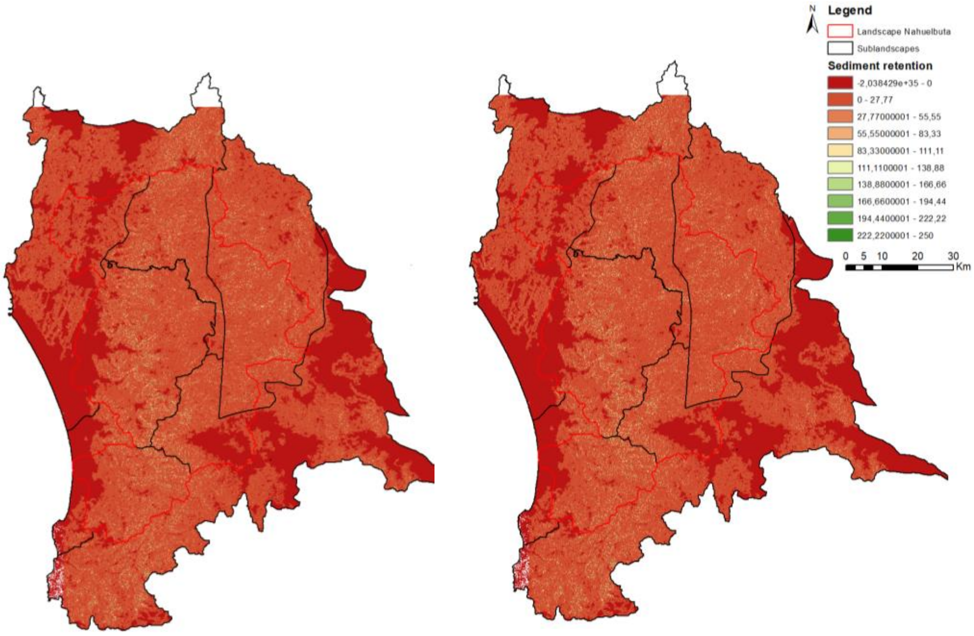


Figure 4.10: Outputs of the SDR model: sediment retention (tons/pixel) for 2008 (left), 2016 (right), maps by author

The sediment retention index (tons/pixel) ranged from -2.3 .10^{34} to 50 tons/pixel with values below zero in areas with lack of input data (Figure J.9). Sediment export ranged from -1.23 .10^{35} to 1 tons/pixel (Figure 4.11) with percentage changes from -150 to 100 % (Figure 4.12). No change values were obtained for areas without input data or where export was 0 tons/pixel. Areas with export between 0.5 and 1 tons/pixel in 2008 mainly showed decreases (Figure 4.11).

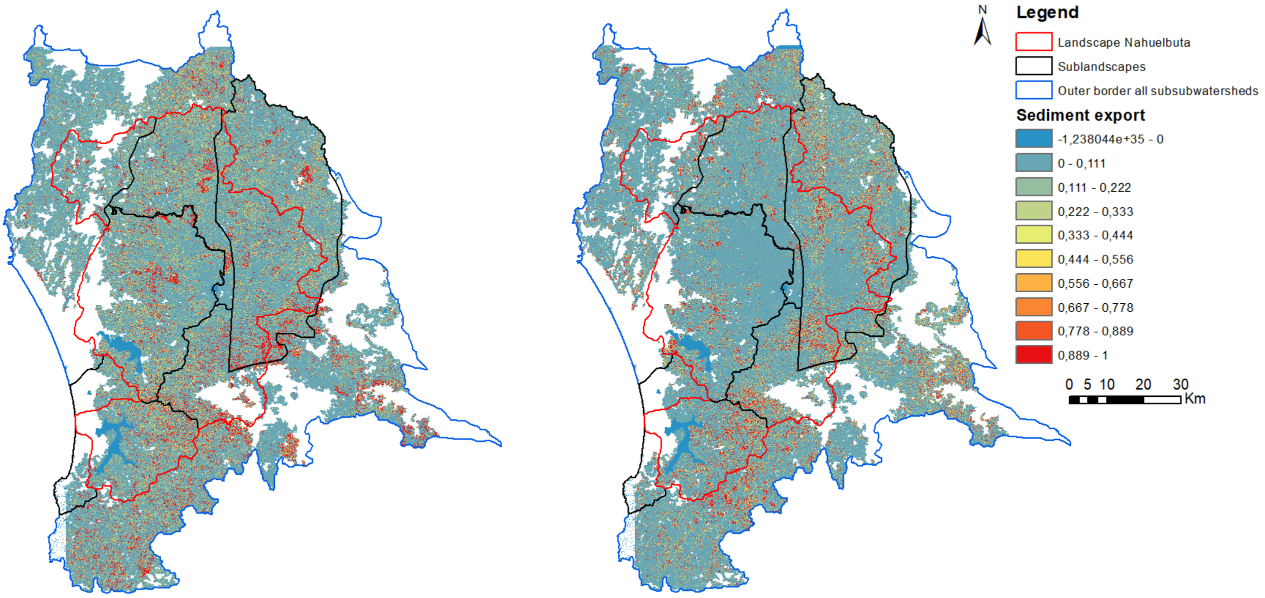


Figure 4.11: Outputs of the SDR model: sediment export (tons/pixel) for 2008 (left), 2016 (middle) and the percentage (%) change, relative to 2008 (right), maps by author

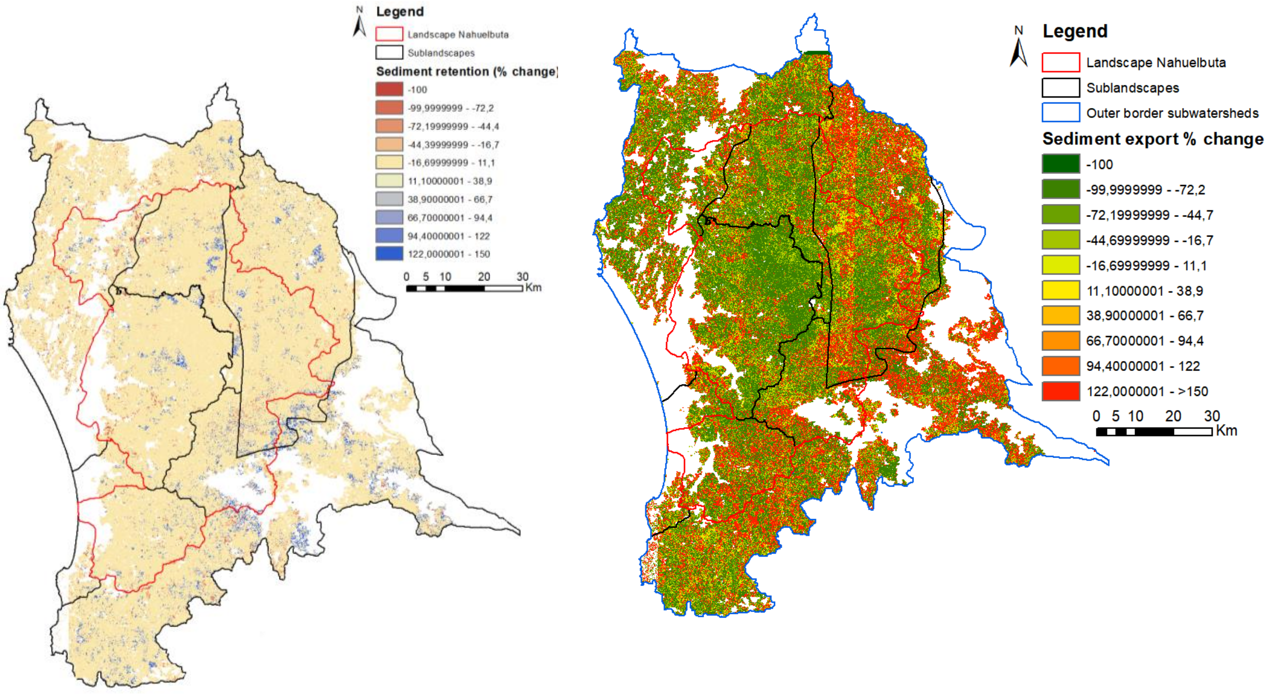


Figure 4.12: Percentage (%) changes, relative to 2008: sediment retention (left), sediment export (right), maps by author

The potential soil loss calculated with the RUSLE equation was marked by values from 0 to 100 tons/pixel with areas with loss of 40-100 tons pixel (Figure J.8) corresponding to areas with the highest export values (Figure 4.11). Changes in loss compared to 2008, mainly range from -100 to 150 % with mostly negative values for SLs 1, 3 and 4 (Figure J.8).

4.3.3 Habitat Quality model

Habitats for plants and animals in the Nahuelbuta landscape were influenced by several threats: the presence of roads (dirt, gravel and paved roads), non-sustainable tourism, urban areas, forest fires, energy transmission lines and agriculture (Appendix G). Input parameters for this model were obtained with the second survey, having a response rate of 60 % (6 participants of the 10 invitations). Results of this survey are given in Appendix: habitat score of land cover classes and their relative sensitivity to the threats on the one hand and relative weights, decay types and maximum distance over which threats are effective. Model results showed visual changes in habitat quality and habitat degradation in the landscape (Figures 4.13, 4.14, 4.15). The HQ in Figure 4.13 reflects pixel-level values between 0 and 1, relative to other parts in the landscape and increased with 0.2 to 0.94 for large parts of SL 1, 3, 4 and 5 (Figures 4.13, 4.15). HQ decreases from 2008 to 2016 were present in some areas in the western parts of SL 1, 2, 3 and 4 (Figure 4.15).

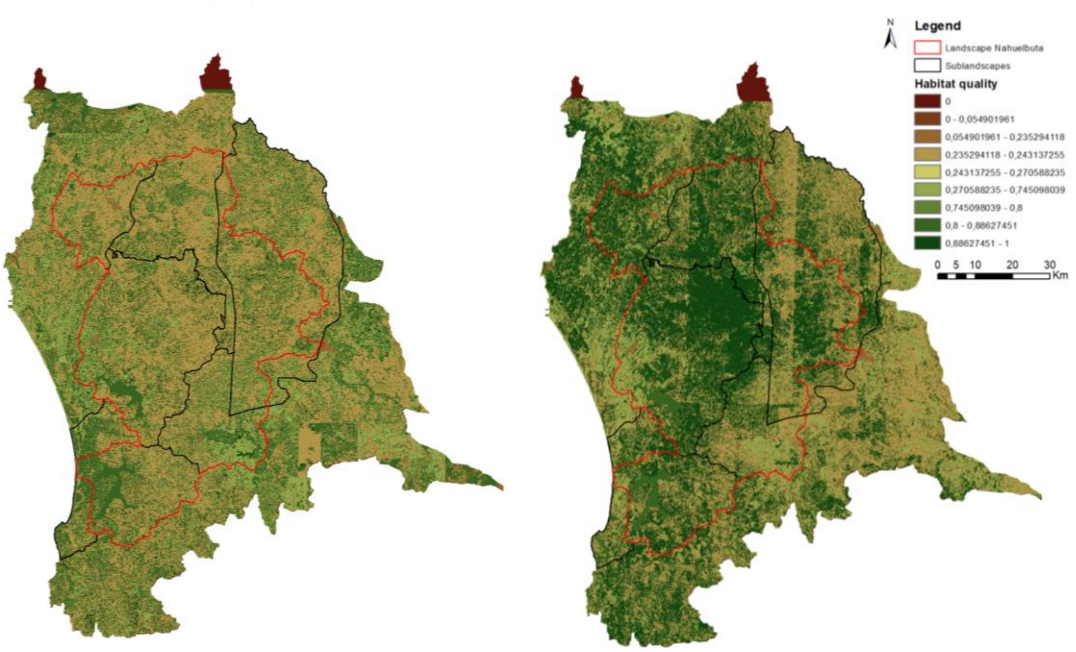


Figure 4.13: HQ (-/pixel), relative to the rest of the landscape, in 2008 (left), in 2016 (right), maps by author

Pixel-level habitat degradation (HD), relative to the rest of the landscape, with values from -3 .10^{17} to 0.15, were relatively high for a Y–shaped area in the south-east of the landscape and a zone in the southern part of SL 2 (0.08 to 0.15) (Figure 4.14). Values between 0.03

and 0.08 were obtained for areas in the western, eastern and northern parts of SL 1, 5 and 4 respectively (Figure 4.14). Negative values corresponded to no data. Mentioned areas with relatively high degradation values in each of the years also showed the largest differences from 2008 to 2016 (changes of mainly of 0.01 to 0.06) (Figure 4.15).

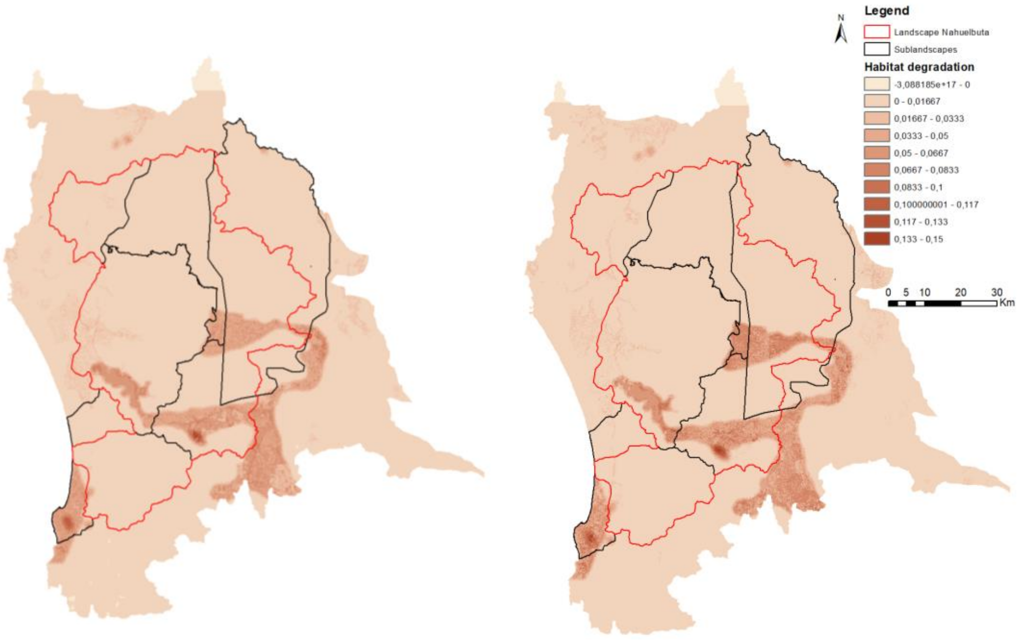


Figure 4.14: HD (-/pixel), relative to the rest of the landscape, in 2008 (left), 2016 (right), maps by author

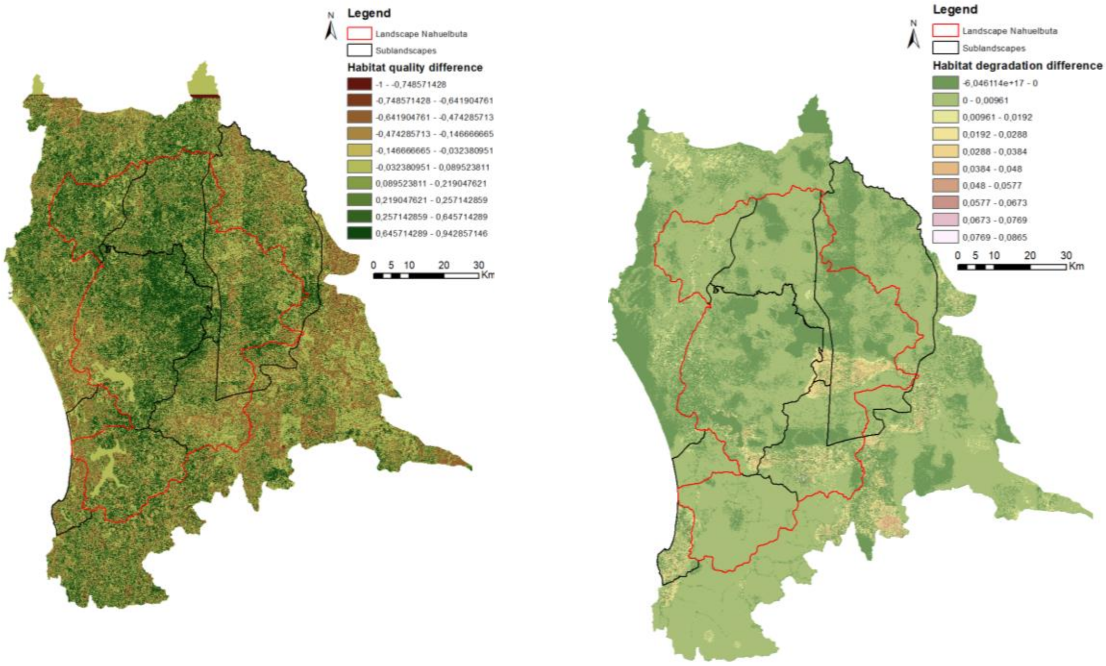


Figure 4.15: Percentage (%) changes, relative to 2008; HQ (-) (left), HD (-) (right) maps by author

4.4 Effects of FSC certification on ecosystem service supply

Analysis showed overall trends in differences between the pre- and post-certification scenarios, both in certified and uncertified areas (Table 4.6; more details in Appendix K).

Table 4.6: Results of paired tests for comparison 2008 and 2016, for FSC and uncertified areas (α=0.05, sign. = significant, SL = sublandscape)

	Export	**Retention**	**HQ**	**HD**	**AWY**
FSC	Sign. ↑ in SL 1, sign. ↓ in SL5	Sign. ↑ in SL4,5 sign. ↓ in SL1	Sign. ↑	Sign. ↑ (except SL3)	Sign. ↑ in SL 1, sign. ↓ in SL5
No FSC	sign. ↓ in SL1,5	sign. ↓ in SL1,2,3,4	Sign. ↑	Sign. ↑ (except SL3)	sign. ↓

Differences of average temporal change between FSC and not FSC properties, sometimes positive and sometimes negative, were mostly significant (Table 4.7; more details in Appendix K).

Table 4.7: Results of tests for comparing temporal change (2008 to 2016) between FSC and uncertified areas (α=0.05, sign. = significant, SL = sublandscape), with percentages as the difference in average temporal change between FSC and not FSC, relative to uncertified areas, significant results are shown in bold, and the statistical test is mentioned if no two-sample t-test was used, and thus no difference of means was tested.

	Export	**Retention**	**HQ**	**HD**	**AWY**
SL1	**365%** (MWW)	-5.8%	**813%**	**190%**	**-179%** (32 plots), **3865%** (36 plots)
SL2	**-16%** (only sign. for KS)	9.7%	**69%**	**58%**	**138%**
SL3	-41%	225%	**400%**	-62%	**150%**
SL4	**-935%**	**1432%**	**208%** (MWW)	**240%** (MWW)	2.7% (MWW, KS)
SL5	**-833%** (MWW)	**4000%** (MWW)	**478%** (MWW)	**852%** (MWW)	**-585%**

5. Discussion and conclusion

5.1 FSC stakeholder survey

Questionnaire analysis suggested an acceptable response rate (32.45 %), compared to scientific publications. Barclay *et al*. (2002) obtained response rates between 30 % and 50 % for 2 to 3 mails (invitation and follow-up mails). In addition, rates of 20 % to 30 % are typical (Henderson, 1991; Baruch, 1999; Deutskens *et al*., 2004). Results of Jaung *et al*. (2016) reveal rates of 36.73 %, 15.46 % and 32.23 % for FSC network partners, FSC certification bodies and FSC certificate owners respectively. Finally, Huang *et al*. (2003) state that the Tailored Design Method can result in response rates of 60-70 % or higher, but doesn't guarantee this. Possible reasons of no-response can be the use of mailing list provided organizations, in this case WWF Chile, and people in leader functions having assistants to screen their mail (Huang *et al*., 2003). Rates could also increase by associating e.g. lottery prices to the survey (Deutskens *et al*., 2004). Stakeholders represented similar shares in the total respondant amount, except for the NGO (16.33 %) and public sector (12.24 %) groups (Figure 4.1) . In addition, companies owning FSC forests (14.29 %) and FSC certification bodies (6.12 %) were underrepresented in the survey (Figure 4.2). Furthermore, some respondants didn't fit in the stakeholder groups (all with 2.04 %, corresponding to one person) (Figure 4.2). Underrepresentations were related to the limited number of contacts of these groups, but also have potential association to the limited available time for people in leader positions.

The most relevant ES to evaluate (Figure 4.3) are related to general rising issues, both locally and globally, and also to the lack of empirical evidence about FSC certification effects on ES supply. First, water regulation and fresh water supply are essential for life on Earth (Corvalan *et al*., 2005) with increasing water demand and also water scarcity, both globally (UN Water, 2018; WWF, 2018b; FAO, 2019) as locally (Little *et al*., 2016; WWF Chile, 2018a). Second, increasing soil erosion and degradation and biodiversity loss are actual problems, globally (WWF, 2018b; FAO, 2019a, 2019b), as well as in Chile (Little *et al*., 2016; WWF Chile, 2018a). Futhermore, climate regulation is considered important, related to the actual climate change issues (IPCC, 2014). Although there is a lack of local and empirical evidence, many scientific studies about FSC effects on biodiversity exist, while only limited publications address impacts on water related ES and soil conservation (section 2.2.2). The relatively low relevance of cultural ES (scores mostly ≥ 10; Figure 4.3; Appendix I) is potentially influenced by the stakeholders, not including indigenous people groups. Nevertheless, the private group suggested high relevance of impact evaluation on spiritual and religious values (2.85), traditional knowledge conservation (4.69), cultural diversity (4.77) and ecotourism (5.00) (Figure I.3). This group included forestry companies, certification body members and FSC network partners, suggesting they value cultural ES, and also partly reflecting the importance of indigenous people in the study area (section 3.1). In addition, FSC certification body members recognized ecotourism and recreation with intermediary relevance (7.79) (Figure I.7). The low relevance of agricultural production can be related to stakeholders opinioning about low potential effects of FSC on this ES, as it is not a forest related ES. Finally, ES relevance can be associated to the importance of the ES for the stakeholder. For example, wood production is considered most relevant (1.29) by forestry companies, together with NTFP production being the third most relevant ES (5.29) (Figure I.9). Other stakeholder groups on the other hand, suggested intermediary to low relevance for these ES (Appendix I).

Long- and short-term evaluation suggestions (Figure 4.4) generally correspond to scientific literature recommendations on ES evaluation periods (e.g. Havstad & Herrick, 2003; Symstad *et al*., 2003; Kariuki *et al*., 2006; Nielsen *et al*., 2009; Balvanera *et al*., 2013; Haase *et al*., 2018). Scientific studies on environmental FSC effects are mostly short-term (Van Kuijk *et al*., 2009; Dias *et al*., 2015; Reyes & Altamirano, 2018), so there is a need for long-term effect assessments. In general, natural cycle and regulation processes have long-term scales, thus effects on cycle and process related ecosystems will likely be visible in the long-term. This is reflected in stakeholder advices for long-term evaluation of climate regulation, carbon capture, nutrient cycle, natural risk regulation and water cycle. Biodiversity is a complex concept, possibly measured by various indicators, each characterized by different spatial and temporal scales (Noss, 1990; Heywood & Watson, 1995; Van Kuijk *et al*., 2009). The evaluation period thus depends on the used variable. The stakeholders suggestion not being clear about the evaluation period (0.51 score, Figure 4.4) is probably linked to this complexity, but also to the actual importance of biodiversity conservation both in the short- as in the long-term in the study area (Wolodarsky-Franke & Herrera, 2011; Montenegro *et al*., 2018). Furthermore, genetic resources are linked to plantation productivity and biodiveristy conservation (Corvalan *et al*., 2005) with existing programs for genetic resources in Chile including research and ex situ conservation (CONAF, 2013; Agricultural Research Institute of Chile (INIA), 2018) The importance of long-term scales in SFM (section 2.1) implies the relevance for assessing effects in the long-term, for genetic resources, but also for wood production. In addition, evaluation suggestions for cultural services, but also for habitats, fresh water and NTFP supply, can be related to the shorter temporal scale of these ES, making effects of FSC more likely to be visible in the short term. Services with scores very close or equal to 0.5 showed differences in vote shares for stakeholder groups, for example for water cycle (academic and private group proposed rather long-term, while NGO and public groups advised short-term), cultural diversity (the private and NGO groups suggested long-term, while the academic group proposed short-term) (Figure I.14). Survey analysis thus suggests, FSC impacts on habitats and fresh water supply could be already visible, since this study assessed rather short-term FSC impacts: the two studied moments have a ten year difference, but forestry companies started management changes for FSC and obtained FSC certification at different moments (sections 1 and 3.1.3). Evaluating longer periods was not possible, due to a lack of available data after 2016 (section 3.5; Appendix D).

Overall results of trade-offs and synergies showed trends, similar to results of scientific literature in different circuimstances. First, synergies and trade-offs are sometimes directly linked to interactions through ecological processes in space and time (Burkhard & Maes, 2017), e.g. for synergies between natural risk regulation (e.g. floods) and soil conservation or water cycle, between habitat supply and biodiveristy conservation, or between cultural ES (Table 4.2; Appendix I) (Boscolo & Vincent, 2003; Raudsepp-Hearne *et al.*, 2010a, 2010b; Burkhard & Maes, 2017). Other examples are the synergies between nutrient cycle and soil conservation, and between carbon capture and storage and climate regulation (Table 4.2; Appendix I) (Burkhard & Maes, 2017). Second, thematic interactions between provisioning, regulating, cultural and supporting ES were present (Table 4.2; Appendix I), also referred to by e.g. Rodríguez *et al.* (2006) and Burkhard & Maes (2017). Examples are interactions between provioning and supporting ES: e.g. trade-offs between wood production or production of agricultural products on the one hand and biodiversity conservation or habitat supply on the other hand (Table 4.2; Appendix I), a result also obtained by Raudsepp-Hearne *et al.*, (2010a, 2010b). In addition, synergies found between wood production and carbon storage or soil conservation are examples of provisioning ES-regulating ES interactions (Table 4.2; Appendix I). Interactions between provioning and cultural ES were e.g. synergies between NTFP supply and traditional knowledge, and trade-offs between wood production on the one hand and ecotourism, spiritual values or traditional knowledge on the other hand (Table 4.2; Appendix I). Third, results suggest possible links of stakeholder answers and the relevance of ES for these groups. For example, synergies between the most relevant ES were found for mostly all partipant groups, e.g.

between water cycle and soil conservation (Table 4.2; Appendix I). Trade-offs between ES and wood production were suggested by all stakeholder groups, except for agriculture production (no public group answers), NTFP, spiritual and religious values and soil conservation (no answers by the private group) (Table 4.2; Appendix I). This reflects the importance of wood production in the study area and in the context of FSC certification, but also the relevance for optimizing balances with other ES. Sometimes, a part of the stakeholders suggested trade-offs, while others suggested synergies. For example, between carbon capture and wood production (Table 4.2; Appendix I). The synergistic relation was likely linked to wood carbon transport to wood products (Ruddell *et al*., 2007; Weslien *et al*., 2009), while the trade-off, was likely related to the possibility of the remaining carbon stock being lower than for unmanaged stands, also stated by e.g. Hynynen *et al*. (2005), Lasch *et al*. (2005), Seidl *et al*. (2007) and Nunery & Keeton, (2010). On the other hand, obtained interaction results were not always two-directional. For example, for carbon capture, stakeholders suggested important synergies with climate regulation, but for climate regulation, carbon capture did not appear in the options of most important synergies (Table 4.2). Although trade-offs and synergies were both explained, concepts remain complex, thus there could also have been participants who misinterpreted this question, leading to some contradictory results (e.g. for carbon capture). Moreover, the question about trade-offs and synergies was not obligated, for being very long, resulting in partipants filling in everything, parts or nothing of the question. Detailed comparison of results between stakeholders or ES was therefore not assessed, making that results are only an indication of some general trends. Nevertheless, results reflect relations between ES in a FSC context, also mentioned in the national FSC principles (e.g. principles 5, 6 and 8) (Appendix C). Although, suggested relations are indications of trade-offs and synergies (as they were not quantified in the field), no scientific studies were found addressing trade-offs and synergies in the context of FSC certification in a similar way, so obtained results could still contribute to this literature gap.

5.2 Collecting and preparing inputs for ecosystem service models

Challenges in obtaining inputs for the InVEST models were mainly related to the requirement of spatial explicity, availability of studied pre- and post-certification periods and sufficient high spatial resolutions. Sometimes, data was only available for one of the studied periods, available but not openly accessible, or not existent for local circumstances. Inconsistencies in data creation and publication dates could also have contributed to some error. Assumptions made by using sometimes globally available averages for the study area, could therefore have led to some accuracy loss, for example for the PAWC in the AWY model. Furthermore, calculated water demand corresponded to demands used by Sharp *et al.* (2018a) (converted to land cover pixel size in this study: about 790 m^3/yr/pixel for commercial and industrial areas and about 875 m^3/yr/pixel for residential and commercial cover). Used values for agriculture and grassland (also including livestock grazing area) (Table F.2) were however overestimated compared to 110 m^3/yr/pixel for irrigated agriculture and grassland of Sharp *et al.* (2018a). On the other hand, not included possible irrigation of plantations can contribute to underestimation of water demand. In addition, the obtained Z value (3.035) was lower than used in other studies, however for other rainfall amount or distribution (e.g. 9 in Argentina (Gaspari *et al.*, 2015), 14 in North Carolina (Hamel & Guswa, 2015) and 7-9 in a Mediterranean basin (Sánchez-Canales *et al.*, 2012)), potentially causing water yield overestimations. Although Z was calculated from local climatic data, the availability of local water yield observations for calibration would improve model results (Hamel & Guswa, 2015). Nevertheless, results could still be reliable indications, since model sensitivity to Z is mostly low (Sánchez-Canales *et al.*, 2012; Hamel & Guswa, 2015).

For the HQ model, expert consultation results of habitat suitability and sensitivity to the different threats (Tables F.4, F.5), showed similarity with used values in other case studies (e.g. Terrado *et al.*, 2016) in terms of relative differences between land cover types. There were however some absolute differences in maximum distance and weight values with other publications, e.g. for maximal distance up to which agriculture has effects on habitat quality was 2.13 km (Table F.4), while a value of 4.0 km was used by Terrado *et al.* (2016) in the Mediterranean region. Nevertheless, these parameters depend on local conditions (Sharp *et al.*, 2018b), making expert consultation result potentially more reliable. The survey approach does however involve subjectivity, resulting in some counter-intuitive results. For example, the sensitivity of agriculture and urban land covers as habitat to these land covers as threats were higher than 0 (0.1600 and 0.0400 respectively) (Table F.5). Results could be improved by surveying more participants (Deutskens *et al.*, 2004). In this case, selection of more, reliable experts will however be a challenge. Combination of expert judgement with slower and more objective field quantification is another, however time consuming option (Martínez-Harms & Balvanera, 2012).

Given the lack of available and accessible data, the combination of open access databases and scientific publications with expert consultation, was found to be a good option to obtain all inputs, including some assumptions, and be able to obtain reasonable outputs. Moreover, the land cover raster as being one of the key inputs determining output resolution, was obtained from high spatial resolution images of both periods.

First, for the land cover classification, both overall accuracy and $\hat{\kappa}$ were larger for 2016 (80.81 % and 65.97 % respectively) than for 2008 (62.84 % and 33.10 % respectively). Higher percentage of correctly classified pixels for 2016 than for 2008, suggest that in general, training polygons in 2016 were possibly more homogeneous and thus better separable, based on their spectra, using definitions of Lillesand *et al*. (2014). The obtained classification being 65.97 % (2016) versus 33.10 % (2008) better than a classification obtained by random chance (following the definition of kappa by Lillesand *et al*. (2014)), is linked to this difference in correctly classified pixels for both years. In general, satisfactory accuracies and kappa values obtained are larger than 70 to 80 %, with values higher than 60 % being acceptable (e.g. De Grandi *et al*., 2000; Jaafari & Nazarisamani, 2013; Zhu, 2013; Collin *et al*., 2014; Guo *et al*., 2016). Therefore, obtained classifications were still acceptable, in terms the of overall accuracies. In terms of kappa, further results obtained from 2008 classified image need to be interpreted carefully.

Furthermore, trends of improving accuracy over time, potentially related to changes in image quality (Echeverría *et al*., 2006), could have contributed to differences in accuracy. Moreover, Google Earth images are a mosaic of images of different sources (Google, 2019). Spatial comparison of spectral characteristics between different images of the mosaic, thus also contributed to some error. Small spatial patterns, e.g. vertical strips for 2016 and differences in contrast between images potentially contributed to the difficulty of spectral separability between some land cover classes. In addition, the same area sometimes had different images sources for 2008 and 2016 (mostly varying between Digital Globe and CNES/Airbus images).

Second, 26.10 % of the native forest test pixels were classified as native forest in 2008 (Table 4.4), while this was more than 60 % for 2016 (Table 4.5). This increase in native forest is an overestimation compared to results of Reyes & Altamirano (2018) for the same study period. The low production accuracy for young plantation (0.60 %, 2008; 69.02 % for 2016), grassland (29.56 %, 2008; 64.26 %, 2016) and shrubland (36.31 %, 2008; 6.77 %, 2016) (Tables 4.4, 4.5) were possibly related to the limited capacity of the classification only using RGB images (combined with 2 texture metrics), to separate similar class spectra (Blaschke, 2010; Lu *et al*., 2010).

Third, low user accuracies were obtained for young plantations (15.76 %, 2008, 85.46 %, 2016), grassland (38.18 %, 2008; 55.12 %, 2016), shrubland (52.47 %, 2008, 14.38 %, 2016) and native forest (39.82 %, 2008, 85.34 %, 2016). Therefore, young plantations and native forest were underrepresented compared to ground truth for 2008 and grassland and shrubland were underrepresented in 2016. In addition, kappa values for grassland (37.11 %, 2008; 52.72 %, 2016), shrubland (47.74 %, 2008; 10.65 %, 2016), adult (23.64 %, 2008; 65.52 %, 2016) and young plantation (0.78 %, 2008; 83.64 %, 2016) also suggest some errors in the classification. For example, native forest pixels were incorrectly included in the plantation and shrubland classes (46 % and 12 % of the plantation and shrubland pixels respectively (Table E.1, 2008)). For 2016, shrubland and plantation pixels were incorrectly included in the native forest class (5% and 10% of native forest pixels respectively) (Table E.2), possibly partly linked to similar vegetation characteristics of native forest and shrubland. Moreover, shrubland and native forest are linked to vegetation with more variation in e.g. structure and species, compared to plantations. Finally, errors were also possibly related to the spectral limits of the used images.

Fourth, main land cover changes from 2008 to 2016, included important changes from adult plantation to young plantation (8.44 %) and to native forest (16.14 %) (Figure E.3). In addition, there were relevant changes from shrubland to native forest (8.14 %) and to plantations (7.13 % to adult plantations, 4.02 % to young plantations, Figure E.3). Observed increases in native forest (9.53 % to 36.37 %) and young plantation (1.47 % to 24.71 %) (Table 4.3) were likely partly related to the user accuracies and partly related to real changes. This was also the case for the decrease in adult plantation (34.96 % to 15.76 %) and shrubland (28.38 % to 2.44 %) (Table 4.3). Furthermore, although small, decreases in bare soil (7.04 % to 4.62 %) with changes to plantation and shrubland, were possibly related to a changed landscape management. Recent scientific evidence for the Nahuelbuta landscape shows there have been average declines from 2008 to 2016 in fragmentation, native forest in riparian buffer zones and native forest conversion (however without statistical significant differences between certified and uncertified areas) and native forest gains in the Angol sector in the eastern part of the landscape (with higher regeneration in uncertified areas compared to not certified areas) (Montenegro *et al.*, 2018; Reyes & Altamirano, 2018). Although not calculated here, classification maps showed similar visible trends (Figure 4.5). Besides, Google Earth images (Figures E.1, E.2) showed smaller clear-cut areas in 2016, compared to 2008, likely linked to FSC standards of FSC CHILE (2012).

The used classification method has both strengths and limitations. First, the fine spatial resolution gives the capacity to detect smaller land cover patches and give more accurate estimations of land cover dynamics, compared to coarse resolution data (Plieninger, 2012; Altamirano *et al*., 2013). Second, Google Earth is a good option for high-resolution images, freely available for different time periods (Google, 2019). Third, the Random Forest classification is proofed to give successful and robust results for multisource high resolution images with large spatial scales (Rogan *et al*., 2003; Gislason *et al*., 2006; Deng & Wu, 2013; Hayes *et al*., 2014; Belgiu & Drăguţ, 2016). Google Earth image pixel-based classifications are however limited by their low spectral resolution (Blaschke, 2010; Lu *et al*., 2010). This was partly improved by including two textural features. Including more textural features can possibly give more accurate classification results (Rodriguez-Galiano *et al*., 2012). This approach however did not produce results here, given the large spatial scale and limited computer memories. Furthermore, including a hierarchical land cover classification in this methodology could give accuracy improvement, especially to differentiate land cover classes with forest characteristics (Sulla-Menashe *et al*., 2011; Glanz & Carvalho, 2015; Ahmed *et al*., 2017; Chen *et al*., 2017). Although an object-based classification was outside the scope of this study, this could also be a good alternative for obtaining accurate classification results with Google Earth images (Laliberte *et al*., 2004; Yu *et al*., 2006; Mathieu *et al*., 2007; Conchedda *et al*., 2008; Mallinis *et al*., 2008; Qian *et al*., 2015). In addition, using two images for comparison has limitations in the sense of seasonality effect captation: changing plant phenology over the seasons is related to ES supply seasonality (Burkhard & Maes, 2017). Using several images for different season can give a more complete view in terms of ecosystem conditions (Burkhard & Maes, 2017). Moreover, trend analysis by looking at time intervals between 2008 and 2016 can be useful for better capturing landscape and ecosystem dynamics (Altamirano *et al*., 2013). Finally, in the context of certification effects, it can be useful to look at future scenarios of land cover distribution over the landscape, linked to FSC standards, e.g. using the InVEST scenario generator tool of Sharp *et al*. (2018b), as it is possible there could not have passed sufficient time from the start of certification to see significant effects for certain ES or landscape indicators in the study area, also mentioned by Montenegro *et al*. (2018) and Reyes & Altamirano (2018). The lack of exact numbers in the FSC standards, related to land cover made it in this case however impossible to create a reliable future scenario. For example, there is not yet an agreement on the minimal slope which needs to stay under forest cover, or on the minimal width of riparian buffer zones (FSC CHILE, 2012; Montenegro *et al*., 2018).

5.3 Overall trends in ecosystem services maps

First, model outputs ranges and patterns reflected spatial patterns in the used inputs. For the AWY model, higher precipitation and lower evapotranspiration possibly had the largest effect on higher water yield areas, while spatial patterns of AWC and root restricting layer depth seemed to have less impact (Figures 4.7, J.1, G.1). Native forest, plantation, water and wetland areas showed higher water yields than other land cover types, by having higher Kc values (Figure 4.5, 4.7, J.1; Table F.1). Changes in water yield from 2008 to 2016 were mainly related to land cover changes, with water yield increase for areas with conversion of adult to young plantations, and shrubland to agriculture, but also for wetland to native forest and shrubland to grassland (Figures 4.5, 4.6, 4.7, J.1, J.4). Decreased yield corresponded to change of adult plantations and shrubland to native forest, but also for bare soil conversion to plantation or shrubland and change of shrubland to plantations (Figures 4.5, 4.6, 4.7, J.1, J.4).

Local research on the land cover-water balance relation showed positive effects of forest land cover on lowering runoff (Iroumé & Palacios, 2013). Besides, exotic plantations have also less interception (Huber & Iroumé, 2001) and strongly lower infiltration rates (Oyarzún & Huber, 1999) than native forest. Because land cover accuracy analysis showed these changes are partly related to classification errors (Tables 4.4, 4.5), water yield changes should also be interpreted with care. In addition, no local research quantifying water yield and supply was found. Total water yields (order of 10^6-10^8 m^3/SSW with area 80–700 km^2, Figure 4.7) were however overestimated compared to results in the Mediterranean Llobregat basin (603 .10^6 m^3/yr for a 4957 km^2 drainage area, however with lower annual average rainfall (939 mm)) (Bangash *et al.*, 2013) and 225 .10^6 m^3/yr for a 112 km^2 forested watershed in Southern Thailand (however with higher average annual rainfall (2825 mm) and lower evapotranspiration (981 mm/year) (Trisurat *et al.*, 2016). Furthermore, mean water yields (200-900 mm/pixel in the SSW, Figure J.1) and pixel-based yields (0–1700 mm/pixel, Figure 4.9) showed the same trend, compared to ranges of 0-680 mm/pixel in North Carolina (Hamel & Guswa, 2015). Water supply (-5.6 .10^8-2.8 .10^8 m^3/yr/subsubbasin) was underestimated compared to the Llobregat basin results (0- 842 .10^6 m^3/yr for drinking water) (Bangash *et al.*, 2013). This underestimation was probably related to the possible overestimation of agricultural and grassland water demand (Table F.2). Moreover, drinking water consumption data were excluded as much as possible, but as consumption data without descriptions on being agricultural or drinking water use were also included, this could also have contributed to the underestimation. Moreover, as AWC and P coarse resolutions (0.083° and 0.05° respectively; Appendix D; Figure G.1) were possibly not able to capture local spatial patterns precisely, this probably contributed to underestimations of Z and thus overestimations of water yield. Similarly, relatively coarse resolutions of precipitation and reference evapotranspiration (30 arc seconds, Appendix D) could have directly contributed to errors in obtained water yield. In addition, although local literature was used as much as possible for Kc values (Table F.1), these could still contain errors, potentially contributing to the accuracy of water yields. Although local field measurement validation would be useful, it was outside of the scope of this study. The availability of higher resolution input data could therefore improve model results, as outputs mostly have the highest sensitivity to climatic inputs (Hamel & Guswa, 2015; Redhead *et al.*, 2016). Detailed sensitivity analyses could quantify errors clearly and indicate which inputs are most important to improve (Sánchez-Canales *et al.*, 2012; Hamel & Guswa, 2015; Redhead *et al.*, 2016; Bagstad *et al.*, 2018). As model sensitivity to Z depends on the basin and the evaluated range (7-9 used by Sánchez-Canales *et al.* (2012) (Hamel & Guswa, 2015), sensitivity to Z could be significant for this study. Furthermore, when observed water yields for model calibration become available, this could also generate more accurate results (Hamel & Guswa, 2015). Moreover, the availablity of empirical results could be useful for model validation and better understanding of estimation uncertainties (Hamel & Guswa, 2015; Redhead *et al.*, 2016). This validation could also clarify the effect of model strengths and limitations.

An important model limitation is for example the pixel-level use of the Budyko equation (Sharp *et al.*, 2018b). Pixel-level results permit to create heterogenous overviews and related results with the input data (Sharp *et al.*, 2018b). These pixel-level water balances were summed and averaged at SSW levels, neglecting lateral in- and outflows, but this assumption is however much less reliable for decision making or hydrological process understanding at smaller scales (Sharp *et al.*, 2018b). In addition, the model does not capture sub-annual water yield patterns, nor differences between baseflow, subsurface flow and surface flow and simplifies water demand (averages/land cover class) (Sharp *et al.*, 2018b). Finally, model results don't differentiate between ES provisoning areas, ES benefitting areas and connections between the two, concepts explained by Burkhard & Maes (2017). For example, water demand input reflects where the water is demanded, but the water is possibly consumed in another location, leading to some spatial disparity in water supply (Sharp *et al.*, 2018b). Hence, using large scale outputs with mapping units of (sub)watersheds will produce the most reliable results (Sharp *et al.*, 2018b).

Second, input spatial variability for the SDR also corresponded to output heterogeneity. Areas with high values for R, K, LS (linked to the DEM) (Figure G.3), C (bare soil, agriculture and young plantations, Table F.3) and low IC (linked to the DEM) spatially coincided with high sediment export (Figure 4.11). Retention compared to bare soil was the highest for areas with the lowest C factor (water, wetland, shrubland, adult forest plantation and native forest) (Figure 4.10, Table F.3). Extreme changes (> 50 % of the value of 2008) were linked to land cover change: decreases in sediment retention and increases in export occurred in areas with conversion of native forest or shrubland to plantations, while increases in retention and decreases in export coincided mainly with conversion to native forest and also linked to a small decrease in bare soil cover (Figures 4.6, 4.12). No local studies quantifying sediment export and retention in the same way were found to exist. For example, Bonilla *et al.* (2010) quantified water erosion (0-1 ton/ha/yr) with the RUSLE equation and a GIS framework. Sediment export results (-1.23 .10^{35} -1 tons/pixel, most areas 0-0.1, Figure 4.11) were however higher but still comparable in terms of order of magnitude, with values for forest under different treatments in southern Chile (after unit conversion to pixel size of this study: about 0.02 ton/pixel for forest under different treatments (Niklitschek, 2007) and about 0.02 tons/pixel for forest and 0.06 tons/pixel for logged forest (Birkinshaw *et al.*, 2011)). Similar to these values, exports of 1.37 .10^6 ton/yr were obtained with the SDR InVEST model for the Mediterranean Llobregat basin, however with less forest cover (31 % cover) (Bangash *et al.*, 2013). In addition, retention for the last basin (2.04 .10^8 ton/yr) was lower than values obtained in this study (-2.03 .10^{35} -2.04 .10^{35} to 250 tons/pixel, mostly 0-83 tons/pixel, Figure 4.10)**.** Negative and no data values corresponded to areas with no data for the D_{dn} factor and were probably linked to very low values for the average slope gradient and the C factor, potentially causing problems in the D-infinity flow algorithm of the model (Sharp *et al.*, 2018b). Although R and K rasters originated from local data, the coarse resolutions (0.05° and 305 m respectively, Appendix D) potentially contributed to output uncertainties. Similarly, the DEM resolution (about 28.2 m, Appendix D) could have had potential impact, as it is a key input in determining the final result resolution (Sharp *et al.*, 2018b). Making existing detailed soil maps (of e.g. the Natural Resources Information Center (CIREN) (2018)) freely accessible could improve accuracy of K, as relationships exist between K and soil properties (e.g. Renard *et al.* (1997)). Furthermore, assuming P factors equal to 1 for all land cover types (Table F.3), probably affected output accuracy, which could be improved by making soil conservation practice information available. Model calibration was limited to adjustment threshold flow accumulation, due to the lack of reliable calibration data on soil loss. In addition, the model capacity allowed capturing only part of the real stream layer (Figure G.4). Moreover, the model neglects sediment trapping in basins, with downstream areas having no retention benefits (Terrado *et al*., 2014), also contributing to possible export overestimations. Furthermore, the SDR index is also strongly related to connectivity (IC factor) with higher values for higher connection to the stream, possibly causing misleading results (e.g. forest pixels could have had lower retention than agriculture pixels if they were less connected) (Sharp *et al*., 2018b). Finally, RUSLE equation parameters uncertainties are often reported, related to the empirical origin and assumptions of the equation (Wang *et al*., 2001; Merritt *et al*., 2003; Kouli *et al*., 2009; Hamel *et al*., 2015). Sensitivity analysis and calibration including k_b and IC_0 parameters could give more insight in and improve model uncertainty, as well as model validation with comparable ground-truth data if this becomes available (Bangash *et al*., 2013; Terrado *et al*., 2014; Hamel *et al*., 2015; Bagstad *et al*., 2018).

Third, the habitat quality was strongly related to land cover and its spatial patterns, reflected by highest values for native forest and wetlands (> 0.8) and lower values for plantations (about 0.24) and urban areas (0-0.05) (Figures 4.5, 4.13). In addition, quality changes from 2008 to 2016 spatially corresponded with mainly conversions to native forest (quality increase) and changes from shrubland to agriculture or plantations (quality decrease) (Figures 4.6, 4.15). Habitat degradation ranged from 0 to 0.15 with temporal differences (2016 minus 2008) between 0 and 0.0865 and the highest values and changes in threat rich areas, especially visible for tourism, forest fires and roads (Figure 4.14; Appendix G). Here, the relevance of these results is suggested by no local similar research being found. Obtained values are comparable to results of Terrado *et al*. (2016) (Llobregat basin) and He *et al*. (2017) (China) with values close to 0 for urban areas, 0.4-0.5 for agriculture and close to 1 for forest cover. The model is focusing on habitats and their threats, to give an overview of the most important spatial heterogeneity of HQ and HD in the landscape, related to decision making (Sharp *et al*., 2018b). Quantified parameters are proxies for biodiversity (Sharp *et al*., 2018b), but however don’t capture all biodiversity aspects. For example, although native forest cover and wetlands had higher habitat quality and lower degradation compared to other land covers, there was few value differentiation within these land cover types. In reality, protected national parks and SNASPEs likely have higher biodiversity than other areas with the same land cover, which was not captured by the model. Including buffer zones as input, could help capturing effects of conservation of core areas. Furthermore, separating endangered and priority species and their habitats from other species could give more detailed maps, in terms of conservation and restoration areas and decision making (Baral *et al.*, 2014). Including invasive species as a threat (e.g. with data of Fuentes *et al.*, (2013)), could also give more complete results, since these species are an increasing threat for biodiversity in Chile, having effects on different scales (Andrade & Morales, 2014). Furthermore, riparian buffer zones have many important ES (e.g. nutrient filter, erosion control, habitat supply, corridor, and climate regulation) (Lee *et al.*, 2004; Van Sickle *et al.*, 2004; Gomi *et al.*, 2005; Karwan *et al.*, 2007; Oyarzun *et al.*, 2011; Romero *et al.*, 2014), but were not captured in model results. Including also small rivers and defining these zones as an extra land cover type could have potential for relevant results. For example, varying widths of these zones in the land cover raster could give overall indications of effects on spatial habitat quality and degradation patterns, but also water yield and erosion, and be useful in determining minimal width for e.g. national FSC standards. Given the errors in input data (survey results and land cover rasters), validation with field data could give indications of output credibility (Terrado *et al.*, 2016), however not possible here because of the limited temporal horizon and the lack of spatially explicit biodiversity data linked to habitats. Finally, although this was outside of this study's scope, an analysis of hot spots and cold spots in ES supply combining all model outputs could give relevant insights on spatial ES supply patterns (Burkhard & Maes, 2017; Lin *et al.*, 2017).

In conclusion, although model results tended to over- or underestimate reality, they can still contribute to useful insights in understanding processes related to water yield, erosion and habitat supply and give relevant indications of biophysical values of these ES.

5.4 Analysing effects of FSC on ecosystem service supply

The relevance of this study is represented by the lack of empirical evidence about FSC effects on ES (section 2.2.2). First, many studies addressed effects on habitat and biodiversity, suggesting positive as well as negative effects (section 2.2.2), but no studies investigating effects on habitat quality and degradation with the same approach are known to exist. In the study area, Reyes & Altamirano (2018) obtained significant temporal increases in the patches' proximity index in uncertified areas and significant decreases in certified areas, but however focused on landscape indicators. Furthermore, few empirical research exists about FSC effects on soil characteristics (e.g. Cline *et al.*, 2006; Newsom *et al.*, 2006; van Dam *et al.*, 2010; Stupak *et al.*, 2011). This is also the case for effects on hydrological ES, with e.g. Dias *et al*. (2015), focusing on ecological conditions of riparian buffer zones as one of the few examples. Obtained results can thus contribute to baseline information, both within as outside the study area.

First, water yield significantly increased in FSC plots of SL 1, while it decreased in FSC areas of SL 5 and uncertified areas in all SLs (Table 4.6). This change was significantly smaller in FSC areas than in uncertified areas for SL 1 (32 samples) (-179 %, Table 4.7) and 5 (-585 %, Table 4.7) while it was sign. larger in in SL 1 (36 samples, 3865 % in Table 4.7) and SL 2 and 3 (> 137 %, Table 4.7). The different result for SL 1 for FSC vs. uncertified areas, illustrates the results of statistical test depend on the number of samples. By including more plots, average temporal differences for FSC were both positive for paired and unpaired tests (Appendix K). Furthermore, similarly to the other models, statistical outcomes were potentially partly influenced by model output uncertainties. For example, the strong increase in water yield for certified areas in SL could be partly attributed to uncertainties in land cover change, e.g. conversion of adult to young plantations (Figures 4.6, 4.7). Outcomes should thus be interpreted carefully, also because of the lower reliability of model results for scales smaller than subwatersheds (Sharp *et al*., 2018b). As uncertified areas were situated in between certified areas, it was not possible to compare FSC certified and uncertified subwatersheds. This approach could however be useful for other study areas, having the advantage of the possibility of water supply comparison, a model output at subwatershed scale.

Second, sediment export increased significantly in FSC plots of SL 1, while it decreased in uncertified areas of SL 1 and in both FSC and no FSC plots in SL 5 (Table 4.6, Appendix K). For SL 1, the temporal change (from 2008 to 2016) was larger in FSC areas than in uncertified areas (365 %) while this was smaller for SL 2 (-16 %), 4 (-935 %) and SL5 (-833 %) (Table 4.7, Appendix K). Statistical analysis for sediment retention however showed no significant temporal change differences between FSC and uncertified areas in SL 1 and 2 (Table 4.7), suggesting conclusions should be taken critically. Nevertheless, results for export and retention in SL 4 and 5 did correspond: the sediment retention increased in certified properties in SL 4 and 5, while it decreased in FSC and no FSC plots of SL1 and uncertified areas of SL 2, 3 and 4 (Table 4.6 appendix K). For SL 4 and 5 this temporal change was significantly higher in FSC areas than in uncertified areas (>1400 %, Table 4.7, Appendix K). The difference in average temporal change for export (-41 %) and retention (225 %) not being significant for SL 3 can be related to being the largest SL (Figure 3.5). Although it is located in one climate zone and geomorphological unit, there was probably still a high variation in other conditions within the SL, e.g. in elevation (with the DEM being an important input for the SDR model (Sharp *et al*., 2018b)) (Figure G.3). Making a more detailed landscape stratification could therefore give more clarity in obtained results. The selection of sufficient plots, especially for uncertified areas, will however be a challenge when using this approach in the study area. Finally, the significance in SL 3 for HQ and AWY (and almost sign. for HD), in line with results of most other SLs (Table 4.7, Appendix K), suggests these results were potentially less sensitive to the variation in the SL.

Third, the HQ showed significant increases from 2008 to 2016 (Table 4.6), with significant higher changes in FSC areas (compared to uncertified areas) (> 68 %, Table 4.7). This was also the case for HD (Table x; > 57 % in Table x), except for SL 3 where FSC temporal changes did not differ significantly from uncertified areas (Table 4.7). Uncertainties in HQ model outputs could however have influenced this result, which should thus be interpreted carefully. For example, native forest, was potentially overestimated in 2016 and underestimated in 2008. By having mostly higher habitat scores and sensitivity to threats than other land covers, it likely influenced the accuracy of final outputs. In addition, taking lower values for k in the HQ model could result in HD having higher impact on HQ scores, with a better relative spreading of the HQ values over the landscape (Sharp *et al*., 2018b). Moreover, the area of forest properties possibly had an influence. As the majority of forest plantations in the landscape are certified, it was a challenge to select a sufficient number of uncertified forest properties. Although all selected properties (both FSC and no FSC) were larger than 20 ha, uncertified properties were sometimes smaller than plots in certified areas. Statistical comparison of mean quality and degradation per pixel in each property could thus give a more decisive answer on the significance of FSC effects, also on water yield and outputs of the SDR model.

Finally, the approach had some limitations. First, not all companies obtained certification at the same time within the study period, so not all areas in the landscape knew the amount of years in which changes could have taken place (Montenegro *et al*., 2018). In addition, changes related to SFM could also be linked to other mechanisms than FSC certification. Forestry companies also meet the Corporate Social Responsibility policies (Beckman *et al*., 2009; Montenegro *et al*., 2018) and Chilean laws linked to forest management (e.g. Native forest Law (from 2009) and the Decree 701 (Agricultural Department, 1974, 2008)). Besides, the forestry companies were possibly influenced by other certification programs, as several also obtained ISO 140015 certification and CERTFOR certification (since 2003, accepted by the international PEFC program) (Arauco, 2018; CERTFOR, 2018; Forestal Mininco, 2018; Montenegro *et al.*, 2018). Second, although certain impacts were already visible for the study period, continued long-term monitoring of FSC effects, important according to survey participants, will give more information on the stability of these effects. Third, although it was possible to compare FSC areas with uncertified areas, the amount of uncertified areas was a limiting factor. In addition, results give indications on effects of FSC certification of the two most important and largest forestry companies in the study area, for which information on certified areas was available. There is however a small chance that selected uncertified plots outside of these areas coincide with properties of other smallholder companies, also being certified, by FSC or other certification programs. Furthermore, the limited access to information could also have influenced model outputs and thus statistical results, as not all inputs were available for both the pre- and post-certification periods, leading to inputs not always completely corresponding to the one of these years and uncertainties in results. Fourth, some conclusions of significance were based on MWW and KS tests, focussing on the data distributions. These tests however result in different conclusions, compared to t-tests focussing on the difference in means of the data. Therefore, overall conclusions on significance should be nuanced. Finally, this approach captured effects in forest properties as a whole. As these sometimes included HCVAs of the forestry companies, the differentiation of these areas and forest plantation areas could give useful insights on ex situ and in situ effects of FSC certification.

5.5 Conclusion

A survey for stakeholders related to FSC certification, with an acceptable response rate (32.35 %) resulted in a top 5 of ES with the highest overall relevance to evaluate in the context of FSC certification: 1) water cycle and water regulation, 2) fresh water supply, 3) biodiversity conservation, 4) habitats for plants and animals and 5) soil conservation and erosion regulation. The suggested evaluation period depended on the ES, with short-term effects potentially visible for some ES (e.g. habitats and fresh water supply), but in general, the importance of long-term evaluation (> 10 years) was emphasized. Proposed trade-offs and synergies between ES were related to ecological processes, thematic interactions, the suggested relevance for the evaluation of the ES and the national FSC standards. Results were however only an indication of existing correlations between ES, not biophysically verified in the field.

One of the challenges was obtaining all necessary information for the InVEST models, given the lack of openly available spatially explicit data for both pre- and post-certification periods (2008-2010 and 2016-2018 respectively). The combination of open access data bases with expert consultation and scientific literature was found to be sufficient for obtaining all necessary inputs. However, assumptions, restricted spatial and spectral resolution and model limitations to capture reality, likely contributed to uncertainties in outputs and thus also final results. The use of Google Earth images allowed to capture small scale landcover patterns, but the limited spectral resolution produced uncertainties in the pixel-based RF classification. Several options to improve this part of the methodology were therefore suggested. In addition, total water yield and supply were likely respectively over- and underestimated and sediment export and retention were also probably respectively over- and underestimated. A detailed sensitivity analysis, model calibration and validation could quantify these uncertainties and clarify to what extent they influenced final results.

Water yield significantly increased in certified areas of sublandscape (SL) 1, while it decreased in SL 5 and for uncertified plots in all SLs. Temporal changes were significantly higher in FSC forest properties compared to uncertified areas in SL 1, 2 and 3 and lower in SL 5. Furthermore, sediment export decreased significantly in FSC certified areas of SL 5 and uncertified areas of SL 1 and 5, while it increased in FSC plots in SL 1. This temporal change from 2008 to 2016 was larger in SL 1, and smaller in SL 2, 3 and 4 comparing FSC forest properties with uncertified forest properties. In addition, sediment retention significantly increased in certified areas in SL 4 and 5, and it decreased in SL 1 and in uncertified properties of SL 1, 2, 3 and 4. The temporal change in SL 4 and 5 was higher for FSC certified areas than in uncertified properties. Finally, habitat quality increased significantly more in FSC certified areas, compared to uncertified areas. This was also the case for habitat degradation, except in SL 3. These significant results were difficult to attribute to only FSC certification, as there were other potentially contributing factors of SFM.. In addition, uncertainties in model inputs, such as land cover rasters, probably contributed to errors in the final results, which should therefore be interpreted with care. Nevertheless, this study gives useful insights for the understanding of FSC certification effects on ES supply in forest landscapes of south-central Chile. These insights, together with the used methodology could contribute to filling the gap of scientific evidence on this topic, both in terms of possibilities to improve FSC certification as for the critical evaluation of its environmental effects.

Popularized summary

Sustainability is becoming more and more important nowadays. Market mechanisms exist to promote sustainable forest management and advice consumers about forest product sustainability. These are called forest certification programs, with the Program for the Endorsement of Forest Certification (PEFC) and the Forest Stewardship Council (FSC) as the most important players worldwide. There is however a lack in knowledge about effects of this certification on forest ecosystems. This study investigated these effects in relation to ecosystem services, i.e. benefits of ecosystems to people, focussing on water yield, habitats for plants and animals and erosion control in south-central Chile. Chile is one of the 10 most important countries for the global forest industry, making it suitable for the evaluation of forest certification impacts. Questionnaires for stakeholders related to FSC were combined with models to quantify differences between certified and uncertified areas. Results showed positive effects on water yield, habitat quality and erosion control. The methodology used in the study and obtained insights can contribute to further understanding of effects of FSC forest certification on ecosystems.

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Appendices

A. Forest certification history overview

Certification of products was originally established as a mechanism for verification of a set of requirements, like safety, technical and quality characteristics (Montenegro *et al.*, 2018). This focus broadened to environmental and social requirements, because of raising consumer concerns (Nussbaum & Simula, 2005). FC knows its origin in increasing concerns about deforestation and forest destruction in the 1980s, demanding a mechanism to verify the sustainability of forest management and resulting products (Nussbaum & Simula, 2005). Environmental NGOs focused on campaigns to decrease pressure on forests and raise awareness, launching campaigns and supporting boycotts (especially of tropical timber) (Nussbaum & Simula, 2005). In 1990, the International Tropical Timber Organization (ITTO) agreed on the ‘ITTO Objective 2000’ requiring all tropical timber trade coming from forests with SFM and in 1992 they developed guidelines for SFM of natural tropical forests in 1992 (Nussbaum & Simula, 2005). In 1992, world leaders created the ‘Forest Principles’ during the Earth Summit in Rio de Janeiro (United Nations Conference on Environment and Development (UNCED)), containing 17 non-legally binding points on forest types with corresponding objectives, identifying the urgency to handle tropical forest destruction and change to a SFM (United Nations, 1992). The demand to the development of similar guidelines for boreal and temperate forests, resulted in tools and guidelines under Forests Europe and the Montreal Process (United Nations, 1992). The Montréal Process Working Group (created in 1994) identified 7 criteria and 67 corresponding indicators under the ‘Santiago Declaration’ (1995) as guidelines for SFM in boreal and temperate forests within the member countries (49 % of the world’s forests, 83 % of the global temperate and boreal forests and 45 % of the global wood products): “1) Conservation of biological diversity, 2) Maintenance of productive capacity of forest ecosystems, 3) Maintenance of forest ecosystem health and vitality, 4) Conservation and maintenance of soil and water resources, 5) Maintenance of forest contribution to global carbon cycles, 6) Maintenance and enhancement of long-term multiple socioeconomic benefits to meet the needs of societies, 7) Legal, institutional and economic framework for forest conservation and sustainable management” (Montréal Process Working Group (MPWG), 1995, pp. 5, 6, 7, 9). Later, Forest Reports with improved indicators followed in 2003 and 2009, together with a Strategic Action Plan in 2007. In Europe, analogous SFM assessment indicators and criteria were created with the Helsinki Process (1993), later known as the Pan-European Process

(Anon, 1995; Ministerial Conference on the Protection of Forests in Europe (MCPFE), 2000).

The alarm of the Earth Summit, the statements of the ITTO with resulting SFM guidelines SFM and the absence of binding global forest principles created collaborations (of i.a. NGOs) to take action in certification of forest management (Viana *et al.*, 1996; Elliott, 2000; Cashore *et al.*, 2004; Auld *et al.*, 2008; Cashore & Auld, 2012; Steering committee of the state-of-knowledge assessment of standards and certification (SCR) (2012). After some attempts to create certification schemes for SFM, biodiversity conservation and illegal deforestation decrease, the first certification mechanism was created in 1993: the Forest Stewardship Council (FSC) (Elliott & Schlaepfer, 2001; Kozak *et al.*, 2004; Nussbaum & Simula, 2005; Cashore *et al.*, 2006). FSC is an "independent, non-profit, non-governmental organization, established to promote environmentally appropriate, socially beneficial, and economically viable management of the world's forests*"* (FSC, 2016d, p. 2). "The vision of FSC is that the world's forests meet the social, ecological, and economic rights and needs of the present generation without compromising those of future generations" (FSC, 2016d, p. 2). FSC members form a General Assembly, representing the highest level of decision power (FSC, 2016d, p. 2). The structure of this Assembly assures that the rule making cannot be dominated by specific interests (FSC, 2018e). This Assembly exists of three chambers: an environmental, an economical and a social chamber, each holding one third of the votes (Elliott, 2000; Nussbaum & Simula, 2005; Synnott, 2005). Every chamber contains stakeholders from developed and developing countries, each holding fifty per cent of the chamber's vote (Nussbaum & Simula, 2005; FSC, 2018b). Decisions are accepted with 66.6 % of the votes of the total General Assembly members (Nussbaum & Simula, 2005). FSC members are spread all over the world to guarantee meeting everyone's demands as well as possible (Nussbaum & Simula, 2005). Members include NGOs (Greenpeace and WWF), members of businesses (Mondi PLC and Tetra Pak), social organizations (e.g. the National Aboriginal Forestry Association of Canada), processing companies, forest managers etc. (FSC, 2018e). FSC itself is a member of the ISEAL Alliance ('the global membership association for credible standards of sustainability', fulfilling i.a. the 'Codes of Good Practice' and having the support of international accreditation bodies) of which Fairtrade and the Rainforest Alliance are also members (FSC, 2018f; ISEAL Alliance, n.d.). For a Forest Management Unit (FMU) to become certified, FSC is contacted directly or indirectly through an independent FSC accredited CB, which reviews the FMU documents (e.g. management plans) (FSC, 2018f;

ISEAL Alliance, n.d.). An interdisciplinary group of this CB carries out a subsequent preliminary assessment visit with a FMU visit and local stakeholder interviews (Nussbaum & Simula, 2005; Cashore *et al.*, 2006; Romero *et al.*, 2013). This is followed by recommendations including practices to be improved in a certain time period before performing a full assessment (Corrective Action Requests (CARs)) (Nussbaum & Simula, 2005; Romero *et al.*, 2013). FSC certification is recommended by the CB when the FMU incorporates the required changes and passes the subsequent audit (Nussbaum & Simula, 2005; Romero *et al.*, 2013). In this case (and without valid disagreements in the public remark period) the FMU is FSC certified for five years with annual controls by the CB (Nussbaum & Simula, 2005; Auld *et al.*, 2008; Romero *et al.*, 2013; FSC, 2018e). In these five years, CARs can include further needed changes to fulfil FSC P & C (Romero *et al.*, 2013; FSC, 2018e). Accreditation of CB started in 1996, and was first carried out by the FSC accreditation unit (Auld *et al.*, 2008). In 2006, the Accreditation Services International (ASI) was created by FSC: an independent body to assure the credibility of CB activities by ASI audits, including e.g. office audits, document inspection and observing CB field audits (Auld *et al.*, 2008); A CB can lose accreditation of FSC when ASI audits report severe incidents after checking if the FSC accredited CB is meeting FSC accreditation requirements (Romero *et al.*, 2013; ASI, 2018; FSC, 2018e). Actual examples of accredited CB for FSC are Scientific Certification Systems (SCS) Global Services, the Rainforest Alliance and the Soil Association Woodmark (Romero *et al.*, 2013; ASI, 2018).

B. Detailed descriptions of the study area's location

B.1 The Valdivian Ecoregion

The study area is located in the Valdivian Ecoregion[2], in the south of Chile (Southern America). This ecoregion (Scientific Code: NT0404) is one of the 867 terrestrial ecoregions on Earth and is situated in "the temperate broadleaf and mixed forests" habitat, defined by WWF (Olson *et al.*, 2000; WWF, 2019a, 2019b, available online: https://www.worldwildlife.org/ecoregions/nt0404). This Neotropical ecoregion (almost 1.600 km length, 150-250 km width) is isolated from Eastern Southern America, with the Andes Mountain Range, while the Pacific Ocean is its Western border (INTA *et al.*, 1999;

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[2] An ecoregion is defined as a "large unit of land or water containing a geographically distinct assemblage of species, natural communities, and environmental conditions" (WWF, 2019, available online: https://www.worldwildlife.org/biomes). These ecoregions represent the distribution pattern of biodiversity on Earth, driven by evolution and geologic, climatic conditions (Olson et al., 2000; WWF, 2018a).

WWF, 2019b). The Ecoregion (34,5 million ha) consists of five administrative Chilean regions (from the region of Maule (7th) (35°S) in the North to the region of Aysén (11th) (48°S) in the South (INTA *et al.*, 1999; WWF, 2019b). The Atacama desert is the northern ecoregion bounder and the southern Andes form the limit in the South (WWF, 2019b).

Several geological events leaded to the current situation: the formation of the Coastal and Andes Mountain Ranges and the Intermediate Depression (Villagrán & Hinojosa, 1997). The North-South orientated Coastal Mountain Range, formed in the Paleozoic (about 570 million years ago), is older the high Andes mountain range (formation about 170 million years ago) (Villagrán & Hinojosa, 1997). The various volcanoes, present in this Coastal Range during the Miocene, don’t have any volcanic activity signs now (Veit *et al*., 1995; Wolodarsky-Franke & Herrera, 2011). The following Intermediate Depression subsidence resulted in a rise of the Andes (Veit *et al.*, 1995). Second, The Central Valley (100-200 m altitude) situated between the two mountain ranges, containing volcanic ash and glacial debris covers, is a lower fault zone (Veit *et al*., 1995). The weathering of the Coastal Range and the young age of the Andean slopes resulted in soils with poor development in both ranges, while sediments from these ranges formed the soils of the Central Valley (Veit *et al*., 1995). Finally, the Andes mountain range (altitudes higher than 3,000 m) having a regular seismic and volcanic activity was a centre during glacials, resulting in a change of the temperate forest biota (Veit *et al*., 1995).

The climate in the ecoregion has a large longitudinal, altitudinal and latitudinal variability and is influenced by orographic, atmospheric, oceanographic and latitudinal factors, which is related to the vegetational variation (Fuenzalida, 1950, 1965a, 1965b; Thomasson, 1963; Pisano, 1966; Hajek *et al.*, 1972; Quintanilla, 1974; Di Castri & Hajek, 1976; Peña & Romero, 1977; Hajek & Gutiérrez, 1978; Espinoza *et al.*, 1979; Acuña *et al.*, 1983; Burgos, 1985; Romero, 1985; Santibañez, 1990; Santibañez & Uribe, 1993; Arroyo *et al*., 1996, 1995; Amigo & Ramírez, 1998; Conti, 1998; Leubert & Pliscoff, 2004). In addition, the ecoregion has a long isolation history, which resulted in a biogeographic island, separated from other biotas by the Andes, the Pacific Ocean and the Atacama Desert. There is a large variability in the annual precipitation over this whole ecoregion: 6,000 mm in the southern and 1,000 in the north part (Huber, 1979; Pérez *et al*. 1998). The average temperature variation is the most noticeable in the West-East direction (< 160 km of longitude), because of the increasing altitudes upwards the Andes, resulting in extreme temperatures in the Andes and milder temperatures on the coast (Conama, 1999; WWF, 2019b). The minimum annual average temperature range is 4°C to 7°C, while the maximum annual average temperatures range between 13°C (in the southern limit) and 21°C (in the northern limit) (Conama, 1999; WWF, 2019). In the ecoregion’s southern part, the tree line is at approximately 1,000 m.a.s.l. (with the Andean mountains altitudes higher than 3,000 m.a.s.l.), while it ascends to 2,400 m.a.s.l in central Chile (35°S). Above this line, temperate forests are replaced by other vegetation (Conama, 1999; WWF, 2019). Furthermore, the Pacific Ocean contributes, with the thermoregulatory effect as oceanographic factor, to the climatic variability in the ecoregion. In addition, with decreasing distance to the sea and thermal oscillations decrease, the climate becomes less continental (Quintanilla, 1974; Di Castri & Hajek, 1976; Hajek & Gutiérrez, 1978; Espinoza *et al*., 1979; Burgos, 1985; Conti, 1998). Besides, a lower humidity and temperature, relative to other regions in the world is created by the Humboldt current (Quintanilla, 1974; Di Castri & Hajek, 1976; Hajek & Gutiérrez, 1978; Espinoza *et al*., 1979; Burgos, 1985; Conti, 1998). Mountain ranges, related to orographic factors, create lifting of air masses loaded with humidity coming from the Pacific Ocean and generate a rain shadow effect (Quintanilla, 1974; Burgos, 1985; Conti, 1998; Pérez *et al*., 1998). This results in high precipitation amounts on the Western slopes of the Coastal Range, decreasing towards the eastern areas with lower elevations (Quintanilla, 1974; Di Castri & Hajek, 1976; Huber, 1979; Burgos, 1985; Conti, 1998; Pérez *et al*., 1998) The effect repeats itself in the Andes mountains, where an altitudinal temperature (decrease) gradient is also present (Quintanilla, 1974; Di Castri & Hajek, 1976; Huber, 1979; Burgos, 1985; Conti, 1998). On the Argentinean side of the Andean slope (East), there is a significant decrease in precipitation with 200 mm or less, 100 km east of the Andean mountain peaks (Huber, 1979; Pérez *et al*., 1998). The seasonality in the rains (concentration during winter months), decreases from north to south (Huber, 1979; Pérez *et al*., 1998) and the position and movement of the Pacific Anticyclone, the position and system of the westward winds and the South Pacific low pressure centre position are controlling the regional air mass circulations (Huber, 1979; Pérez *et al*., 1998). These factors lead to the rainfall regime seasonality and the intensification of rainfall, in amounts and regularity, towards the south (Hajek *et al*., 1972; Quintanilla, 1974; Burgos, 1985; Conti, 1998). Furthermore, thermal regimes are affected by latitudinal factors: a decreasing temperature gradient to the south is produced by the lower solar radiation incidence at higher latitudes, and there is an influence of ice mass of Antarctica (Quintanilla, 1974; Hajek & Gutiérrez, 1978; Espinoza *et al*., 1979; Burgos, 1985; Conti, 1998). In the southern ecoregion zone (starting from the intermediate high areas of the Andean slope), a temperate macrobioclimate is present with creation of summers without water deficit areas, because of the high annual precipitation regularity (Hajek *et al.*, 1972; Quintanilla, 1974; Hajek & Gutiérrez, 1978; Burgos, 1985; Conti, 1998; Romero, 1985). On the other hand, in the northern ecoregion zone (up to the lower areas of the Andean slopes), a Mediterranean macrobioclimate is present, representing cold, rainy winters without water deficit and hot, dry summers with water deficit (Hajek *et al.*, 1972; Quintanilla, 1974; Di Castri & Hajek, 1976; Hajek & Gutiérrez, 1978; Acuña *et al.*, 1983; Burgos, 1985; Romero, 1985; Conti, 1998).

The ecoregion has a long isolation history, which resulted in a biogeographic island, separated from other biotas by the Andes, the Pacific Ocean and the Atacama Desert. Temperate forests of southern Latin America were isolated from other ecosystems of the continent during the Tertiary (Axelrod *et al.*, 1991; Villagrán & Hinojosa, 1997). Furthermore, tropical genera extinctions in the final Tertiary half in Chilean forests, were approx. 60 % of the species present during the first Tertiary half (Villagrán & Hinojosa, 1997). The southern South America temperate forest range narrowed to the western limit in the cool glacials while it broadened in the short and warm interglacials of the Quaternary (Villagrán & Hinojosa, 1997). Hence, the immigration of species from tropical areas was no longer possible, because of the high aridity in the eastern mountain barrier of the Andes and the western Southern American part (Arroyo et al., 1995; WWF, 2019). Therefore, the temperate forest isolation and reduced area extinction of numerous congeneric plant species with a net loss of especially species from tropical ancestry taxons caused the current high monotypic portion in the austral forest flora (Arroyo et al., 1995; WWF, 2019). The species-rich temperate rainforests were close to their northern present distribution bounder, when the maximum glacier extension was gained in the southern hemisphere (WWF, 2019b). In this northern part, oceanic effects resulted in mild temperatures and during the glacial periods, rainfall was higher (Arroyo *et al.*, 1996). Some plant communities could have represented regional biodiversity recovery sources after deglaciation: several parts of the coastal range (38°S-40°S) and particular Argentinian Patagonian parts could have stayed ice-free and free of periglacial processes (WWF, 2019b). The refuge role (or biodiversity of the coastal range in this period, could possible repeat itself in actual climate change scenarios (Arroyo *et al*., 1995; Villagran, 1990).

The temperate forests of the ecoregion feature have a remarkable biodiversity and endemism. Almost 50 % of the Chilean flora plant families are found in these forests (while only 7.8 % the Chilean flora species are present in the forests) (Villagrán & Hinojosa, 1997). The Valdivian temperate rainforest in this region is the second largest of the five temperate rainforests in the world with an area of approximately 166,248 km^2 (WWF, 2018b). These forests hold a spectacular biodiversity and endemism with 122 vascular plant species, like the endemic conifer Alerce (*Fitzroya cupressoides*), the single living species of Fitzroya genus, Nothofagus spp. and the Chilean pine (*Araucaria araucana*) (WWF, 2018b). This collection of ancient species remains as relicts from Gondwanaland (WWF, 2018b). Moreover, the Chilean pine, the long living species (up to 1,500 years), being a living fossil from the Mesozoic, and the Alerce became natural monuments in Chile in 1976 and 1977 respectively and are both of importance for the indigenous Mapuche groups (Agricultural Department (Ministerio de Agricultura, 1990a, 1990b). The Chilean pine was very recently (December 2018) declared as endangered (International Union for Conservation of Nature's Red List of Threatened Species (IUCN, 2018). The species only exists in Chile and Argentina covering 52 % of the cover in 1550 with 48.4 % of its cover present in Protected areas, mainly in the Andes Range (where 97.1 % of its cover is located, while 2.9 % is present in the Cordillera Range) (Wolodarsky-Franke & Herrera, 2011). Furthermore, the population in the Nahuelbuta Range mainly present in 'Villa Las Araucarias' has different genetic properties than other populations and is the smallest and worst conserved population (Wolodarsky-Franke & Herrera, 2011). In addition, there are 700 to 800 vascular plant species in the ecoregion, belonging to more than 200 genera (WWF, 2019). Moreover, the ecoregion is part of one of the 25 biodiversity hotspots worldwide (Neira *et al.*, 2002; Myers, 2003) and 'Birdlife International' classifies it as a zone with global importance avian species endemism (Stattersfield *et al.*, 2005). The Valdivian forests have 32 tree genera, of which 81% (26) are monotypic (Arroyo *et al.*, 1996). Additionally, the Gondwanic origin is present for one third or more of the woody plants, having their closest relationships with New Zealand, Tasmania, Australia and New Caledonia (WWF, 2019). The endemism is seen in the many taxonomically isolated genera belonging to monogeneric families (*Eucryphiaceae, Desfontaineaceae, Aextoxicaceae, Gomotergaceae, Misodendraceae* etc.) (WWF, 2019) This long isolation history and high extinction rates in the Pleistocene resulted i.a. in this endemism of almost 34 % and 90 % of the seed plants genera and species, respectively (Villagrán & Hinojosa, 1997; Tecklin *et al.*, 2002). In this context, one third of the 82 woody plant genera originate from the southern Gondwana part and 25 % of these genera have neotropical relations (WWF, 2019).

Furthermore the species level endemism estimates are: 45 % for all vertebrate species, 76 % for amphibian species, 30 % for birds, 33 % for mammals, 36 % for reptiles, 50 % fresh water fish (Armestó *et al.*, 1996; Tecklin *et al.*, 2002), 53 % for hemiparasites and 50 % for vines (Arroyo *et al*., 1996). Besides, endemic mammal species show geographically remote groups (Palma & Spotorno, 1999), while numerous amphibian species show very narrow distribution ranges (especially in the coastal range) (WWF, 2019)**.** Moreover, the woody habitats of the coastal range belong currently to the most critically endangered ecoregions habitats (Jara, 1982) and pollination and spreading of plants by animals is one of the highest of all temperate biomes (Armesto & Rozzi, 1989; WWF, 2019b).

A heterogenous forest type mosaic is present in the ecoregion, because of the long isolation history with biogeographic and geological events, gradients in precipitation and temperature and climatic changes. There are five forest ecosystem types, mainly based on a scheme (Wolodarsky-Franke & Herrera, 2011) and classification (Veblen, 1983): 1) Evergreen forests and bogs with bogs of Sphagnum (*Sphagnum* spp.) and evergreen Magellan's beech (N*othofagus betuloides*) forests, 2) Patagonian Andean forests, with Andean shrublands containing *Nothofagus* spp., and Chilean pine, 3) northern Patagonian forests, predominated by evergreen species (e.g. Yellow pine ('pino amarillo') (*Podocarpus nubigena*), canelo (*Drimys* winteri) and coigüe (*Nothofagus dombeyi*), 4) Valdivian laurel-leaved forests with a dominance of various tree species, for example: tiaca (*Caldcluvia paniculate*), ulmo (*Eucryphia cordifolia*), tepa (*Laureliopsis philippiana*), tineo (*Weinmannia trichosperma*) and olivillo (*Aextoxicon punctatum*) and 5) deciduous forests of Maula province, being the transition between the wet temperate southern forests and the Mediterranean-like schlerophyllous forests, and dominated by deciduous *Nothofagus* spp. (many of these being endemic to the area) (Gajardo, 1994). Furthermore the 'ciprés' (*Austrocedrus chilensis*) is predominating in an Eastern part of the ecoregion, in zones with less than 400 mm yearly average precipitation (INTA *et al*., 1999).

The large variability in climate, geography, geology etc. also leads to vegetational floors, classified by Luebert & Pliscoff (2006) and defined as: "spaces characterized by a set of zonal plant communities with uniform structure and physiognomy, located under mesoclimatically homogenous conditions, occupying a determined position along an elevation gradient, at a specific spatio-temporal scale" (Luebert & Pliscoff, 2006, p. 13). In the Valdivian Ecoregion in Chile, there is a presence of 55 vegetational floors (of the 127 floors un Chile) (Luebert & Pliscoff, 2006).

The ecoregion and its ecosystems are currently threatened (status: critical/endangered), for which actions for habitat preservation and restoration of what remains are urgent (WWF, 2019). The Valdivian ecoregion was almost completely forest covered before the Spaniards landing (with some open cultivated areas of the indigenous Mapuche groups) (Wolodarsky-Franke & Herrera, 2011; WWF, 2019b). In this moment, 17 vegetation types including 12 forest types were present in the ecoregion (INTA *et al.*, 1999; Armesto, 1995). Since the arrival of the Spaniards, the native forest cover is estimated to have declined by more than one third, now covering approx. 12,600,000 ha (WWF, 2019). Few primary forests survived: these remaining forests are particularly present in the coastal range, while about 50 % of the remaining forest cover are secondary forests (WWF, 2019). Moreover, the Ecoregion has a critical location in terms of socio-economics, resulting in a concentration of 54 % of the forestry and agricultural Chilean companies, and being a crucial area for primary and secondary energy sources (Wolodarsky-Franke & Herrera, 2011). Unsustainable forest management (for firewood, commercial ends), native forest conversion to exotic plantations or agriculture and human caused forest fires are mainly threatening the Valdivian temperate forests (Wolodarsky-Franke & Herrera, 2011; WWF, 2019b). According to Labarías & Wilken (2006;) and Wolodarsky-Franke & Herrera (2011), these threats can further increase under climate change. In fact, the named hazards leaded to a decrease in native forest cover in the ecoregion, estimated by 40 %, with a native forest conversion (Lara *et al.*, 1999; Lara *et al.*, 2003; Wolodarsky-Franke & Herrera, 2011). This forest loss was unequally distributed in space since forest cover especially decreased in the Central Valley (>90 % loss, 9 % remaining) and Coastal Range (> 80 % loss, 14 % remaining), while the high Andean zone forests and forests more in the southern part of the ecoregion remain relatively untouched (> 60 % native forest cover) (Lara *et al.*, 1999; Lara *et al.*, 2003; WWF Chile, 2008; Wolodarsky-Franke & Herrera, 2011). Furthermore, there are some remaining relatively large areas in the Coastal Valdivian Range with virgin native forests, but in general fragmentation and degradation is present (WWF Chile, 2008). Deforestation leaded to a significant fragmentation and reduction of the native forest area between 1975 and 2007 (Echeverría *et al.*, 2006; Jiménez, 2011). In addition, the deforestation on the Andean and Coastal range foothills, was the fastest and largest deforestation in Latin America before 1980 (Veblen, 1983). Besides, 15,000 to 49,000 ha of natural vegetation were burned yearly (Forest Institute of Chile (INFOR), 1997). Furthermore, the export of amphibians (in total 24,064 individuals) and reptiles (from 3,548 to 60, 000) increased and intensified between 1985 and 1992 (Veloso *et al.*, 1995; WWF, 2019b).

There is an urgent need to reduce threats and conserve this unique ecoregion (WWF, 2019). Taken protection and conservation measures mainly consists of more than 50

National Parks, reserves and monuments creation and preservation (together > 10 million ha in the temperate Chilean region) (WWF, 2019). With some parks already opened in beginning of the 1900s, these are seen as pioneer protected Latin American areas (Armesto & Rozzi, 1989). The geographic vertebrate and tree species distribution does however not fully correspond to the protected area distribution (Armesto & Rozzi, 1989). Moreover, the biodiversity is the highest of Chile, between 41.3º S and 35.6ºS, while this corresponds to the area with the fewest protected areas (< 10% of the total protected areas). (WWF, 2019). Additionally, the areas with the highest species richness coincide with highest human density characterised areas and with large threats and pressure from plantation forestry and agriculture (Armesto & Rozzi, 1989). Moreover, the protected areas between 41.3º S and 35.6º S, show their largest species richness above 600 m.a.s.l., where there is an accentuation of physical processes, reducing endemism and speciation (Armesto & Rozzi, 1989). In addition, 99 % of the protected areas in southern South America are present in the Argentinean of Chilean Andes, and not in the coastal ranges of these latitudes; Andean forests have more imposive landscape elements, than coastal forests: large lakes, views on impressive volcanoes and small lagoons (Smith-Ramirez, 1993; Smith-Ramirez & Armesto, 1994; WWF, 2019). Finally, 11 vegetational floors are not represented in the system of national protected areas (National System of Protected Areas or SNASPEs) (Luebert & Pliscoff, 2006) and 30 are represented in this system by less than 10 % of its remaining area (Wolodarsky-Franke & Herrera, 2011). There are besides no areas protected in the Intermediate depression (except for the small municipal park, close to Puerto Montt) (WWF, 2019). Hence, even without considering climate change scenarios, this system of protected areas is not fitting the biodiversity protection need over time in the whole ecoregion (Wolodarsky-Franke & Herrera, 2011)

More recently, WWF Chile identified 12 priority areas to focus on, in terms of biodiversity conservation (WWF Chile, 2008). In addition, WWF Chile (2011) created a strategic plan of the ecoregion to contribute to sustainable conservation and use of its natural resources, where all stakeholders are participating. However, the majority of the areas needed to accomplish the proposed conservation measures are privately owned, leading to necessary public-private collaborations (Wolodarsky-Franke & Herrera, 2011). The strategic plan includes four priority strategies: management of private areas under protection, promoting environmental alliances in the private financial sector, empowering sustainable livelihoods and governance models and promoting FSC certification in forest plantations for nature conservation in the ecoregion (Wolodarsky-Franke & Herrera, 2011). Part of this last strategy is voluntary FSC certification of forestry companies, in relation to markets demanding this certification (Wolodarsky-Franke & Herrera, 2011). The current monitoring of this certification impacts on social and environmental levels by WWF Chile has to evaluate the meaning of this strategy (WWF Chile, 2008).

B.2 The Nahuelbuta Coastal Mountain Range

The Nahuelbuta mountain range, is the part of the Coastal range between the Bío Bío river (northern limit, 37°11’ S) and the Imperial river (southern limit, 38°45’S), having a longitude of 190 km and width of 50 km (at the widest part between Angol and Cañete) (Wolodarsky-Franke & Herrera, 2011). Furthermore, it was entitled as world Biodiversity reserve (Wolodarsky-Franke & Herrera, 2011). The Nahuelbuta range is one of the Coastal range parts with the highest endemism and biodiversity levels, while it is also has very scarce ecosystem conservation and is suffering from the greatest environmental modifications and a high fragmented native forest landscape (Wolodarsky-Franke & Herrera, 2011). The interaction of different ecosystem, such as the overlap between two vegetation types (‘Evergreen Valdivian forests’ and ‘Deciduous forests and shrubland of the Mediterranean zone’) partly contribute to one of the world’s highest biodiversity, making it one of the 25 global biodiversity hotspots (Wolodarsky-Franke & Herrera, 2011). Furthermore, the topographic variation (400 m in the north to more than 1000 m altitude in the southern part) create a climatic variation in the Range with a subhumid warm Mediterranean climate in the north and a temperate humid and rainy climate in the South, creating a variability in ecological environments, for hosting the large biodiversity (Wolodarsky-Franke & Herrera, 2011). The Range is a habitat for 690 native vascular plant species, of which 265 are endemic, being 55 % of the 480 Chilean endemic species (Wolodarsky-Franke & Herrera, 2011). Species with conservation priorities, including pitao (*Pitavia punctata* Mol.*),* queule (*Gomortega keule*), coral plant (*Berberidopsis corallina*) and the Chilean pine are being threatened by mainly human activities causing decrease and fragmentation of their habitat (Wolodarsky-Franke & Herrera, 2011). There are no endemic reptiles in the Range, but the large variety of amphibian species present, benefiting ecosystem balance are all protected (Wolodarsky-Franke & Herrera, 2011). The 17 amphibian species present are 33 % of the Chilean frogs and toads, of which five are endemic to the Nahuelbuta range (Ibarra-Vidal & Ortiz, 2011). Nine reptile species (none being endemic and having a wide distributional range in Chile) are found the Nahuelbuta Range representing 5 % of the Chilean herpetofauna (Ibarra-Vidal & Ortiz, 2011). The amphibian and reptile species are threatened by the native forest fragmentation (Ibarra-Vidal & Ortiz, 2011). In addition, about 108 avian species have been found in the Nahuelbuta Range, of which minimum 34 bird species native forest linked (Wolodarsky-Franke & Herrera, 2011). Furthermore, approximately 20 native mammalian species are present in the Nahuelbuta Range and most have wide distribution ranges in Chile (Wolodarsky-Franke & Herrera, 2011). Moreover, new species of amphibians, insect etc. are still being discovered in the Nahuelbuta Range (Jiménez, 2011; Wolodarsky-Franke & Herrera, 2011)

One of the most relevant areas of the Nahuelbuta range is the ‘Quebrada de Caramávida’ (37°41’ S, 73°13’ W, WGS 84, Arauco Province, Bio Bio range): because of its geographic location (heart of the range, western slope), an important part of the fragmented primary and secondary native forests remained (Pauchard, 2011). In the Nahuelbuta range, many species of dryer forests (e.g. Mediterranean forests) and more humid and southern forests like the Valdivian forests are coexisting, because of the altitude variability (Pauchard, 2011). Chilean pine adults are e.g. dominating in the highest parts, while conservation problematic species (e.g. queule and coral plant) are present in the lowest zones (Pauchard, 2011). These Chilean pine populations, being difficult accessible, survived the large exploitations in the past (starting from the mid-20th century) (Pauchard, 2011). Cutting these trees became prohibited in the 1980s (Pauchard, 2011). Their regeneration is however difficult, because of fire and constant animal browsing (Pauchard, 2011). The increase of forest plantation area, replacing native forests and shrubs, and dense road network creation mainly threatened the area in the 1980s, 1990s (Pauchard, 2011). Nowadays, the majority of remaining forests are owned by large forestry firms, including them in their protected areas and aiming for long-term conservation (Pauchard, 2011). The ‘Quebrada de Caramávida’ is still connected to other large native vegetation fragments of Nahuelbuta (like the Nahuelbuta National Park) and the ‘Trongol’ sector (Pauchard, 2011). Additionally, the Caramávida ecosystem is one of the important parts of the biodiversity hotspots in the ecoregion and recently became a priority site for regional conservation (Pauchard, 2011).

During the last centuries, more than 70 % of the natural vegetation was lost in the Nahuelbuta Range (Wolodarsky-Franke & Herrera, 2011). Only 3.5 % (7,000 ha of the 200,000 ha) of the native forest are in the Range are protected as SNASPEs, e.g the Natural Contulmo Monument and the Nahuelbuta National Park, however not covering all the habitats and natural vegetation present in the mountain range (Wolodarsky-Franke & Herrera, 2011). The Nahuelbuta National Park (created in 1939; 6,832 ha), having camping areas and four walking trails, contains an association of several *Nothofagus* species with Chilean pine trees in the highest parts and is an important refuge for endemic species, such as the Darwin's fox (*Pseudalopex fulvipes*) (Wolodarsky-Franke & Herrera, 2011). The Natural Contulmo Monument (created in 1982; 82 ha), also contains walking trails, and is characterized by a Mediterranean climate because of coastal rainfall generating winds, leading to a large species diversity (120 native species of the 146 plant species present, with also diverse epiphytic species (e.g. 26 fern varieties) on tree trunks) (Wolodarsky-Franke & Herrera, 2011). In addition, 51 animal species are found in this small native forest fragment (Wolodarsky-Franke & Herrera, 2011). The Range is threatened by human activities, such as forest exploitation and extensive agriculture, partly responsible for among others water quality and soil degradation (Wolodarsky-Franke & Herrera, 2011). In this context, the Decree 701 increased the forest plantation area, and decreased the native forest exploitation, but also leaded to a conversion of native forest to forest plantations (e.g. 15,600 hectares in the period 1998-2006 in the 'Los Rios' region) (Donoso & Otero, 2005). This law (approved in 1974) focuses on recovering degraded and agricultural lands, regulating forest use and management and also promoting afforestation (Boletín de Leyes y Decretos del Gobierno, 1974). This leaded to legal enlargement of the forest plantation area in the Central Valley and Coastal Range, from the Bío Bío Region to the Los Lagos Region (Wolodarsky-Franke & Herrera, 2011). In 2011, forest plantations covered about 45 % of the Nahuelbuta landscape (Wolodarsky-Franke & Herrera, 2011).

The Nahuelbuta Range is threatened by the native forest fragmentation (with about 12,000 native forest fragments, only 3 having areas larger than 500 ha), land degradation and the interaction with exotic species of forest plantations (radiata pine and eucalypts), all hindering natural regeneration (Wolodarsky-Franke & Herrera, 2011). Only 3.5 % (7,000 ha of the 200,000 ha) of the native forest are in the range are protected as SNASPEs, e.g Natural Contulmo Monument and the Nahuelbuta National Park (Wolodarsky-Franke & Herrera, 2011).

Moreover, there has been a transformation of the forest management with time with remaining tolerant native species in the understorey and a lower planting density in the 1970s, in contrast with current more frequent harvests and higher densities, preventing native seed germination and causing soil erosion, increasing sedimentation in rivers and fertility loss (Wolodarsky-Franke & Herrera, 2011). Illegal extraction of timber and NTFP (e.g. mushrooms, seeds, fuelwood etc.) from native forests, an important income for farmer and indigenous families (with traditional knowledge of the use and applications of these products), is currently contributing to native forest degradation with difficult regeneration (Wolodarsky-Franke & Herrera, 2011). The creation of markets for these NTFP benefits both native forest revaluation and local family income, with nutritional and medicinal products, such as the Chilean pine seeds, mushrooms and tree bark of several native species being among the most demanded products (Wolodarsky-Franke & Herrera, 2011). Furthermore, various seeds have ornamental value and various plant species are used as natural dye-material (Wolodarsky-Franke & Herrera, 2011).

Other threats for native forests and their biodiversity are forest fires (annual average of 5,800 (CONAF, 2013)), mostly caused by human actions, also emitting large CO_2 amounts (Wolodarsky-Franke & Herrera, 2011). Moreover, the Nahuelbuta Range biodiversity and habitat value was mostly unknown by people, taking few actions for conserving this area, but recently ecotourism increased (doubled in 2000-2011, with more than 6000 visitors/year in the Nahuelbuta National Park; with other important touristic areas being for example the Natural Contulmo Monument, the Lake 'Lleu-Lleu' and Lake 'Lanalhue') (Wolodarsky-Franke & Herrera, 2011).

Because of the 19th century political focus to benefit animal husbandry and agriculture, both the indigenous people (who didn't get stable work in the extensive agriculture in the valleys) and forest sector moved to the higher mountains (Wolodarsky-Franke & Herrera, 2011). The political promotion for native forest conversion into agriculture, together with this migration, caused deforestation, erosion, decreasing soil fertility, soil compaction and biodiversity and ES (e.g. water supply) losses (Wolodarsky-Franke & Herrera, 2011). With the Decree 701, the exotic forest plantations expanded, leading to the concentration of people and farmers in rural villages and small cities, where they could find work in the forest sector (Wolodarsky-Franke & Herrera, 2011). In addition, the majority of the remaining 200,000 ha native forest in Nahuelbuta is owned by forestry companies, while just 19,000 ha is owned by indigenous communities and smallholders (Wolodarsky-Franke & Herrera, 2011). In 2011, about 145,000 indigenous and rural people were living in the Nahuelbuta range, living from agriculture, fuelwood extraction, animal husbandry and NTFP collection (Wolodarsky-Franke & Herrera, 2011). The Mapuche communities, partly depending on native forests for their income and receiving ES (e.g. fresh water supply), are suffering from the exotic plantation expansion and some conflicts remain with forestry firms (Wolodarsky-Franke & Herrera, 2011).

The actual FSC certification of some large forestry companies reduced the threat of native forest conversion into exotic plantations (Wolodarsky-Franke & Herrera, 2011).

Recently, ES are being more included in research with attempts to also incorporate their value in economic analysis's, and e.g. one of the most appreciated ES being the scenic beauty of the SNASPEs in the area, benefitting tourism (Wolodarsky-Franke & Herrera, 2011). In contrast, the fresh water supply of the native forest ecosystem to cities, such as Contulmo (approx. 7,000 habitants) and Angol (approx. 48,996 habitants), is largely undervalued by local people (Wolodarsky-Franke & Herrera, 2011). Streams and rivers from native forest covered watersheds have a summer water flow of three to six times higher than watersheds covered with other vegetation (e.g. exotic forest plantations or meadows) (Wolodarsky-Franke & Herrera, 2011). Protection of this ES should be obtained by encouraging sustainable water use and degraded watershed recovery (Wolodarsky-Franke & Herrera, 2011).

In the Angol community, the Territorial Grouping Nahuelbuta (‘Agrupación Territorial Nahuelbuta (ATN)’) was created by farmer families, expressing the importance of biodiversity and ES in Nahuelbuta for the whole community and giving sustainable development options, e.g. water supply conservation of rivers supplying Angol, participation in municipal authorization for creation of a buffer zone around the Nahuelbuta National Park, and possibilities to stop monoculture plantation expansion (Wolodarsky-Franke & Herrera, 2011).

In conclusion, the Nahuelbuta Range is a unique zone, being part of an important biodiversity hotspot, needing urgent conservation because of the current threats, decreasing ES provisioning (e.g. climate change contribution, erosion, habitat fragmentation of unique species) and negatively influencing the life of people living there (Wolodarsky-Franke & Herrera, 2011). In order to do this, a participatory approach between all stakeholders (private and public property owners, universities, local communities, municipalities, civil society organizations and governmental agencies) is important with clear objectives, including priority areas for conservation with efficient management and conservation, ecotourism, educational programs to increase valuation of this conservation and research about ES in the area (Wolodarsky-Franke & Herrera, 2011).

B.3 The Nahuelbuta landscape

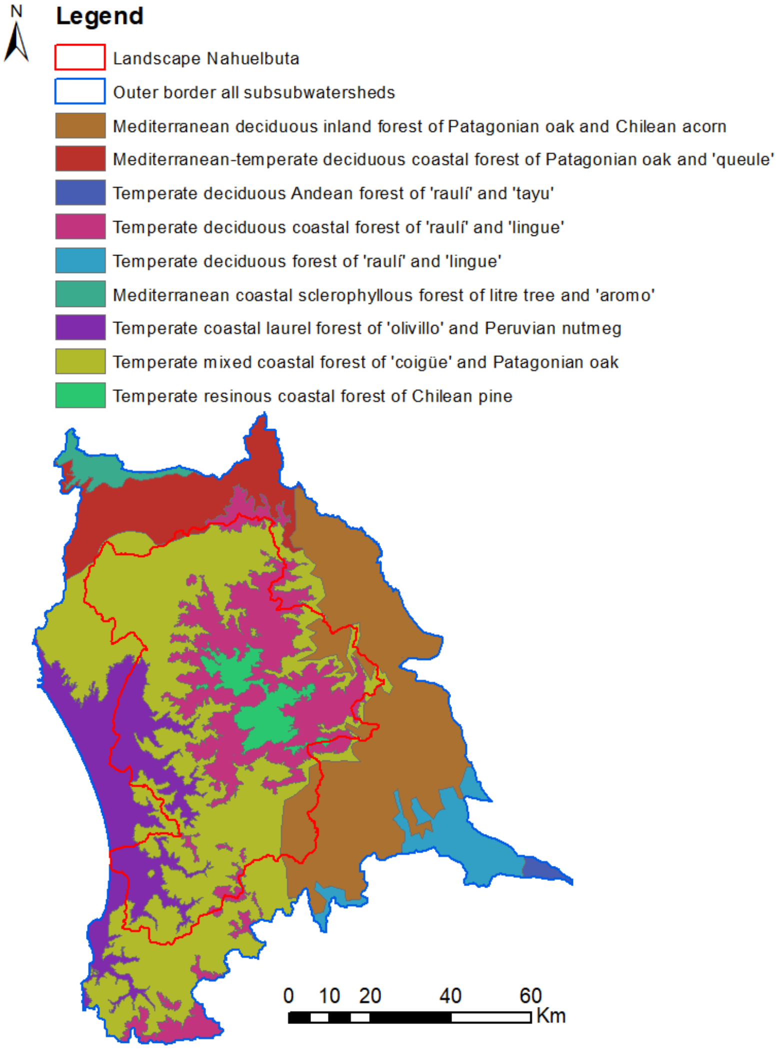

Figure B.3.1: Vegetational floors (Ministry of Environment Chile, 2014) in the Nahuelbuta landscape (WWF Chile, 2018b), translated to English, map by author

C. Relations between the national FSC standards and ecosystem services

Table C.1: Provisioning Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
PROVISIONING ES		
Timber production (Corvalan *et al.*, 2005)	P1: C1.3: I1.3.1 (FSC CHILE, 2012)	“PRINCIPLE 1: Compliance with laws and FSC Principles (…) Forest management shall respect all applicable laws of the country in which they occur, and international treaties and agreements to which the country is a signatory, and comply with all FSC Principles and Criteria.” (FSC CHILE, 2012, p. 2)
		“CRITERION 1.3 In signatory countries, the provisions of all binding international agreements such as CITES, ILO Conventions, ITTA, and Convention on Biological Diversity, shall be respected.” (FSC CHILE, 2012, p. 5)
		1.3.1 “In the FMP there are internal procedures to fulfil the international agreement tools endorsed by the country, applicable to the nature of the project being developed.” (FSC CHILE, 2012, p. 5)
	P5: C5.2: I5.2.1, 5.2.2, I5.2.4 (FSC CHILE, 2012)	“PRINCIPLE 5: Benefits from the forest (…). Forest management operations shall encourage the efficient use of the forest’s multiple products and services to ensure economic viability and a wide range of environmental and social benefits.” (FSC CHILE, 2012, p. 32)
		“CRITERION 5.2 Forest management and marketing operations should encourage the optimal use and local processing of the forest’s diversity of products.” (FSC CHILE, 2012, p. 34)
		5.2.1 “The FMP considers the largest diversity possible of timber and non- timber products feasible to be produced, in the frame of the resource and markets conditions.” (FSC CHILE, 2012, p. 34)
		5.2.4 “Support actions to local processing of forest products are developed in the FMP.” (FSC CHILE, 2012, p. 35)
	P5: C5.3: I5.3.1- I5.3.2 (FSC CHILE, 2012)	“CRITERION 5.3 Forest management should minimize waste associated with harvesting and on-site processing operations and avoid damage to other forest resources.” (FSC CHILE, 2012, p. 36)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
PROVISIONING ES		
Timber production (Corvalan *et al.*, 2005)	P5: C5.3: I5.3.1-I5.3.2 (FSC CHILE, 2012)	5.3.1 "The FMP demonstrates there is not significant timber volume left logged in the plantation site, that all minor timber qualities are profited if economically and marketable possible (i.e. fuelwood) and the remains without use do not difficult future plantation development." (FSC CHILE, 2012, p. 36)
		5.3.2 "In the FMP there are management and harvesting instructions available to forest workers including management of remains related to management operations." (FSC CHILE, 2012, p. 36)
	P5: C5.6: I5.6.1-I5.6. (FSC CHILE, 2012)	"CRITERION 5.6 The rate of harvest of forest products shall not exceed levels which can be permanently sustained." (FSC CHILE, 2012, p. 39)
		5.6.1 "In the FMP a long term planning exists making compatible the harvest rates with the reforestation rates with the intention to ensure periodic production flows." (FSC CHILE, 2012, p. 39)
		5.6.2 "In the FMP the expected harvest level is clearly justified in terms of an annual or periodic sustainable yield." (FSC CHILE, 2012, p. 39)
Timber production (Corvalan *et al.*, 2005)	P8: C8.1: I8.1.1, P8: C8.2: I8.2.1-8.2.2 (FSC CHILE, 2012)	"PRINCIPLE 8: MONITORING AND ASSESSMENT (…)Monitoring shall be conducted—appropriate to the scale and intensity of forest management—to assess the condition of the forest, yields of forest products, chain of custody, management activities and their social and environmental impacts." (FSC CHILE, 2012, p. 71)
		"CRITERION 8.1 The frequency and intensity of monitoring should be determined by the scale and intensity of forest management operations as well as the relative complexity and fragility of the affected environment. Monitoring procedures should be consistent and replicable over time to allow comparison of results and assessment of change." (FSC CHILE, 2012, p. 71)
		8.1.1 "The FMP has a monitoring and evaluation system of the Forestry Plan including social and environmental aspects in relation with the project scale and characteristics." (FSC CHILE, 2012, p. 71)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
PROVISIONING ES		
Timber production (Corvalan *et al*., 2005)	P8: C8.1: I8.1.1, P8: C8.2: I8.2.1-8.2.2 (FSC CHILE, 2012)	“CRITERION 8.2 Forest management should include the research and data collection needed to monitor, at a minimum, the following indicators: a) Yield of all forest products harvested. b) Growth rates, regeneration and condition of the forest. c) Composition and observed changes in the flora and fauna. d) Environmental and social impacts of harvesting and other operations. e) Costs, productivity, and efficiency of forest management.” (FSC CHILE, 2012, p. 72)
		8.2.1 “In the FMP there is a record of all the forest timber products and written information of the non-timber products harvested in the site.” (FSC CHILE, 2012, p. 72)
		8.2.2 “The FMP has a detailed control of the production.” (FSC CHILE, 2012, p. 72)
	P8: C8.3: I8.3.1-8.3.2 (FSC CHILE, 2012)	“CRITERION 8.3 Documentation shall be provided by the forest manager to enable monitoring and certifying organizations to trace each forest product from its origin, a process known as the “chain of custody.” (FSC CHILE, 2012, p. 75)
		8.3.1 “The FMP accredits by marks or documents the chain of custody control of timber to the point of sale.” (FSC CHILE, 2012, p. 75)
		8.3.2 “In the FMP the point of origin (site and stand) of timber and species involved and the type of product are registered appropriately in the invoice or bill of landing.” (FSC CHILE, 2012, p. 75)
Provisioning of NTFPs (e.g.: products of wild plants and animals, natural medicines, mushrooms) (Corvalan *et al*., 2005)	P5: C5.2: I5.2.1, I5.3.4,I5.2.5 (FSC CHILE, 2012)	“PRINCIPLE 5: Benefits from the forest (…)Forest management operations shall encourage the efficient use of the forest’s multiple products and services to ensure economic viability and a wide range of environmental and social benefits.” (FSC CHILE, 2012, p. 32)
		“CRITERION 5.2 Forest management and marketing operations should encourage the optimal use and local processing of the forest’s diversity of products.” (FSC CHILE, 2012, p. 34)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
PROVISIONING ES		
Provisioning of NTFPs (e.g.: products of wild plants and animals, natural medicines, mushrooms) (Corvalan *et al.*, 2005)	P5: C5.2: I5.2.1, I5.3.4,I5.2.5 (FSC CHILE, 2012)	5.2.1 "The FMP considers the largest diversity possible of timber and non- timber products feasible to be produced, in the frame of the resource and markets conditions." (FSC CHILE, 2012, p. 34)
		5.2.4 "Support actions to local processing of forest products are developed in the FMP." (FSC CHILE, 2012, p. 35)
		5.2.5 "The FMP must allow to neighbouring communities to profit harvest residues and other forest associated products, only if they do not interfere in the FMP productive activities based on agree mechanisms established by the parties." (FSC CHILE, 2012, p. 35)
	P5: C5.5: I5.5.1 (FSC CHILE, 2012)	"CRITERION 5.5 Forest management operations shall recognize, maintain, and, where appropriate, enhance the value of forest services and resources such as watersheds and fisheries." (FSC CHILE, 2012, p. 38)
		5.5.1 "The FMP implements measures, defined in the forestry management plan, directed to sustain or increase the forest functions such as: - Soil protection - Watershed protection (water quality) - Landscape - Other local values (biodiversity, cultural, etc.)." (FSC CHILE, 2012, p. 38)
	P5: C5.6: I5.6.1-I5.6.2 (FSC CHILE, 2012)	"CRITERION 5.6 The rate of harvest of forest products shall not exceed levels which can be permanently sustained." (FSC CHILE, 2012, p. 39)
		5.6.1 "In the FMP a long term planning exists making compatible the harvest rates with the reforestation rates with the intention to ensure periodic production flows." (FSC CHILE, 2012, p. 39)
		5.6.2 "In the FMP the expected harvest level is clearly justified in terms of an annual or periodic sustainable yield." (FSC CHILE, 2012, p. 39)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
PROVISIONING ES		
Provisioning of NTFPs (e.g.: products of wild plants and animals, natural medicines, mushrooms) (Corvalan *et al.*, 2005)	P8: C8.1: I8.2.1-8.2.2 (FSC CHILE, 2012)	"PRINCIPLE 8: MONITORING AND ASSESSMENT (…)Monitoring shall be conducted—appropriate to the scale and intensity of forest management—to assess the condition of the forest, yields of forest products, chain of custody, management activities and their social and environmental impacts." (FSC CHILE, 2012, p. 71)
		"CRITERION 8.1 The frequency and intensity of monitoring should be determined by the scale and intensity of forest management operations as well as the relative complexity and fragility of the affected environment. Monitoring procedures should be consistent and replicable over time to allow comparison of results and assessment of change." (FSC CHILE, 2012, p. 71)
		8.1.1 "The FMP has a monitoring and evaluation system of the Forestry Plan including social and environmental aspects in relation with the project scale and characteristics." (FSC CHILE, 2012, p. 71)
		"CRITERION 8.2 Forest management should include the research and data collection needed to monitor, at a minimum, the following indicators: a) Yield of all forest products harvested. b) Growth rates, regeneration and condition of the forest. c) Composition and observed changes in the flora and fauna. d) Environmental and social impacts of harvesting and other operations. e) Costs, productivity, and efficiency of forest management." (FSC CHILE, 2012, p. 72)
		8.2.1 "In the FMP there is a record of all the forest timber products and written information of the non-timber products harvested in the site." (FSC CHILE, 2012, p. 72)
		8.2.2 "The FMP has a detailed control of the production." (FSC CHILE, 2012, p. 72)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
PROVISIONING ES		
Production of agricultural products (fish, crops, livestock) (Corvalan *et al.*, 2005)	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	"PRINCIPLE 3: Indigenous peoples' Rights (…)The legal and customary rights of indigenous peoples to own, use and manage their lands, territories, and resources shall be recognized and respected." (FSC CHILE, 2012, p. 14)
		"CRITERION 3.2 Forest management shall not threaten or diminish, either directly or indirectly, the resources or tenure rights of indigenous peoples." (FSC CHILE, 2012, p. 17)
		3.2.2 "Any damage from the FMP to indigenous resources and their lands, such as water, wildlife, and others, are evaluated, compensated and restored in common agreement with the community itself and in a document signed by both parties." (FSC CHILE, 2012, p. 17)
	P5: C5.5: I5.5.1 (FSC CHILE, 2012)	"PRINCIPLE 5: Benefits from the forest (…)Forest management operations shall encourage the efficient use of the forest's multiple products and services to ensure economic viability and a wide range of environmental and social benefits." (FSC CHILE, 2012, p. 32)
		"CRITERION 5.5 Forest management operations shall recognize, maintain, and, where appropriate, enhance the value of forest services and resources such as watersheds and fisheries." (FSC CHILE, 2012, p. 38)
		5.5.1 "The FMP implements measures, defined in the forestry management plan, directed to sustain or increase the forest functions such as: - Soil protection - Watershed protection (water quality) - Landscape - Other local values (biodiversity, cultural, etc.)." (FSC CHILE, 2012, p. 38)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
PROVISIONING ES		
Production of agricultural products (fish, crops, livestock) (Corvalan *et al.*, 2005)	P6: C6.3: I6.3.1 (FSC CHILE, 2012)	"PRINCIPLE 6: ENVIRONMENTAL IMPACT (…) Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest." (FSC CHILE, 2012, p. 40)
		"CRITERIO 6.3 Ecological functions and values shall be maintained intact, enhanced, or restored, including: a) Forest regeneration and succession. b) Genetic, species, and ecosystem diversity. c) Natural cycles that affect the productivity of the forest ecosystem." (FSC CHILE, 2012, p. 45)
		6.3.1: "In the FMP the areas under regeneration (natural, sowing, plantation) are protected against browsing by cattle or other herbivores." (FSC CHILE, 2012, p. 45)
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	"PRINCIPLE 10 PLANTATIONS (…) Plantations shall be planned and managed in accordance with Principles and Criteria 1 - 9, and Principle 10 and its Criteria. While plantations can provide an array of social and economic benefits, and can contribute to satisfying the world's needs for forest products, they should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests." (FSC CHILE, 2012, p. 83)
		"CRITERIO 10.8 Appropriate to the scale and diversity of the operation, monitoring of plantations shall include regular assessment of potential on-site and off-site ecological and social impacts, (e.g. natural regeneration, effects on water resources and soil fertility, and impacts on local welfare and social well-being), in addition to those elements addressed in principles 8, 6 and 4. No species should be planted on a large scale until local trials and/or experience have shown that they are ecologically well-adapted to the site, are not invasive, and do not have significant negative ecological impacts on other ecosystems. Special attention will be paid to social issues of land acquisition for plantations, especially the protection of local rights of ownership, use or access." (FSC CHILE, 2012, p. 97)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
PROVISIONING ES		
Production of agricultural products (fish, crops, livestock) (Corvalan *et al.*, 2005)	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	10.8.1: "In the FMP there is a monitoring and evaluation system of the Forestry Plan including social and environmental aspects according to the project scale and characteristics." (FSC CHILE, 2012, p. 97)
		10.8.2 "The FMP does not apply undue pressure to implement its policy concerning the purchase of lands." (FSC CHILE, 2012, p. 98)
Genetic resources (Corvalan *et al.*, 2005)	P1: C1.3: I1.3.1 (FSC CHILE, 2012)	"PRINCIPLE 1: Compliance with laws and FSC Principles (…) Forest management shall respect all applicable laws of the country in which they occur, and international treaties and agreements to which the country is a signatory, and comply with all FSC Principles and Criteria." (FSC CHILE, 2012, p. 2)
		"CRITERION 1.3 In signatory countries, the provisions of all binding international agreements such as CITES, ILO Conventions, ITTA, and Convention on Biological Diversity, shall be respected." (FSC CHILE, 2012, p. 5)
		1.3.1. "In the FMP there are internal procedures to fulfil the international agreement tools endorsed by the country, applicable to the nature of the project being developed." (FSC CHILE, 2012, p. 5)
	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	"PRINCIPLE 3: Indigenous peoples' Rights (…)The legal and customary rights of indigenous peoples to own, use and manage their lands, territories, and resources shall be recognized and respected." (FSC CHILE, 2012, p. 14)
		"CRITERION 3.2: Forest management shall not threaten or diminish, either directly or indirectly, the resources or tenure rights of indigenous peoples." (FSC CHILE, 2012, p. 17)
		3.2.2 "Any damage from the FMP to indigenous resources and their lands, such as water, wildlife, and others, are evaluated, compensated and restored in common agreement with the community itself and in a document signed by both parties." (FSC CHILE, 2012, p. 17)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	Standards	Description
Genetic resources (Corvalan *et al.*, 2005)	P5: C5.5: I5.5.1 (FSC CHILE, 2012)	"PRINCIPLE 5: Benefits from the forest (…)Forest management operations shall encourage the efficient use of the forest's multiple products and services to ensure economic viability and a wide range of environmental and social benefits." (FSC CHILE, 2012, p. 32)
		"CRITERION 5.5 Forest management operations shall recognize, maintain, and, where appropriate, enhance the value of forest services and resources such as watersheds and fisheries." (FSC CHILE, 2012, p. 38)
		5.5.1 "The FMP implements measures, defined in the forestry management plan, directed to sustain or increase the forest functions such as: - Soil protection - Watershed protection (water quality) - Landscape - Other local values (biodiversity, cultural, etc.)." (FSC CHILE, 2012, p. 38)
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	"PRINCIPLE 6: ENVIRONMENTAL IMPACT (…) Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest." (FSC CHILE, 2012, p. 40)
		"CRITERION 6.1 Assessment of environmental impacts shall be completed—appropriate to the scale, intensity of forest management and the uniqueness of the affected resources—and adequately integrated into management systems. Assessments shall include landscape level considerations as well as the impacts of on-site processing facilities. Environmental impacts shall be assessed prior to commencement of site-disturbing operations." (FSC CHILE, 2012, p. 40)
		6.1.1 "In the FMP there is an environmental impact assessment study according with the magnitude of the PMF. This assessment must be participative." (FSC CHILE, 2012, p. 40)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
Genetic resources (Corvalan *et al.*, 2005)	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	6.1.2 "In the FMP the prevention, mitigation and repair measures established in the environmental impact assessment study are implemented." (FSC CHILE, 2012, p. 41)
	P6: C6.2: I6.2.1-I6.2.9 (FSC CHILE, 2012)	"CRITERIO 6.2 Safeguards shall exist which protect rare, threatened and endangered species and their habitats (e.g., nesting and feeding areas). Conservation zones and protection areas shall be established, appropriate to the scale and intensity of forest management and the uniqueness of the affected resources. Inappropriate hunting, fishing, trapping and collecting shall be controlled." (FSC CHILE, 2012, p. 42)
		6.2.1 "In the FMP the species with existing problems of conservation in the management area included in the Flora and Fauna of Chile Red Books are known, as well as their updates and pertinent official lists, which are properly, identified in the management plan maps." (FSC CHILE, 2012, p. 42)
		6.2.2 "In the FMP the areas where these species are detected are preserved or conserved according to a plan that considers the situation of the species in particular at regional level." (FSC CHILE, 2012, p. 42)
		6.2.3 "In the FMP all the permanent and nonpermanent water courses with defined streambeds are protected and maintained with wooded cover preferably and native if possible." (FSC CHILE, 2012, p. 43)
		6.2.4 "In the FMP the Natural Monuments existing in the patrimony are conserved." (FSC CHILE, 2012, p. 43)
		6.2.5 "In the FMP a buffer zone of native vegetation or at least of plantations is established around wetlands (such as: peat bogs, flooded meadows and marshes) and his ecotone, in agreement with parameters indicated in the management plan and are evaluated in the monitoring plan." (FSC CHILE, 2012, p. 43)
		6.2.6 "In the FMP the protection forests of ravines or water courses will also serve as "Fauna corridors" or biological corridors and new corridors are designed through intervened areas connecting different forests." (FSC CHILE, 2012, p. 44)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
Genetic resources (Corvalan *et al.*, 2005)	P6: C6.2: I6.2.1-I6.2.9 (FSC CHILE, 2012)	6.2.7 "In the FMP at least 10% of the forest areas are kept as protection or conservation zones, identified in the cartography, with the purpose to contribute to biodiversity." (FSC CHILE, 2012, p. 44)
		6.2.8 "The FMP denounces illegal tree harvest, hunting or fishing actions to the competent authorities." (FSC CHILE, 2012, p. 44)
		6.2.9 "The FMP distributes posters or other promotional/broadcasting public information materials about the protected species by law, between their contractors and local community." (FSC CHILE, 2012, p. 45)
	P6: C6.3: I6.3.1 (FSC CHILE, 2012)	"CRITERIO 6.3 Ecological functions and values shall be maintained intact, enhanced, or restored, including: a) Forest regeneration and succession. b) Genetic, species, and ecosystem diversity. c) Natural cycles that affect the productivity of the forest ecosystem." (FSC CHILE, 2012, p. 45)
		6.3.1: "In the FMP the areas under regeneration (natural, sowing, plantation) are protected against browsing by cattle or other herbivores." (FSC CHILE, 2012, p. 45)
	P6: C6.9: I6.9.1-6.9.2 (FSC CHILE, 2012)	"PRINCIPLE 6: ENVIRONMENTAL IMPACT (…) Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest." (FSC CHILE, 2012, p. 40)
		"CRITERION 6.9 The use of exotic species shall be carefully controlled and actively monitored to avoid adverse ecological impacts." (FSC CHILE, 2012, p. 60)
		6.9.1 "In the FMP there is a plan to control the exotic species invasion used in the plantation, to adjacent areas." (FSC CHILE, 2012, p. 60)
		6.9.2 "In the FMP there are studies to evaluate the invading potential of new exotic species to be introduced in the FMP." (FSC CHILE, 2012, p. 60)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	Standards	Description
Genetic resources (Corvalan *et al.*, 2005)	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	“PRINCIPLE 9: MAINTENANCE OF HIGH CONSERVATION VALUE FORESTS (…) Management activities in high conservation value forests shall maintain or enhance the attributes which define such forests. Decisions regarding high conservation value forests shall always be considered in the context of a precautionary approach.” (FSC CHILE, 2012, p. 78)
		“CRITERION 9.1 Assessment to determine the presence of the attributes consistent with High Conservation Value Forests will be completed, appropriate to scale and intensity of forest management.” (FSC CHILE, 2012, p. 78)
		9.1.1 “The FMP has a procedure to define the High Conservation Value Forests (HCVF) based on the national, regional and local criteria.” (FSC CHILE, 2012, p. 78)
		9.1.2 “In the FMP the High Conservation Value Forests following the criteria defined at national are identified, characterized and are mapped e incorporated in the Forestry Plan.” (FSC CHILE, 2012, p. 79)
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	“CRITERIO 9.2 The consultative portion of the certification process must place emphasis on the identified conservation attributes, and options for the maintenance thereof.” (FSC CHILE, 2012, p. 79)
		9.2.1 “On the base of the criteria defined at national level, the FMP consults with experts and the local communities if the forestry operations disturb these areas and/ or there are new areas to be considered which have not been identified.” (FSC CHILE, 2012, p. 79)
		9.2.2 “The adjacent community to the Project has been adequately informed, by the FMP, of the High Conservation Value Forests. Existence unless this implies a risk of damages to the HCVF attributes to be protected.” .(FSC CHILE, 2012, p. 80)
		9.2.3 “The Forestry Plan public summary of FMP shows the location and extent of the HCVF, as well as the planned and applied measures in them, unless it is identified a risk of damage to the HCVF attributes to be protected.” (FSC CHILE, 2012, p. 80)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
Genetic resources (Corvalan *et al.*, 2005)	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	“CRITERION 9.3 The management plan shall include and implement specific measures that ensure the maintenance and/or enhancement of the applicable conservation attributes consistent with the precautionary approach. These measures shall be specifically included in the publicly available management plan summary.” (FSC CHILE, 2012, p. 81)
		9.3.1 “In the FMP are implemented measures for the maintenance or increase of the HCVF attributes and they are incorporated to the Forestry Plan and its public summary. These measures are registered.” (FSC CHILE, 2012, p. 81)
		9.3.2 “The persons responsible for the forest management and the workers locate the High Conservation Value Forests of the FMP and know the management to be applied to them.” (FSC CHILE, 2012, p. 81)
	P9: C9.4: C9.4.1-9.1.2 (FSC CHILE, 2012)	“CRITERION 9.4 Annual monitoring shall be conducted to assess the effectiveness of the measures employed to maintain or enhance the applicable conservation attributes.” (FSC CHILE, 2012, p. 82)
		9.4.1 “The monitoring plan of the FMP includes the HCVF and it is executed at least once a year.” (FSC CHILE, 2012, p. 82)
		9.4.2 “In the FMP there is a public summary with the HCVF monitoring results.” (FSC CHILE, 2012, p. 82)
	P10: C10.3: I10.3.3 (FSC CHILE, 2012)	“PRINCIPLE 10 PLANTATIONS (…) Plantations shall be planned and managed in accordance with Principles and Criteria 1 - 9, and Principle 10 and its Criteria. While plantations can provide an array of social and economic benefits, and can contribute to satisfying the world’s needs for forest products, they should complement the management of, reduce pressures on, and promote the restoration and conservation of natural forests.” (FSC CHILE, 2012, p. 83)
		“CRITERION 10.3 Diversity in the composition of plantations is preferred, so as to enhance economic, ecological and social stability. Such diversity may include the size and spatial distribution of management units within the landscape, number and genetic composition of species, age classes and structures.” (FSC CHILE, 2012, p. 88)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	Standards	Description
Genetic resources (Corvalan *et al.*, 2005)	P10: C10.3: I10.3.3 ((FSC CHILE, 2012)	10.3.3 “In the FMP diverse adapted provenances and/or genotypes are used as plant material.” (FSC CHILE, 2012, p. 88)
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	“CRITERIO 10.8 Appropriate to the scale and diversity of the operation, monitoring of plantations shall include regular assessment of potential on-site and off-site ecological and social impacts, (e.g. natural regeneration, effects on water resources and soil fertility, and impacts on local welfare and social well-being), in addition to those elements addressed in principles 8, 6 and 4. No species should be planted on a large scale until local trials and/or experience have shown that they are ecologically well-adapted to the site, are not invasive, and do not have significant negative ecological impacts on other ecosystems. Special attention will be paid to social issues of land acquisition for plantations, especially the protection of local rights of ownership, use or access.” (FSC CHILE, 2012, p. 97)
		10.8.1: “In the FMP there is a monitoring and evaluation system of the Forestry Plan including social and environmental aspects according to the project scale and characteristics.” (FSC CHILE, 2012, p. 97)
		10.8.2 “The FMP does not apply undue pressure to implement its policy concerning the purchase of lands.” (FSC CHILE, 2012, p. 98)
Biochemicals, natural medicines, nutraceuticals and pharmaceutical products (Corvalan *et al.*, 2005)	P1: C1.3: I1.3.1 (FSC CHILE, 2012)	SEE ABOVE
	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.6: I5.6.1-I5.6. (FSC CHILE, 2012)	SEE ABOVE

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
Biochemicals, natural medicines, nutraceuticals and pharmaceutical products (Corvalan *et al*., 2005)	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Ornamental resources (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.6: I5.6.1-I5.6.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Fresh water supply (Corvalan *et al*., 2005)	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.6: I5.6.1-I5.6.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.6: I6.6.1-I6.6.8 (FSC CHILE, 2012)	“PRINCIPLE 6: ENVIRONMENTAL IMPACT (…) Forest management shall conserve biological diversity and its associated values, water resources, soils, and unique and fragile ecosystems and landscapes, and, by so doing, maintain the ecological functions and the integrity of the forest.” (FSC CHILE, 2012, p. 40)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	Standards	Description
Fresh water supply (Corvalan *et al.*, 2005)	P6: C6.6: I6.6.1-I6.6.8 (FSC CHILE, 2012)	"CRITERION 6.6 Management systems shall promote the development and adoption of environmentally friendly non-chemical methods of pest management and strive to avoid the use of chemical pesticides. World Health Organization Type 1A and 1B and chlorinated hydrocarbon pesticides; pesticides that are persistent, toxic or whose derivatives remain biologically active and accumulate in the food chain beyond their intended use; as well as any pesticides banned by international agreement, shall be prohibited. If chemicals are used, proper equipment and training shall be provided to minimize health and environmental risks." (FSC CHILE, 2012, p. 54)
		6.6.1 "In the FMP chemical pesticides 1a and 1B and those prohibited by FSC are not used." (FSC CHILE, 2012, p. 54)
		6.6.2 "In the FMP the justification to use chemical products permitted by FSC has considered the documented analysis of the viability of nonchemical alternatives." (FSC CHILE, 2012, p. 54)
		6.6.3 "In the FMP all the chemical products applications are documented in their stages, activities and products." (FSC CHILE, 2012, p. 55)
		6.6.4 "In the FMP previous to the application of chemical products, all workers taking part in their manipulation become trained indicating them the risks of its work, the preventive measures and the right method to work." (FSC CHILE, 2012, p. 55)
		6.6.5 "The FMP gives a written guideline to the workers who manipulate chemical products about the correct method of application and accident prevention." (FSC CHILE, 2012, p. 55)
		6.6.6 "The FMP has a registry of all the training events related to chemical products." (FSC CHILE, 2012, p. 55)
		6.6.7 "In the FMP there is a registry of the periodic maintenance of the equipment used in the application of chemical products." (FSC CHILE, 2012, p. 56)
		6.6.8 "In the FMP there is a procedure for handling dangerous substances." FSC CHILE, 2012, p. 56)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
Fresh water supply (Corvalan *et al.*, 2005)	P6: C6.7: I6.7.1-I6.7.4 (FSC CHILE, 2012)	"CRITERION 6.7 Chemicals, containers, liquid and solid non-organic wastes including fuel and oil shall be disposed of in an environmentally appropriate manner at off-site locations." (FSC CHILE, 2012, p. 57)
		6.7.1 "In the FMP there is a specific area, out of the working site, to deposit domestic residues, chemical, containers, liquids, organic solids and in an environmentally adequate form in agreement with the law, in special with the D.S. 594. There are not evidences of residues in places different to those specified." (FSC CHILE, 2012, p. 57)
		6.7.2 "In the FMP the final elimination of chemical product containers is made by making them innocuous or by recycling them. Previous to the final elimination, a triple washing is made and the water is re- used in the application area." (FSC CHILE, 2012, p. 57)
		6.7.3 "In the FMP there is an emergency procedure to solve situations originated from spills, chemical manipulation, residues and other dangerous substances that affect the environment and people." (FSC CHILE, 2012, p. 58)
		6.7.4 "In the FMP the camp garbage and other residues are placed in distinct and appropriate places as such, out of the work place, out of water courses or its area of influence, in agreement with a manual available for such practice." (FSC CHILE, 2012, p. 58)
	P6: C6.8: I6.8.1-I6.8.2 (FSC CHILE, 2012)	"CRITERION 6.8 Use of biological control agents shall be documented, minimized, monitored and strictly controlled in accordance with national laws and internationally accepted scientific protocols. Use of genetically modified organisms shall be prohibited." (FSC CHILE, 2012, p. 59)
		6.8.1 "In the FMP the disease management and control considers the biological control according to the legal norms established." (FSC CHILE, 2012, p. 59)
		6.8.2 "The FMP demonstrates that there are not genetically modified organisms in the plantations or in adjacent areas that belong to the same landowner." (FSC CHILE, 2012, p. 59)

Table C.1 continued: Provisioning Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
Fresh water supply (Corvalan *et al.*, 2005)	P8: C8.2: I8.2.5 (FSC CHILE, 2012)	“CRITERION 8.2 Forest management should include the research and data collection needed to monitor, at a minimum, the following indicators: a) Yield of all forest products harvested. b) Growth rates, regeneration and condition of the forest. c) Composition and observed changes in the flora and fauna. d) Environmental and social impacts of harvesting and other operations. e) Costs, productivity, and efficiency of forest management.” (FSC CHILE, 2012, p. 72)
		8.2.5 “In the FMP there is a documented monitoring of the impacts on soil and water associated to the forestry operations.” (FSC CHILE, 2012, p. 74)
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE

Table C.2: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Soil conservation and erosion regulation (Corvalan *et al.*, 2005)	P5: C5.5: I5.5.1 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Soil conservation and erosion regulation (Corvalan *et al*., 2005)	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	“CRITERION 6.5 Written guidelines shall be prepared and implemented to: control erosion; minimize forest damage during harvesting, road construction, and all other mechanical disturbances; and protect water resources.” (FSC CHILE, 2012, p. 49)
		6.5.1 “In the FMP there are technical procedures about the requirements to design and construct new roads to prevent or diminish their environmental impact.” (FSC CHILE, 2012, p. 49)
		6.5.2 “In the FMP there is a established, documented and implemented procedure to diminish the entry and impact of machineries to the site.” (FSC CHILE, 2012, p. 49)
		6.5.3 “In the FMP new roads planning identifies in a topographic map its layout and the existence of streams and rivers.” (FSC CHILE, 2012, p. 49)
		6.5.4 “In the FMP roads through HVCF are built only if there is a justification that demonstrates that other alternatives are not technically feasible.” (FSC CHILE, 2012, p. 50)
		6.5.5 “In the FMP roads are indicated on site previously to their construction.” (FSC CHILE, 2012, p. 50)
		6.5.6 “In the FMP roads do not show severe soil erosion evidence or if there is, this is under control.” (FSC CHILE, 2012, p. 50)
		6.5.7 “In the FMP the periodic road maintenance includes prevention of damages to adjacent areas.” (FSC CHILE, 2012, p. 50)
		6.5.8 “In the FMP there are evidences of a program and/or measures applied to control soil erosion.” (FSC CHILE, 2012, p. 51)

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Soil conservation and erosion regulation (Corvalan *et al*., 2005)	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	6.5.9 “In the FMP fire is not used a management tool, except for exceptions properly justified through an analysis of the technical and economic feasibility of options and preventive measures to avoid propagation, including the potential fires risk.” (FSC CHILE, 2012, p. 51)
		6.5.10 “In the FMP logging activities are not carried out on water saturated soil and there are winter forests in case of continuous operations. Logging operations are not made in periods of defrost (austral zone).” (FSC CHILE, 2012, p. 51)
		6.5.11 “In the FMP there are soil conservation and protection measures in eroded areas or with erosion risk.”).” (FSC CHILE, 2012, p. 52)
		6.5.12 “Soil alterations resulting from logging are corrected with impact mitigation measures, as established in the harvest procedure.” (FSC CHILE, 2012, p. 52)
		6.5.13 “In the FMP when harvesting land over 35% of slope logging is carried out only with animals, logging towers or other low impact alternatives.” (FSC CHILE, 2012, p. 52)
		6.5.14 “In the FMP the extraction roads are planned to diminish the negative environmental impacts and are indicated on sites in the field previously to the entrance of machinery.” (FSC CHILE, 2012, p. 53)
		6.5.15 “In the FMP the technical prescriptions related to harvest contracts with services companies contain clear guidelines to use of the resource and to guarantee the fulfilment of previous indicators.” (FSC CHILE, 2012, p. 53)
		6.5.16 “In the FMP there is a road , including its infrastructure, maintenance program and a guide.” (FSC CHILE, 2012, p. 53)
		6.5.17 “In the PMF area there are not evidences of water streams modification without a properly justified reason.” (FSC CHILE, 2012, p. 53)
	P6: C6.6: I6.6.1-I6.6.8 (FSC CHILE, 2012)	SEE ABOVE

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Soil conservation and erosion regulation (Corvalan *et al*., 2005)	P6: C6.7: I6.7.1-I6.7.4 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.8: I6.8.1-I6.8.2 (FSC CHILE, 2012)	SEE ABOVE
	P8: C8.2: I8.2.5 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	9.1.1 “The FMP has a procedure to define the High Conservation Value Forests (HCVF) based on the national, regional and local criteria.” (FSC CHILE, 2012, p. 78)
		9.1.2 “In the FMP the High Conservation Value Forests following the criteria defined at national are identified, characterized and are mapped e incorporated in the Forestry Plan.” (FSC CHILE, 2012, p. 79)
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.2: I10.2.7 (FSC CHILE, 2012)	“CRITERION 10.2 The design and layout of plantations should promote the protection, restoration and conservation of natural forests, and not increase pressures on natural forests. Wildlife corridors, streamside zones and a mosaic of stands of different ages and rotation periods, shall be used in the layout of the plantation, consistent with the scale of the operation. The scale and layout of plantation blocks shall be consistent with the patterns of forest stands found within the natural landscape.” (FSC CHILE, 2012, p. 84)

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	Standards	Description
SUPPORTING ES		
Soil conservation and erosion regulation (Corvalan *et al*., 2005)	P10: C10.2: I10.2.7(FSC CHILE, 2012)	10.2.7 "In the FMP the final harvests size and methods and the harvest regime are directed to diminish the impact on soil, water and the fragmentation of wildlife flora and fauna habitat." (FSC CHILE, 2012, p. 86)
	P10: C10.6: I10.6.1 (FSC CHILE, 2012)	"CRITERION 10.6 Measures shall be taken to maintain or improve soil structure, fertility, and biological activity. The techniques and rate of harvesting, road and trail construction and maintenance, and the choice of species shall not result in long term soil degradation or adverse impacts on water quality, quantity or substantial deviation from stream course drainage patterns." (FSC CHILE, 2012, p. 92)
		10.6.1 "The road characteristics are well established in the Forestry Plan or roads study." (FSC CHILE, 2012, p. 92)
	P10: C10.6: I10.6.2 (FSC CHILE, 2012)	"In the FMP there are not environmental alterations or soil erosion no controlled because of roads construction." (FSC CHILE, 2012, p. 92)
	P10: C10.6: I10.6.3 (FSC CHILE, 2012)	"In the FMP there is an applied procedure to trace the road on site previous to its construction." (FSC CHILE, 2012, p. 92)
	P10: C10.6: I10.6.5 (FSC CHILE, 2012)	"The FMP has a study including the current soils map, previous to planning of activities, road construction, site preparation and establishment." (FSC CHILE, 2012, p. 93)
	P10: C10.6: I10.6.6 (FSC CHILE, 2012)	"The FMP has a procedure to forbid machinery traffic on sectors with soils vulnerable to severe erosion; as well in water courses." (FSC CHILE, 2012, p. 93)
	P10: C10.6: I10.6.7 (FSC CHILE, 2012)	"In the FMP the worn out soils in landings, no longer used roads and forest roads are recuperated once the harvest is finished." (FSC CHILE, 2012, p. 93)
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Water cycle, and watershed protection (water regulation and purification) (Corvalan *et al*., 2005)	P3: C3.2: I3.2.2 FSC (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.6: I6.6.1-I6.6.8 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.7: I6.7.1-I6.7.4 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.8: I6.8.1-I6.8.2 (FSC CHILE, 2012)	SEE ABOVE
	P8: C8.2: I8.2.5 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.2: I10.2.7 ((FSC CHILE, 2012)	SEE ABOVE
	P10: C10.6: I10.6.4 (FSC CHILE, 2012)	"In the FMP the permanent water courses are free of obstructions of harvest remains or landslides originated from roads." (FSC CHILE, 2012, p. 93)
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Nutrient cycle (Corvalan *et al*., 2005)	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.3: I5.3.1-I5.3.2 (FSC CHILE, 2012)	SEE ABOVE

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Nutrient cycle (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.6: I6.6.1-I6.6.8 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.7: I6.7.1-I6.7.4 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.8: I6.8.1-I6.8.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.2: I10.2.7 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.6: I10.6.4 (FSC CHILE, 2012)	SEE ABOVE
Seed dispersal (Nasi *et al.*, 2002; Brown *et al.*, 2007; FSC, 2017)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Maintenance of habitats for plants and animals (Nasi *et al.*, 2002; Brown *et al.*, 2007; FSC, 2017)	P1: C1.3: I1.3.1 (FSC Chile, 2012)	SEE ABOVE
	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.2: I6.2.1-I6.2.9 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 ((FSC CHILE, 2012)	SEE ABOVE

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Maintenance of habitats for plants and animals (Nasi *et al.*, 2002; Brown *et al.*, 2007; FSC, 2017)	P6: C6.4: I6.4.1 (FSC CHILE, 2012)	“CRITERION 6.4 Representative samples of existing ecosystems within the landscape shall be protected in their natural state and recorded on maps, appropriate to the scale and intensity of operations and the uniqueness of the affected resources.” (FSC CHILE, 2012, p. 47)
		6.4.1 “In the FMP natural vegetation areas are retained or recuperated as wildlife habitats and/or biological corridors and/or productive management purposes.” (FSC CHILE, 2012, p. 47)
	P6: C6.10: I6.10.1-I6.10.2 (FSC CHILE, 2012)	“CRITERION 6.10 Forest conversion to plantations or non-forest land uses shall not occur, except in circumstances where conversion: a) entails a very limited portion of the forest management unit; and b) does not occur on high conservation value forest areas; and c) will enable clear, substantial, additional, secure, long term conservation benefits across the forest management unit.” (FSC CHILE, 2012, p. 61)
	P6: C6.10: I6.10.1-I6.10.2 (FSC CHILE, 2012)	6.10.1 “The FMP has procedures to change the land use in agreement with the requirements established in letters “A”, “B” and “C” of the criterion.” (FSC CHILE, 2012, p. 61)
		6.10.2 “In the FMP forest conversions for farming purposes are exceptionally made in sites where the forestry management plan, and/or the commercial venture and the FMP income source, considers this aspect. When these are indispensables for the site management and are made in soils with no severe restrictions for this use, with an appropriate soil and culture management to the site conditions.” (FSC CHILE, 2012, p. 61)

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Maintenance of habitats for plants and animals (Nasi *et al.*, 2002; Brown *et al.*, 2007; FSC, 2017)	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.2: I10.2.2 (FSC CHILE, 2012)	“In the FMP plantations are planned in a way they do not disrupt the connectivity between wildlife flora and fauna habitats, especially at harvest time.” (FSC CHILE, 2012, p. 84)
	P10: C10.3: I10.3.1 (FSC CHILE, 2012)	“In the FMP the natural vegetation in protection and/or retention zones are kept and/or restaurated with the purpose to keep or improve diversity.” (FSC CHILE, 2012, p. 88)
	P10: C10.1: I10.1.1-10.1.2 (FSC CHILE, 2012)	“CRITERION 10.1 The management objectives of the plantation, including natural forest conservation and restoration objectives, shall be explicitly stated in the management plan, and clearly demonstrated in the implementation of the plan.” (FSC CHILE, 2012, p. 83)
		10.1.1 “The management purpose in the plantation Forestry Plan includes and aspects related to native forests conservation and restauration in the FMP.” (FSC CHILE, 2012, p. 83)
		10.1.2 “In the FMP there are evidences of the restauration and conservation of native forests.” (FSC CHILE, 2012, p. 83)

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	Standards	Description
SUPPORTING ES		
Maintenance of habitats for plants and animals (Nasi *et al.*, 2002; Brown *et al.*, 2007; FSC, 2017)	P10: C10.2: I10.2.3 (FSC CHILE, 2012)	“CRITERION 10.2 The design and layout of plantations should promote the protection, restoration and conservation of natural forests, and not increase pressures on natural forests. Wildlife corridors, streamside zones and a mosaic of stands of different ages and rotation periods, shall be used in the layout of the plantation, consistent with the scale of the operation. The scale and layout of plantation blocks shall be consistent with the patterns of forest stands found within the natural landscape.” (FSC CHILE, 2012, p. 84)
		10.2.3 “In the FMP there are degraded areas where recuperation activities or native forests restauration have carried out.” (FSC CHILE, 2012, p. 85)
	P10: C10.3: I10.3.1 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.4: I10.4.3 (FSC CHILE, 2012)	“CRITERION 10.4 The selection of species for planting shall be based on their overall suitability for the site and their appropriateness to the management objectives. In order to enhance the conservation of biological diversity, native species are preferred over exotic species in the establishment of plantations and the restoration of degraded ecosystems. Exotic species, which shall be used only when their performance is greater than that of native species, shall be carefully monitored to detect unusual mortality, disease, or insect outbreaks and adverse ecological impacts.” (FSC CHILE, 2012, p. 90)
		10.4.3 “The FMP includes restauration actions with natives species according to 10.2.3 and 10.3.1.” (FSC CHILE, 2012, p. 91)

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Maintenance of habitats for plants and animals (Nasi *et al.*, 2002; Brown *et al.*, 2007; FSC, 2017)	P10: C10.5: I10.5.1 (FSC CHILE, 2012)	“CRITERION 10.5 A proportion of the overall forest management area, appropriate to the scale of the plantation and to be determined in regional standards, shall be managed so as to restore the site to a natural forest cover.” (FSC CHILE, 2012, p. 91)
		10.5.1 “In the FMP, each site under management or in groups of sites nearby that share the eco-region, there is a native forest recuperated area or under restauration of a 10% minimum of the managed area, with an strategy that considers the increase of this surface to reach 15% when feasible, as it is clearly specified in the forestry plan.” (FSC CHILE, 2012, p. 91)
	P10: C10.9: I10.9.1-10.9.2 (FSC CHILE, 2012)	“CRITERION 10.9 Plantations established in areas converted from natural forests after November 1994 normally shall not qualify for certification. Certification may be allowed in circumstances where sufficient evidence is submitted to the certification body that the manager/owner is not responsible directly or indirectly of such conversion.” (FSC CHILE, 2012, p. 99)
		10.9.1 “In the FMP plantations are not established based on conversion of natural forests and its successional stages after November 1, 1994 (see 6.10 and 10.9). If this exists there must be clear evidence that the current landowner is not directly or indirectly involved with the substitution.” (FSC CHILE, 2012, p. 99)

Table C.2 continued: Supporting Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
SUPPORTING ES		
Maintenance of habitats for plants and animals (Nasi *et al.*, 2002; Brown *et al.*, 2007; FSC, 2017)	P10: C10.9: I10.9.1-10.9.2 (FSC CHILE, 2012)	10.9.2 "The FMP does not promote the native forest harvest in sites that are to be bought directly from landowners or through intermediaries." (FSC CHILE, 2012, p. 100)

Table C.3: Regulating Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Watershed protection (water regulation and purification) (Nasi *et al.*, 2002; Corvalan *et al.*, 2005; Brown *et al.*, 2007; FSC, 2017)	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.3: I5.3.1-I5.3.3 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.4: I6.4.2 (FSC CHILE, 2012)	"PMF identifies, in the Managements Plan s cartography , and protect, no wooded ecosystems presents in the area of the project, such as wetlands , marshes and peat bogs, as is mentioned in 6.2.5, and defined water streams as is mentioned in 6.2.3." (FSC CHILE, 2012, p. 47)

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Watershed protection (water regulation and purification) (Nasi *et al.*, 2002; Corvalan *et al.*, 2005; Brown *et al.*, 2007; FSC, 2017)	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.6: I6.6.1-I6.6.8 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.7: I6.7.1-I6.7.4 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.8: I6.8.1-I6.8.2 (FSC CHILE, 2012)	SEE ABOVE
	P8: C8.2: I8.2.5 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
Carbon capture and storage (Nasi *et al.*, 2002; Brown *et al.*, 2007; FSC, 2017)	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.10: I6.10.1-I6.10.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
	P8: C8.2: I8.2.5 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Climate regulation (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.3 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.10: I6.10.1-I6.10.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Biological control of forest and agricultural diseases and pests (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.8: I6.8.1-I6.8.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.4: I10.4.2 (FSC CHILE, 2012)	“In the FMP monitoring plan, an evaluation of the plantation phytosanitary condition is incorporated according to P 8.” (FSC CHILE, 2012, p. 90)

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Biological control of forest and agricultural diseases and pests (Corvalan *et al*., 2005)	P10: C10.7: I10.7.1 (FSC CHILE, 2012)	“CRITERION 10.7 Measures shall be taken to prevent and minimize outbreaks of pests, diseases, fire and invasive plant introductions. Integrated pest management shall form an essential part of the management plan, with primary reliance on prevention and biological control methods rather than chemical pesticides and fertilizers. Plantation management should make every effort to move away from chemical pesticides and fertilizers, including their use in nurseries. The use of chemicals is also covered in Criteria 6.6 and 6.7.” (FSC CHILE, 2012, p. 94)
		10.7.1 “In the FMP plantations are monitored to detect pest and diseases presence.” (FSC CHILE, 2012, p. 94)
	P10: C10.7: I10.7.2 (FSC CHILE, 2012)	“The FMP has a phytosanitary protection plan that includes detection and control measures adequate to the pest and diseases that attack plantations. The integrated pest control is preferred.” (FSC CHILE, 2012, p. 94)
	P10: C10.7: I10.7.3 (FSC CHILE, 2012)	“In the FMP the aerial fumigations are made when absolute necessary and are subject to a procedure manual clearly established that includes information for the community to prevent damaging the environment and people.” (FSC CHILE, 2012, p. 95)
	P10: C10.7: I10.7.4 (FSC CHILE, 2012)	“In the FMP the land fumigations are focused and are executed following strict procedures to prevent environmental, workers and communities damage.” (FSC CHILE, 2012, p. 95)
	P10: C10.7: I10.7.5 (FSC CHILE, 2012)	“In the FMP there is a fire prevention and control plan, detection and communication systems.” (FSC CHILE, 2012, p. 95)
	P10: C10.7: I10.7.6 (FSC CHILE, 2012)	“In the FMP there are measures taken against highly aggressive or invasive species.” (FSC CHILE, 2012, p. 96)

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Biological control of forest and agricultural diseases and pests (Corvalan *et al*., 2005)	P10: C10.7: I10.7.7 (FSC CHILE, 2012)	“In the FMP there is a periodical Monitoring Plan that includes in a detailed form the different steps, activities and products used in the control of pest and diseases in the nursery.”(FSC CHILE, 2012, p. 95) (FSC CHILE, 2012, p. 96)
	P10: C10.7: I10.7.8 (FSC CHILE, 2012)	“In the FMP a gradual policy is applied to replace and/or reduce use of permitted pesticides (including herbicides) by other control methods.”(FSC CHILE, 2012, p. 95) (FSC CHILE, 2012, p. 96)
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Pollination (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Regulation of natural risks (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2011)	SEE ABOVE

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Regulation of natural risks (Corvalan *et al*., 2005)	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Regulation of natural risks (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2011)	SEE ABOVE
	P8: C8.2: I8.2.3 (FSC CHILE, 2012)	“In the FMP there is an updated registry of natural negative effects and antropic damages.” (FSC CHILE, 2012, p. 73)
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Conservation of biodiversity (Nasi *et al*., 2002; Corvalan *et al*., 2005; Brown *et al*., 2007; FSC, 2017)	P1: C1.3: I1.3.1 (FSC CHILE, 2012)	SEE ABOVE
	P3: C3.2: I3.2.2 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.3 (FSC CHILE, 2012)	SEE ABOVE

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Conservation of biodiversity (Nasi *et al*., 2002; Corvalan *et al*., 2005; Brown *et al*., 2007; FSC, 2017)	P6: C6.2: I6.2.1-I6.2.9 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.9: I6.9.1-6.9.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.10: I6.10.1-I6.10.2 (FSC CHILE, 2012) (FSC CHILE, 2012)	SEE ABOVE
	P8: C8.2: I8.2.4 (FSC CHILE, 2012)	“In the FMP there is a documented monitoring of the forestry operations impact on the presence and abundance of flora and fauna species, with emphasis on those with conservation problems, previously identified.” (FSC CHILE, 2012, p. 74)
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.1: I10.1.1-10.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.2: I10.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.3: I10.3.1 (FSC CHILE, 2012)	SEE ABOVE

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Conservation of biodiversity (Nasi *et al*., 2002; Corvalan *et al*., 2005; Brown *et al*., 2007; FSC, 2017)	P10: C10.3: I10.3.2 (FSC CHILE, 2012)	“If the FMP has mixed plantations, these are made in agreement with local environmental and site conditions and the management objectives.” (FSC CHILE, 2012, p. 88)
	P10: C10.3: I10.3.3 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.3: I10.3.6 (FSC CHILE, 2012)	“The FMP includes considerations related to age diversification in the stands spatial arrangement and planning.” (FSC CHILE, 2012, p. 89)
	P10: C10.4: I10.4.1 (FSC CHILE, 2012)	“CRITERION 10.4 The selection of species for planting shall be based on their overall suitability for the site and their appropriateness to the management objectives. In order to enhance the conservation of biological diversity, native species are preferred over exotic species in the establishment of plantations and the restoration of degraded ecosystems. Exotic species, which shall be used only when their performance is greater than that of native species, shall be carefully monitored to detect unusual mortality, disease, or insect outbreaks and adverse ecological impacts.” (FSC CHILE, 2012, p. 90)
		10.4.1 “When FMP monitoring plan indicators, according to P 8, give site degradation evidences, a plantation or recuperation program with native species is implemented as a measure to contribute to reestablish the ecosystem integrity.” (FSC CHILE, 2012, p. 90)
	P10: C10.4: I10.4.3 (FSC CHILE, 2012)	SEE ABOVE

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Conservation of biodiversity (Nasi *et al*., 2002; Corvalan *et al*., 2005; Brown *et al*., 2007; FSC, 2017)	P10: C10.5: I10.5.1 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.9: I10.9.1-10.9.2 (FSC CHILE, 2012)	SEE ABOVE
Regulation of air quality (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.3 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Regulation of erosion (Corvalan *et al*., 2005)	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.3 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 ((FSC CHILE, 2012)	SEE ABOVE
	P8: C8.2: I8.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P8: C8.2: I8.2.5 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.2: I10.2.7 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.6: I10.6.1 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.6: I10.6.2 (FSC CHILE, 2012)	SEE ABOVE

Table C.3 continued: Regulating Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
REGULATING ES		
Regulation of erosion (Corvalan *et al*., 2005)	P10: C10.6: I10.6.3 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.6: I10.6.5 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.6: I10.6.6 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.6: I10.6.7 (FSC CHILE, 2012)	SEE ABOVE

Table C.4: Cultural Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
CULTURAL ES		
Ecotourism (cultural experience, experience in biodiversity, scenic beauty) (Corvalan *et al*., 2005)	P1: C1.3: I1.3.1 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.3 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.4: I6.4.1-I6.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.5: I6.5.1-I6.5.17 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.2: I10.2.1 (FSC CHILE, 2012)	“Plantation planning is made in agreement with landscape appearances and the distinctiveness of localities.” (FSC CHILE, 2012, p. 84)
	P10: C10.3: I10.3.1 (FSC CHILE, 2012)	SEE ABOVE

Table C.4 continued: Cultural Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
CULTURAL ES		
Ecotourism (cultural experience, experience in biodiversity, scenic beauty) (Corvalan *et al.*, 2005)	P10: C10.3: I10.3.4 (FSC CHILE, 2012)	“The FMP includes considerations related to landscape appearances according to indicator 10.2.1 in the plantation stands design and spatial planning.” (FSC CHILE, 2012, p. 89)
	P10: C10.3: I10.3.6 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Cultural diversity (Corvalan *et al.*, 2005)	P10: C10.3: I10.3.6 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
		2.2.1 “In the FMP there is an identification and communication system of the local communities land use rights. The corresponding areas are indicated in the map or design of the management plan.” .” (FSC CHILE, 2012, p. 10)
		2.2.2 “In the FMP the transference of rights to forests and its resources, by the local communities or farmers are in public or private written documents as it corresponds, and indicating clearly the type of operation the company will undertake, the rights and obligations being transferred, the time frame agreed by both parties and those rights kept by the communities or farmers.” (FSC CHILE, 2012, p. 11)
		2.2.3 “In the FMP there is a compensation for the use of resources transferred by contract to the company or the landowner (for example prices paid by volume or area).” (FSC CHILE, 2012, p. 11)
	P2: C2.2: I2.2.1-2.2.4 (FSC CHILE, 2012)	2.2.4 “The FMP responsibles allow access to traditional use of forests goods and services by local communities, based on common agreed norms.” (FSC CHILE, 2012, p. 11)
	P2: C2.3: I2.3.1-I2.3.6 (FSC CHILE, 2012)	“PRINCIPLE 2: Tenure and use rights and responsibilities (…) Long-term tenure and use rights to the land and forest resources shall be clearly defined, documented and legally established.” (FSC CHILE, 2012, p. 9)

Table C.4 continued: Cultural Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	Standards	Description
CULTURAL ES		
Cultural diversity (Corvalan *et al*., 2005)	P2: C2.3: I2.3.1-I2.3.6 (FSC CHILE, 2012)	“CRITERION 2.3 Appropriate mechanisms shall be employed to resolve disputes over tenure claims and use rights. The circumstances and status of any outstanding disputes will be explicitly considered in the certification evaluation. Disputes of substantial magnitude involving a significant number of interests will normally disqualify an operation from being certified.” (FSC CHILE, 2012, p. 12)
		2.3.1 “In the FMP there is evidence of relationships with the community based on principles of understanding, transparency and participation.” (FSC CHILE, 2012, p. 12)
		2.3.2 “The FMP has established participatory mechanisms on conflict resolution considering all pertinent interests and compensations in a given time frames.” (FSC CHILE, 2012, p. 12)
		2.3.3 “In case of land tenure conflicts, the FMP gives evidences that they are under a resolution process of legal disputes.” (FSC CHILE, 2012, p. 12)
		2.3.4 “The FMP has evidence that significant land use and tenure disputes have been considered by conflict resolutions mechanisms.” (FSC CHILE, 2012, p. 13)
		2.3.5 “In the FMP the contracts established between the company and the community considers a mediator or “negotiator arbitrator” agree by the parties.” (FSC CHILE, 2012, p. 13)

Table C.4 continued: Cultural Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
CULTURAL ES		
Cultural diversity (Corvalan *et al*., 2005)	P2: C2.3: I2.3.1-I2.3.6 (FSC CHILE, 2012)	2.3.5 “In the FMP the contracts established between the company and the community considers a mediator or “negotiator arbitrator” agree by the parties.” (FSC CHILE, 2012, p. 13)
		2.3.6 “In the FMP all land and use right claims are documented, with cartography and incorporated into the Management Forestry Plan (and/or Management Plan).” (FSC CHILE, 2012, p. 13)
	P3: C3.1: I3.1.6; C3.2: I3.2.1-3.2.2; C3.3: I3.3.1-3.3.2 (FSC CHILE, 2012)	“CRITERION 3.1 Indigenous peoples shall control forest management on their lands and territories unless they delegate control with free and informed consent to other agencies.” (FSC CHILE, 2012, p. 14)
		3.1.6 “The FMP report back to the community the monitoring and its results when a community allocates the forest management to them.” (FSC CHILE, 2012, p. 16)
		“CRITERION 3.2 Forest management shall not threaten or diminish, either directly or indirectly, the resources or tenure rights of indigenous peoples.” (FSC CHILE, 2012, p. 17)
		3.2.1 “In the FMP the areas under interventions neighboring indigenous land will require to be physically marked, before the forest operation, and with the community participation.” (FSC CHILE, 2012, p. 17)
		3.2.2 “Any damage from the FMP to indigenous resources and their lands, such as water, wildlife, and others, are evaluated, compensated and restored in common agreement with the community itself and in a document signed by both parties.” .” (FSC CHILE, 2012, p. 17)

Table C.4 continued: Cultural Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
CULTURAL ES		
Cultural diversity (Corvalan *et al*., 2005)	P3: C3.1: I3.1.6; C3.2: I3.2.1-3.2.2; C3.3: I3.3.1-3.3.2 (FSC CHILE, 2012)	“CRITERION 3.3 Sites of special cultural, ecological, economic or religious significance to indigenous peoples shall be clearly identified in cooperation with such peoples, and recognized and protected by forest managers.” (FSC CHILE, 2012, p. 18)
		3.3.1 “In the FMP Forestry Management Plan cartography, are identify the sites of archeological,religious,historical,eco-nomic importance or other cultural activities defined with the participation of the indigenous communities with the purpose to keep or improve the present conservation state of identified sites and warrant free access.” (FSC CHILE, 2012, p. 18)
		3.3.2 “In the FMP the identified sites in 3.3.1 are part of the High Conservation Value Areas.” (FSC CHILE, 2012, p. 18)
	P4: C4.4: I4.4.1-4.4.3 (FSC CHILE, 2012)	“PRINCIPLE 4: Community relations and worker’s rights (…) Forest management operations shall maintain or enhance the long-term social and economic well-being of forest workers and local communities.” (FSC CHILE, 2012, p. 20)
		“CRITERION 4.4 Management planning and operations shall incorporate the results of evaluations of social impact. Consultations shall be maintained with people and groups (both men and women) directly affected by management operations.” (FSC CHILE, 2012, p. 29)

Table C.4 continued: Cultural Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
CULTURAL ES		
Cultural diversity (Corvalan *et al*., 2005)	P4: C4.4: I4.4.1-4.4.3 (FSC CHILE, 2012)	4.4.1 “The FMP has a public participative system, to manage social impacts –positives and/or negatives- for local communities, resulting of the forest operations. The system includes: - Identification of potentially affected groups - Identification with participation of the operations practices causing social impact - Consulting mechanism with such groups, local communities and interested groups - Preventative measures, elimination, mitigation and/or compensation planned and implemented.” (FSC CHILE, 2012, p. 29)
		4.4.2 “In the FMP there is a list of local, regional or national interest groups and there are registries of periodical consultation regarding the impacts of the management operations.” (FSC CHILE, 2012, p. 30)
		4.4.3 “The FMP prepares pertinent personnel about the activity: “relations with the community strategy”.” (FSC CHILE, 2012, p. 30)
	P4: C4.5: I4.5.1-I4.5.3 (FSC CHILE, 2012)	“CRITERION 4.5 Appropriate mechanisms shall be employed for resolving grievances and for providing fair compensation in the case of loss or damage affecting the legal or customary rights, property, resources, or livelihoods of local peoples. Measures shall be taken to avoid such loss or damage.” (FSC CHILE, 2012, p. 31)
		4.5.1 “The FMP has established participatory conflict resolutions mechanisms that guarantee the consideration of all pertinent interests and considers adequate compensations.” (FSC CHILE, 2012, p. 31)

Table C.4 continued: Cultural Ecosystem services (ES), related national FSC standards and their description from 'indicators of the national FSC standards of plantations at large scale' (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
CULTURAL ES		
Cultural diversity (Corvalan *et al*., 2005)	P4: C4.5: I4.5.1-I4.5.3 (FSC CHILE, 2012)	4.5.2 "In the FMP there are prevention measures for potential damages that can affect the local population because of the forestry operations." (FSC CHILE, 2012, p. 31)
		4.5.3 "In the FMP are established the mechanisms to provide a compensation to the local population, when their legal or customary rights, of ownership, resources or the population's life have been damaged." (FSC CHILE, 2012, p. 32)
	P5: C5.2: I5.2.4-I.5.2.5 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE
Systems of traditional knowledge, inspiration and educational values (Corvalan *et al*., 2005)	P2: C2.2: I2.2.1-2.2.4 (FSC CHILE, 2012)	SEE ABOVE
	P2: C2.3: I2.3.1-I2.3.6 (FSC CHILE, 2012)	SEE ABOVE

Table C.4 continued: Cultural Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	**Standards**	**Description**
CULTURAL ES		
Systems of traditional knowledge, inspiration and educational values (Corvalan *et al*., 2005)	P3: C3.4: I3.4.1-3.4.2 (FSC CHILE, 2012)	“CRITERION 3.4 Indigenous peoples shall be compensated for the application of their traditional knowledge regarding the use of forest species or management systems in forest operations. This compensation shall be formally agreed upon with their free and informed consent before forest operations commence.” (FSC CHILE, 2012, p. 19)
		3.4.1 “In the FMP the traditional practices and knowledge which are being used or could be used with commercial purposes by the FMP are properly documented.” (FSC CHILE, 2012, p. 19)
		3.4.2 “The FMP compensate persons and /or indigenous communities that contribute with their knowledge to the management of a forest area, which is expressed through a written agreement before to the operations start- up.” (FSC CHILE, 2012, p. 19)
	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE

Table C.4 continued: Cultural Ecosystem services (ES), related national FSC standards and their description from ‘indicators of the national FSC standards of plantations at large scale’ (FSC CHILE, 2012); P=Principle, C=Criterion, I=Indicator

Ecosystem service	Standards	Description
CULTURAL ES		
Spiritual and religious values (Corvalan *et al*., 2005)	P2: C2.2: I2.2.1-2.2.4 (FSC CHILE, 2012)	SEE ABOVE
	P2: C2.3: I2.3.1-I2.3.6 ((FSC CHILE, 2012)	SEE ABOVE
	P3: C3.3: I3.3.1-3.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P5: C5.5: I5.5.1-5.5.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.1: I6.1.1-6.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P6: C6.3: I6.3.1-I6.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.1: C9.1.1-9.1.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.2: C9.2.1-9.2.3 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.3: C9.3.1-9.3.2 (FSC CHILE, 2012)	SEE ABOVE
	P9: C9.4: C9.4.1-9.4.2 (FSC CHILE, 2012)	SEE ABOVE
	P10: C10.8: I10.8.1-10.8.2 (FSC CHILE, 2012)	SEE ABOVE

D. InVEST model input descriptions, sources and processing methods

Table D.1: Annual Water Yield inputs, description, source and processing method

Input	Description	Source	Processing method
Workspace (required)	“Folder where model outputs will be written. Make sure that there is ample disk space, and write permissions are correct.” (Sharp *et al*., 2018b, p. 113)	/	/
Suffix (optional)	“Text string that will be appended to the end of output file names, as “_Suffix”. Use a Suffix to differentiate model runs, for example by providing a short name for each scenario. If a Suffix is not provided, or changed between model runs, the tool will overwrite previous results.” (Sharp *et al*., 2018b, p. 113)	/	/

Table D.1 continued: Annual Water Yield inputs, description, source and processing method

Input	Description	Source	Processing method
Precipitation (P) (required)	"GIS raster dataset with a non-zero value for average annual precipitation for each cell. [units: millimeters]" (Sharp *et al.*, 2018b, p. 113)	Satellite based precipitation rasters (Centro de Ciencia del Clima y la Resiliencia (CR)2, 2018a): 3B42v7 (TRMM Multi-Satellite Precipitation Analysis) (1998-2016, 0.25° latitude-longitude spatial resolution), CHIRPSv2 (Climate Hazards Group InfraRed Precipitation with Station data) (1981-2016, 0.05° latitude-longitude spatial resolution), MSWEPv11 (Multi-Source Weighted-Ensemble Precipitation) (1979-2014, 0.25° latitude-longitude spatial resolution), observation-based raster CR2MET (1979-2016, 0.05° latitude-longitude spatial resolution) (CR2, 2018b)	Calculation annual averages in QGIS, comparing different data sources. Finally, CHIRPSv2 was used for input, because of the relatively high resolution and having less no data values than CR2MET. Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6 and clipping to study area with a buffer of width the pixel width in QGIS.
Average Annual Reference Evapotranspiration (required)	"GIS raster dataset, with an annual average evapotranspiration value for each cell. Reference evapotranspiration is the potential loss of water from soil by both evaporation from the soil and transpiration by healthy alfalfa (or grass) if sufficient water is available. [units: millimetres]" (Sharp *et al.*, 2018b, p. 113)	(Trabucco & Zomer, 2009)	Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6 and clipping to study area with a buffer of width the pixel width in QGIS.

Table D.1 continued: Annual Water Yield inputs, description, source and processing method

Input	Description	Source	Processing method
Root restricting layer depth (required)	"GIS raster dataset with an average root restricting layer depth value for each cell. Root restricting layer depth is the soil depth at which root penetration is strongly inhibited because of physical or chemical characteristics. [units: millimetres]" (Sharp *et al*., 2018b, p. 113)	Depth to R horizon, 250 m spatial resolution (Hengl *et al*., 2017)	Multiplying by 10 to convert to mm (QGIS). Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6 and clipping to study area with a buffer of width the pixel width in QGIS.
Plant Available Water Content (PAWC) (required)	"A GIS raster dataset with a plant available water content value for each cell. Plant Available Water Content fraction (PAWC) is the fraction of water that can be stored in the soil profile that is available for plants' use. [fraction from 0 to 1]" (Sharp *et al*., 2018b, p. 113)	'WCavail': the "Available water content (between pF2 and pF4.2)" in m^3/m^3) (de Boer, 2016, p. 7) from the HiHydroSoil database version 1.2 (global, 1 km spatial resolution), obtained by contacting Gijs Simons (g.simons@futurewater.nl)	Dividing by 10,000 to obtain original values. Weighted average for topsoil by: (WCavailtopsoil*0.3)+ (WCavailsubsoil*0.7) (de Boer, 2016, p. 7) Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6 and clipping to study area with a buffer of width the pixel width in QGIS.
Land use/land cover (required)	"A GIS raster dataset, with an integer LULC code for each cell. These LULC codes must match *lucode* values in the Biophysical table." (Sharp *et al*., 2018, p. 114)	see section 3	See section 3

Table D.1 continued: Annual Water Yield inputs, description, source and processing method

Input	Description	Source	Processing method
Watersheds (required)	"A shapefile, with one polygon per watershed. This is a layer of watersheds such that each watershed contributes to a point of interest where hydropower production will be analysed. An integer field named *ws_id* is required, with a unique integer value for each watershed." ." (Sharp *et al*., 2018, p. 114)	Shapefile with national watersheds (Dirección General de Aguas, 2017a) and subwatersheds including area and name (m^2) (Ministerio de obras Publicas, 2017)	Watersheds intersecting with the study area were too large to analyse. Therefore, subwatersheds intersecting with the study area were used for this input. Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6
Subwatersheds (required)	"A shapefile, with one polygon per subwatershed within the main watersheds specified in the Watersheds shapefile. An integer field named *subws_id* is required, with a unique integer value for each subwatershed." (Sharp *et al*., 2018, p. 114)	Shapefile with national subsubwatersheds including area and name (m2) (Dirección General de Aguas, 2017b)	Because of the above-mentioned reason, subsub-watersheds intersecting with the study area were used for this input. Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6
Biophysical Table (required)	"A .csv (Comma Separated Value) table containing model information corresponding to each of the land use classes in the LULC raster. *All LULC classes in the LULC raster MUST have corresponding values in this table.* Each row is a land use/land cover class and columns must be named and defined as follows:" ." (Sharp *et al*., 2018, p. 114)	Scientific literature-based values, Table F.1	Created in Microsoft Excel and converted to a .csv file.

Table D.1 continued: Annual Water Yield inputs, description, source and processing method

Input	Description	Source	Processing method
lucode (required)	“Unique integer for each LULC class (e.g., 1 for forest, 3 for grassland, etc.) Every value in the LULC map MUST have a corresponding lucode value in the biophysical table.” (Sharp *et al.*, 2018, p. 114)	Codes of Table 3.3 were used, see Table F.1	
LULC_desc (optional)	“Descriptive name of land use/land cover class.” .” (Sharp *et al.*, 2018, p. 114)	See Table F.1	
LULC_veg (required)	“Specifies which AET equation to use (Eq. 1 or 2). Values must be 1 for vegetated land use except wetlands, and 0 for all other land uses, including wetlands, urban, water bodies, etc.” (Sharp *et al.*, 2018, p. 114)		
root_depth **(required)**	“The maximum root depth for vegetated land use classes, given in integer millimetres. This is often given as the depth at which 95% of a vegetation type’s root biomass occurs. For land uses where the generic Budyko curve is not used (i.e. where evapotranspiration is calculated from Eq. 2), rooting depth is not needed. In these cases, the rooting depth field is ignored, and may be set as a value such as -1 to indicate the field is not used.” .” (Sharp *et al.*, 2018, p. 114)	Scientific literature-based values see Table F.1	
Kc (required)	“Plant evapotranspiration coefficient for each LULC class, used to calculate potential evapotranspiration by using plant physiological characteristics to modify the reference evapotranspiration, which is based on alfalfa. The evapotranspiration coefficient is a decimal in the range of 0 to 1.5 (some crops evapotranspire more than alfalfa in some very wet tropical regions and where water is always available).” .” (Sharp *et al.*, 2018, p. 114)	Scientific literature-based values see Table F.1	

Table D.1 continued: Annual Water Yield inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
Z parameter (required)	"Floating point value on the order of 1 to 30 corresponding to the seasonal distribution of precipitation (see the Appendix for more information)." ." (Sharp *et al*., 2018, p. 114)	Formula: $Z=((\omega-1.25)P)/AWC$ with AWC=Minimum(Root restricting layer depth,,root_depth)*PAWC (Sharp *et al*., 2018b, p. 122) with $\omega=2.6$ (Choudhury, 1999; Donohue *et al*., 2012; Xu *et al.*, 2013) AWC the average Available Water Capacity and P the average annual precipitation (Sharp *et al*., 2018b, p. 122) or the subwatershed. Average z over all subwatersheds was 3.03536963.	
***lucode* (required)**	"Unique integer for each LULC class (e.g., 1 for forest, 3 for grassland, etc.), must match the LULC raster above." ." (Sharp *et al*., 2018, p. 114)	Codes of Table 3.3	
demand (required):	"The estimated average consumptive water use for each landuse/landcover type. Demand must be given in cubic meters per year per pixel in the land use/land cover map. Note that accounting for pixel area is important since larger pixels will consume more water for the same land cover type." ." (Sharp *et al*., 2018, p. 114)	Excel document with coordinates associated with registered water use rights (flow rates in l/s) for the Araucanía and Bío Bío regions (Dirección General de Aguas, 2018) Excel files were imported as .csv in ArcMap. Coordinates were reprojected to WGS 84 UTM zone 18S [EPSG:32718]. Next, consumptive water use points were selected (excluding drinking water consumption where possible) and average flow rates were calculated for each land cover class (Table F.4)	

Table D.2: Sediment Delivery Ratio model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
Workspace (required)	“Folder where model outputs will be written. Make sure that there is ample disk space, and write permissions are correct.” (Sharp *et al*., 2018, p. 146)	/	/
Suffix (optional)	“Text string that will be appended to the end of output file names, as “_Suffix”. Use a Suffix to differentiate model runs, for example by providing a short name for each scenario. If a Suffix is not provided, or changed between model runs, the tool will overwrite previous results.” (Sharp *et al*., 2018, p. 146)	/	/
Digital Elevation Model (DEM) (required)	“Raster dataset with an elevation value for each cell. Make sure the DEM is corrected by filling in sinks, and compare the output stream maps with hydrographic maps of the area. To ensure proper flow routing, the DEM should extend beyond the watersheds of interest, rather than being clipped to the watershed edge. [units: meters].” (Sharp *et al*., 2018, p. 146)	ASTER Global Digital Elevation Model Version 2 (1 arc second pixel size, 28.2109 m pixel size in study area, 2011), downloaded with Earth Explorer (United States Geological Survey, 2018)	Combining different DEM tiles, reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6 and clipping to study area with a buffer of width the pixel width in QGIS.
Rainfall erosivity index (R) (required)	“Raster dataset, with an erosivity index value for each cell. This variable depends on the intensity and duration of rainfall in the area of interest. The greater the intensity and duration of the rain storm, the higher the erosion potential. The erosivity index is widely used, but in case of its absence, there are methods and equations to help generate a grid using climatic data. [units: MJ·mm·(ha·h·yr)−1MJ·mm·(ha·h·yr)−1] ” (Sharp *et al*., 2018, p. 146)	Calculated with formula of (Bonilla & Vidal, 2011) for Central Chile: $R = 0.028 .P^{1.534}$ with R in (MJ mm)/(ha.hr.yr), P the average annual precipitation (mm) (using the same as for the Annual Water Yield model)	

Table D.2 continued: Sediment Delivery Ratio model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
Soil erodibility (K) (required)	“Raster dataset, with a soil erodibility value for each cell. Soil erodibility, K, is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. [units:$tons\cdot ha\cdot h\cdot (ha\cdot MJ \cdot mm)-1$]” p(Sharp *et al*., 2018, p. 146)	Soil erodibility map by (Bonilla & Johnson, 2012, p. 120, Figure 6)	Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6 and clipping to study area with a buffer of width the pixel width in QGIS.
Land use/land cover (required)	“Raster dataset, with an integer LULC code for each cell. All values in this raster MUST have corresponding entries in the Biophysical table.” (Sharp *et al*., 2018, p. 146)	see section 3.5	
Watersheds (required)	“A shapefile of polygons. This is a layer of watersheds such that each watershed con- tributes to a point of interest where water quality will be analyzed. Format: An integer field named ws_id is required, with a unique integer value for each watershed.” (Sharp *et al*., 2018, p. 146)	Shapefile with national watersheds (Dirección General de Aguas, 2017a) and subwatersheds including area and name (m2) (Ministerio de obras Publicas, 2017)	Watersheds intersecting with the study area were too large to analyse. Therefore, subwatersheds intersecting with the study area were used for this input. Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6

Table D.2 continued: Sediment Delivery Ratio model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
Biophysical table (required).	"A .csv (Comma Separated Value) table containing model information corresponding to each of the land use classes in the LULC raster. All LULC classes in the LULC raster MUST have corresponding values in this table. Each row is a land use/land cover class and columns must be named and defined as follows:" (Sharp *et al.*, 2018, p. 146)	Created in Microsoft Excel and converted to a .csv file.	
lucode	"Unique integer for each LULC class (e.g., 1 for forest, 3 for grassland, etc.) Every value in the LULC map MUST have a corresponding lucode value in the biophysical table." (Sharp *et al.*, 2018, p. 146)	Codes of Table 3.3	
usle_c	"Cover-management factor for the USLE, a floating point value between 0 and 1." (Sharp *et al.*, 2018, p. 146)	see Table F.3 Values were obtained from scientific literature found with search engines Limo and Google Scholar and combinations of the following key words in English and Spanish: "USLE", "RUSLE", "Cover-management factor", "C", "factor", "Chile", "South-America".	
usle_p	"Support practice factor for the USLE, a floating point value between 0 and 1." (Sharp *et al.*, 2018, p. 147)	see Table F.3	

Table D.2 continued: Sediment Delivery Ratio model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
Threshold flow accumulation (TFA) (required)	“The number of upstream cells that must flow into a cell before it is considered part of a stream, which is used to classify streams from the DEM. This threshold directly affects the expression of hydrologic connectivity and the sediment export result: when a flow path reaches the stream, sediment deposition stops and the sediment exported is assumed to reach the catchment outlet. It is important to choose this value carefully, so modeled streams come as close to reality as possible. See Appendix 1 for more information on choosing this value. Integer value, with no commas or periods - for example “1000”. (Sharp *et al.*, 2018, p. 147) “Larger values of TFA will create a stream network with fewer tributaries, smaller values of TFA will create a stream network with more tributaries. A good value to start with is 1000, but note that this can vary widely depending on the resolution of the DEM, local climate and topography.” (Sharp *et al.*, 2018, p. 153)	Iteration with start value of 1000. After every run, the output file ‘stream.tif’ was compared with a real stream layer to match reality as closely as possible. Used real stream layers: - river estuaries (‘rios esteros’, .shp) (Albers, 2018b) - large rivers (‘rios grandes’,.shp) (Albers, 2018b) - ‘quebradas’ (.shp) (Albers, 2018b) - Older and major rivers (‘rios mayores’,.shp) (Albers, 2018b) - hydrography shapefile (hidrografia escala’,.shp) (CONAF, 2018b) A value of 180 was used.	

Table D.2 continued: Sediment Delivery Ratio model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
K_b and IC_0 (required)	“Two calibration parameters that determine the shape of the relationship between hydrologic connectivity (the degree of connection from patches of land to the stream) and the sediment delivery ratio (percentage of soil loss that actually reaches the stream; cf. Figure 3). The default values are kb = 2 and$IC0$ = 0.5.” (Sharp *et al*., 2018, p. 147)	Use of default values.	
SDRmax (required)	“The maximum SDR that a pixel can reach, which is a function of the soil texture. More specifically, it is defined as the fraction of topsoil particles finer than coarse sand (1000 μm; Vigiak *et al.* 2012). This parameter can be used for calibration in advanced studies. Its default value is 0.8.” p. (Sharp *et al*., 2018, p. 147)	Use of default value	

Table D.3: Habitat Quality model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
Workspace (required)	“Folder where model outputs will be written. Make sure that there is ample disk space, and write permissions are correct.” (Sharp *et al*., 2018, p. 30)	/	/
Suffix (optional)	“Text string that will be appended to the end of output file names, as “_Suffix”. Use a Suffix to differentiate model runs, for example by providing a short name for each scenario. If a Suffix is not provided, or changed between model runs, the tool will overwrite previous results.” (Sharp *et al*., 2018, p. 30)	/	/

Table D.3 continued: Habitat Quality model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
Current Land Cover (required)	"A GIS raster dataset, with an integer LULC code for each cell. The LULC raster should include the area of interest, as well as a buffer of the width of the greatest maximum threat distance. Otherwise, locations near the edge of the area of interest may have inflated habitat quality scores, because threats outside the area of interested are not properly accounted for. *The LULC codes must match the codes in the "Sensitivity of land cover types to each threat" table below.*" (Sharp *et al*., 2018, p. 30)	See section 3.5	Land cover map of 2008 Clipping to the study area with a buffer of the largest maximum threat distance.
Future Land Cover (optional)	"A GIS raster dataset that represents a future projection of LULC in the landscape with an integer LULC code for each cell. This file should be formatted exactly like the "Current Land Cover" above. LULC classes that appear on both the current and future maps should have the same LULC code. LULC types unique to the future map should have codes not used in the current LULC map. Again, the LULC raster should include the area of interest, as well as a buffer of the width of the greatest maximum threat distance. Otherwise, locations near the edge of the area of interest may have inflated habitat quality scores, because threats outside the area of interested are not properly accounted for." (Sharp *et al*., 2018, p. 30)	See section 3.5	Land cover Map of 2016 Clipping to the study area with a buffer of the largest maximum threat distance.

Table D.3 continued: Habitat Quality model inputs, description, source and processing method

Input	Description	Source	Processing method
Folder Containing Threat Rasters (required)	"Folder containing GIS raster files of the distribution and intensity of each individual threat, with values between 0 and 1. You will have as many of these maps as you have threats. These threat maps should cover the area of interest, as well as a buffer of the width of the greatest maximum threat distance. Otherwise, locations near the edge of the area of interest may have inflated habitat quality scores, because threats outside the area of interested are not properly accounted for." p. 30 "Each cell in the raster contains a value that indicates the density or presence of a threat within it (e.g., area of agriculture, length of roads, or simply a 1 if the grid cell is a road or crop field and 0 otherwise). All threats should be measured in the same scale and units (i.e., all measured in density terms or all measured in presence/absence terms) and not some combination of metrics. The extent and resolution of these raster datasets does not need to be identical to that of the input LULC maps. In cases where the threats and LULC map resolutions vary, the model will use the resolution and extent of the LULC map. Do not leave any area on the threat maps as 'No Data'. If pixels do not contain that threat set the pixels' threat level equal to 0." (Sharp *et al.*, 2018, p. 31)	See Figures G.5-G.11	Shapefiles were converted to rasters (30 m spatial resolution) with value 1 for presence and 0 for absence. Reprojecting to WGS 84 UTM zone 18S [EPSG:32718] in ArcMap 10.6 and clipping to study area with a buffer of width the maximum distance.
Threats data (required)	"A CSV (comma-separated value, .csv) table of all threats you want the model to consider. The table contains information on the each threat's relative importance or weight and its impact across space. Each row in the Threats data CSV table is a degradation source, and columns must be named as follows:" (Sharp *et al.*, 2018, p. 31)	Values obtained with questionnaire for experts (see section 3.5)	See Table F.5

Table D.3 continued: Habitat Quality model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
THREAT	"The name of the specific threat. Threat names must not exceed 8 characters." (Sharp *et al.*, 2018, p. 31)	See section 3.5	See Table F.5
MAX_DIST	"The maximum distance over which each threat affects habitat quality (measured in kilometers). The impact of each degradation source will decline to zero at this maximum distance." (Sharp *et al.*, 2018, p. 31)		See Table F.5
WEIGHT	"The impact of each threat on habitat quality, relative to other threats. Weights can range from 1 at the highest impact, to 0 at the lowest." (Sharp *et al.*, 2018, p. 31)		See Table F.5
DECAY	"The type of decay over space for the threat. Can have the value of either "linear" or "exponential"." (Sharp *et al.*, 2018, p. 31)		See Table F.5
Sensitivity of Land Cover Types to Each Threat (required)	"A CSV (comma-separated value, .csv) table of LULC types, whether or not they are considered habitat, and, for LULC types that are habitat, their specific sensitivity to each threat. Each row in the Sensitivity CSV table is an LULC type, and columns must be named as follows:" (Sharp *et al.*, 2018, p. 32)	Values obtained with questionnaire for experts (see section 3.5)	See section 3.5 See Table F.5
LULC	"Numeric integer code for each LULC type. Values must match the codes used in the current, future and baseline LULC rasters. All LULC types that appear in the current, future, or baseline maps must have a row in this table." (Sharp *et al.*, 2018, p. 32)	Codes of Table 3.3	
NAME	"The name of each LULC" (Sharp *et al.*, 2018, p. 32)	names of Table 3.3	

Table D.3 continued: Habitat Quality model inputs, description, source and processing method

Input	**Description**	**Source**	**Processing method**
HABITAT	“Each LULC type is assigned a habitat score (H_j in the equations above), from 0 to 1. If you want to simply classify each LULC as habitat or not without reference to any particular species group then use 0s and 1s where a 1 indicates habitat. Otherwise, if sufficient information is available on a species group’s habitat preferences, assign the LULC a relative habitat suitability score between 0 and 1 where 1 indicates the highest habitat suitability.” (Sharp *et al*., 2018, p. 32)	See section 3.5	A scale of 0 to 1 was used, see Table F.5
L_THREAT1, *L_THREAT2*, etc	“The relative sensitivity of each habitat type to each threat. You will have as many columns named like this as you have threats, and the “_THREAT1”, “_THREAT2” etc portions of the column names must match row names in the “Threat data” table noted above. Values range from 0 to 1, where 1 represents high sensitivity to a threat and 0 represents no sensitivity. Note: Even if the LULC is not considered habitat, do not leave its sensitivity to each threat as Null or blank, instead enter a 0 and the model will convert it to NoData.” (Sharp *et al*., 2018, p. 32)		
Half-saturation constant (required)	“By default, it is set to 0.5 but can be set equal to any positive floating point number.” (Sharp *et al*., 2018, p. 32)	Preliminary run with default value 0.5. Next, a value of 0.8 was used.	

E. Extra information on the land cover classification

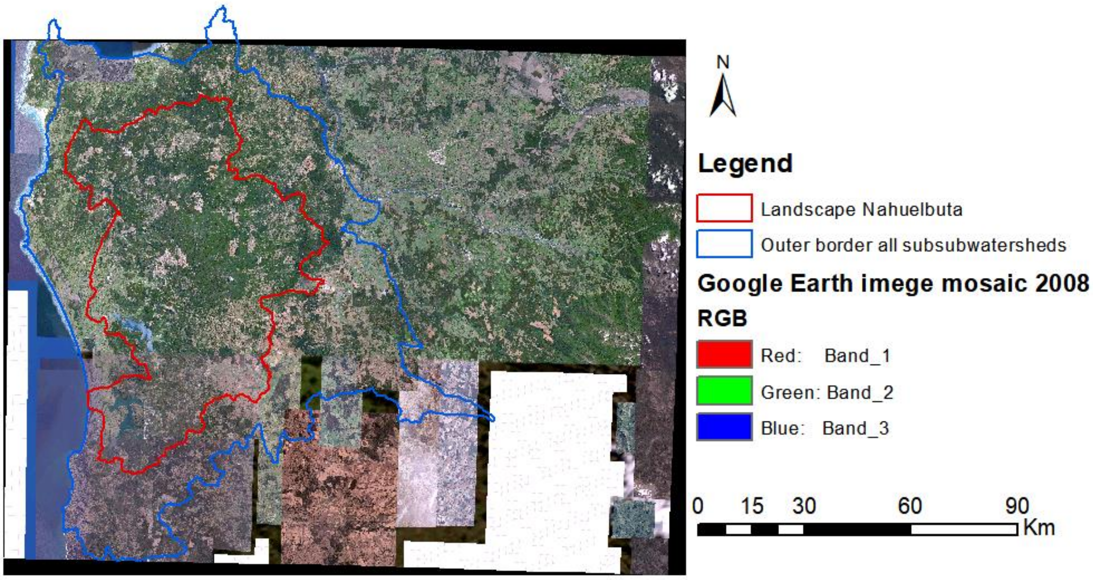

Figure E.1: downloaded and combined Google Earth images of 2008 (Allmapsoft, 2019), after georeferencing and reprojecting to WGS 84 UTM zone 18S [EPSG:32718]

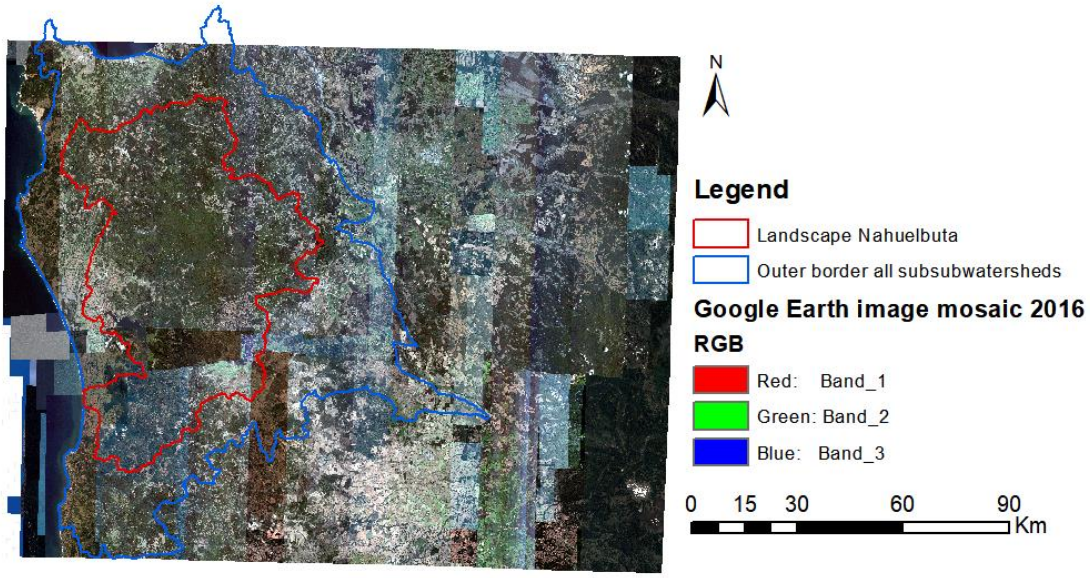

Figure E.2: downloaded and combined Google Earth images of 2016 (Allmapsoft, 2019), after georeferencing and reprojecting to WGS 84 UTM zone 18S [EPSG:32718]

Table E.1: confusion matrix of accuracy analysis of land cover classification for 2008

	1	**2**	**3**	**7**	**8**	**10**	**13**
1	636772	172446	113595	72	368	46317	1
2	3145	1127	1728	0	0	1159	0
3	39302	12022	44424	1011	272	14519	0
7	284	28	553	24096	3204	4480	3
8	224	45	388	4461	6307	4975	118
10	10962	3274	9567	3077	10043	41196	95
13	125	56	13	0	1145	757	28892

Table E.2: confusion matrix of accuracy analysis of land cover classification for 2016

	1	**2**	**3**	**7**	**8**	**10**	**13**
1	53638	1625	20909	0	0	1041	0
2	1687	69176	4334	1470	581	3431	137
3	39191	14505	474409	1936	38	25800	0
7	5	675	1152	25152	6239	457	436
8	2	277	152	11604	16067	730	310
10	13	12322	790	206	396	2331	44
13	2	624	0	760	500	93	18807

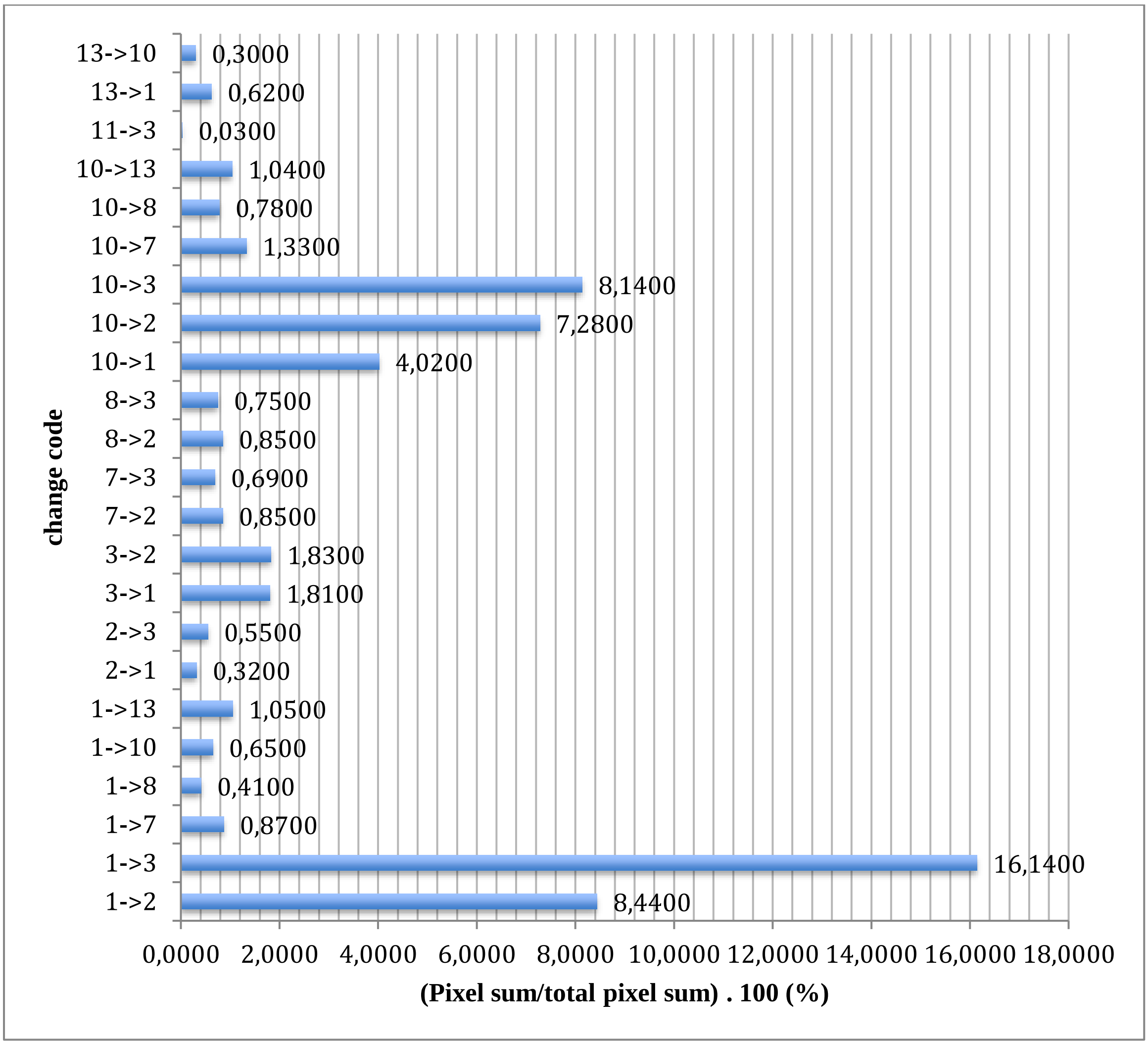

Figure E.3: Most important land cover changes from 2008 to 2016, with the number of pixels undergoing that change as a percentage of the total pixel amount (horizontal axis) and the change codes on the vertical axis (reference class ID→ new class ID)

F. InVEST model input biophysical tables

Table F.1: Biophysical table as input for the Annual Water Yield model

* formula: ET = K_c.ET_0 (Allen *.et al* , 1998) so $\frac{ET2}{ET1}=\frac{KC2}{KC1}$

lucode	LULC_desc	LULC_veg	root_depth	Source root depth	Kc	Source Kc
1	Adult plantation	1	4550	Average of values of temperate coniferous forest and sclerophyllous forest of Canadell *et al*. (1996)	0.89	Average of Kc of coniferous trees (0.95) (Allen *et al.*, 1998) and *Eucalyptus* spp. (0.83) (Stibbe, 1975; Sharma, 1984; Dong *et al.*, 1992)
2	Young plantation	1	4550	Average of values of temperate coniferous forest and sclerophyllous forest of Canadell *et al*. (1996)	0.70	(Alves, 2009)
3	Native forest	1	4000	Average of values of temperate coniferous and deciduous forest and sclerophyllous forest of Canadell *et al*. (1996)	0.92	Calculation with formula of Allen *et al.* (1998)* and values of Olivera, *et al.* (2013), assuring the correct ratio between Kc values in this table
7	Agriculture	1	2100	Value of cropland of Canadell *et al*. (1996)	0.59	Calculation with formula of Allen *et al.* (1998)* and values of Olivera, *et al.* (2013), assuring the correct ratio between Kc values in this table

Table F.1 continued: Biophysical table as input for the Annual Water Yield model

* formula: ET = $K_c.ET_0$ (Allen .*et al* , 1998) so $\frac{ET2}{ET1} = \frac{KC2}{KC1}$

lucode	**LULC_desc**	**LULC_veg**	**root_ depth**	**Source root depth**	**Kc**	**Source Kc**
8	Grassland	1	2600	Value of grassland of Canadell *et al*. (1996)	0.64	Calculation with formula of Allen *et al.* (1998)* and values of Olivera, *et al.* (2013), assuring the correct ratio between Kc values in this table
9	Water	0	-1	/	0.90	(Allen *et al.*, 1998)
10	Shrubland	1	4000	(Canadell *et al*., 1996)	0.66	Calculation with formula of Allen *et al.* (1998)* and values of Olivera, *et al.*, 2013), assuring the correct ratio between Kc values in this table
11	Wetland	0	-1	/	1.10	(Allen *et al.*, 1998)
12	Built/urban areas/industry	0	-1	/	0.40	(Allen *et al.*, 1998; Hamel & Guswa, 2015)
13	Bare soil	0	-1	/	0.50	(Allen *et al.*, 1998)
14	Beaches and dunes	0	-1	/	0.50	(Allen *et al.*, 1998)

Table F.2: Demand table for the Annual Water Yield model, with assumptions of no human water consumption for plantations, native forest, water, shrubland, wetland, bare soil and beaches and dunes. Demand is given in m^3(yr .pixel of the land cover raster).

lucode	**LULC_desc**	**demand**	**lucode**	**LULC_desc**	**demand**
1	Adult plantation	0	11	Wetland	0
2	Young plantation	0	12	Built/urban areas/industry	767.50
3	Native forest	0	13	Bare soil	0
7	Agriculture	881.39	14	Beaches and dunes	0
8	Grassland	575.53			
9	Water	0			
10	Shrubland	0			

Table F.3: Biophysical table as input for the Sediment Delivery Ratio Model Note: A value of 1 was assumed for usle_p for all land cover classes, since no clear information on erosion control measures was available.

lucode	**LULC_desc**	**usle_c**	**Source value usle_c**	**usle_p**
1	Adult plantation	0.047	Value for the watershed of river Picoiquén by Ortega (1993)	1
2	Young plantation	0.130	Value for 50 % crown closure by Özhan *et al*., (2005)	1
3	Native forest	0.004	Value for the Santo Domingo native forests of the Valparaíso region by Bonilla, *et al.*, (2010)	1
7	Agriculture	0.070	Value for the Bío Bío and Araucanía regions by Honorato *et al*. (2001)	1
8	Grassland	0.024	Average of values by Honorato *et al*. (2001) and Bonilla *et al*. (2010)	1
9	Water	0.000	Bonilla, *et al.* (2010)	1
10	Shrubland	0.006	Value for the Santo Domingo mixed brush of the Valparaíso region by Bonilla, *et al.*, (2010)	1
11	Wetland	0	Bonilla, *et al.* (2010)	1
12	Built/urban areas/industry	0.001	Bonilla, *et al.* (2010)	1
13	Bare soil	1	Value for the Bío Bío region of (Dissmeyer & Foster, 1980; Contreras *et al*. 2012)	1
14	Beaches and dunes	1	Assumed the same value as for bare soil	1

Table F.4: Table of threats data as input for the Habitat quality model, resulting from the second questionnaire. Dirt_R = dirt roads, Paved_R = paved roads, Gravel_R = gravel roads, Tourism = Non-sustainable tourism, Transmission = Energy power transmission lines

THREAT	**MAX_DIST**	**WEIGHT**	**DECAY**
Dirt_R	0.35	0.1898	linear
Paved_R	0.64	0.8540	linear
Gravel_R	0.40	0.0000	linear
Agriculture	2.13	0.6277	linear
Tourism	1.03	0.2409	linear
Forest_fires	1.93	1.0000	linear
Urban_Areas	3.00	0.4599	linear
Transmission	0.49	0.1168	linear

Table F.5: habitat scores of the land cover classes and sensitivities of land cover types to each threat as input table for the Habitat Quality model.

Dirt_R = dirt roads, Paved_R = paved roads, Gravel_R = gravel roads,

LULC	Name	Habitat	L_Dirt_R	L_Paved_R	L_Gravel_R	L_Agriculture
1	Adult plantation	0.2357	0.2143	0.2857	0.2286	0.2800
2	Young plantation	0.2429	0.2286	0.3714	0.2286	0.3200
3	Native forest	1,0000	0.5143	0.8714	0.6429	0.8000
11	Wetland	1,0000	0.6286	0.8857	0.7429	0.8800
8	Grassland	0.74286	0.4143	0.6571	0.5	0.4200
9	Water	0.8857	0.6143	0.7857	0.6714	0.7600
10	Shrubland	0.8000	0.5000	0.7571	0.5714	0.7400
7	Agriculture	0.2714	0.1714	0.3714	0.3	0.1600
13	Bare_soil	0.2714	0.2571	0.4571	0.3143	0.2600
12	Built/urban areas/industry	0.0571	0.1000	0.1286	0.0286	0.1800
14	Beaches and dunes	0.2714	0.2571	0.4571	0.31423	0.2600

Table F.5 continued: habitat scores of the land cover classes and sensitivities of land cover types to each threat as input table for the Habitat Quality model, Tourism = Non-sustainable tourism, Transmission = Energy power transmission lines

LULC	Name	L_Tourism	L_Forest_fires	L_Urban_Areas	L_Transmission
1	Adult plantation	0.4400	0.9000	0.4200	0.4000
2	Young plantation	0.4600	0.8400	0.4600	0.4000
3	Native forest	0.8200	0.8000	0.8200	0.7800
11	Wetland	0.8800	0.6800	0.8200	0.7400
8	Grassland	0.7000	0.7800	0.6800	0.5400
9	Water	0.6000	0.6200	0.8600	0.6400
10	Shrubland	0.6000	0.8400	0.6800	0.5800
7	Agriculture	0.3800	0.6200	0.3400	0.3600
13	Bare_soil	0.3200	0.2800	0.1200	0.1200
12	Built/urban areas/industry	0.4000	0.3400	0.0400	0.2400
14	Beaches and dunes	0.3200	0.2800	0.1200	0.1200

G. Mapped inputs of the InVEST models

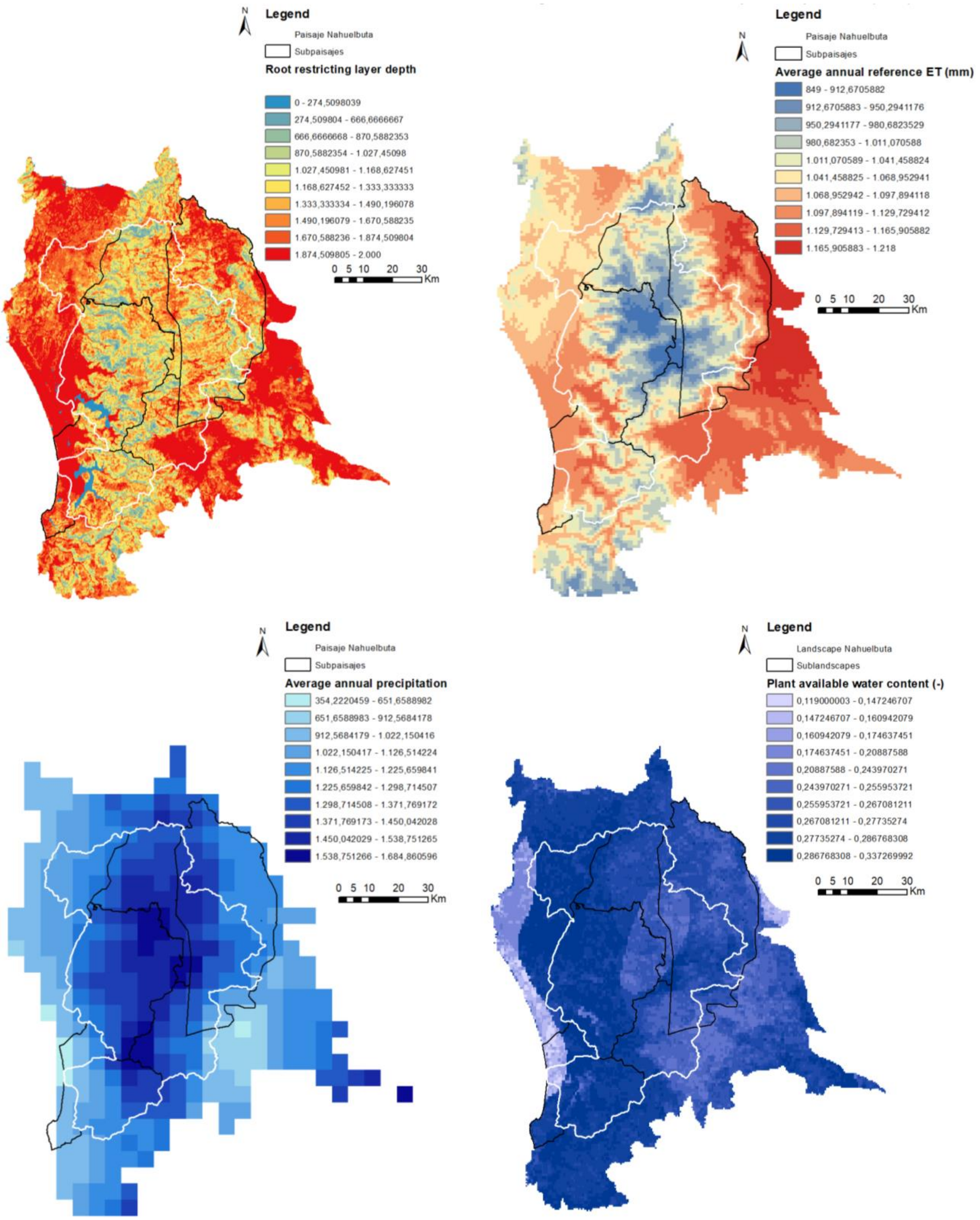

Figure G.1 inputs for the Annual Water Yield model: root restricting layer depth (mm) (top left), average annual reference evapotranspiration (mm) (top right), average annual precipitation (mm) (bottom left) and plant available water content (-) (bottom right) with limits of landscape Nahuelbuta (WWF Chile, 2018b) and the selected sublandscapes, maps by author

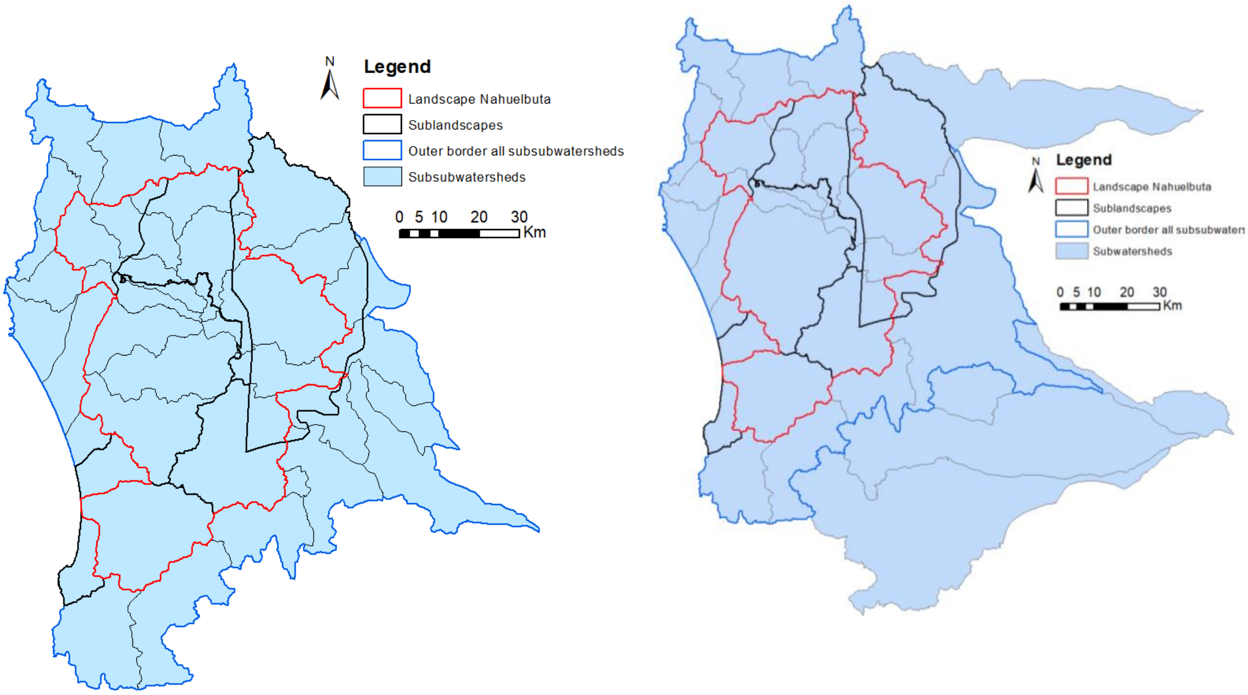

Figure G.2: subsubwatersheds (left) and subwatersheds (right) borders, with limits of the landscape (WWF Chile, 2018b) and sublandscapes (descriptions, references and processing methods given in Appendix D), maps by author

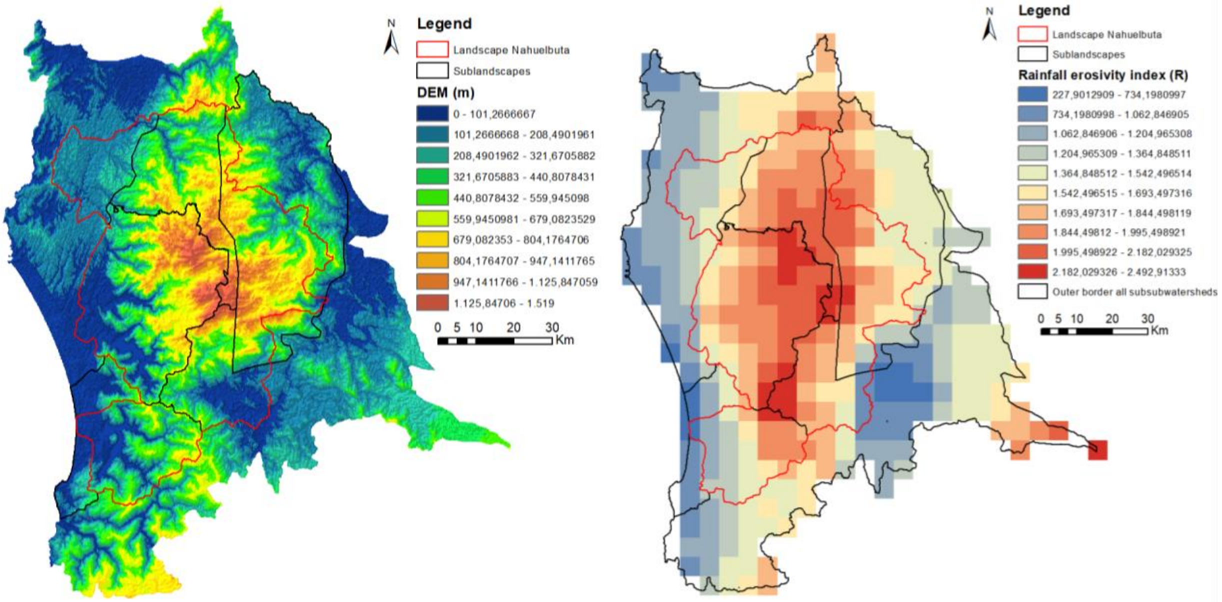

Figure G.3: inputs of the SDR model: Digital Elevation Model (DEM) (m) (left), rainfall erosivity index (R) (MJ.mm/(ha.h.yr)) (right) (descriptions, references and processing methods given in Appendix D), with limits of the landscape (WWF Chile, 2018b) and sublandscapes, maps by author

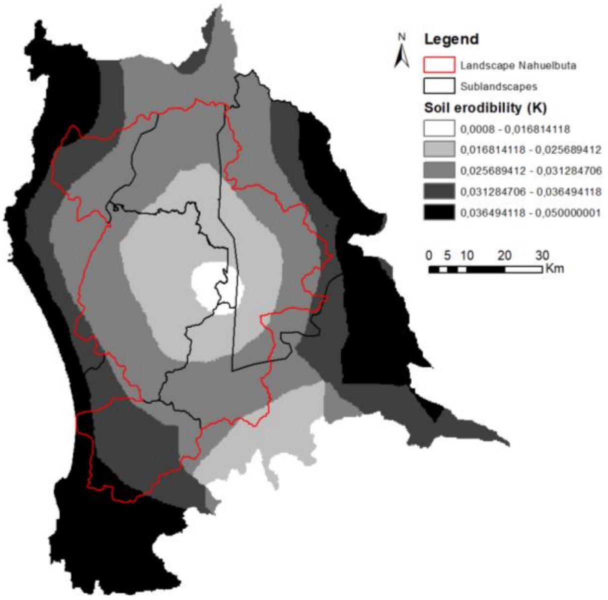

Figure G.3 continued: inputs of the SDR model: soil erodibility (K) (tons.ha.h/(ha.MJ.mm)) (descriptions, references and processing methods given in Appendix D), with limits of the landscape (WWF Chile, 2018b) and sublandscapes, maps by author

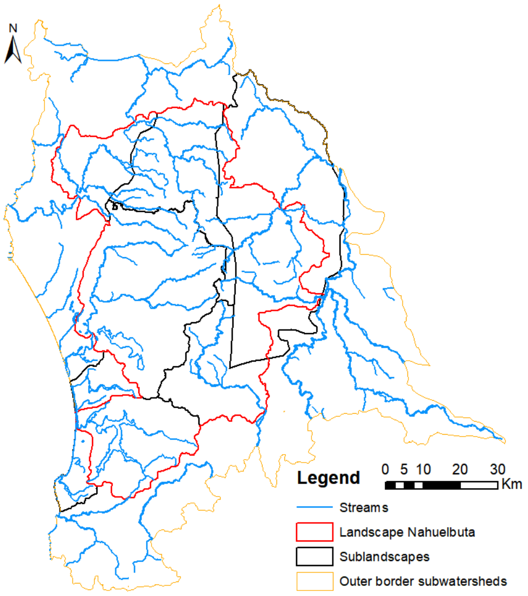

Figure G.4: real stream layers used for the calibration with the threshold flow parameter of the SDR model: a combination of river estuaries (‘rios esteros’, .shp) (Albers, 2018b), large rivers (‘rios grandes’,.shp) (Albers, 2018b), ‘quebradas’ (.shp) (Albers, 2018b), older and major rivers (‘rios mayores’,.shp) (Albers, 2018b) and a hydrography shapefile (hidrografia escala’,.shp) (CONAF, 2018b), within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018b), map by author

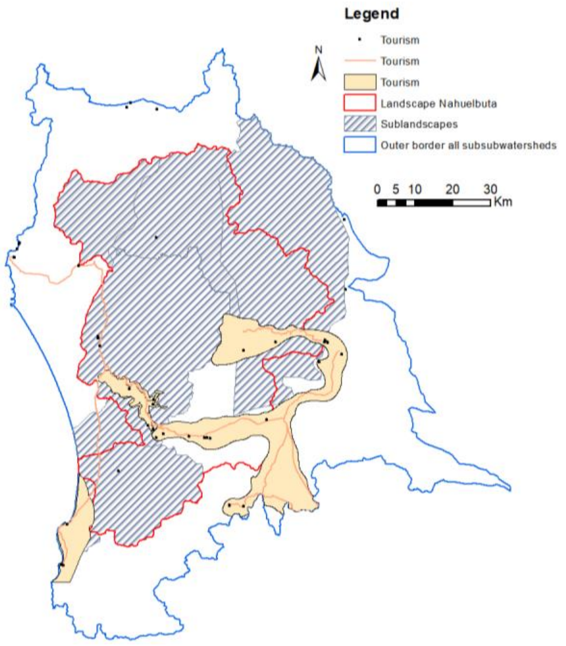

Figure G.5: location of non-sustainable tourism areas (SERNATUR, 2015, 2018; Servicio Nacional de Turismo, 2018) within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018b), map by author

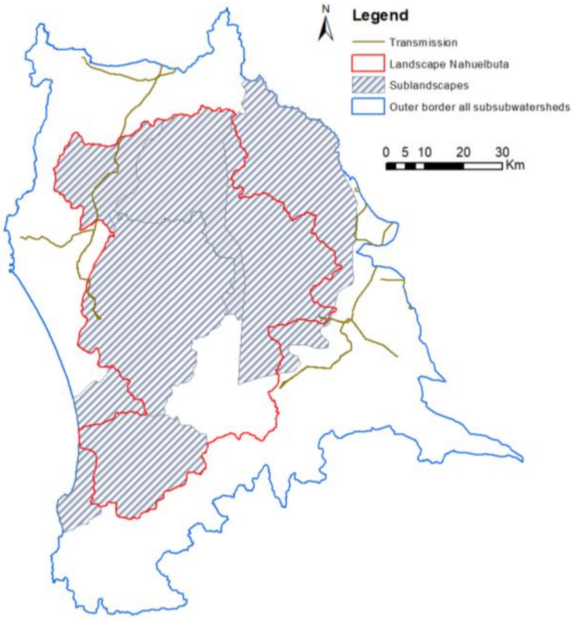

Figure G.6: location of energy transmission lines (Ministerio de Energía, 2016, 2018) within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018b), map by author

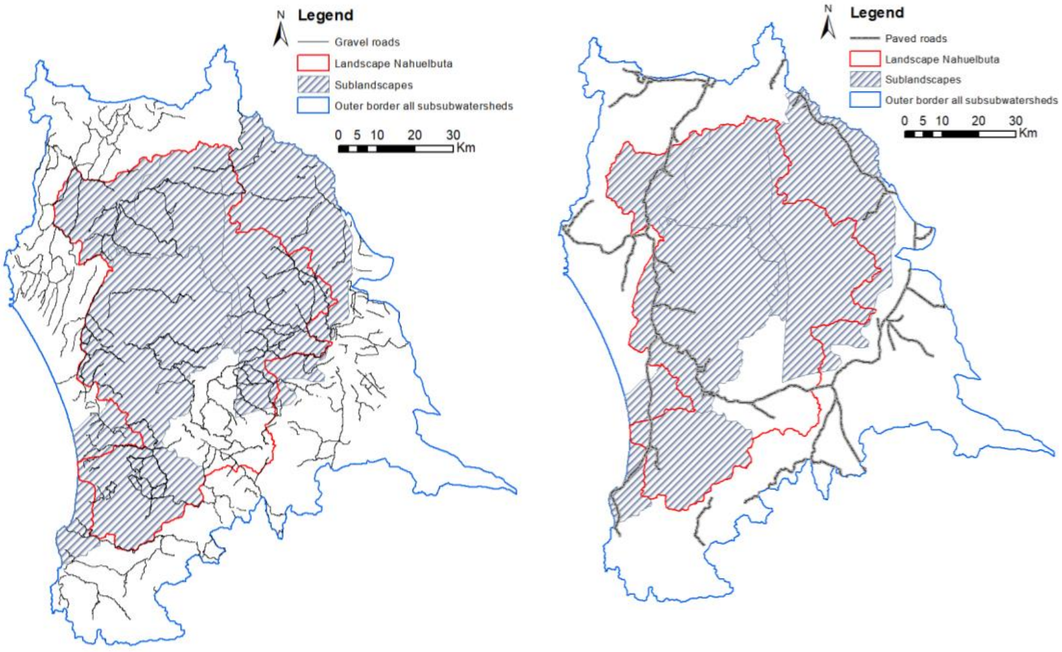

Figure G.7: location of gravel roads (left) (Ministerio de Obras Públicas (MOP), 2018) and paved roads (right) (Ministerio de Obras Públicas (MOP), 2018), within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018b), maps by author

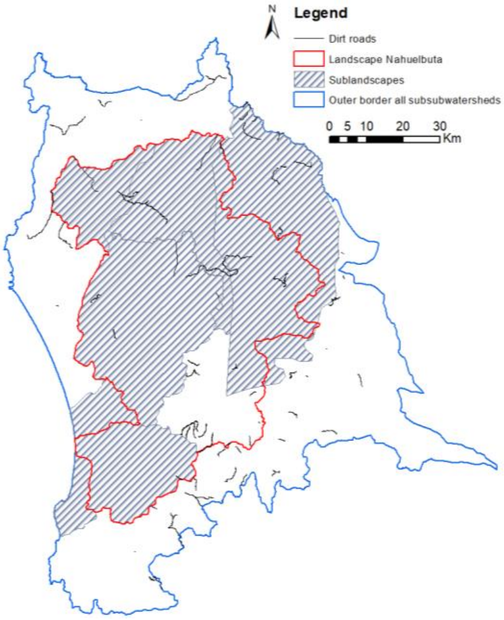

Figure G.8: location of dirt roads (Ministerio de Obras Públicas (MOP), 2018) within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018b), map by author

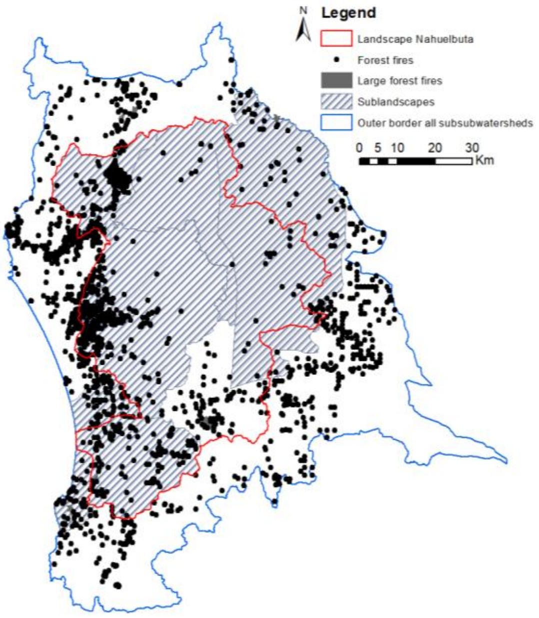

Figure G.9: location of all fires (CONAF, 2016b), forest fires (CONAF, 2016a) and large forest fires source layer (CONAF, 2018a) within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018b), map by author

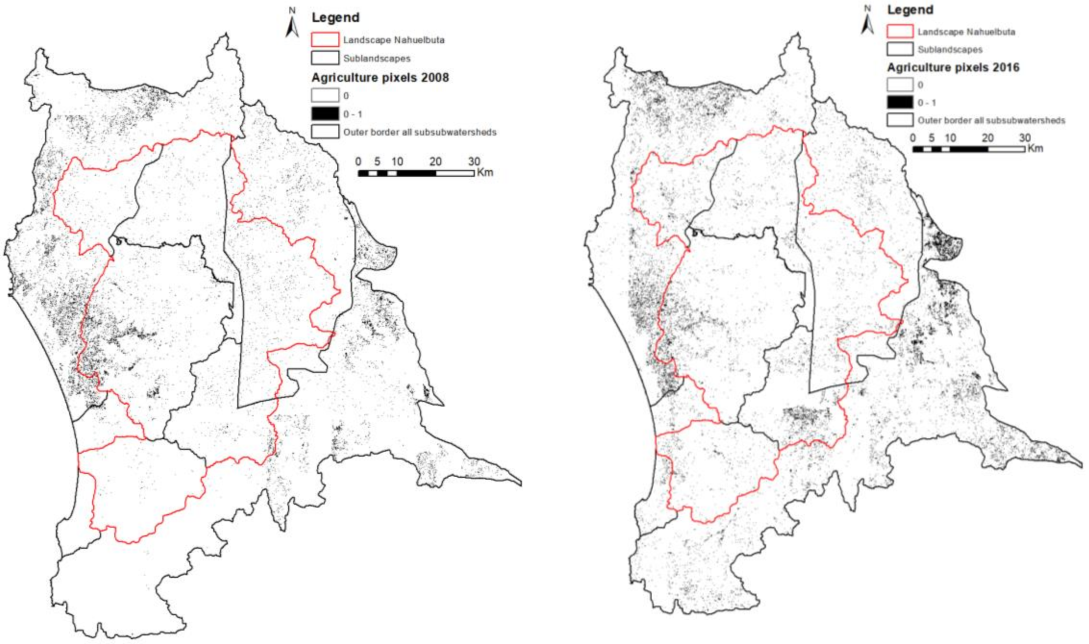

Figure G.10: location of agriculture pixels extracted from the classified land cover rasters for 2008 (left) and 2016 (right) within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018b), maps by author

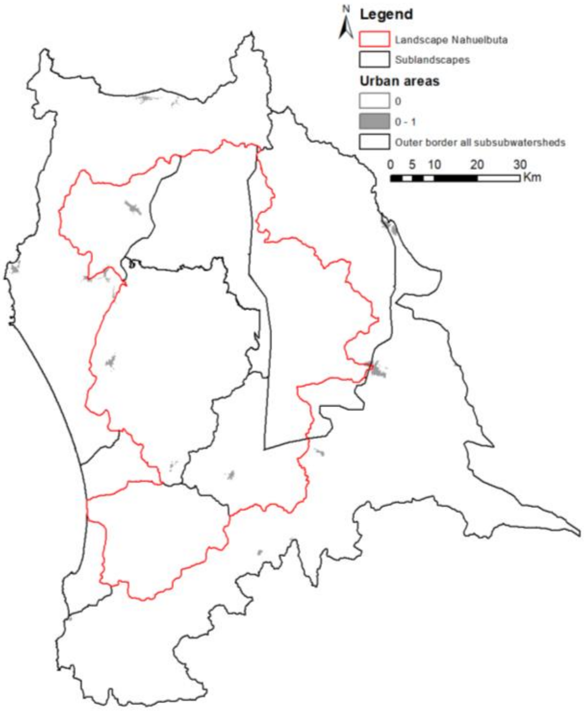

Figure G.11: location of urban areas (Ministerio de Vivienda Y Urbanismo, 2016) within the outer border of all subsubwatersheds (Dirección General de Aguas, 2017b) intersecting the landscape (WWF Chile, 2018b), map by author

H. InVEST model outputs descriptions

Table H.1: Annual Water Yield model outputs with description (note: watersheds and subwatersheds in the table are subwatersheds and subsubwatersheds respectively for this study)

Output	**Description**
"Parameter log" (Sharp *et al.*, 2018b, p. 115)	"Each time the model is run, a text (.txt) file will be created in the Workspace. The file will list the parameter values and output messages for that run and will be named according to the service, the date and time." (Sharp *et al.*, 2018b, p. 115)
"per_pixel folder:" (Sharp *et al.*, 2018b, p. 115)	"Useful for intermediate calculations but should NOT be interpreted at the pixel level, as model assumptions are based on processes understood at the subwatershed scale." (Sharp *et al.*, 2018b, p. 115)
"output\per_pixel\fractp_[Suffix].tif (fraction):" (Sharp *et al.*, 2018b, p. 115)	"Estimated actual evapotranspiration fraction of precipitation per pixel (Actual Evapotranspiration / Precipitation). It is the mean fraction of precipitation that actually evapotranspires at the pixel level." (Sharp *et al.*, 2018b, p. 115)
"output\per_pixel\aet_[Suffix].tif "(mm) (Sharp *et al.*, 2018b, p. 115)	"Estimated actual evapotranspiration per pixel." (Sharp *et al.*, 2018b, p. 115)
"output\per_pixel\wyield_[Suffix].tif "(Sharp *et al.*, 2018b, p. 115) (mm)	"Estimated water yield per pixel." (Sharp *et al.*, 2018b, p. 115)
"output\subwatershed_results_wyield_[Suffix].shp and output\subwatershed_results_wyield_[Suffix].csv" (Sharp *et al.*, 2018b, p. 115)	"Shapefile and table containing biophysical output values per subwatershed, with the following attributes:" (Sharp *et al.*, 2018b, p. 115)
"precip_mn" (Sharp *et al.*, 2018b, p. 115) (mm)	"Mean precipitation per pixel in the subwatershed." (Sharp *et al.*, 2018b, p. 115)
"PET_mn" (Sharp *et al.*, 2018b, p. 115) (mm)	"Mean potential evapotranspiration per pixel in the subwatershed." (Sharp *et al.*, 2018b, p. 115)

Table H.1 continued: Annual Water Yield model outputs with description (note: watersheds and subwatersheds in the table are subwatersheds and subsubwatersheds respectively for this study)

Output	**Description**
"AET_mn" (Sharp *et al*., 2018b, p. 115) (mm)	"Mean actual evapotranspiration per pixel in the subwatershed." (Sharp *et al*., 2018b, p. 115)
"wyield_mn" (Sharp *et al*., 2018b, p. 115) (mm)	"Mean water yield per pixel in the subwatershed." (Sharp *et al*., 2018b, p. 115)
"wyield_vol" (Sharp *et al*., 2018b, p. 115) (m3)	"Volume of water yield in the subwatershed." (Sharp *et al*., 2018b, p. 115)
"Output\watershed_results_wyield_[Suffix].shp and output\watershed_results_wyield_[Suffix].csv:" (Sharp *et al*., 2018, p. 116)	"Shapefile and table containing output values per watershed, with the following attributes:" (Sharp *et al*., 2018, p. 116)
"precip_mn" (Sharp *et al*., 2018, p. 116) (mm)	"Mean precipitation per pixel in the watershed." (Sharp *et al*., 2018, p. 116)
"PET_mn" (Sharp *et al*., 2018, p. 116) (mm)	"Mean potential evapotranspiration per pixel in the watershed." (Sharp *et al*., 2018, p. 116)
"AET_mn" (Sharp *et al*., 2018, p. 116) (mm)	"Mean actual evapotranspiration per pixel in the watershed." (Sharp *et al*., 2018, p. 116)
"wyield_mn" (Sharp *et al*., 2018, p. 116) (mm)	"Mean water yield per pixel in the watershed." (Sharp *et al*., 2018, p. 116)
"wyield_vol" (Sharp *et al*., 2018, p. 116) (m3)	"Volume of water yield in the watershed." (Sharp *et al*., 2018b, p. 115)

Table H.1 continued: Annual Water Yield model outputs with description (note: watersheds in the table are subwatersheds and subsubwatersheds respectively for this study

Output	**Description**
"If the Water Scarcity option is run, the following attributes will also be included for watersheds and subwatersheds:" (Sharp *et al.*, 2018, p. 116)	
"consum_vol" (Sharp *et al.*, 2018, p. 116) (m3)	"Total water consumption for each watershed." (Sharp *et al.*, 2018, p. 116)
"Consum_mn" (Sharp *et al.*, 2018, p. 116) (m3/ha)	"Mean water consumptive volume per hectare per watershed." (Sharp *et al.*, 2018, p. 116)
"rsupply_vl" (Sharp *et al.*, 2018, p. 116) (m3)	"Total realized water supply (water yield – consumption) volume for each watershed." (Sharp *et al.*, 2018, p. 116)
"rsupply_mn" (Sharp *et al.*, 2018, p. 116) (m3/ha)	"Mean realized water supply (water yield – consumption) volume per hectare per watershed." (Sharp *et al.*, 2018, p. 116)
intermediate:	"This directory contains data that represent intermediate steps in calculations of the final data in the output folder. It also contains subdirectories that store metadata used internally to enable avoided re-computation." (Sharp *et al.*, 2018, p. 116)

Table H.2: Sediment Delivery Ratio model outputs with description (note: watersheds in the table are subwatersheds for this study)

Output	**Description**
Parameter log	"Each time the model is run, a text (.txt) file will be created in the Workspace. The file will list the parameter values and output messages for that run and will be named according to the service, the date and time." (Sharp *et al.*, 2018, p. 147)
"rkls_[Suffix].tif (type: raster; units: tons/pixel)" (Sharp *et al.*, 2018, p. 147);	"Total potential soil loss per pixel in the original land cover without the C or P factors applied from the RKLS equation. Equivalent to the soil loss for bare soil." (Sharp *et al.*, 2018, p. 147)
"sed_export_[Suffix].tif (type: raster; units: tons/pixel)"	"The total amount of sediment exported from each pixel that reaches the stream." (Sharp *et al.*, 2018, p. 147)

Table H.2 continued: Sediment Delivery Ratio model outputs with description (note: watersheds in the table are subwatersheds for this study)

Output	**Description**
"stream_[Suffix].tif (type: raster)" (Sharp *et al*., 2018, p. 147);	"Stream network generated from the input DEM and Threshold Flow Accumulation. Values of 1 represent streams, values of 0 are non-stream pixels. Compare this layer with a real-world stream map, and adjust the Threshold Flow Accumulation so that stream.tif matches real-world streams as closely as possible." (Sharp *et al*., 2018, p. 147)
"usle_[Suffix].tif (type: raster; units: tons/pixel)" (Sharp *et al*., 2018, p. 147)	"Total potential soil loss per pixel in the original land cover calculated from the USLE equation.". (Sharp *et al*., 2018, p. 147)
"sed_retention_[Suffix].tif (type:raster; units: tons/pixel)" (Sharp *et al*., 2018, p. 148)	"Map of sediment retention with reference to a watershed where all LULC types are converted to bare ground." (Sharp *et al*., 2018, p. 148)
"Sed_retention_index_[Suffix].tif (type: raster; units: tons/pixel, but should be interpreted as relative values, not absolute)" (Sharp *et al*., 2018, p. 148)	"Index of sediment retention, used to identified areas contributing more to retention with reference to a watershed where all LULC types are converted to bare ground. This is NOT the sediment retained on each pixel (see Section on the index in "Evaluating Sediment Retention Services" above)." (Sharp *et al*., 2018, p. 148)
"watershed_results_sdr_[Suffix].shp" (Sharp *et al*., 2018, p. 148)	"Table containing biophysical values for each watershed, with fields as follows:" (Sharp *et al*., 2018, p. 148)

Table H.2 continued: Sediment Delivery Ratio model outputs with description (note: watersheds in the table are subwatersheds for this study)

Output	**Description**
"sed_export (units: tons/watershed)" (Sharp *et al.*, 2018, p. 148)	"Total amount of sediment exported to the stream per watershed. This should be compared to any observed sediment loading at the outlet of the watershed. Knowledge of the hydrologic regime in the watershed and the contribution of the sheetwash yield into total sediment yield help adjust and calibrate this model." (Sharp *et al.*, 2018, p. 148)
"usle_tot (units: tons/watershed)" (Sharp *et al.*, 2018, p. 148)	"Total amount of potential soil loss in each watershed calculated by the USLE equation." (Sharp *et al.*, 2018, p. 148)
"sed_retent (units: tons/watershed)" (Sharp *et al.*, 2018, p. 148)	"Difference in the amount of sediment delivered by the current watershed and a hypothetical watershed where all land use types have been converted to bare ground." (Sharp *et al.*, 2018, p. 148)
[Workspace]\intermediate_outputs folder:	
"slope, thresholded_slope, flow_direction, flow_accumulation" (Sharp *et al.*, 2018, p. 148)	"hydrologic rasters based on the DEM used for flow routing (outputs from RouteDEM, see corresponding chapter in the User's Guide" (Sharp *et al.*, 2018, p. 148)
"ls_[Suffix].tif" (Sharp *et al.*, 2018, p. 148)	"LS factor for USLE" (Sharp *et al.*, 2018, p. 148)

Table H.2 continued: Sediment Delivery Ratio model outputs with description (note: watersheds in the table are subwatersheds for this study)

Output	**Description**
“w_bar_[Suffix].tif” (Sharp *et al*., 2018, p. 148)	“mean weighting factor (C factor) for upslope contributing area” (Sharp *et al*., 2018, p. 148)
“s_bar_[Suffix].tif” (Sharp *et al*., 2018, p. 148)	“mean slope factor for upslope contributing area” (Sharp *et al*., 2018, p. 148)
“d_up_[Suffix].tif (and bare_soil)” (Sharp *et al*., 2018, p. 148)	“upslope factor of the index of connectivity” (Sharp *et al*., 2018, p. 148)
“w_[Suffix].tif” (Sharp *et al*., 2018, p. 148)	“denominator of the downslope factor” (Sharp *et al*., 2018, p. 148)
“d_dn_[Suffix].tif (and bare_soil)” (Sharp *et al*., 2018, p. 148)	“downslope factor of the index of connectivity” (Sharp *et al*., 2018, p. 148)
“ic_[Suffix].tif (and bare_soil)” (Sharp *et al*., 2018, p. 148) “sdr_factor_[Suffix].tif (and bare_soil)” (Sharp *et al*., 2018, p. 148)	“index of connectivity” (Sharp *et al*., 2018, p. 148) “sediment delivery ratio” (Sharp *et al*., 2018, p. 148)

Table H.3: Habitat Quality model outputs with description

Output	**Description**
Parameter log	"Each time the model is run, a text (.txt) file will be created in the Workspace. The file will list the parameter values and output messages for that run and will be named according to the service, the date and time." (Sharp *et al.*, 2018, p. 33)
"deg_sum_out_c_[Suffix].tif" (Sharp *et al.*, 2018, p. 33)	"Relative level of habitat degradation on the current landscape. A high score in a grid cell means habitat degradation in the cell is high relative to other cells. Grid cells with non- habitat land cover (LULC with $H_j = 0$) get a degradation score of 0."(Sharp *et al.*, 2018, p. 33) results equation of D(xj) in paragraph 3.6.3
"deg_sum_out_f_[Suffix].tif" (Sharp *et al.*, 2018, p. 33)	"Relative level of habitat degradation on the future landscape. A high score in a grid cell means habitat degradation in the cell is high relative to other cells. This output is only created if a future LULC map is given as input. Grid cells with non-habitat land cover (LULC with $H_j = 0$) get a degradation score of 0." (Sharp *et al.*, 2018, p. 33) results equation of D(xj) in paragraph 3.6.3
"quality_out_c_[Suffix].tif" (Sharp *et al.*, 2018, p. 33)	"Relative level of habitat quality on the current landscape. Higher numbers indicate better habitat quality vis-a-vis the distribution of habitat quality across the rest of the landscape. Areas on the landscape that are not habitat get a quality score of 0. This quality score is unitless and does not refer to any particular biodiversity measure." (Sharp *et al.*, 2018, p. 33-34) results equation of Q(xj) in paragraph 3.6.3
"quality_out_f_[Suffix].tif" (Sharp *et al.*, 2018, p. 34)	"Relative level of habitat quality on the future landscape. Higher numbers indicate better habitat quality vis-a-vis the distribution of habitat quality across the rest of the landscape. This output is only created if a future LULC map is given as input. Areas on the landscape that are not habitat get a quality score of 0. This quality score is unitless and does not refer to any particular biodiversity measure." (Sharp *et al.*, 2018, p. 34) results equation of Q(xj) in paragraph 3.6.3
"rarity_c_[Suffix].tif" (Sharp *et al.*, 2018, p. 34)	"Relative habitat rarity on the current landscape vis-a-vis the baseline map. This output is only created if a baseline LULC map is given as input. This map gives each grid cell's value ofR_x (see equation (6)). The rarer the habitat type in a grid cell is vis-a-vis its abundance on the baseline landscape, the higher the grid cell's value in rarity_c.tif." (Sharp *et al.*, 2018, p. 34) equation (6) is equation for R(x) in paragraph 3.6.3

Table H.3: Habitat Quality model outputs with description

Output	Description
"rarity_f_[Suffix].tif" (Sharp *et al*., 2018, p. 34)	"Relative habitat rarity on the future landscape vis-a-vis the baseline map. This output is only created if both baseline and future LULC maps are given as input. This map gives each grid cell's value of R_x (see equation (6)). The rarer the habitat type in a grid cell is vis-a-vis its abundance on the baseline landscape, the higher the grid cell's value in rarity_f.tif." (Sharp *et al*., 2018, p. 34) equation (6) is equation for R(x) in paragraph 4.5.3
"[Workspace]\intermediate folder" (Sharp *et al*., 2018, p. 34)	"This folder contains some of the intermediate files created during the model run. Usually you do not need to work with these files, unless you are trying to better understand how the model works, or debugging a model run. They include maps of habitats (habitat__[b,c,f].tif), threats layers processed with Threats data table attributes ([threat]_filtered_[b,c,f].tif), sensitivity applied to different threats (sens_[threat]_[b,c,f].tif), and a rasterized version of the Access input (access_layer.tif)." (Sharp *et al*., 2018, p. 34)

I. Questionnaire analysis results for each FSC stakeholder group

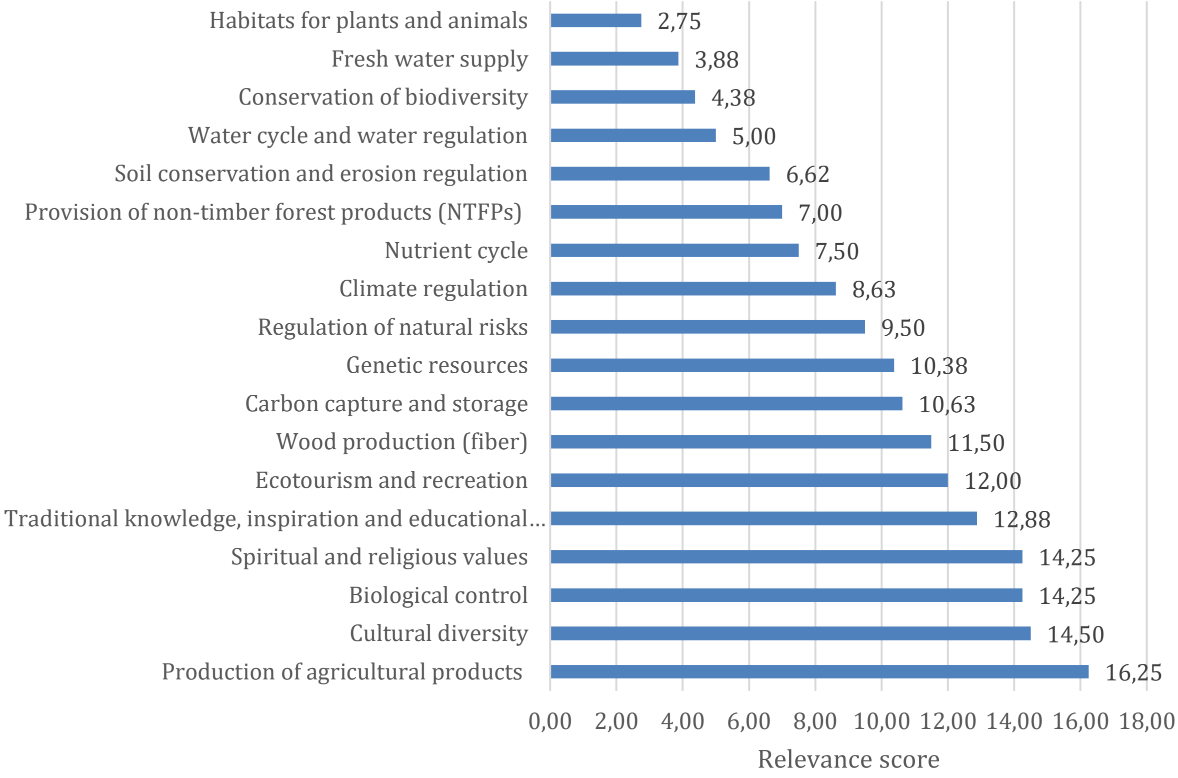

Figure I.1: Relevance scores, for the NGO stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

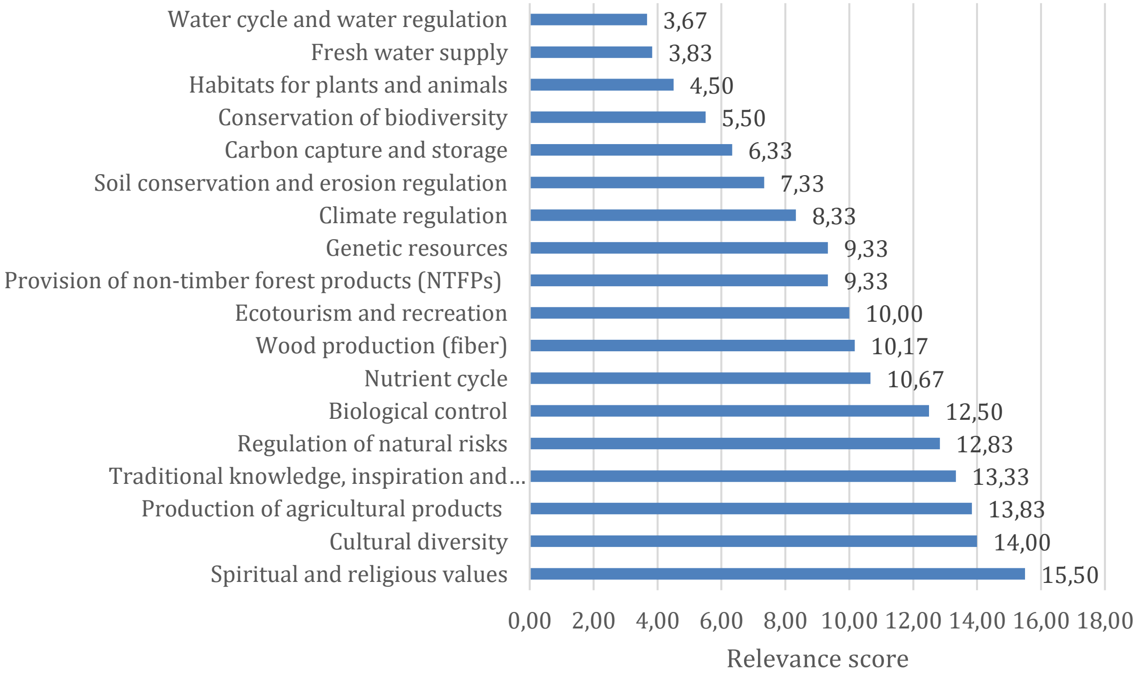

Figure I.2: Relevance scores, for the public stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

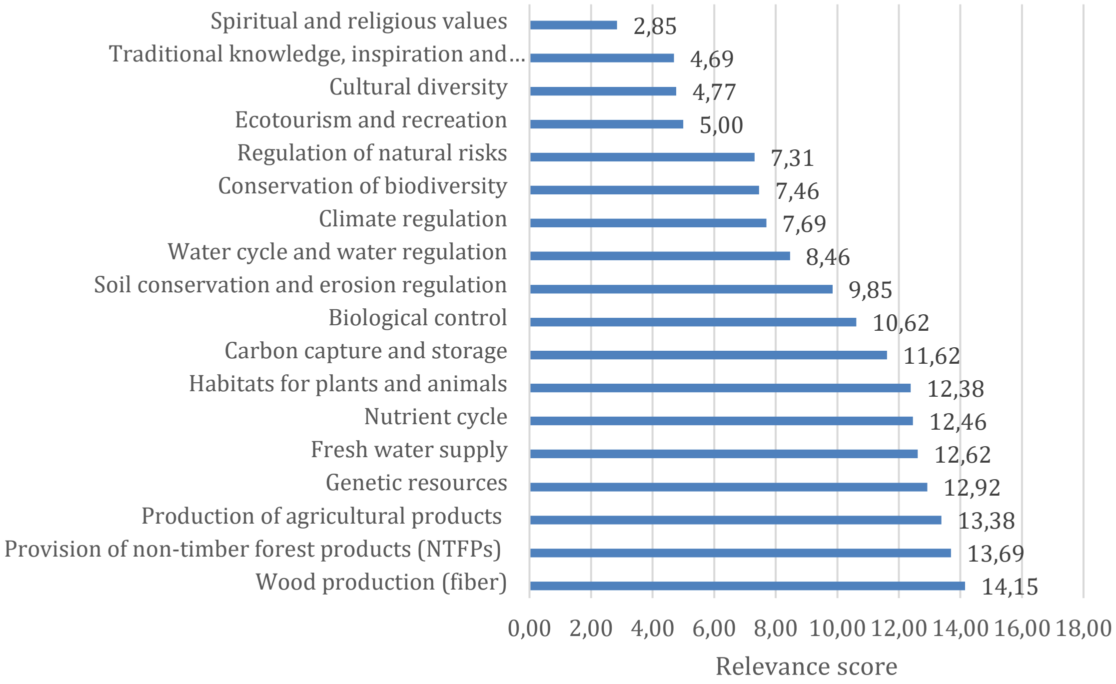

Figure I.3: Relevance scores, for the private stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

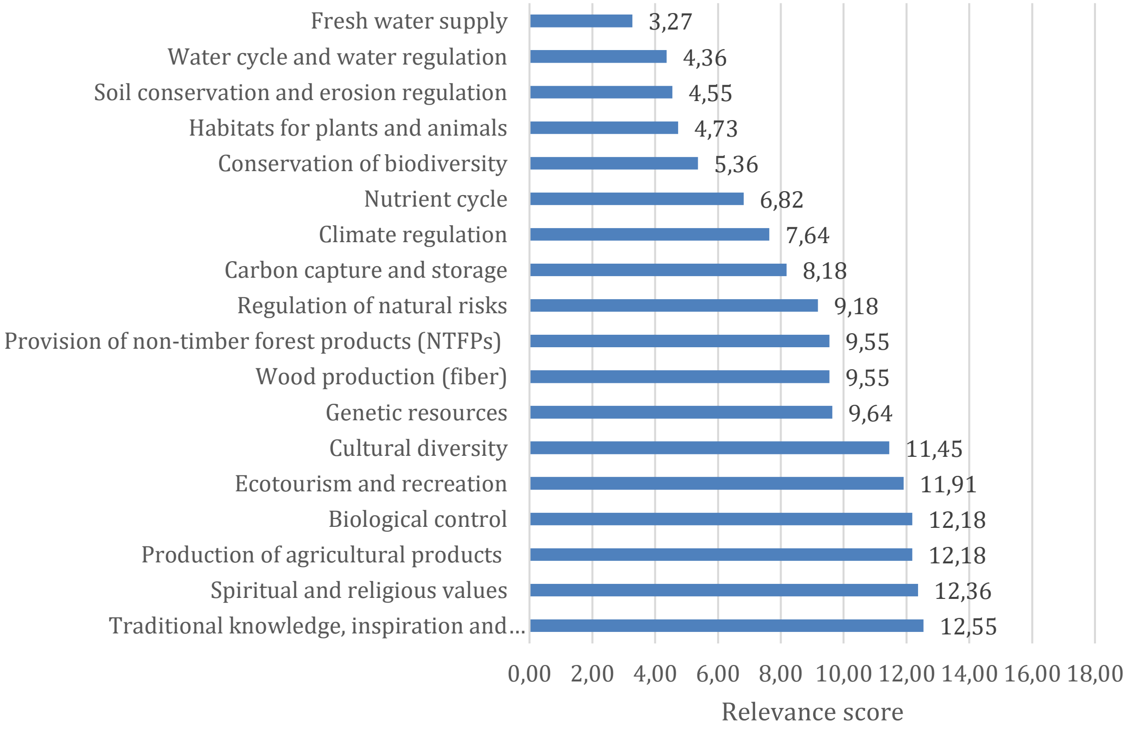

Figure I.4: Relevance scores, for the ‘academic: students’ stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

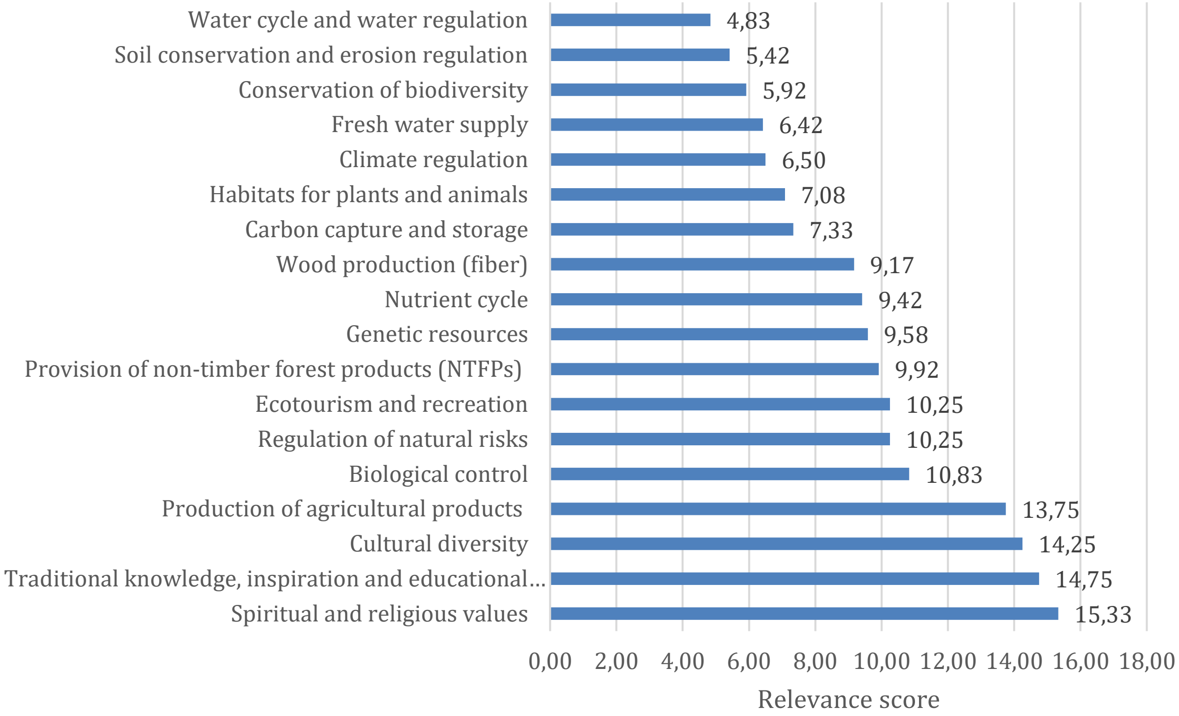

Figure I.6: Relevance scores, for the 'academic: work' stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

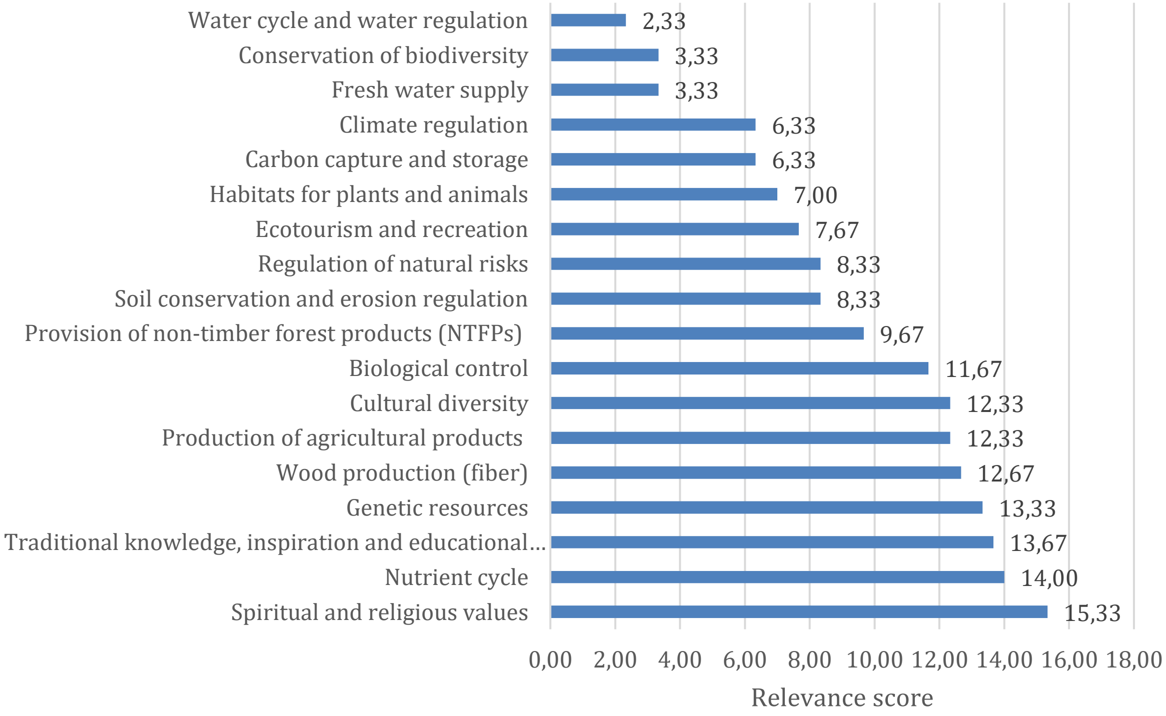

Figure I.7: Relevance scores, for the 'A FSC certification body, responsible for the allocation and management of FSC certification' stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

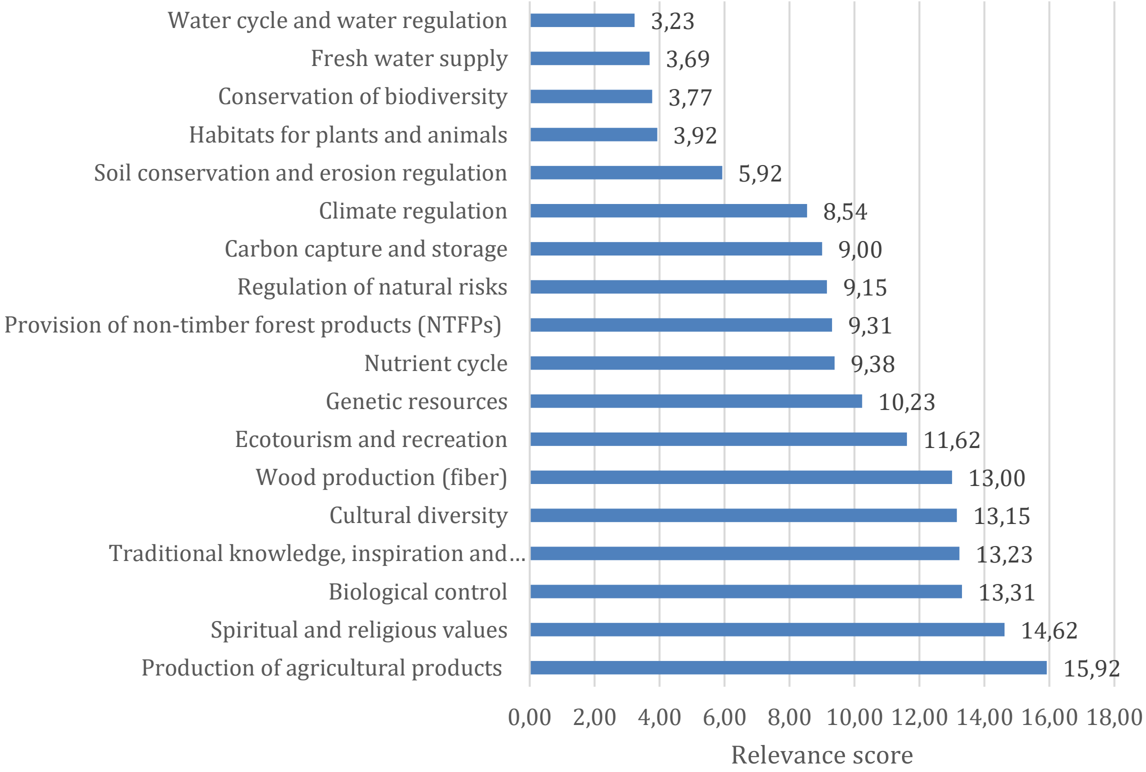

Figure I.8: Relevance scores, for the ‘partner of the FSC network’ stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance

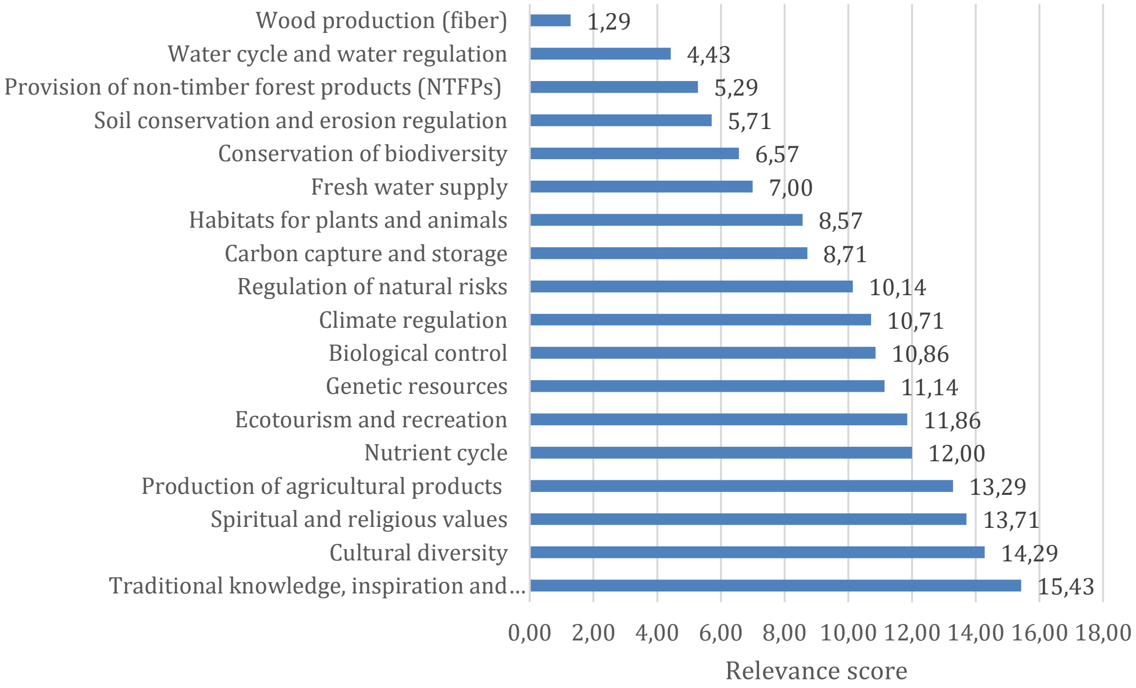

Figure I.9: Relevance scores, for the ‘company owning FSC certified forests’ stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

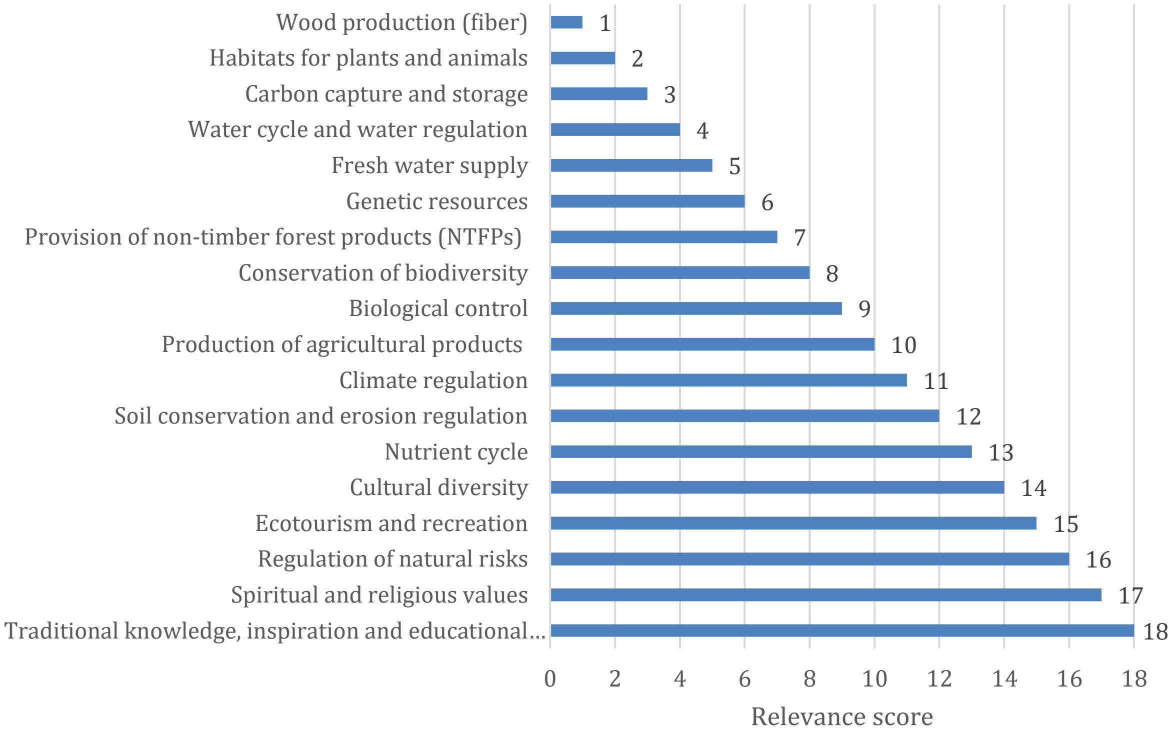

Figure I.10: Relevance scores, for the 'Investigation, but at private institution, not academy' stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

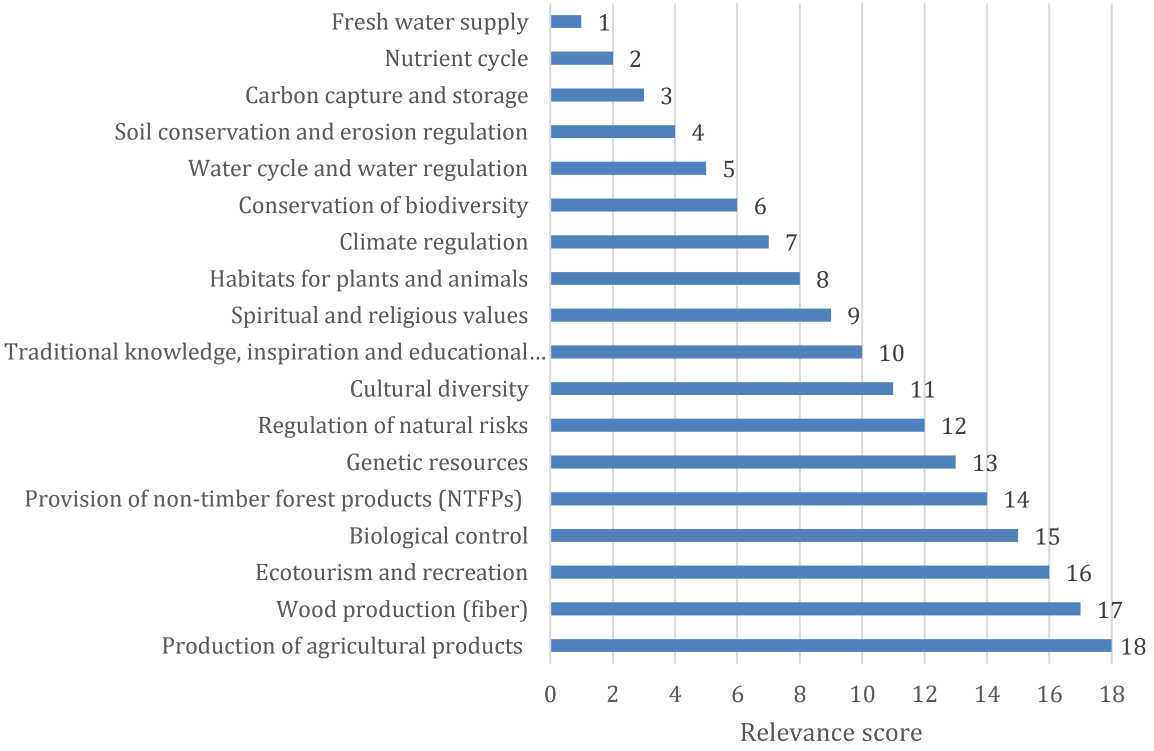

Figure I.11: Relevance scores, for the 'Ex-member of the FSC network' stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance

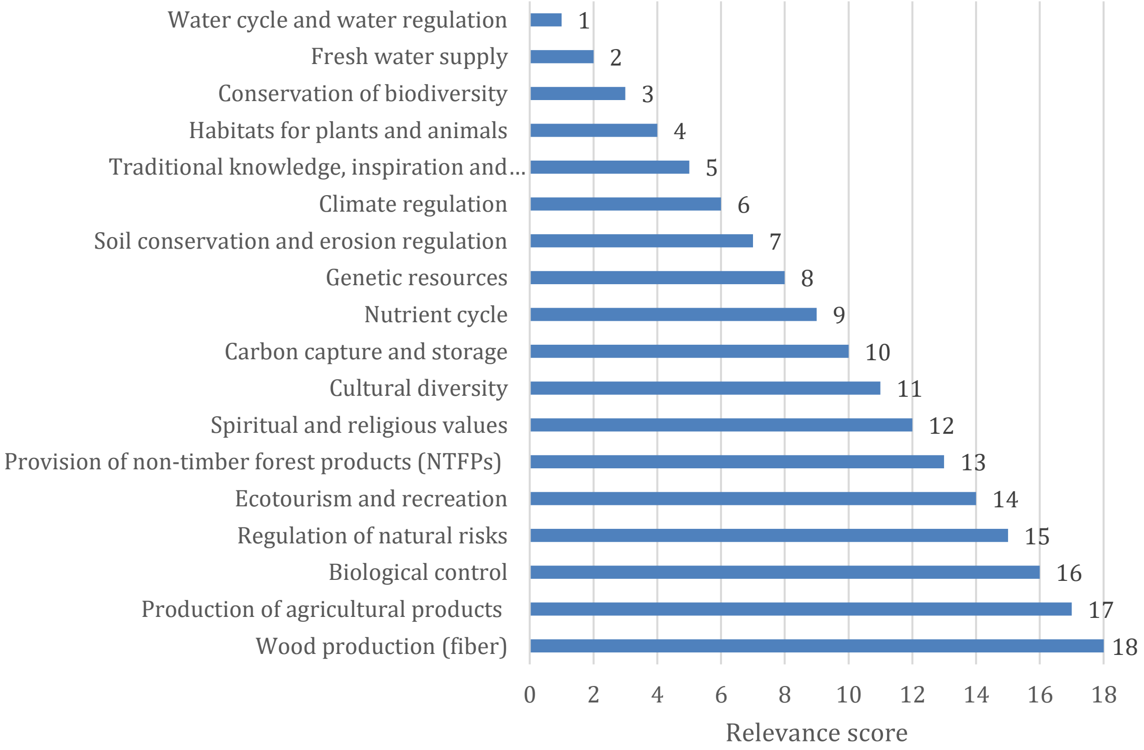

Figure I.12: Relevance scores, for the 'Eventual informant within the processes of the FSC evaluation processes' stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

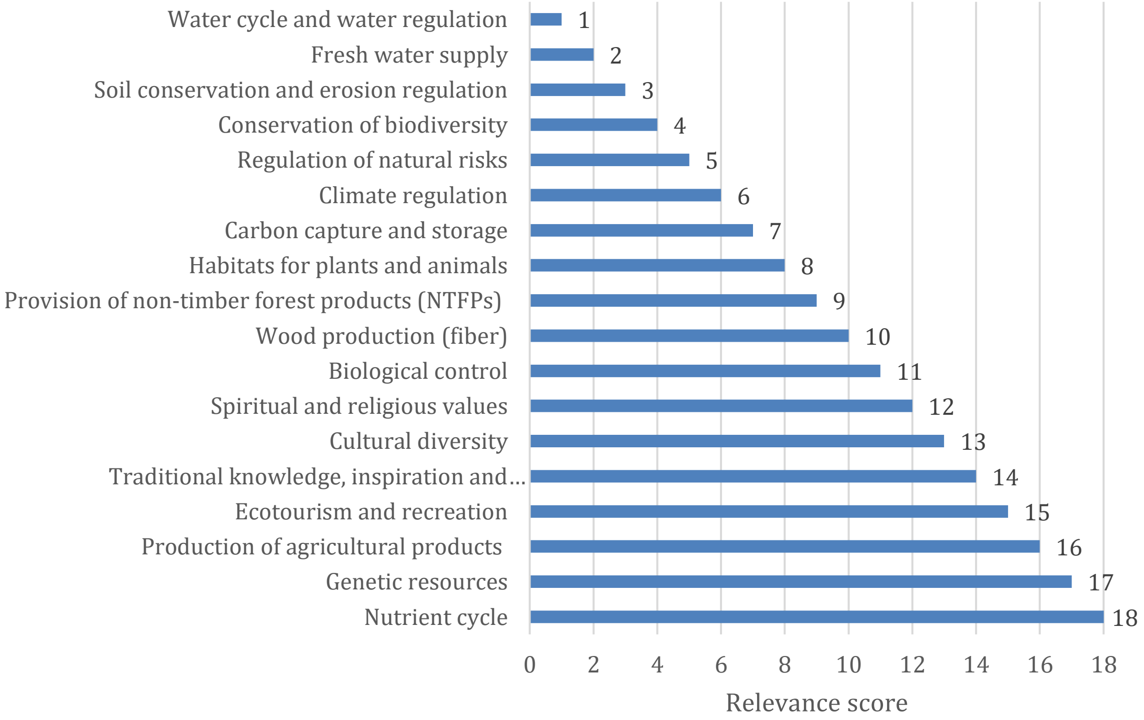

Figure I.13: Relevance scores, for the 'scarce relation' stakeholder group, representing the relevance of each ES to be evaluated in relation to FSC certification impacts (lower relevance scores correspond to the highest relevance)

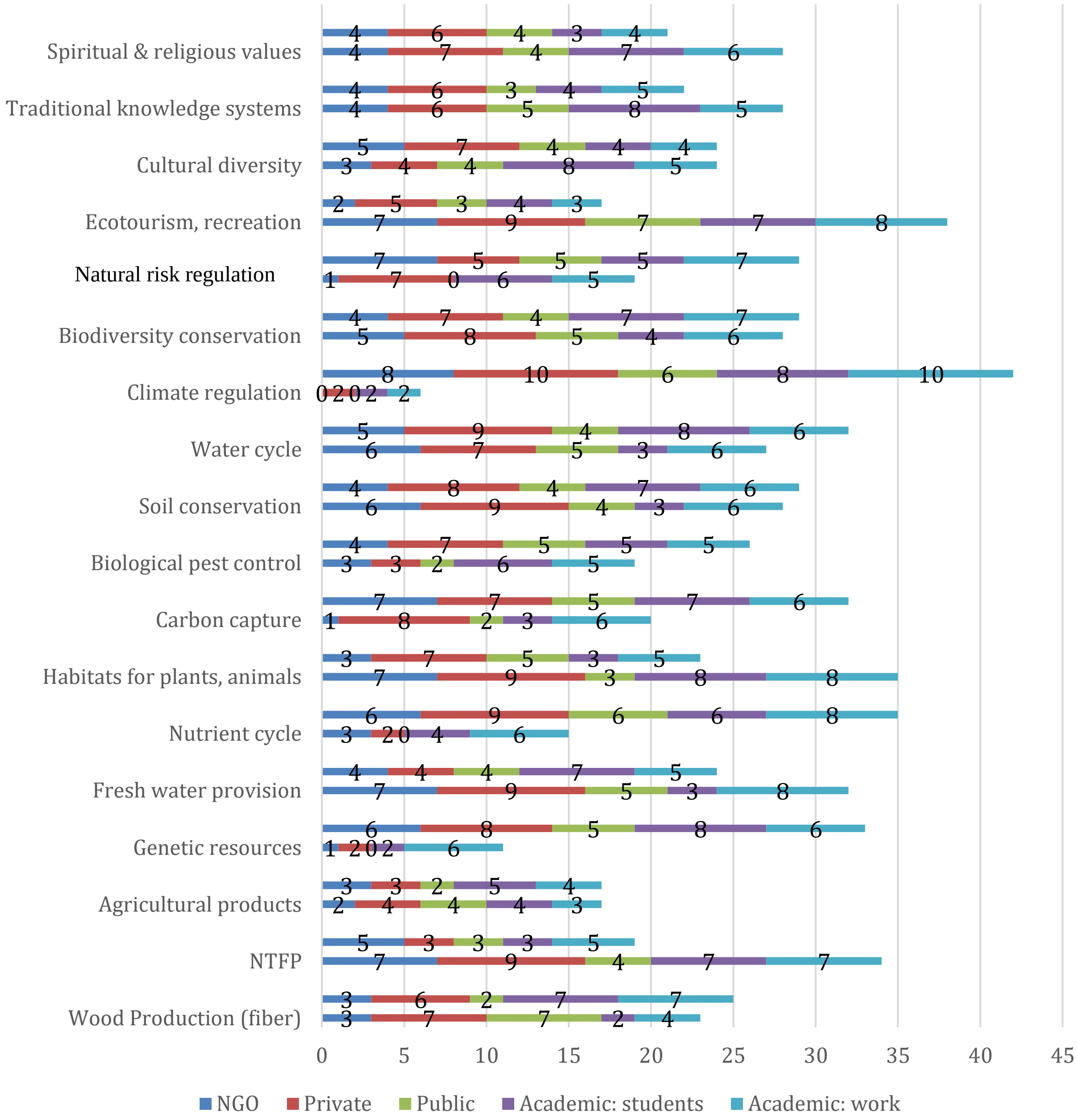

Figure I.14: Number of stakeholder votes for each ES, related to the relevance for evaluation in the short term (≤ 10 years, lower bar) and in the long term (> 10 years, upper bar)

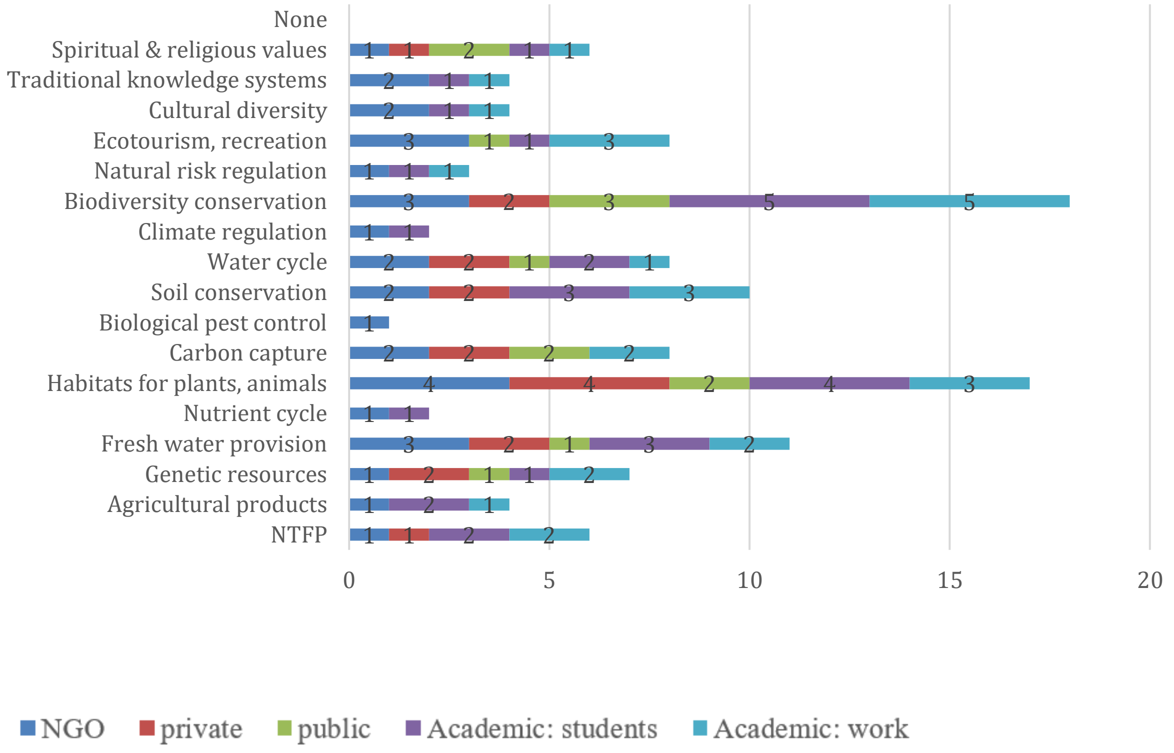

Figure I.15: Trade-offs between wood production and other ES, with the number of votes of each stakeholder groups for the trade-off

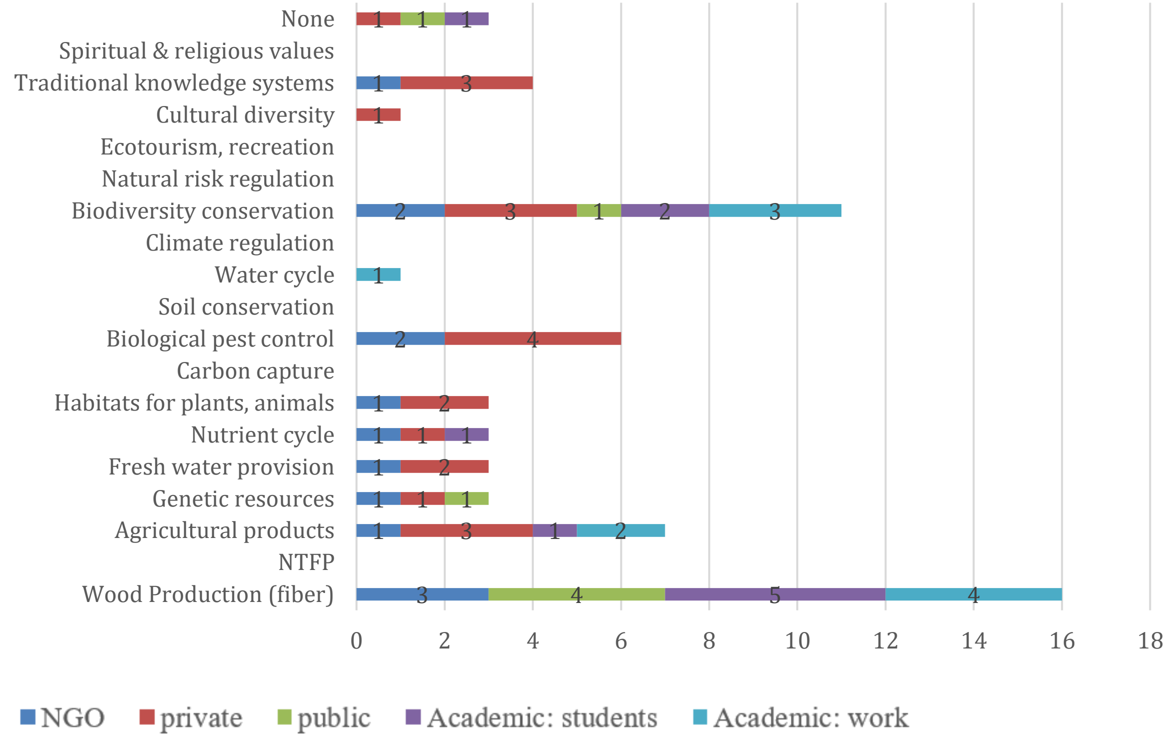

Figure I.16: Trade-offs between NTFPs supply and other ES, with the number of votes of each stakeholder groups for the trade-off

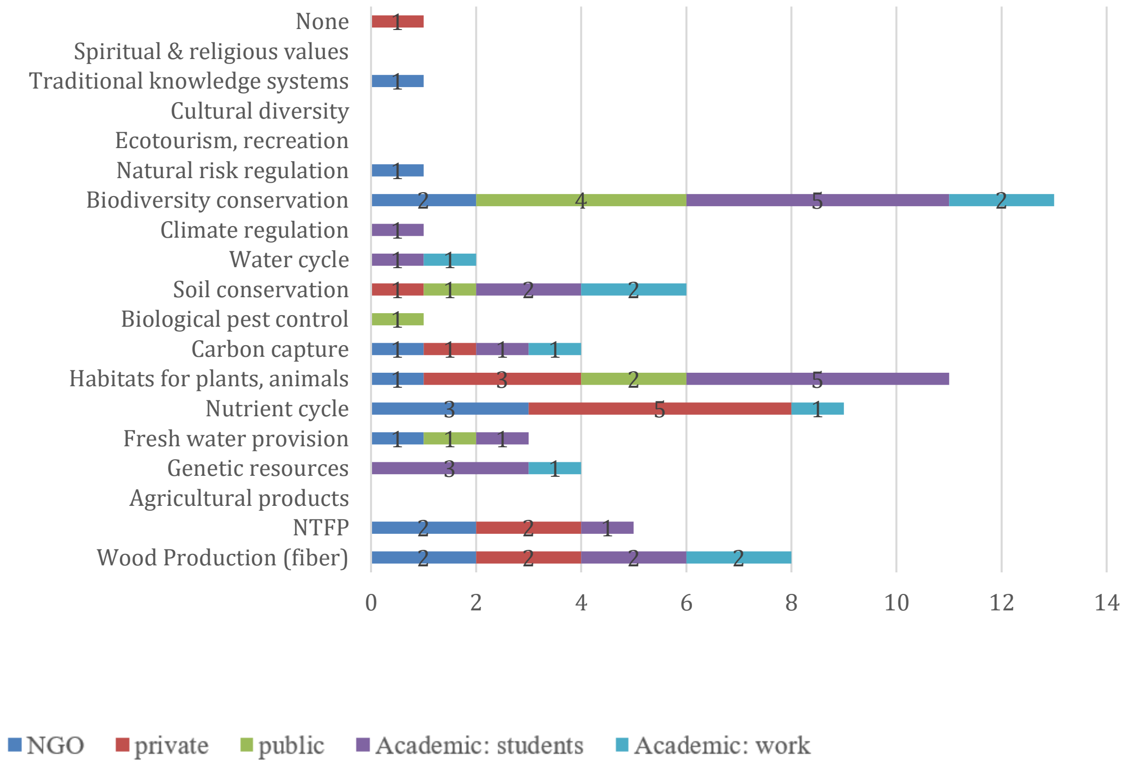

Figure I.17: Trade-offs between the production of agricultural products and other ES, with the number of votes of each stakeholder groups for the trade-off

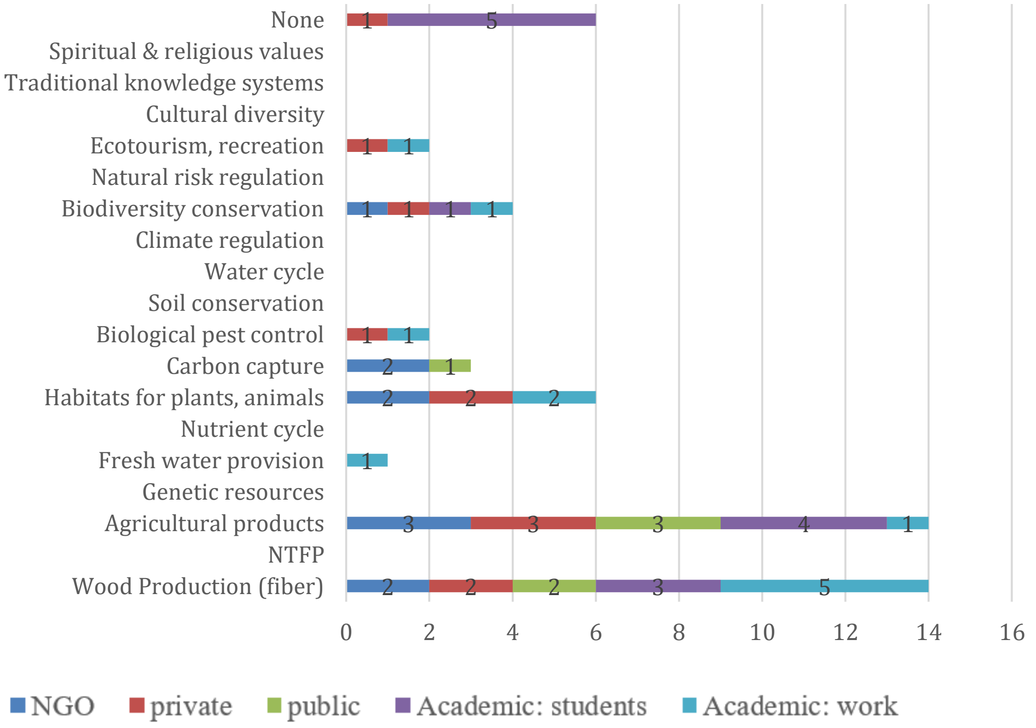

Figure I.18: Trade-offs between genetic resources and other ES, with the number of votes of each stakeholder groups for the trade-off

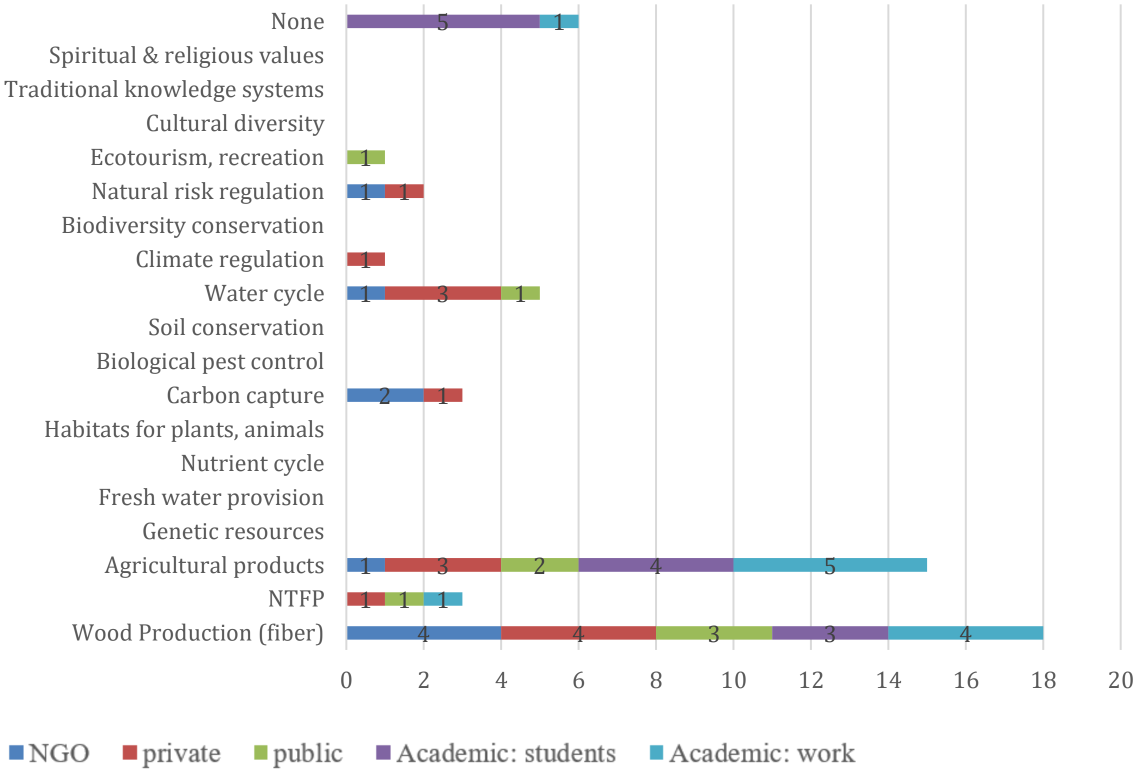

Figure I.19: Trade-offs between fresh water supply and other ES, with the number of votes of each stakeholder groups for the trade-off

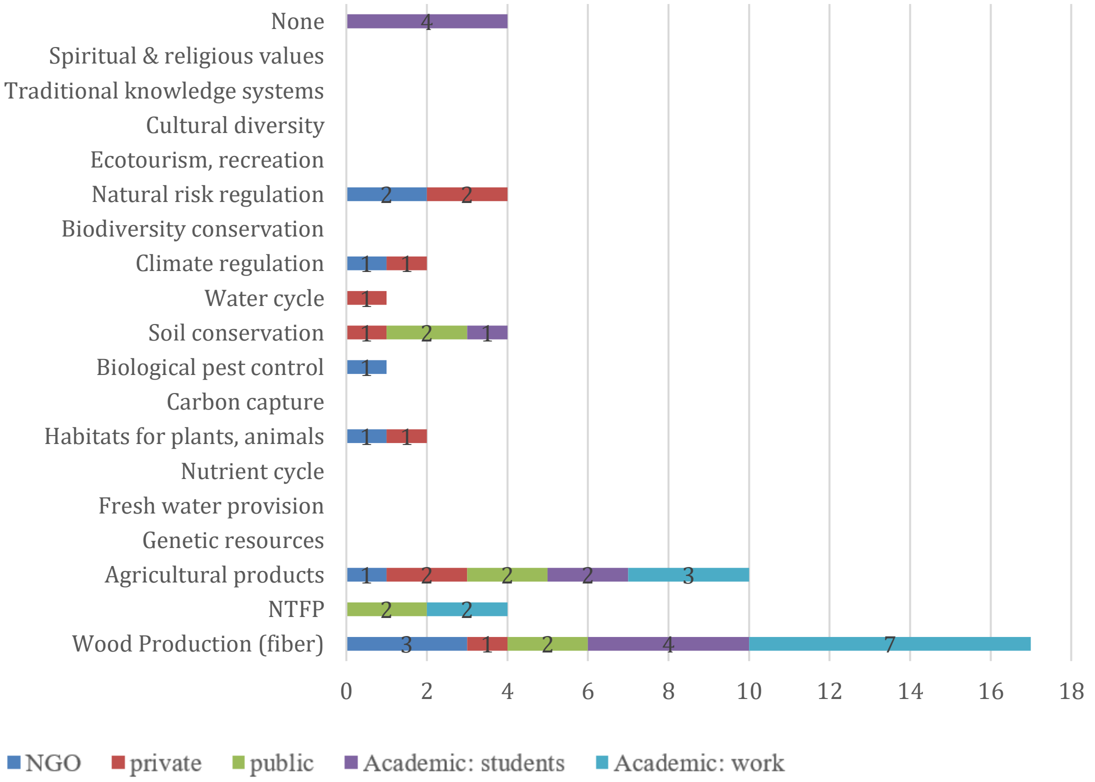

Figure I.20: Trade-offs between nutrient cycle and other ES, with the number of votes of each stakeholder groups for the trade-off

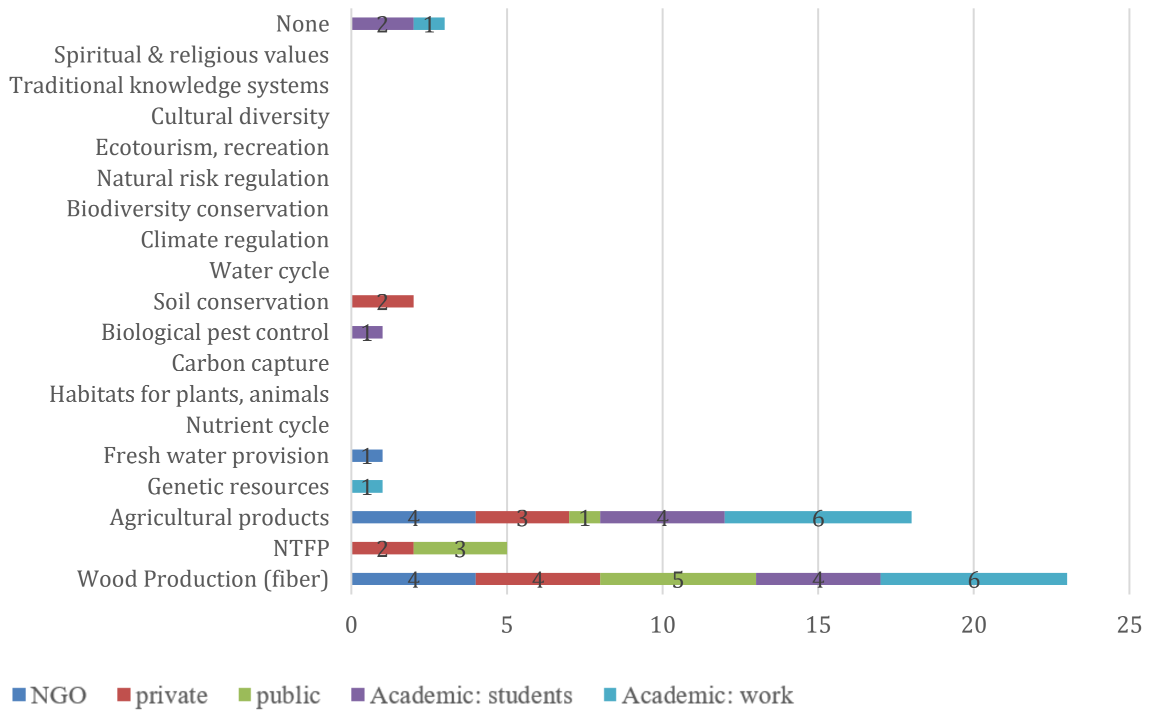

Figure I.21: Trade-offs between habitats for plants and animals and other ES, with the number of votes of each stakeholder groups for the trade-off

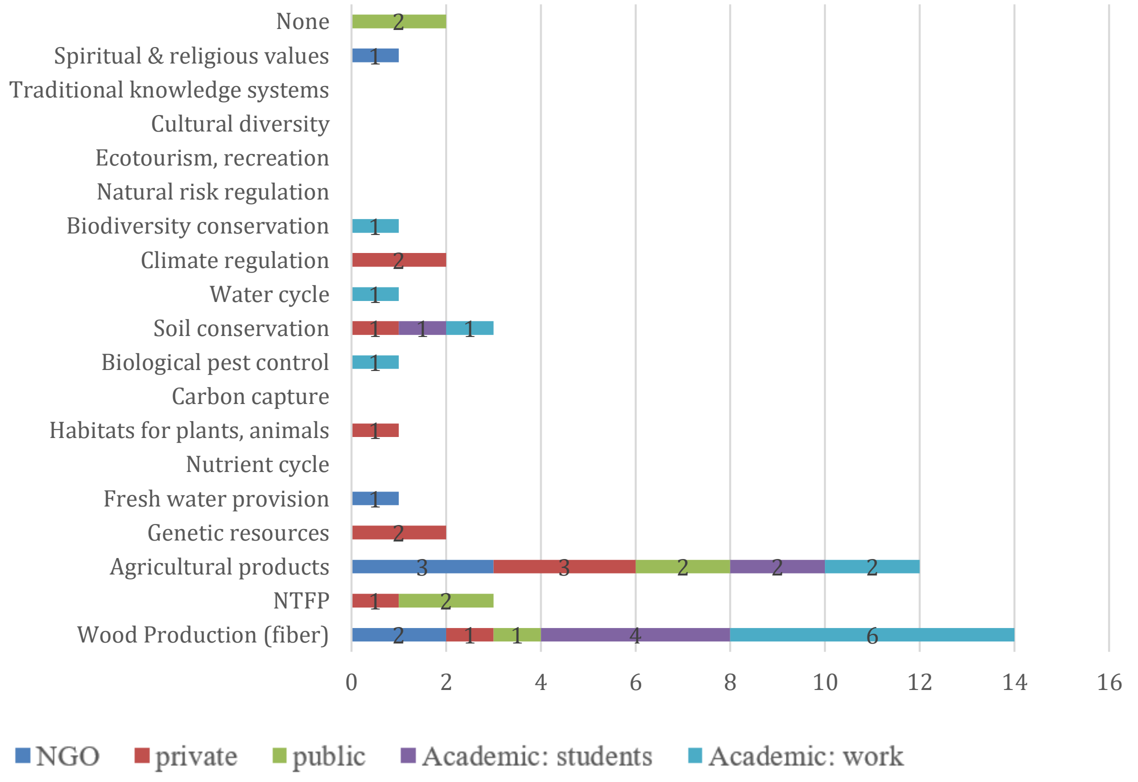

Figure I.22: Trade-offs between carbon capture and storage and other ES, with the number of votes of each stakeholder groups for the trade-off

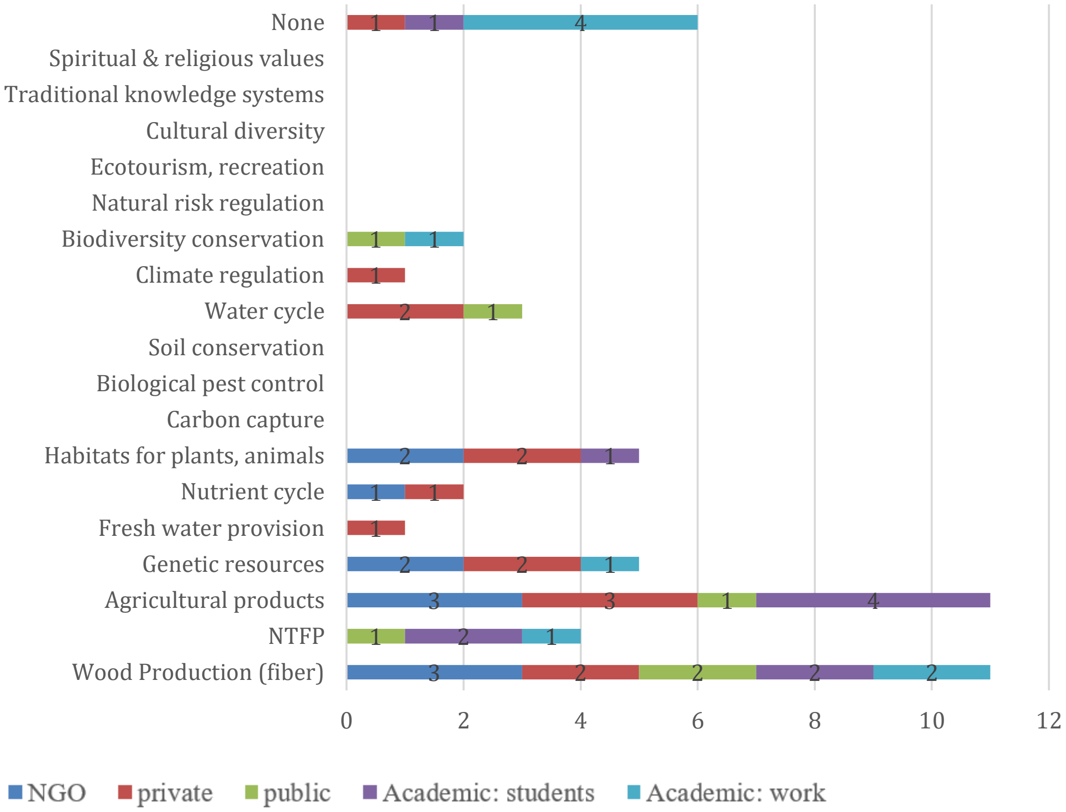

Figure I.23: Trade-offs between biological pest control and other ES, with the number of votes of each stakeholder groups for the trade-off

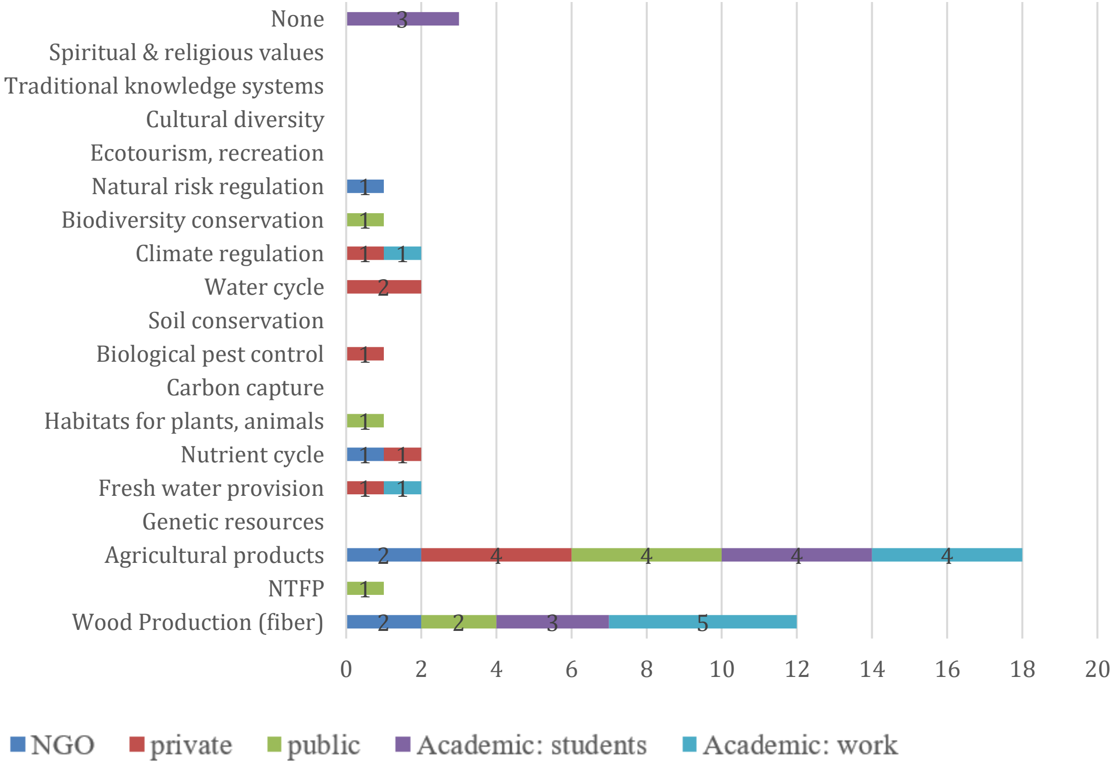

Figure I.24: Trade-offs between soil conservation and erosion regulation and other ES, with the number of votes of each stakeholder groups for the trade-off

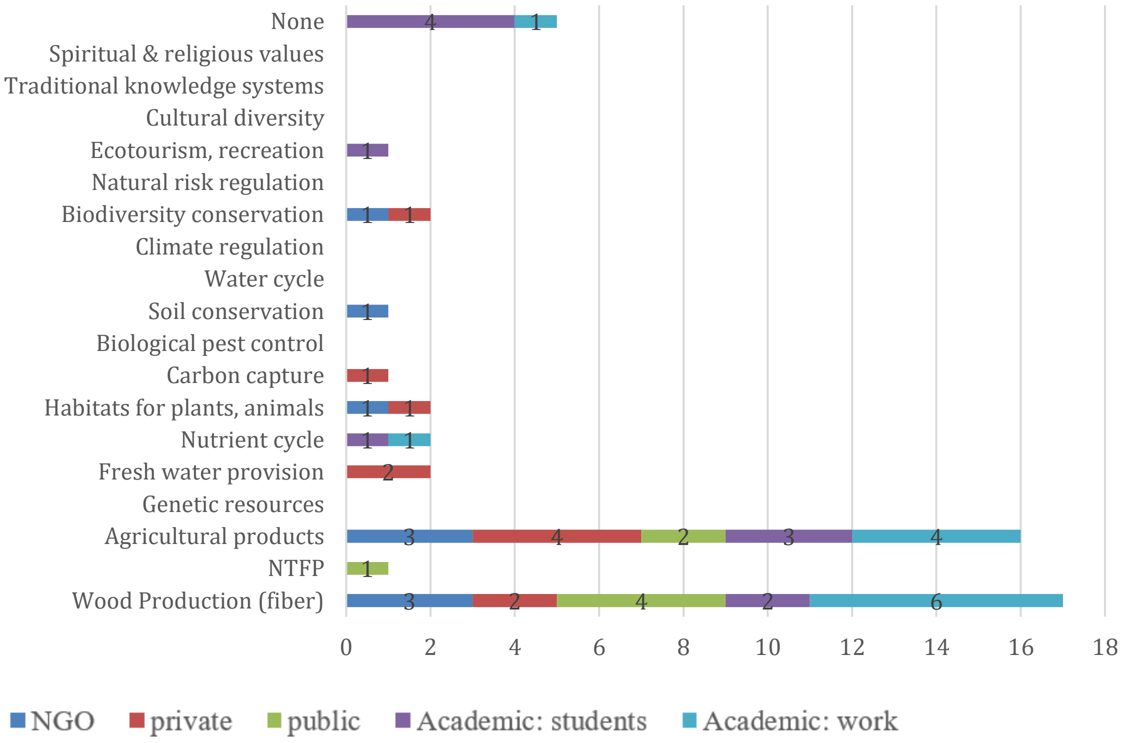

Figure I.25: Trade-offs between water cycle and water regulation and other ES, with the number of votes of each stakeholder groups for the trade-off

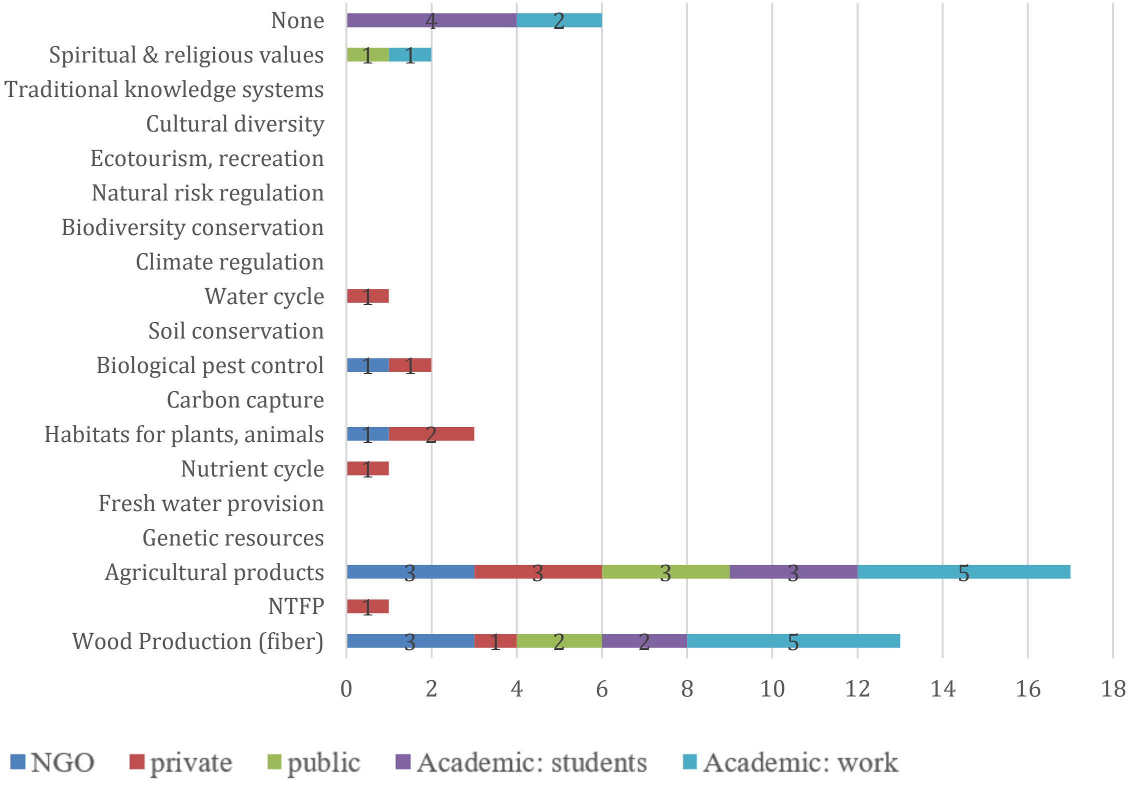

Figure I.26: Trade-offs between climate regulation and other ES, with the number of votes of each stakeholder groups for the trade-off

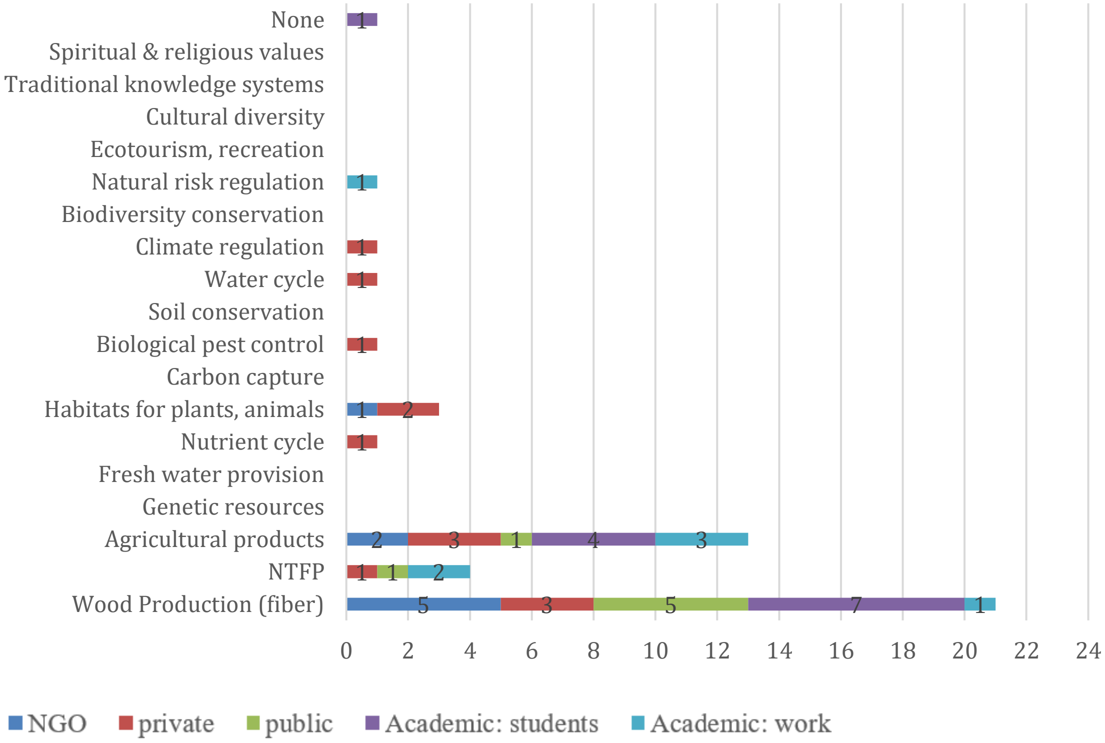

Figure I.27: Trade-offs between biodiversity conservation and other ES, with the number of votes of each stakeholder groups for the trade-off

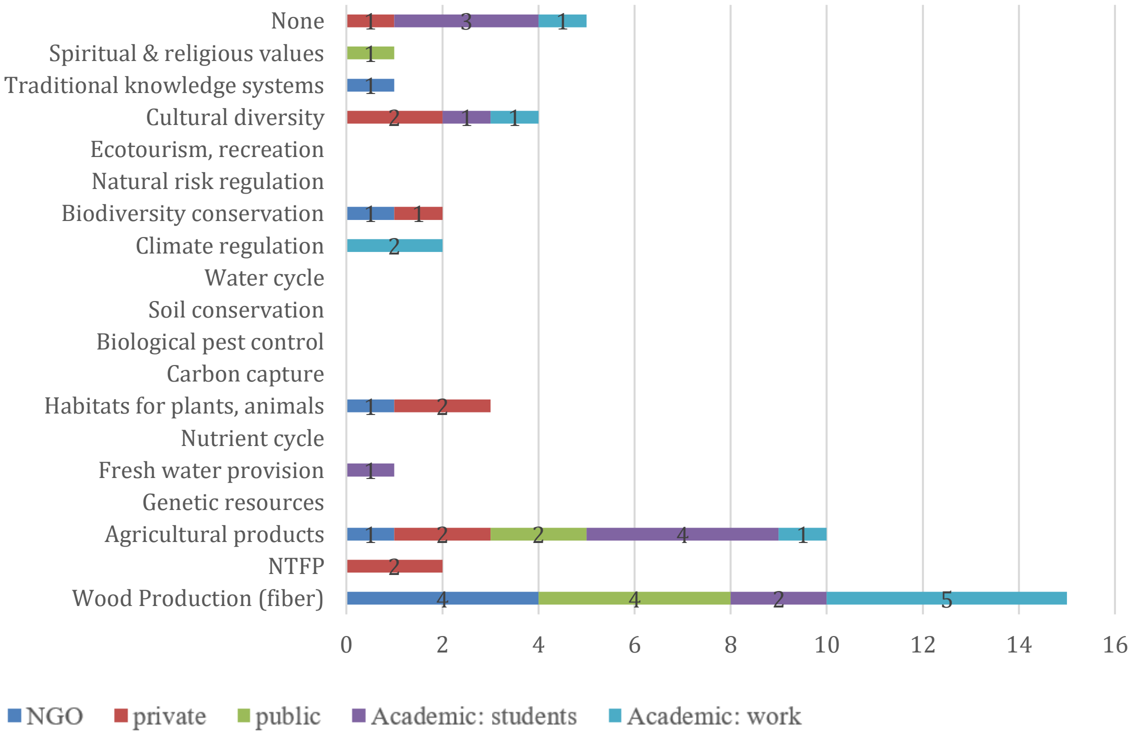

Figure I.28: Trade-offs between natural risk regulation and other ES, with the number of votes of each stakeholder groups for the trade-off

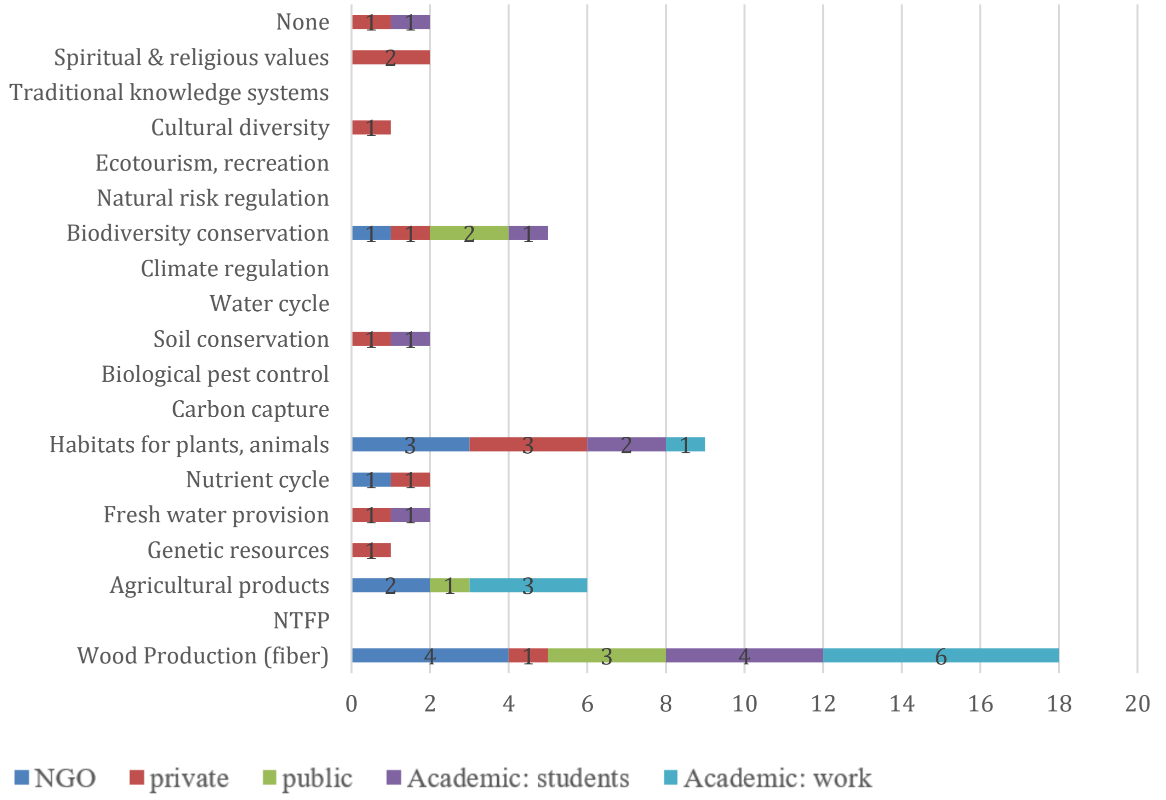

Figure I.29: Trade-offs between ecotourism and recreation and other ES, with the number of votes of each stakeholder groups for the trade-off

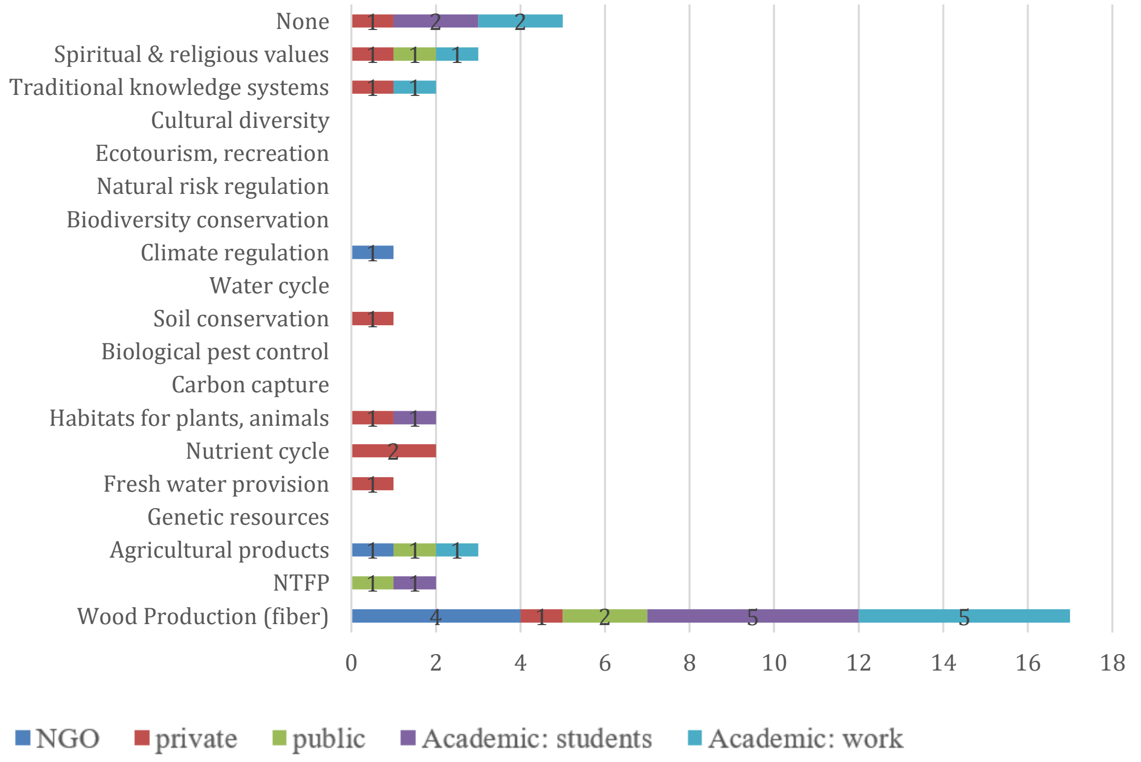

Figure I.30: Trade-offs between cultural diversity and other ES, with the number of votes of each stakeholder groups for the trade-off

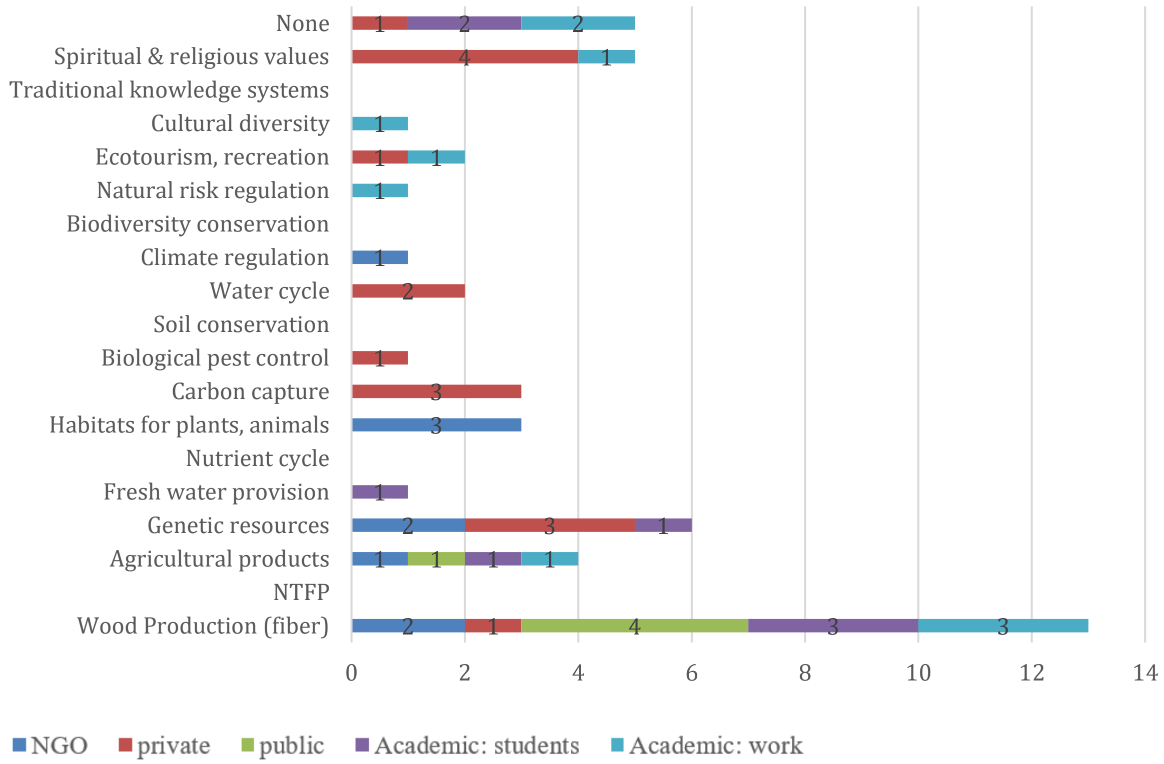

Figure I.31: Trade-offs between traditional knowledge, inspiration and educational values and other ES, with the number of votes of each stakeholder groups for the trade-off

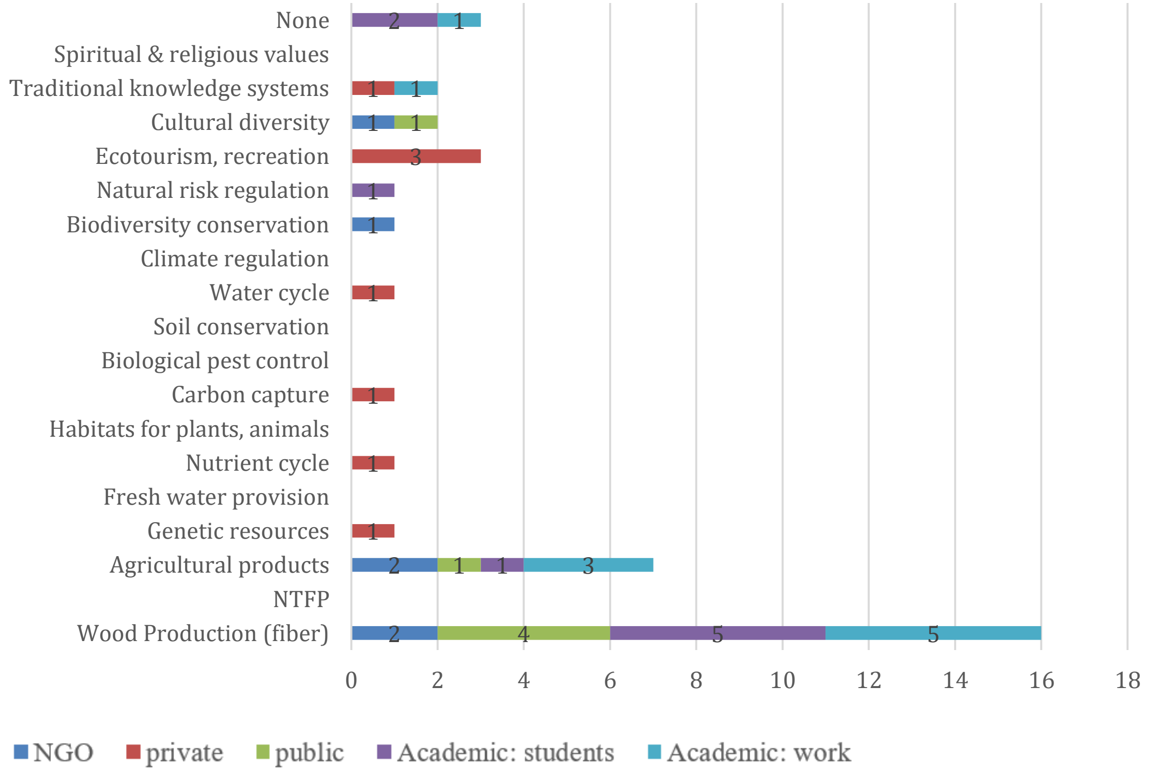

Figure I.32: Trade-offs between spiritual and religious values and other ES, with the number of votes of each stakeholder groups for the trade-off

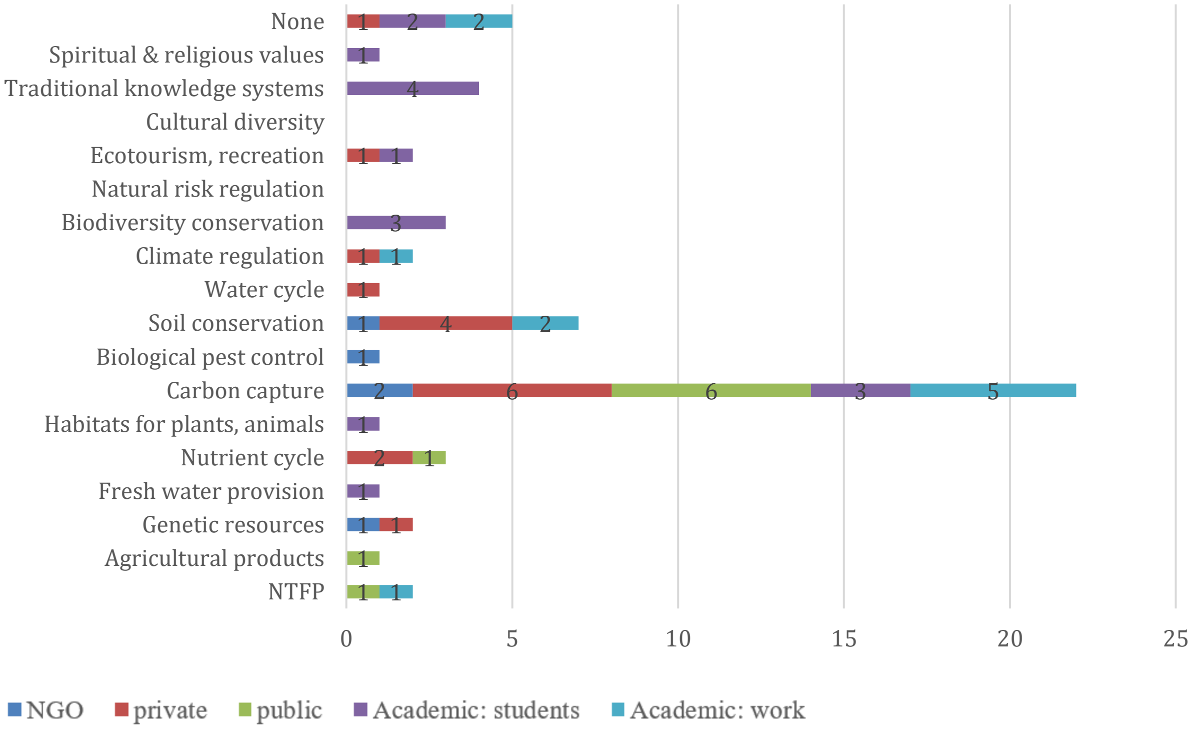

Figure I.33: Synergies between wood production and other ES, with the number of votes of each stakeholder groups for the synergies

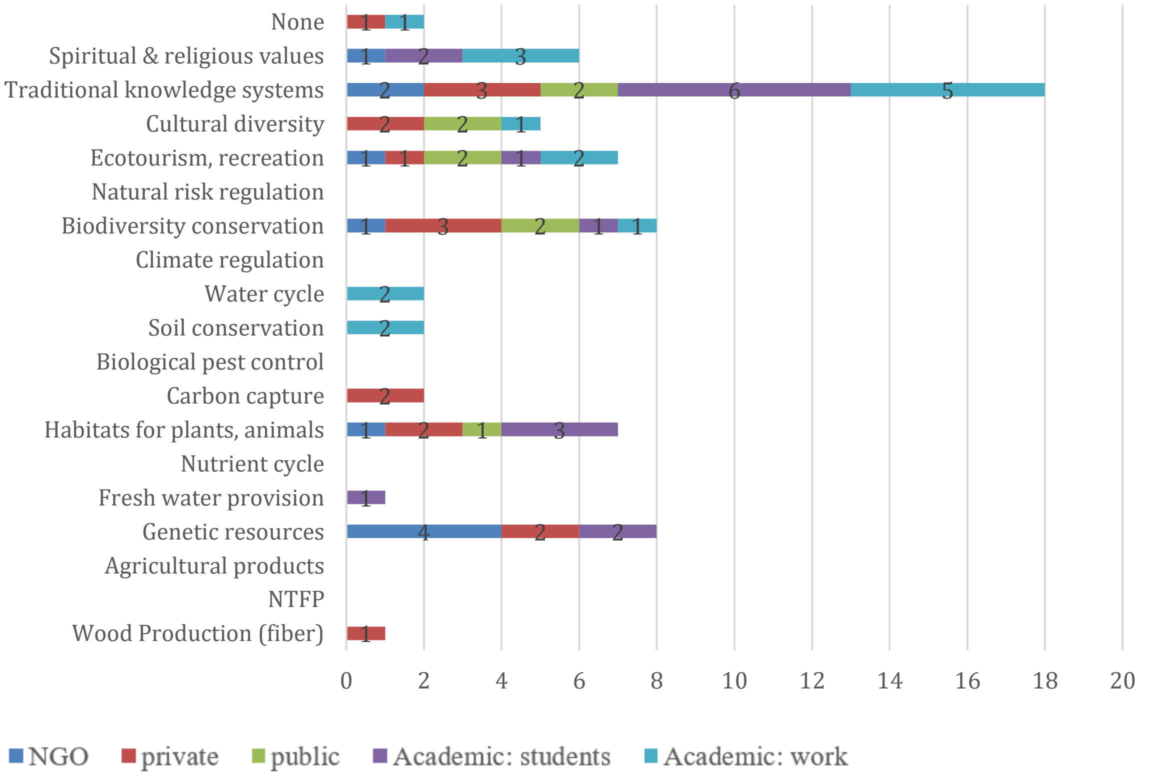

Figure I.34: Synergies between provision of NTFPs and other ES, with the number of votes of each stakeholder groups for the synergies

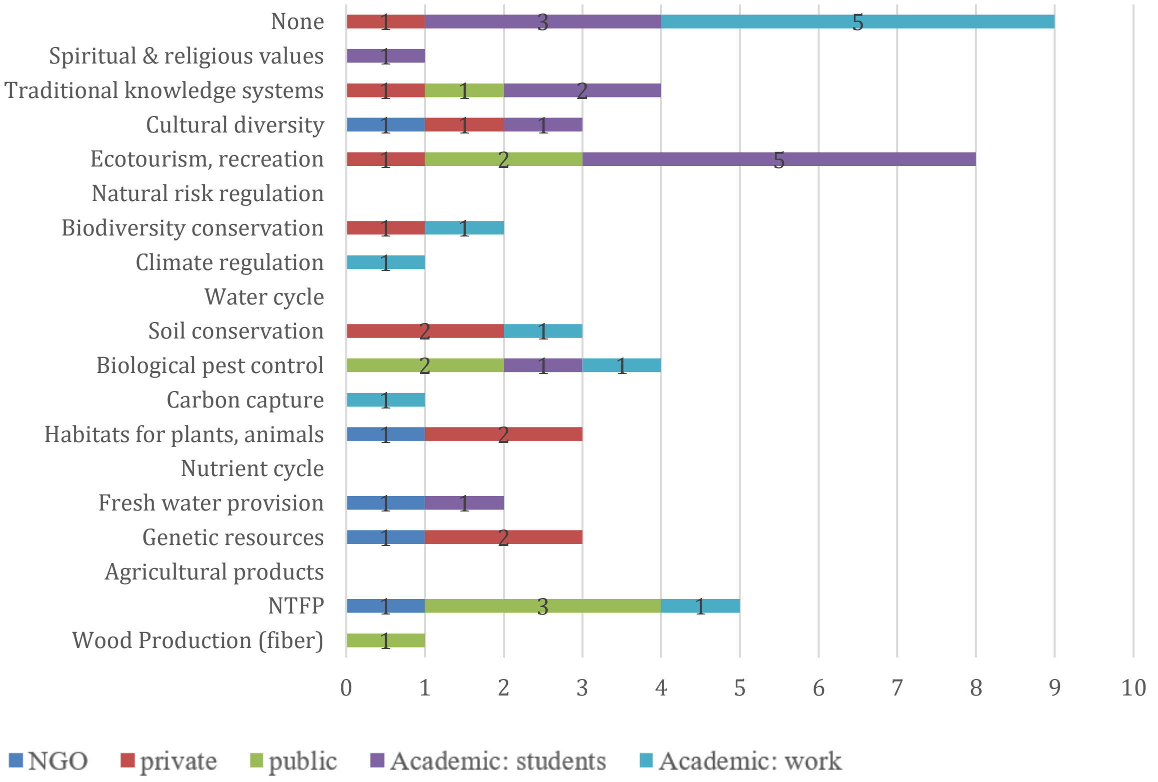

Figure I.35: Synergies between the production of agricultural products and other ES, with the number of votes of each stakeholder groups for the synergies

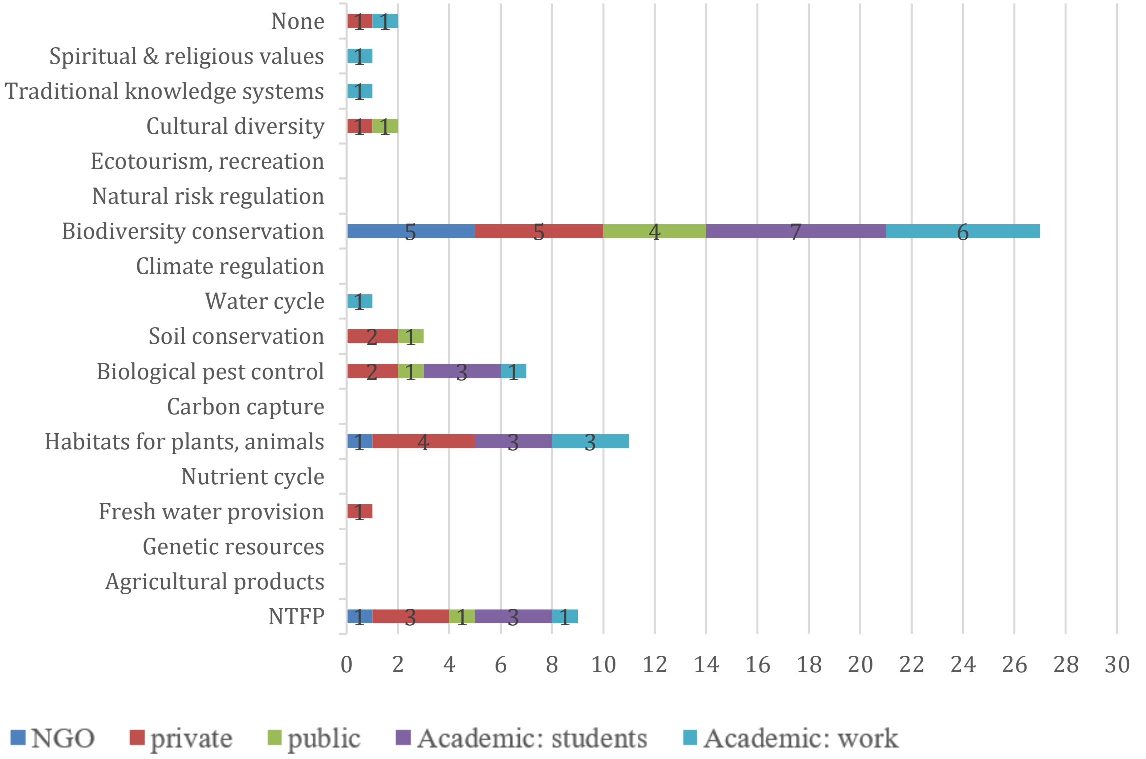

Figure I.36: Synergies between genetic resources and other ES, with the number of votes of each stakeholder groups for the synergies

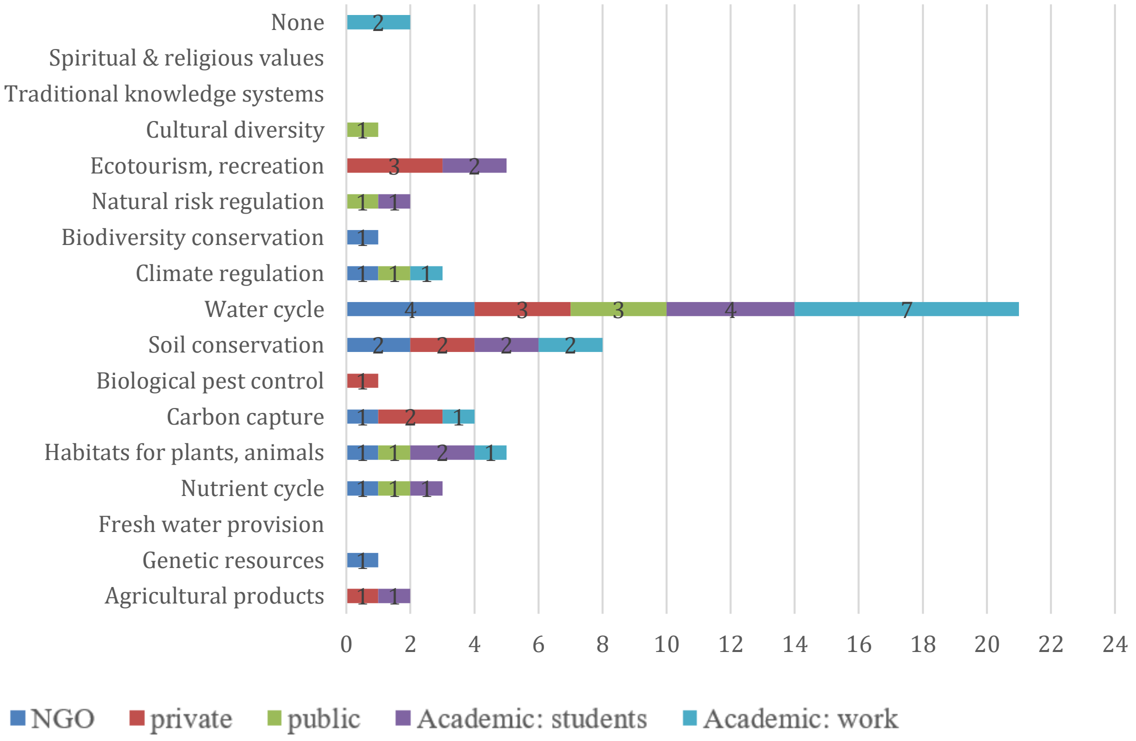

Figure I.37: Synergies between fresh water supply and other ES, with the number of votes of each stakeholder groups for the synergies

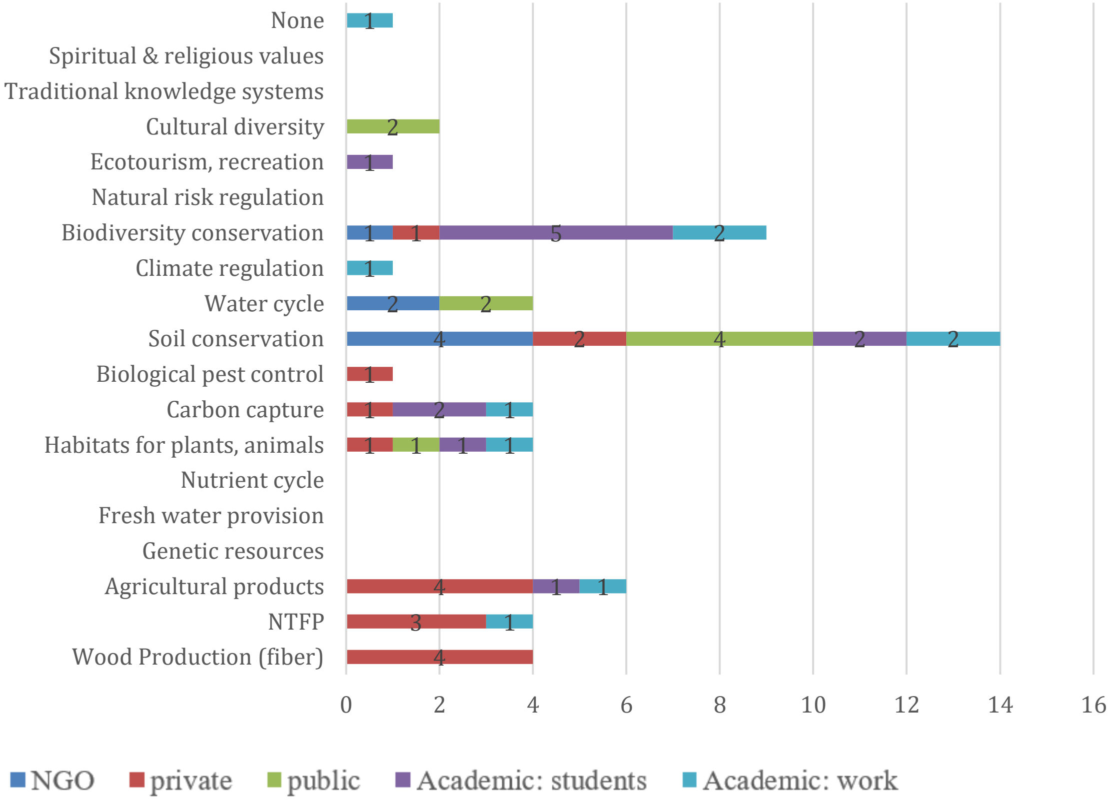

Figure I.38: Synergies between nutrient cycle and other ES, with the number of votes of each stakeholder groups for the synergies

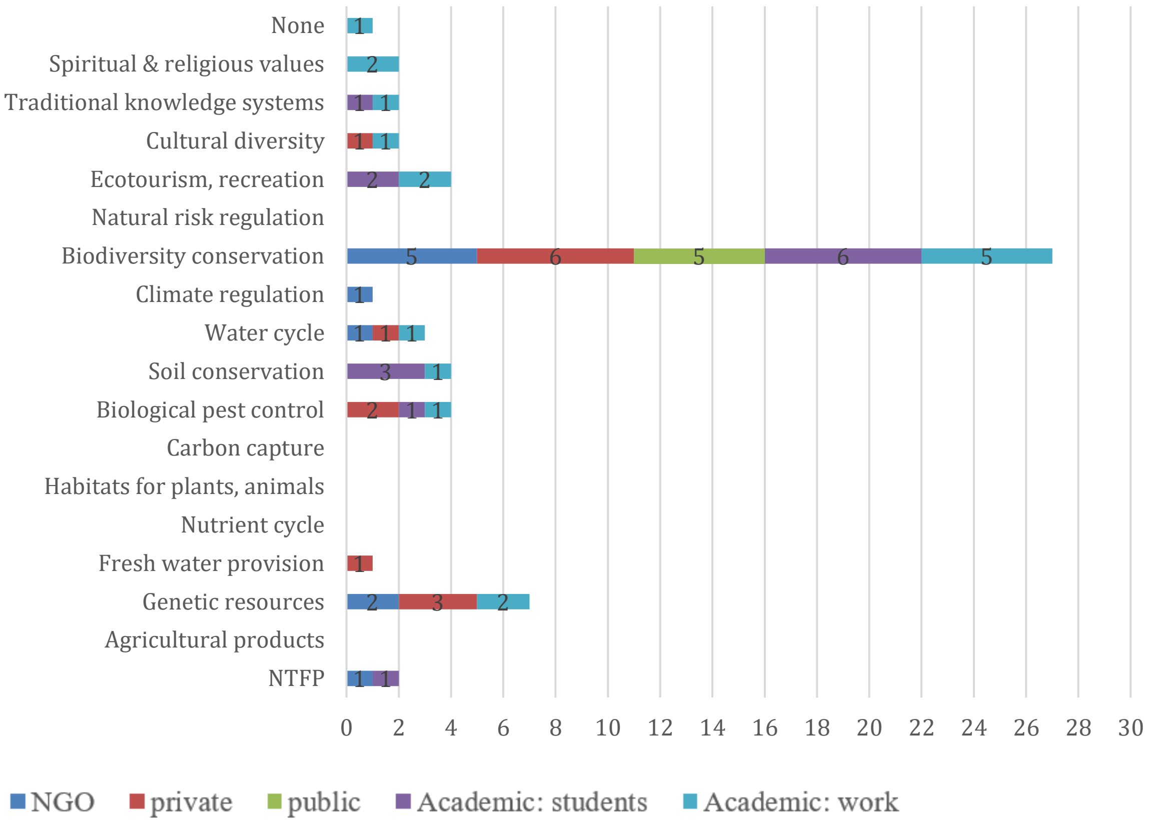

Figure I.39: Synergies between habitats for plants and animals and other ES, with the number of votes of each stakeholder groups for the synergies

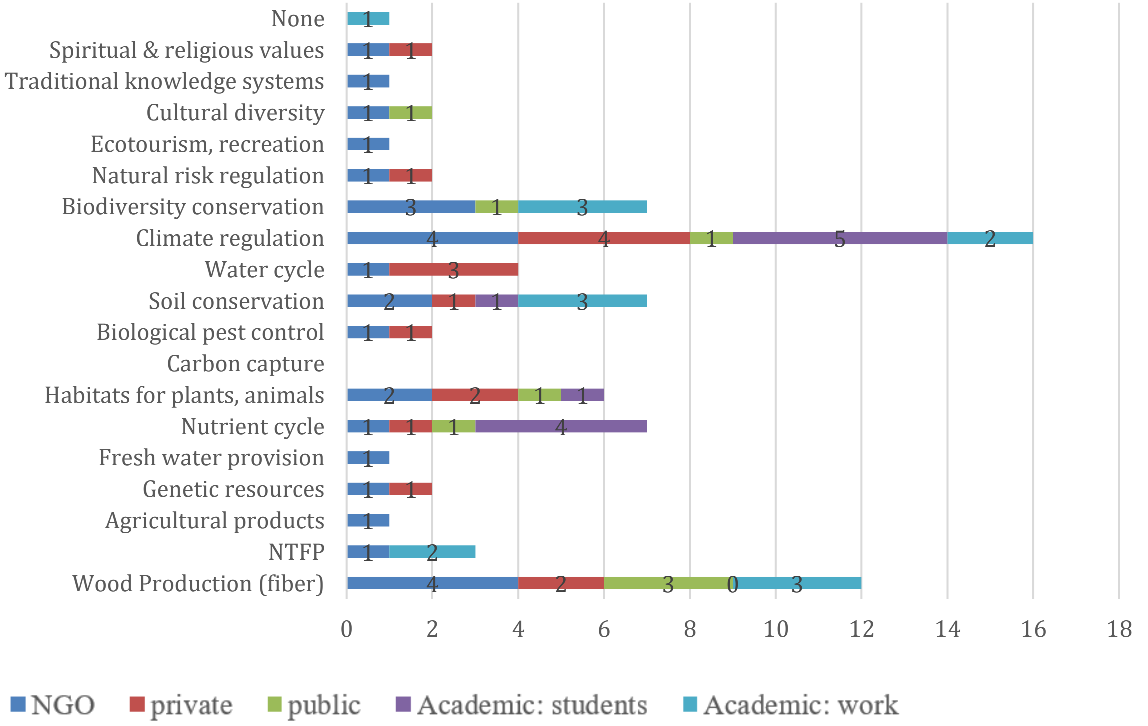

Figure I.40: Synergies between carbon capture and storage and other ES, with the number of votes of each stakeholder groups for the synergies

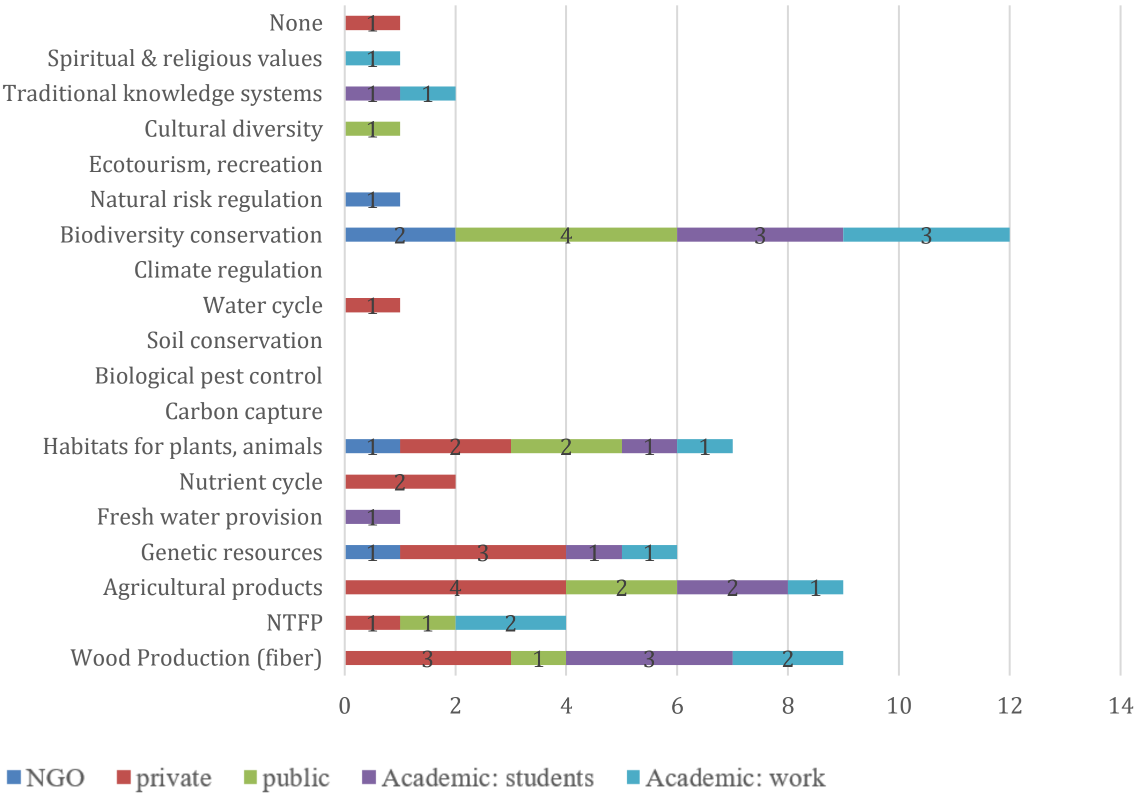

Figure I.41: Synergies between biological pest control and other ES, with the number of votes of each stakeholder groups for the synergies

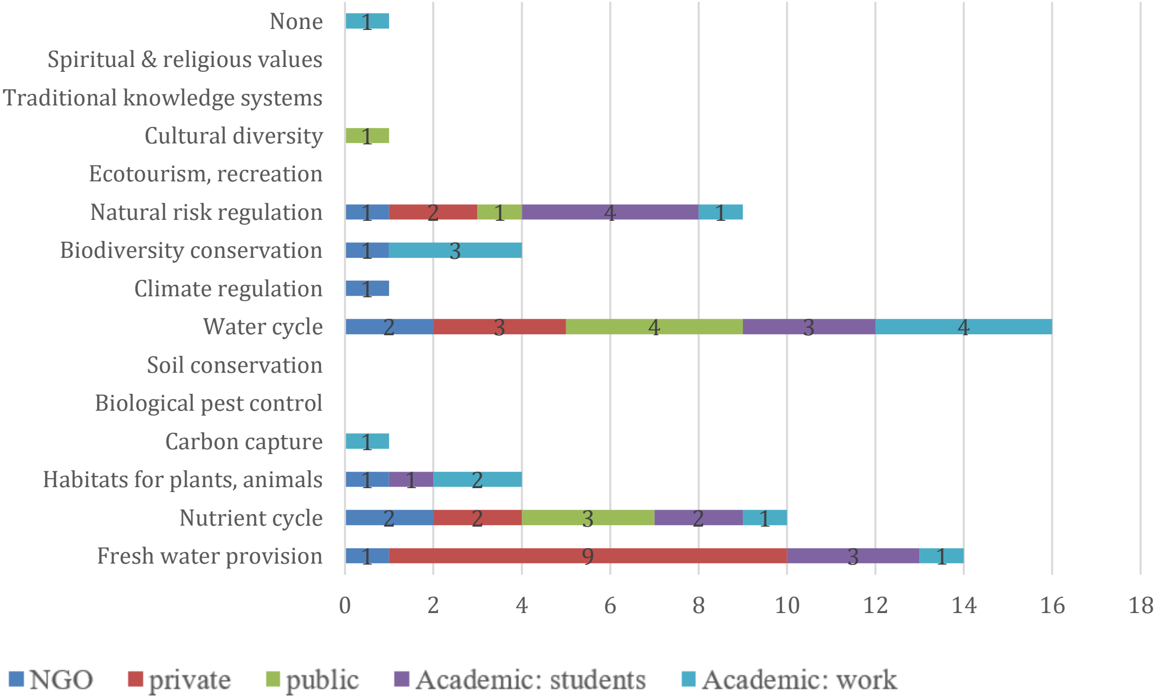

Figure I.42: Synergies between soil conservation and erosion regulation and other ES, with the number of votes of each stakeholder groups for the synergies

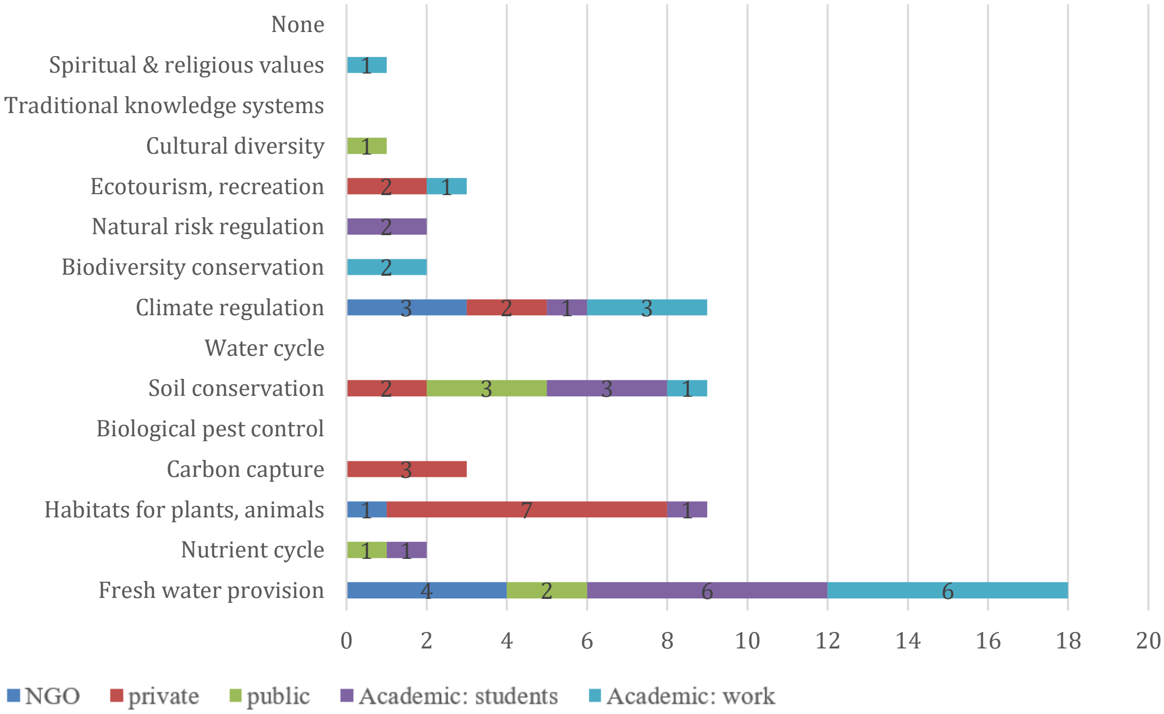

Figure I.43: Synergies between water cycle and water regulation and other ES, with the number of votes of each stakeholder groups for the synergies

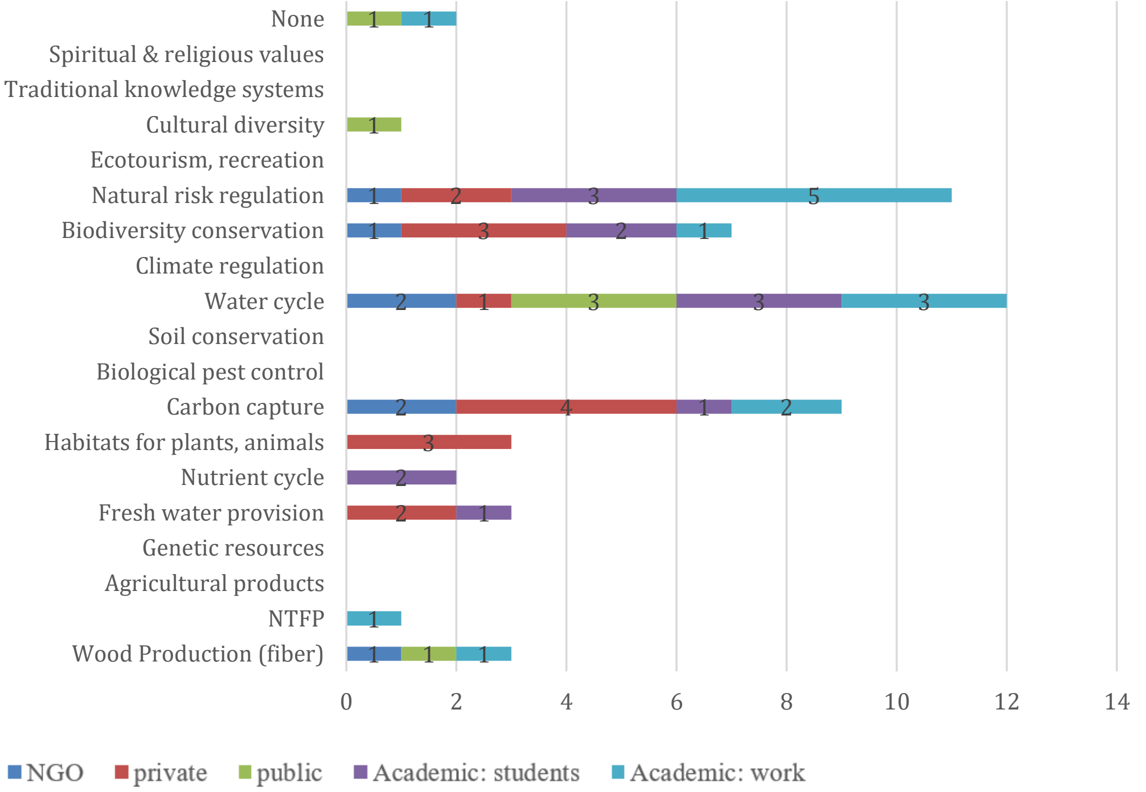

Figure I.44: Synergies between climate regulation and other ES, with the number of votes of each stakeholder groups for the synergies

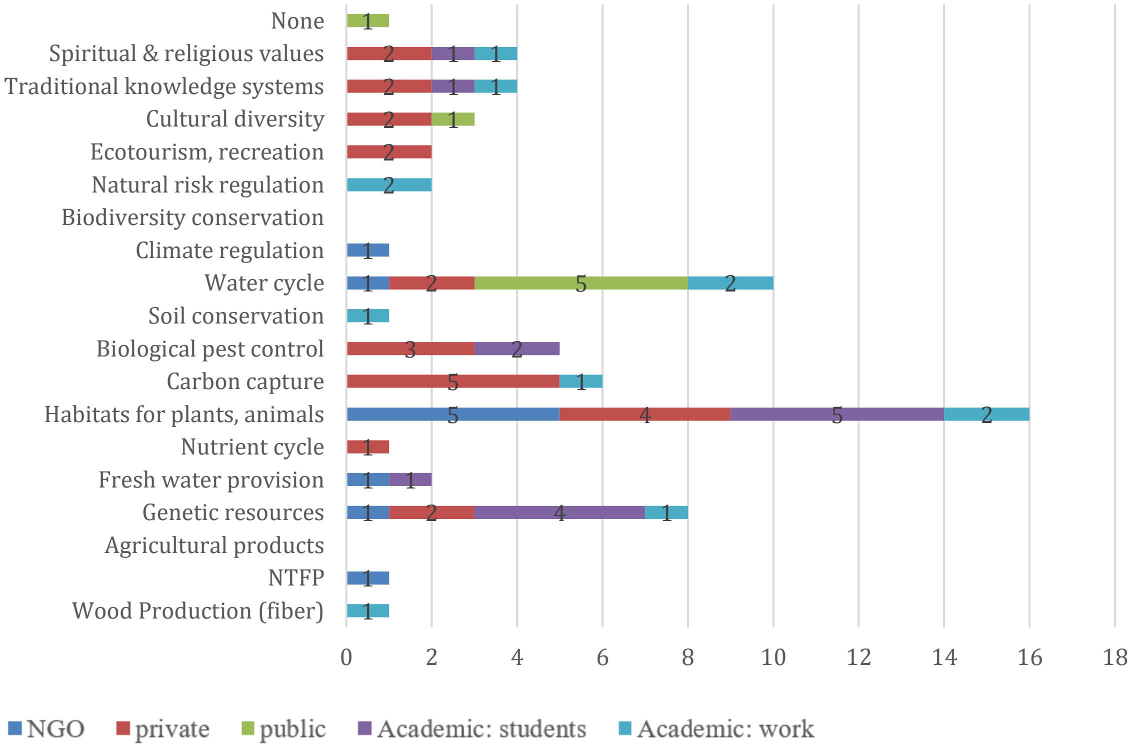

Figure I.45: Synergies between biodiversity conservation and other ES, with the number of votes of each stakeholder groups for the synergies

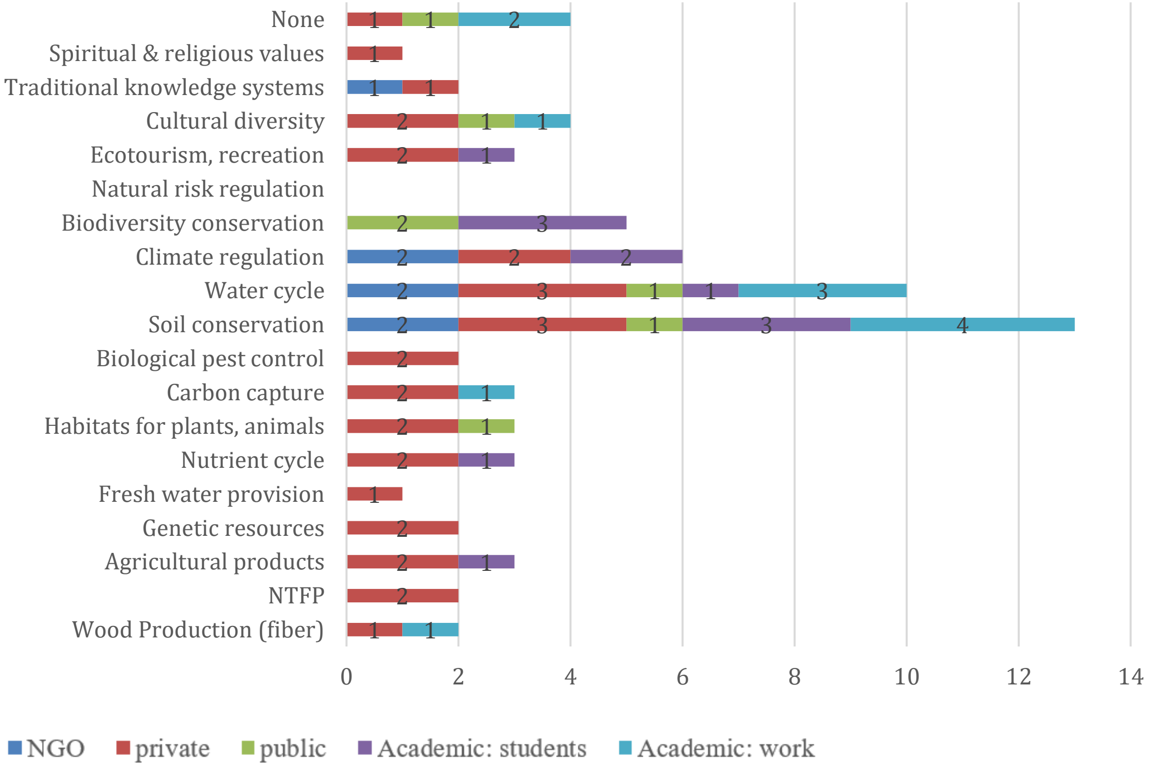

Figure I.46: Synergies between natural risk regulation and other ES, with the number of votes of each stakeholder groups for the synergies

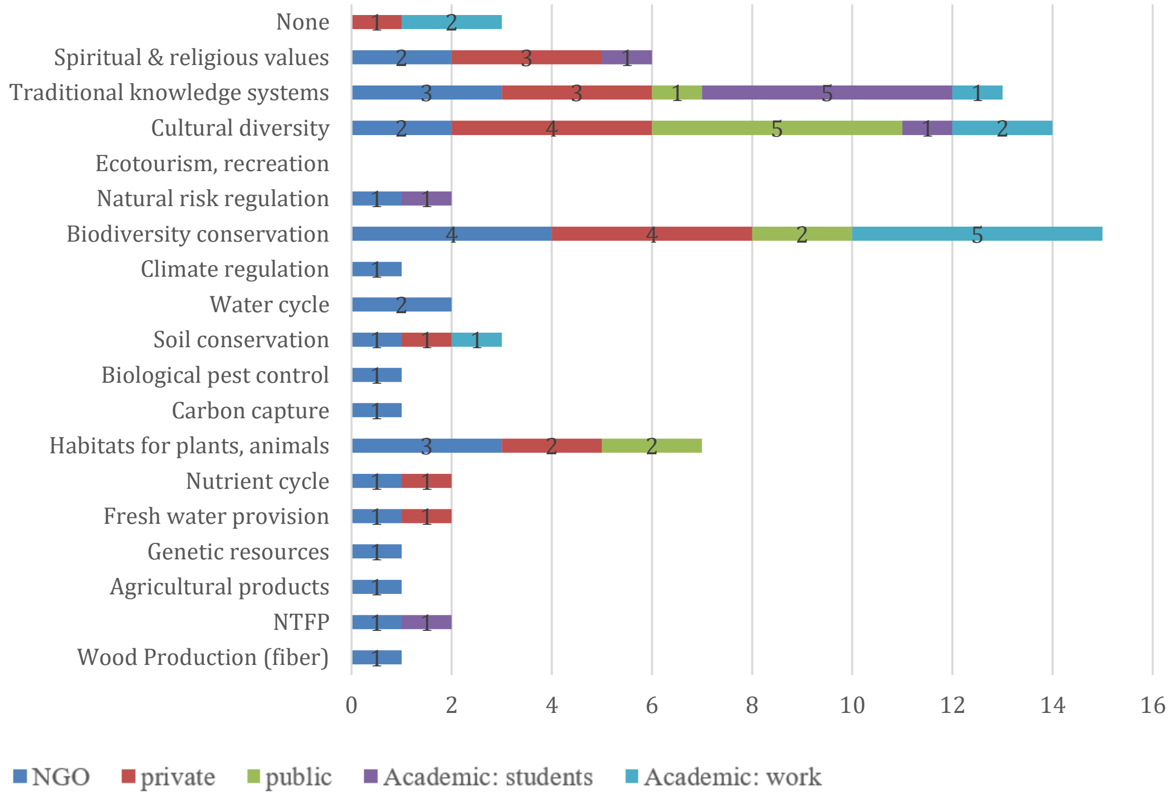

Figure I.47: Synergies between ecotourism and recreation and other ES, with the number of votes of each stakeholder groups for the synergies

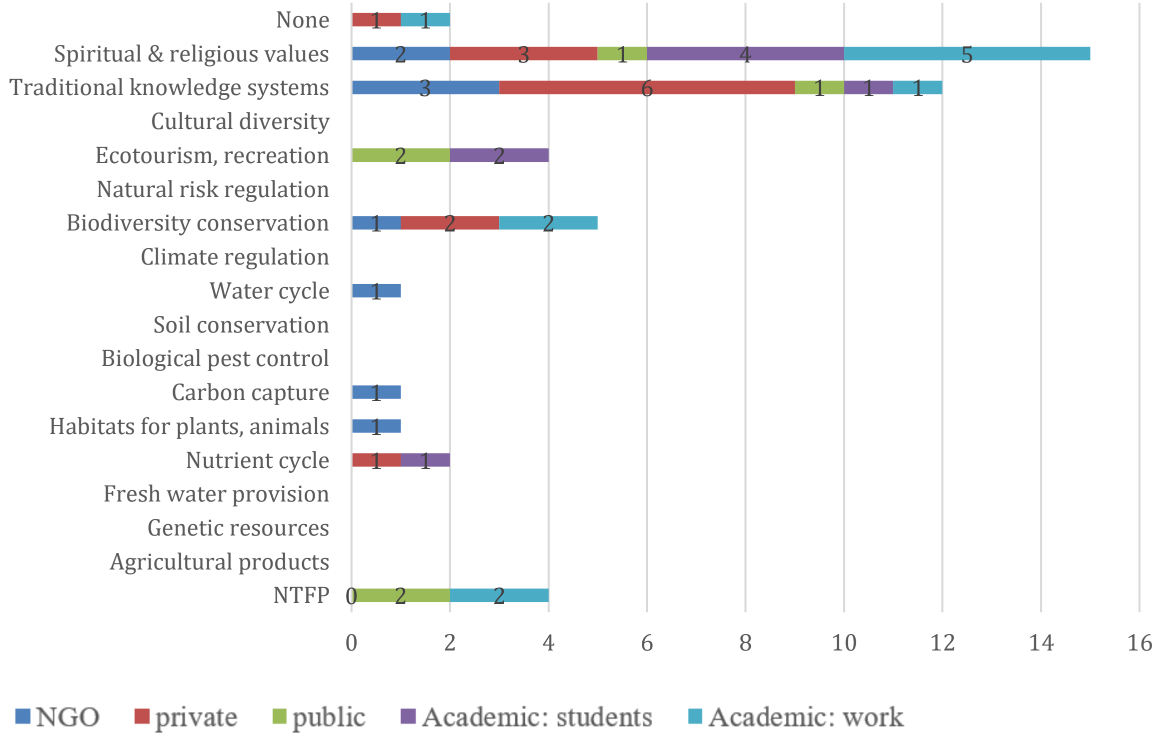

Figure I.48: Synergies between cultural diversity and other ES, with the number of votes of each stakeholder groups for the synergies

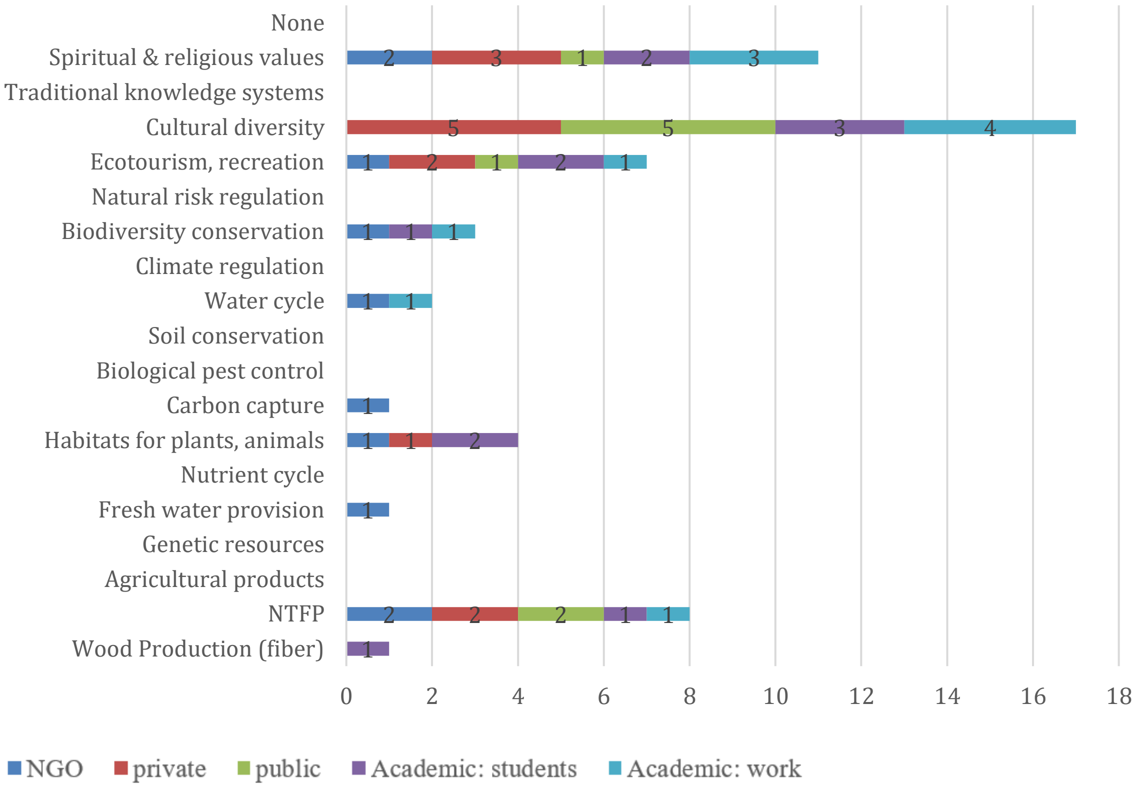

Figure I.49: Synergies between traditional knowledge, inspiration and educational values and other ES, with the number of votes of each stakeholder groups for the synergies

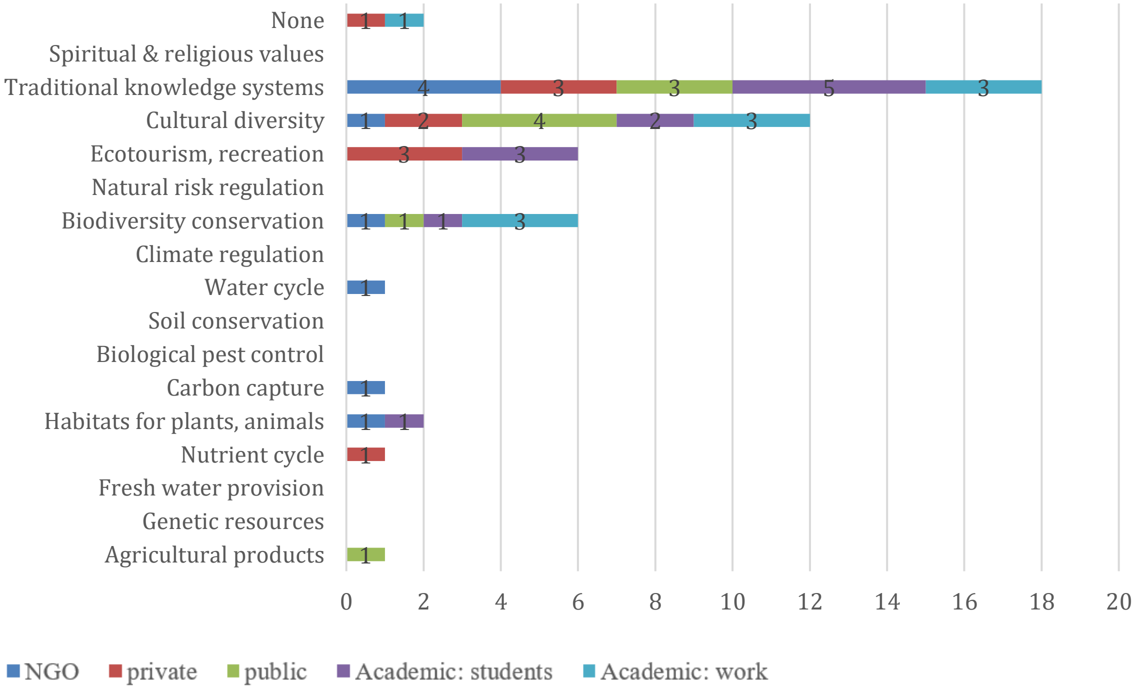

Figure I.50: Synergies between spiritual and religious values and other ES, with the number of votes of each stakeholder groups for the synergies

J. InVEST model outputs

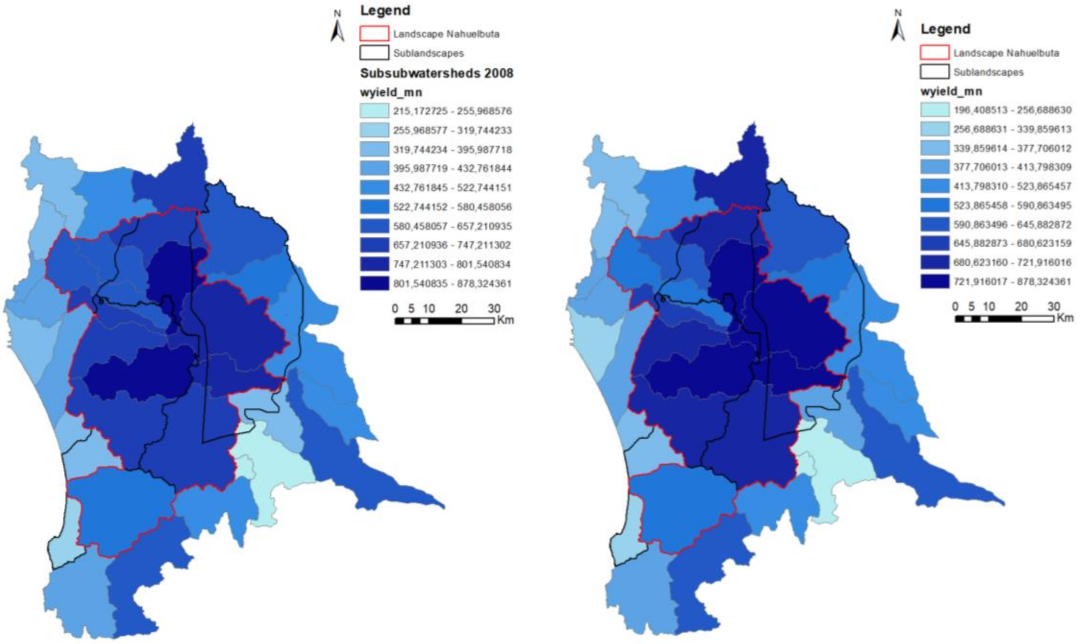

Figure J.1: outputs Annual Water Yield model per subsubwatershed: mean water yield (mm/pixel) for 2008 (left) and 2016 (right), maps by author

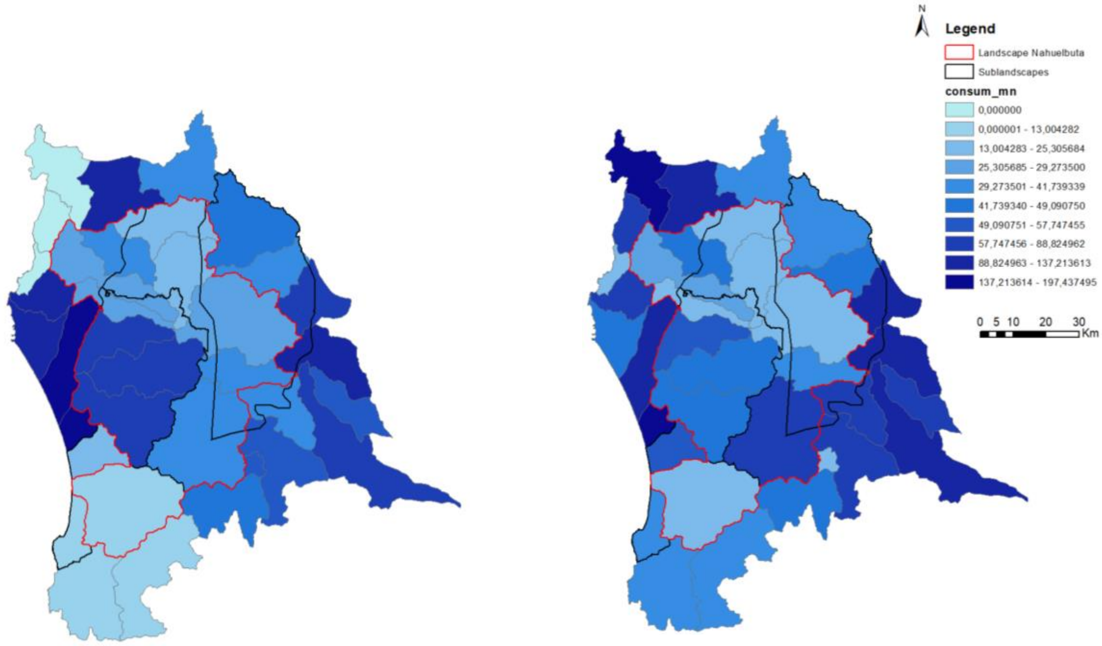

Figure J.2: outputs Annual Water Yield model per subsubwatershed: mean water consumptive volume (m^3/ha) for 2008 (left) and 2016 (right), maps by author

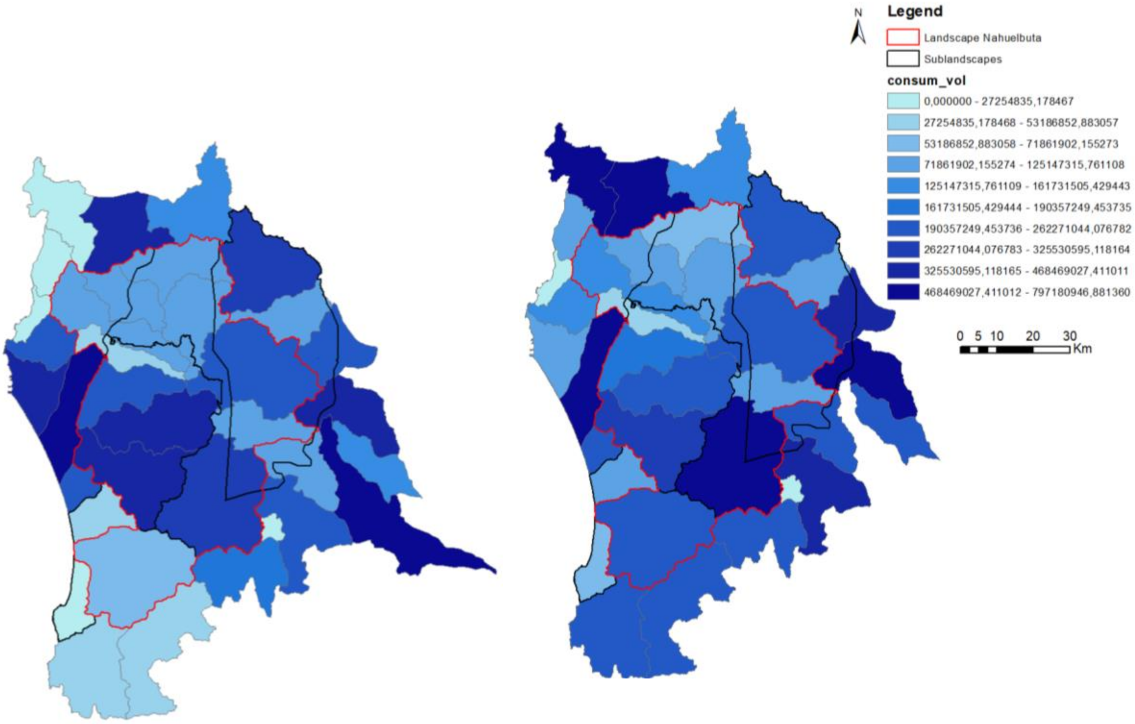

Figure J.2 continued: outputs Annual Water Yield model per subsubwatershed: water consumptive volume (m^3/subsubwatershed) for 2008 (left) and 2016 (right), maps by author

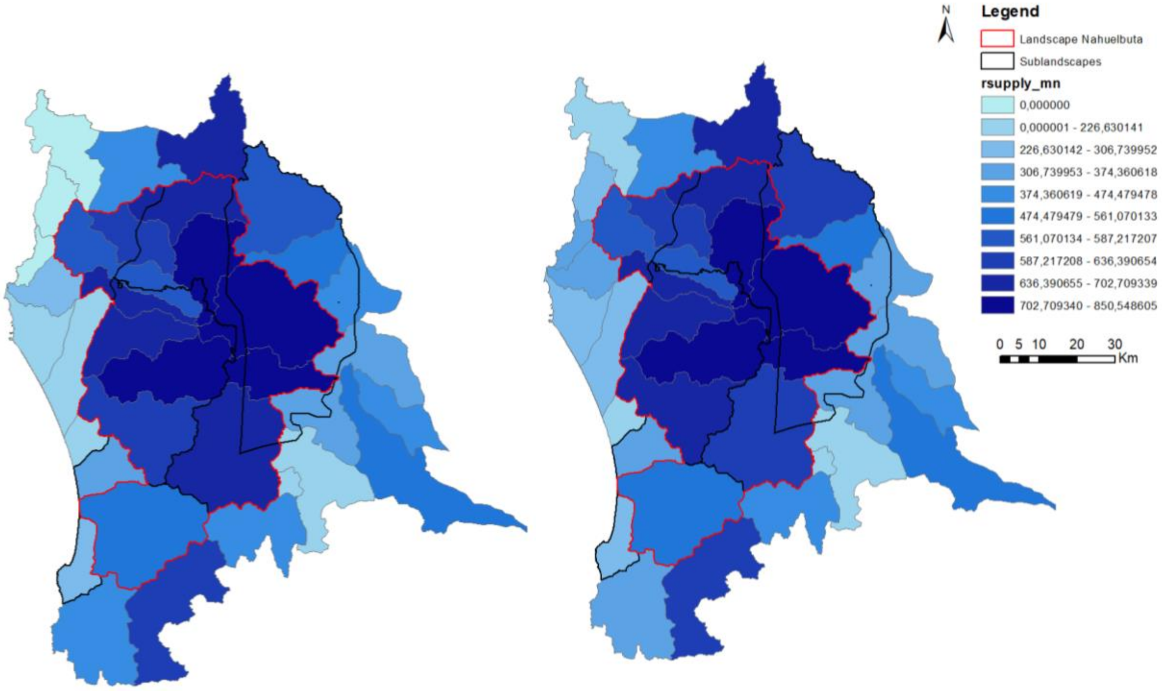

Figure J.3: mean water supply volume (m^3/ha) for 2008 (left) and 2016 (right), maps by author

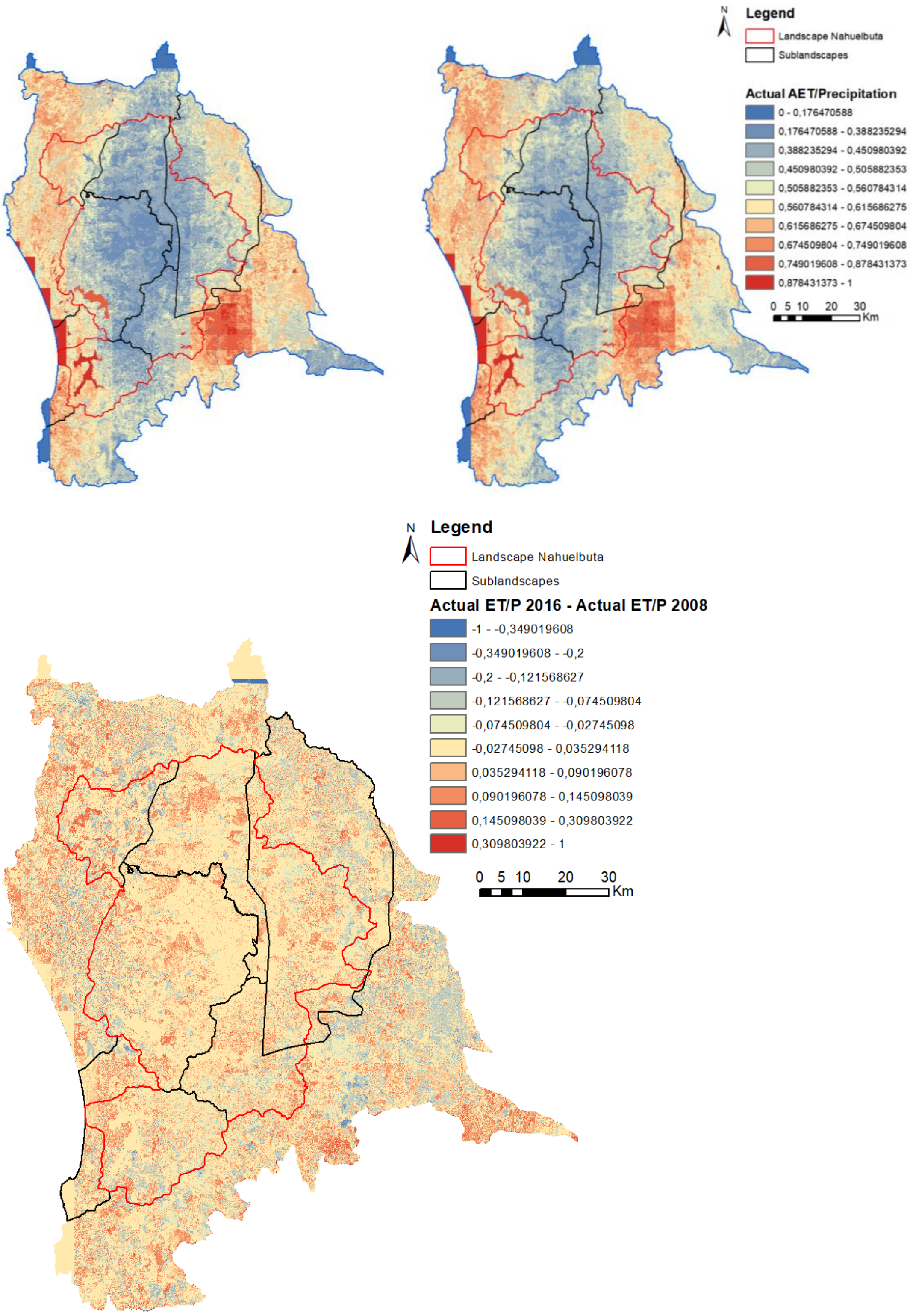

Figure J.4: outputs Annual Water Yield model: estimated actual evapotranspiration (mm/pixel) in 2008 (top left), 2016 (top right) and their difference (bottom), maps by author

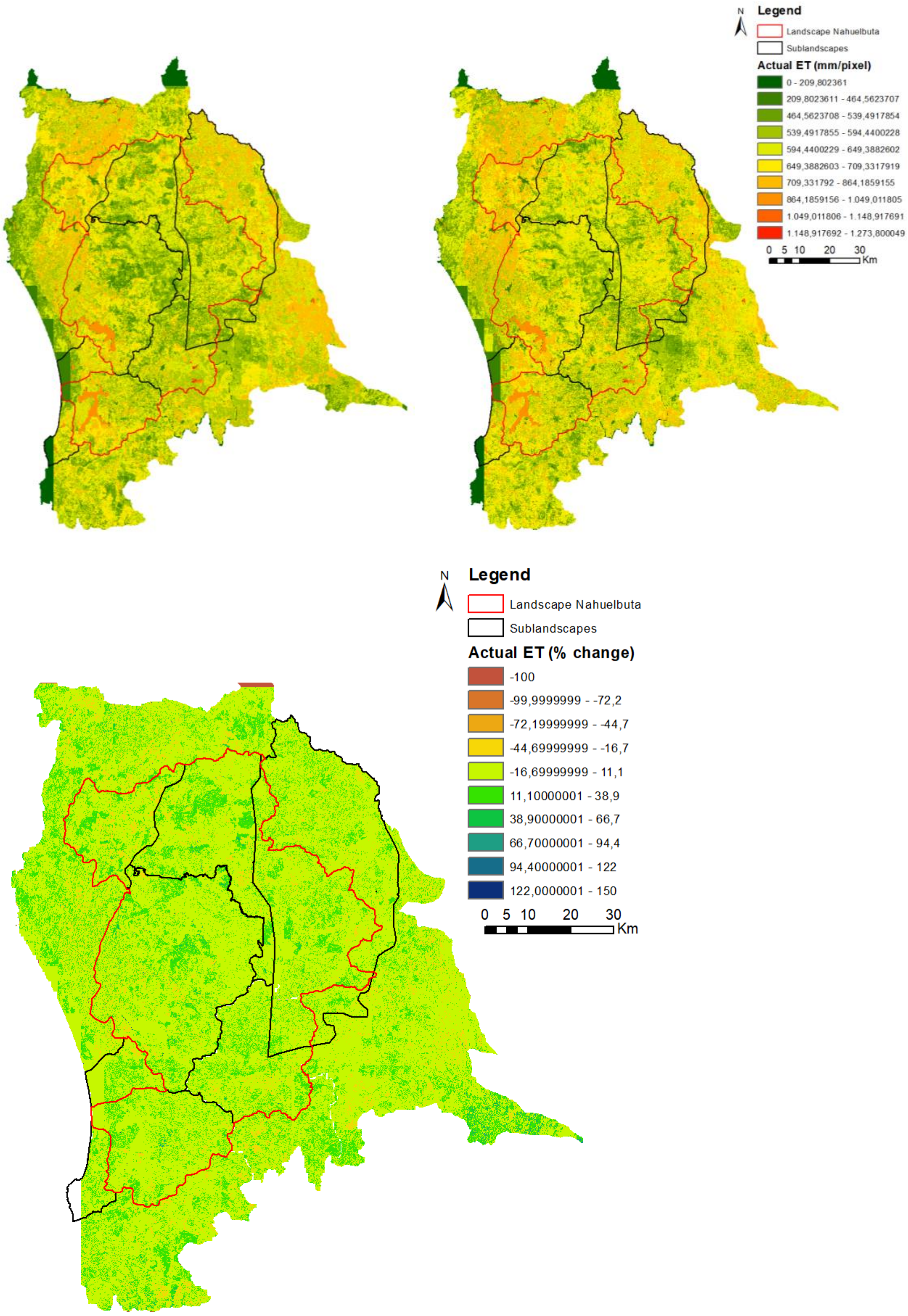

Figure J.5: outputs Annual Water Yield model: estimated actual evapotranspiration divided by the precipitation for each pixel (-) in 2008 (top left), 2016 (top right) and their difference (bottom), maps by author

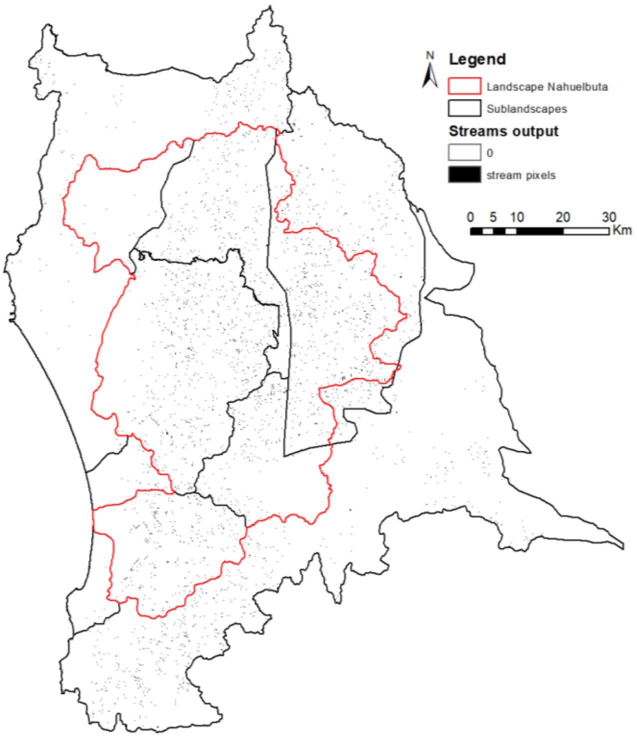

Figure J.6: streams output of the SDR model, map by author

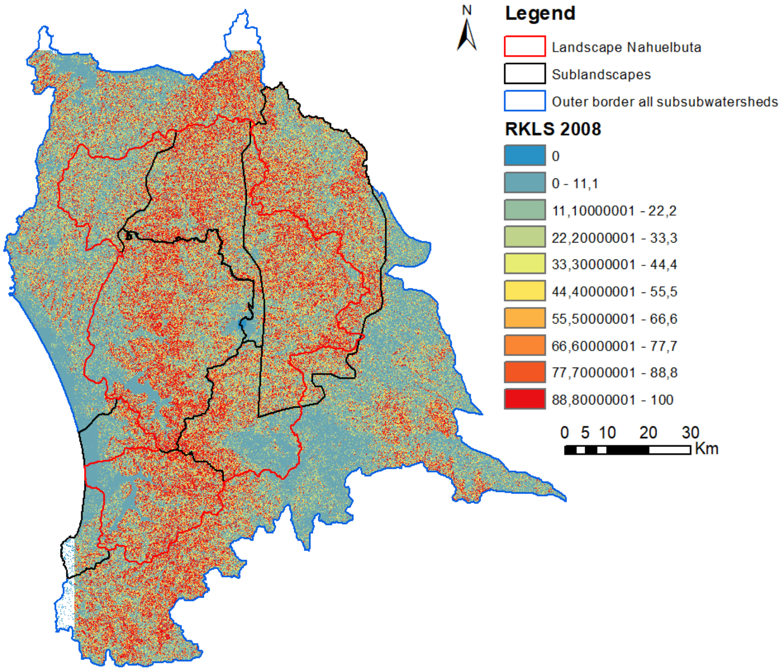

Figure J.7: RKLS (tons/pixel) output of the SDR model, map by author

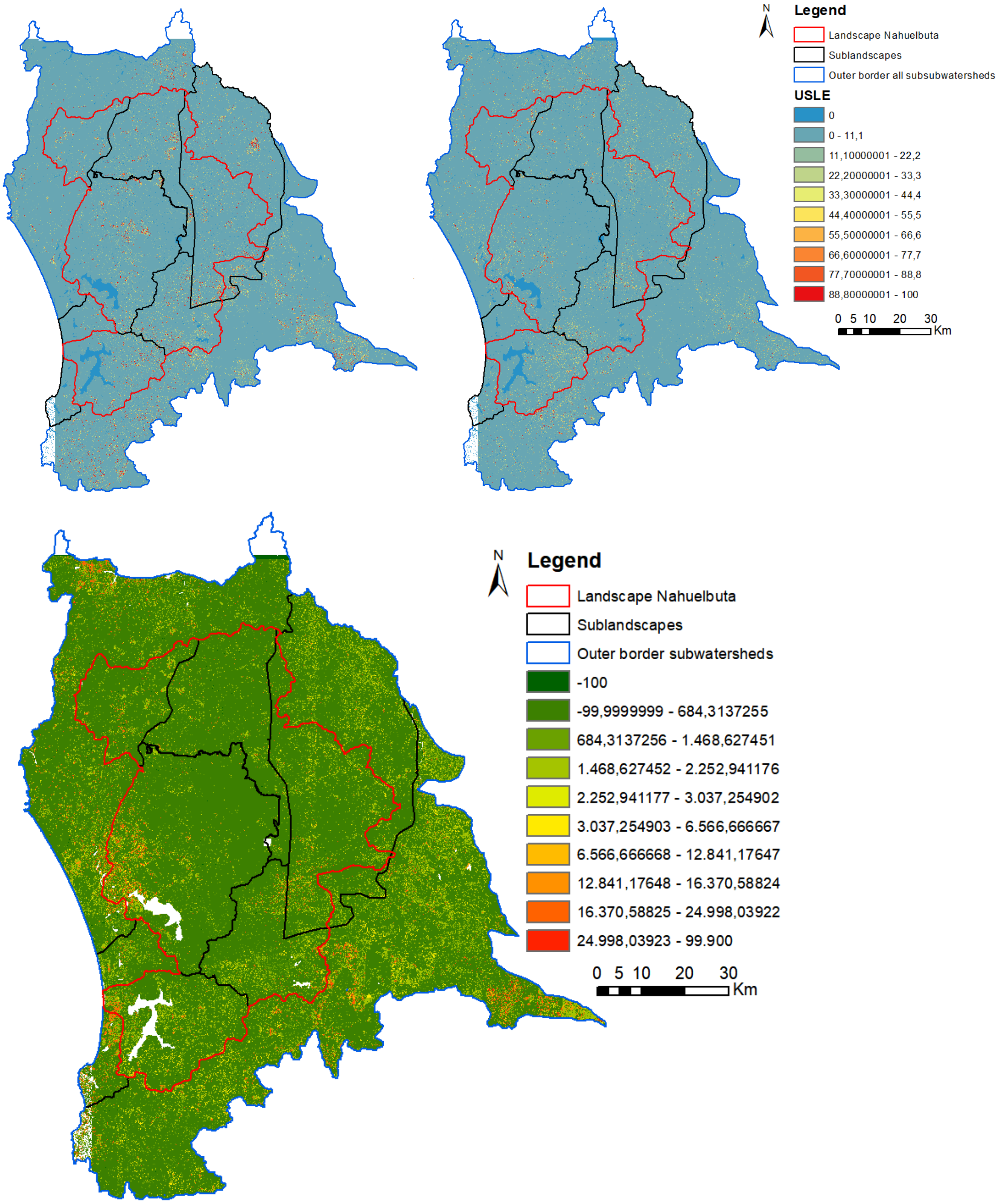

Figure J.8: outputs of the SDR model: potential soil loss (tons/pixel) for 2008 (top left), 2016 (top right) and the percentage (%) change, relative to 2008 (bottom), maps by author

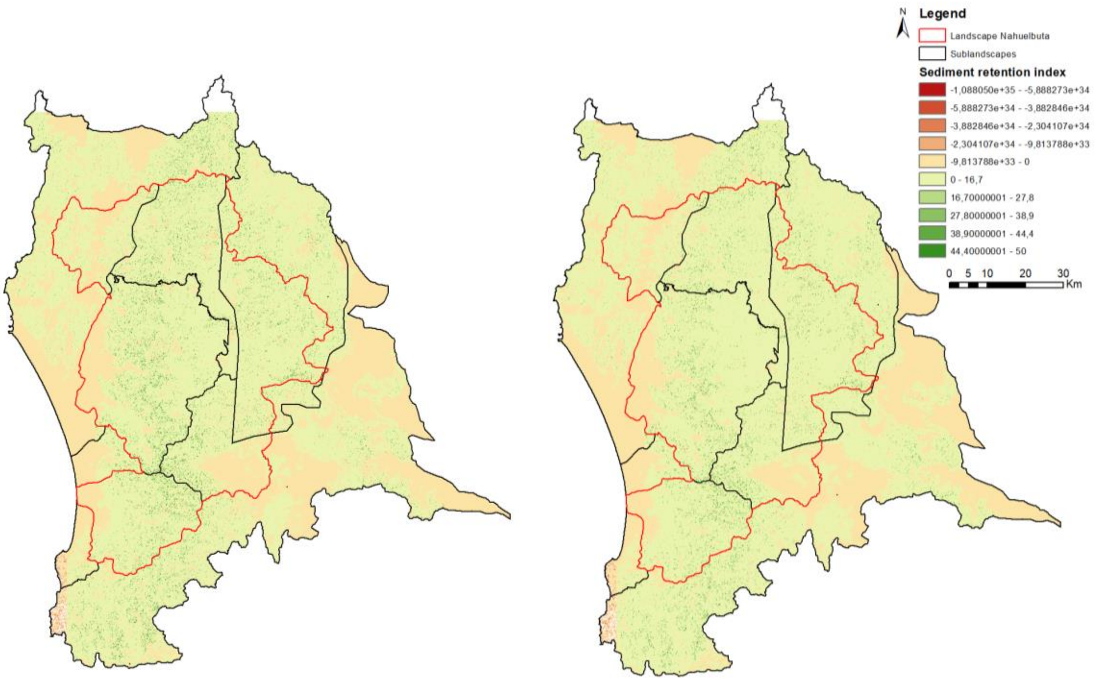

Figure J.9: outputs of the SDR model: sediment retention index for 2008 (left) and 2016 (right), maps by author

K. Statistical analysis: effects of FSC certification on ecosystem service supply

Table K.1: results of paired tests between 2008 and 2016, for habitat degradation in FSC certified areas, significant results are shown in bold

DEGRADATION **α = 0.05, FSC**		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	0.09502	**0.0005882**	0.05028	**0.01757**	0.05076
	2016 p value	**0.00247**	**0.0498**	0.05881	0.1302	**0.00679**
Sample number		36	36	36	36	36
Paired sample t-test						
	Mean 2008	40.00000	0.8660526	8.752703	18.36842	28.20605
	Mean 2016	47.86921	6.004474	8.366486	38.90947	57.82711
	Difference of means	-7.86921	-5.138421	-0.386216	-20.54105	29,62105
Two-tailed, p-value				0.6764		
Lower-tailed, p-value				0.6764		
Upper-tailed, p- value				0.3382		
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**0.01549**	**7.276e-12**	0.9169	**4.627e-07**	**1.019e-10**
Left-sided, p-value		**0.00774**	**3.638e-12**	0.5475	**2.313e-07**	**5.093e-11**
Right-sided, p-value		0.9926	1	0.4585	1	1
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		0.1445	**4.441e-16**	0.8881	**0.000111**	**0.000111**
Left-sided, p-value		1	1	0.5088	1	1
Right-sided, p-value		0.07196	**2.259e-16**	0.6489	**7.485e-05**	**7.485e-05**

Table K.2: results of paired tests between 2008 and 2016, for habitat degradation in uncertified areas, significant results are shown in bold

DEGRADATION **α = 0.05, NO FSC**		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	**0.01119**	0.06355	**0.0003418**	**0.001138**	**0.001422**
	2016 p value	**0.01928**	**0.001456**	**0.0007666**	**0.0007103**	0.1729
Sample number		36	36	36	36	36
Paired sample t-test						
	Mean 2008	-7.26473	1.58	20.65711	5.159211	4.869474
	Mean 2016	14.56553	6.132368	23.11447	10.64079	10.75079
	Difference of means	21.83026	-4.552368	-2.45737	-5.481579	-5.88132
Two-tailed, p-value			**2.134e-09**			
Lower-tailed, p-value			**2.134e-09**			
Upper-tailed, p- value						
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**2.061e-05**	**8.727e-08**	0.6566	**5.093e-11**	**8.054e-08**
Left-sided, p-value		**1.03e-05**	**4.364e-08**	0.3283	**2.547e-11**	**4.027e-08**
Right-sided, p-value		1	1	0.6769	1	1
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		**0.04521**	**9.32e-09**	0.7379	**0.0009956**	**5.224e-07**
Left-sided, p-value		1	1	0.7891	1	1
Right-sided, p-value		**0.02261**	**4.66e-09**	0.3878	**0.0004978**	**2.612e-07**

Table K.3: results of paired tests between 2008 and 2016, for habitat quality in FSC certified areas, significant results are shown in bold

QUALITY **α = 0.05, FSC**		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	0.1876	0.05624	**0.01059**	**0.001978**	**0.006951**
	2016 p value	**0.01099**	0.4793	**0.008716**	**0.00613**	**0.03574**
Sample number		36	36	36	36	36
Paired sample t-test						
	Mean 2008	5067.083	3828.658	13574.8	10013.68	8473.943
	Mean 2016	9568.973	5740.243	18819.52	17999.63	14463.01
	Difference of means	-4501.891	-1911.585	-5244.717	-7985.955	-5989.062
Two-tailed, p-value			**1.237e-10**			
Lower-tailed, p-value			**6.187e-11**			
Upper-tailed, p- value			1			
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**7.276e-12**	**8.004e-10**	**1.019e-10**	**7.276e-12**	**3.638e-11**
Left-sided, p-value		**3.638e-12**	**4.002e-10**	**5.093e-11**	**3.638e-12**	**1.819e-11**
Right-sided, p-value		1	1	1	1	1
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		**9.002e-09**	**0.01151**	**0.0003163**	**7.276e-12**	**0.0008434**
Left-sided, p-value		1	**0.00575**	1	**3.638e-12**	1
Right-sided, p-value		**1.88e-08**	1	**0.0001982**	1	**0.0004978**

Table K.4: results of paired tests between 2008 and 2016, for habitat quality in uncertified areas, significant results are shown in bold

QUALITY **α = 0.05, NO FSC**		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	**0.01379**	**0.02501**	**0.0009519**	**0.002485**	**0.01861**
	2016 p value	0.1368	0.05993	0.08429	**0.0124**	0.3181
Sample number		36	36	36	36	36
Paired sample t-test						
	Mean 2008	3600.265	1948.874	5183.255	1943.591	843.4632
	Mean 2016	6162.711	2895.969	6672.45	3380.01	1347.381
	Difference of means	-2562.445	-947.095	- 1489.194	-1436.419	-503.9176
Two-tailed, p-value						
Lower-tailed, p-value						
Upper-tailed, p- value						
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**7.276e-12**	**4.125e-07**	**6.6e-06**	**1.455e-11**	**1.3e-07**
Left-sided, p-value		**3.638e-12**	**2.062e-07**	**3.3e-06**	**7.276e-12**	**6.498e-08**
Right-sided, p-value		1	1	1	1	1
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		**8.243e-07**	**0.002109**	**0.004951**	**0.004951**	**5.364e-05**
Left-sided, p-value		1	0.974	1	1	1
Right-sided, p-value		**8.998e-07**	**0.001186**	**0.002682**	**0.002682**	**2.682e-05**

Table K.5: results of paired tests between 2008 and 2016, for sediment export (tons/forest property) in FSC certified areas, significant results are shown in bold

EXPORT **α = 0.05, FSC**		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	**0.0005882**	0.142	0.08514	**0.01382**	**0.00257**
	2016 p value	**0.0498**	**0.006654**	0.1168	**0.0007616**	**0.0003373**
Sample number		**36**	**36**	36	**36**	**36**
Paired sample t-test						
	Mean 2008	0.8660526	197.2861	463.7689	361.5908	75.14053
	Mean 2016	6.004474	205.4579	403.4108	307.3226	17.54289
	Difference of means	-5.13842	-8.171.842	60.358	54.26816	57.59763
Two-tailed, p-value				0.1753		
Lower-tailed, p-value						
Upper-tailed, p- value						
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**7.276e-12**	0.5371	0.2432	0.1843	**6.577e-09**
Left-sided, p-value		**3.638e-12**	0.2686	0.8813	0.9102	1
Right-sided, p-value		1	0.7362	0.1216	0.09215	**3.289e-09**
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		**4.441e-16**	0.5453	0.1445	0.3727	**1.824e-05**
Left-sided, p-value		1	0.2754	0.07196	0.1856	**9.118e-06**
Right-sided, p-value		**2.259e-16**	0.6564	0.5179	0.9001	1

Table K.6: results of paired tests between 2008 and 2016, for sediment export (tons/forest property) in uncertified areas, significant results are shown in bold

EXPORT α = 0.05, NO FSC		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	0.0653	0.142	0.08514	**0.01382**	**0.00257**
	2016 p value	**0.008848**	**0.006654**	0.1168	**0.0007616**	**0.0003373**
Sample number		**36**	**36**	36	**36**	**36**
Paired sample t-test						
	Mean 2008	98.565	114.2395	295.4882	16.68026	14.26526
	Mean 2016	54.549	84.97868	146.7392	7.764737	7.120526
	Difference of means	-44.016	29.26079	148.7489	8.915526	7.144737
Two-tailed, p-value				0.1753		
Lower-tailed, p-value						
Upper-tailed, p- value						
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**6.457e-06**	0.5371	0.2432	0.1843	**6.577e-09**
Left-sided, p-value		**1**	0.2686	0.8813	0.9102	1
Right-sided, p-value		**3.237e-06**	0.7362	0.1216	0.09215	**3.289e-09**
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		**0.9998434**	0.5453	0.1445	0.3727	**1.824e-05**
Left-sided, p-value		**0.0004978**	0.2754	0.07196	0.1856	**9.118e-06**
Right-sided, p-value		1	0.6564	0.5179	0.9001	1

Table K.7: results of paired tests between 2008 and 2016, for sediment retention (tons/forest property) in FSC certified areas, significant results are shown in bold

RETENTION α = 0.05, FSC		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	**0.01317**	**0.006406**	**0.007796**	**0.006603**	**0.01499**
	2016 p value	**0.01354**	**0.007397**	**0.006414**	**0.00678**	**0.007771**
Sample number		**36**	**36**	36	**36**	**36**
Paired sample t-test						
	Mean 2008	22701.44	15891.32	39744.6	43589.28	8579.429
	Mean 2016	22437.06	15960.44	39886.81	42811.93	8507.744
	Difference of means	-264.3855	69.11132	142.2116	-777.3503	-71.68514
Two-tailed, p-value						
Lower-tailed, p-value						
Upper-tailed, p- value						
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**0.004697**	0.3499	0.5112	**0.009564**	**0.001059**
Left-sided, p-value		0.9978	0.175	0.7492	**0.004782**	**0.0005296**
Right-sided, p-value		**0.002349**	0.8287	0.2556	0.9954	0.9995
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		0.9999	1	0.9998	0.9866	0.9998
Left-sided, p-value		0.7891	0.9001	0.7841	0.9001	0.8975
Right-sided, p-value		0.9001	0.9001	0.8975	0.6564	0.7841

Table K.8: results of paired tests between 2008 and 2016, for sediment retention (tons/forest property) in uncertified areas, significant results are shown in bold

RETENTION α = 0.05, NO FSC		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	**0.01801**	0.1312	**0.01608**	**0.01499**	**0.0011**
	2016 p - value	**0.02353**	0.136	**0.006429**	**0.007771**	**0.001105**
Sample number		**36**	**36**		**36**	**36**
Paired sample t-test						
	Mean 2008	8361.078	9919.763	9526.947	2331.359	932.8613
	Mean 2016	8269.574	9823.137	9352.548	2305.368	933.4826
	Difference of means	- 91.50316	-96.62579	-174.3992	-25.99026	0.6213158
Two-tailed, p-value			**0.03225**			
Lower-tailed, p-value			**0.01612**			
Upper-tailed, p- value			0.9839			
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**6.289e-05**	**0.01549**	0.05881	**0.001059**	0.1352
Left-sided, p-value		**3.145e-05**	**0.007745**	**0.02941**	**0.0005296**	0.06762
Right-sided, p-value		1	0.9926	0.9716	0.9995	0.9343
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		0.9999	0.9999	1	0.9998	0.9998
Left-sided, p-value		0.974	0.974	0.974	0.8975	0.9001
Right-sided, p-value		0.7891	0.7891	0.9001	0.7841	0.7891

Table K.9: results of paired tests between 2008 and 2016, for water yield (mm/forest property) in FSC certified areas, significant results are shown in bold

WATER YIELD α = 0.05, FSC		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	0.265	**0.006846**	**0.002956**	0.2861	**0.002481**
	2016 p value	**7.026e-05**	**0.004087**	**0.01188**	0.509	**0.003831**
Sample number		**36**	**36**	36	**36**	**36**
Paired sample t-test						
	Mean 2008	7716039	7167763	21169878	14680228	8189746
	Mean 2016	15187993	7233844	21226627	14421143	7392724
	Difference of means	-7471955	-66080.37	-56748.69	259084.8	797021.4
Two-tailed, p-value					0.07754	
Lower-tailed, p-value					0.9612	
Upper-tailed, p- value					0.03877	
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**7.882e-05**	0.6462	0.4294	0.1569	**3.267e-07**
Left-sided, p-value		**3.941e-05**	0.3231	0.2147	0.9237	1
Right-sided, p-value		1	0.682	0.7895	0.07845	**1.633e-07**
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		**0.004951**	0.9999	0.9999	0.9999	0.7379
Left-sided, p-value		1	0.7891	0.7891	0.7891	0.7379
Right-sided, p-value		**0.002682**	0.7891	0.7891	0.9001	1

Table K.10: results of paired tests between 2008 and 2016, for water yield (mm/forest property) in uncertified areas, significant results are shown in bold

WATER YIELD α = 0.05, NO FSC		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**2008 p value**	**0.04031**	0.1319	**0.0143**	**0.001352**	**0.04188**
	2016 p value	0.07281	0.2452	**0.01599**	**0.001312**	**0.02316**
Sample number		**36**	**36**	36	**36**	**36**
Paired sample t-test						
	Mean 2008	5858410	3720175	10690019	1714916	890078.8
	Mean 2016	5638939	3581123	10362664	1636446	842950.9
	Difference of means	219470.2	139052	327355.7	78469.67	47127.87
Two-tailed, p-value			**1.937e-05**			
Lower-tailed, p-value			1			
Upper-tailed, p- value			**9.684e-06**			
Mann-Whitney-Wilcoxon test (paired)						
Two-sided, p-value		**5.093e-11**	**5.184e-07**	**3.673e-07**	**5.093e-11**	**0.0009229**
Left-sided, p-value		1	1	1	1	0.9996
Right-sided, p-value		**2.547e-11**	**2.592e-07**	**1.836e-07**	**2.547e-11**	**0.0004614**
Kolmogorov-Smirnov test (paired)						
Two-sided, p-value		0.9033	0.9033	0.9866	0.9866	0.7379
Left-sided, p-value		0.5179	0.5179	0.6564	0.6564	0.3878
Right-sided, p-value		1	0.974	0.974	0.974	0.7891

Table K.11: results of tests for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, for habitat degradation, significant results are shown in bold

DEGRADATION α = 0.05		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**FSC p value**	0.9261	0.498	0.6652	0.6882	0.3428
	no FSC p value	0.6062	0.1073	0.2788	**0.001152**	**0.0005213**
Sample number		32	32	32	32	32
Two sample t-test						
	Mean FSC	6.385	4.846	2.223	14.818	34.532
	Mean no FSC	-7.104	3.064	5.783	4.291	3.626
	Difference of means	13.489	1.782	-3.560	10.5278	30.906
Two-tailed, p-value		**1.524e-06**	**0.02791**	0.1407		
Lower-tailed, p-value		1	0.986	0.07035		
Upper-tailed, p- value		**7.619e-07**	**0.01395**	0.92960		
Mann-Whitney-Wilcoxon test						
Two-sided, p-value		**3.248e-07**	**0.01912**	0.1351	**0.008328**	**2.32e-12**
Left-sided, p-value		1	0.99080	0.06754	0.996	1
Right-sided, p-value		**1.624e-07**	**0.009561**	0.9342	**0.004164**	**1.16e-12**
Kolmogorov-Smirnov test						
Two-sided, p-value		**3.584e-06**	0.08787	0.4337	**0.0006709**	**8.321e-12**
Left-sided, p-value		**3.727e-06**	**0.04394**	1	**0.0003355**	**1.277e-10**
Right-sided, p-value		1	1	0.2163	0.4578	1

Table K.12: results of tests for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, for habitat quality, significant results are shown in bold

QUALITY α = 0.05		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**FSC p value**	0.8302	0.5428	0.2646	**0.01475**	0.0825
	no FSC p value	0.09349	0.6485	0.8691	**0.0001081**	**0.01174**
Sample number		32	32	32	32	32
Two sample t-test						
	Mean FSC	5472.573	1702.765	3200.774	7302.713	2913.307
	Mean no FSC	-767.908	1005.814	633.171	2365.458	503.557
	Difference of means	6240.481	696.9513	2567.602	4937.255	2409.751
Two-tailed, p-value		**2.2e-16**	**0.04877**	**9.776e-06**		
Lower-tailed, p-value		1	0.9756	1		
Upper-tailed, p- value		**< 2.2e-16**	**0.02438**	**4.888e-06**		
Mann-Whitney-Wilcoxon test						
Two-sided, p-value		**< 2.2e-16**	0.06864	**2.183e-05**	**2.401e-06**	**2.015e-14**
Left-sided, p-value		1	0.9667	1	1	1
Right-sided, p-value		**< 2.2e-16**	**0.03432**	**1.091e-05**	**1.201e-06**	**1.007e-14**
Kolmogorov-Smirnov test						
Two-sided, p-value		**2.22e-16**	0.1601	**0.0001741**	**0.0005331**	**6.937e-13**
Left-sided, p-value		**1.907e-13**	0.07956	**0.0001196**	**0.0003355**	**2.29e-11**
Right-sided, p-value		1	0.9692	0.9692	1	1

Table K.13: results of tests for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, for sediment export (tons/property), significant results are shown in bold

EXPORT α = 0.05		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**FSC p value**	0.2438	0.8872	0.4382	0.1704	0.1059
	no FSC p value	**0.04716**	0.7771	0.8037	0.976	**0.004845**
Sample number		32	32	32	32	32
Two sample t-test						
	Mean FSC	145.751	-22.561	-32.320	-81.379	-51.220
	Mean no FSC	-57.852	-19.330	-55.774	-7.855	-5.433
	Difference of means	203.602	-3.231	23.454	-73.523	-45.786
Two-tailed, p-value			0.8922	0.6823	**0.02691**	
Lower-tailed, p-value			0.4461	0.6589	**0.01345**	
Upper-tailed, p- value			0.5539	0.3411	0.9865	
Mann-Whitney-Wilcoxon test						
Two-sided, p-value		**1.757e-11**	0.8572	0.7338	0.05398	**0.0001447**
Left-sided, p-value		1	0.5767	0.6381	**0.02699**	**7.237e-05**
Right-sided, p-value		**8.786e-12**	0.4286	0.3669	0.9738	0.9999
Kolmogorov-Smirnov test						
Two-sided, p-value		**8.182e-11**	0.08768	0.9993	**0.001768**	**2.521e-05**
Left-sided, p-value		**6.692e-10**	**0.04394**	0.7548	0.4578	0.8825
Right-sided, p-value		1	0.1353	0.8825	**0.0008838**	**1.261e-05**

Table K.14: results of tests for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, for sediment retention (tons/property), significant results are shown in bold

RETENTION α = 0.05		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**FSC p value**	0.871	0.9367	0.2006	0.7236	**0.02698**
	no FSC p value	0.6891	0.806	0.6056	0.9993	0.1706
Sample number		32	32	32	32	32
Two sample t-test						
	Mean FSC	-50.376	17.600	61.946	135.690	37.334
	Mean no FSC	-53.543	16.041	18.994	8.849	0.903
	Difference of means	3.168	1.560	42.952	126.842	36.431
Two-tailed, p-value		0.8706	0.946	0.3856	**0.002917**	
Lower-tailed, p-value		0.5647	0.527	0.8072	0.9985	
Upper-tailed, p- value		0.4353	0.473	0.1928	**0.001458**	
Mann-Whitney-Wilcoxon test						
Two-sided, p-value		0.9616	0.9947	0.3195	**0.0004478**	**0.002408**
Left-sided, p-value		0.4808	0.508	0.8435	0.9998	0.9988
Right-sided, p-value		0.5247	0.4973	0.1597	**0.0002239**	**0.001204**
Kolmogorov-Smirnov test						
Two-sided, p-value		0.9711	0.08768	0.4337	**4.83e-09**	**7.453e-06**
Left-sided, p-value		0.6211	**0.04394**	0.2163	**1.523e-08**	**3.727e-06**
Right-sided, p-value		0.7892	**0.04394**	0.6065	0.1353	0.4578

Table K.15: results of tests for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, for water yield (mm/property), significant results are shown in bold

WATER YIELD α = 0.05		**SL 1**	**SL 2**	**SL 3**	**SL 4**	**SL 5**
Shapiro-Wilk normality test	**FSC p value**	0.457	0.3005	0.3781	**0.003191**	0.2547
	no FSC p -value	0.3775	0.4974	0.3606	**0.0001545**	0.6909
Sample number		32	32	32	32	32
Two sample t-test						
	Mean FSC	-264161.40	20791.26	87079.10	-198197.20	-347945.70
	Mean no FSC	-94670.51	-55240.75	-173074.50	-204786.10	-50806.85
	Difference of means	-169490.80	76032.01	260153.50	6588.89	-297138.90
Two-tailed, p-value		**0.01901**	**0.02504**	**0.004221**		**0.0005406**
Lower-tailed, p-value		**0.009503**	0.9875	0.9979		**0.0002703**
Upper-tailed, p- value		0.9905	**0.01252**	**0.00211**		0.9997
Mann-Whitney-Wilcoxon test						
Two-sided, p-value		**0.01027**	**0.01027**	**0.008032**	0.7119	**0.0001108**
Left-sided, p-value		**0.005135**	0.9951	0.9961	0.649	**5.539e-05**
Right-sided, p-value		0.9951	**0.005135**	**0.004016**	0.356	0.9999
Kolmogorov-Smirnov test						
Two-sided, p-value		**0.0005331**	**0.009516**	**0.04486**	0.27	**3.584e-06**
Left-sided, p-value		0.4578	**0.005086**	**0.02279**	0.1353	0.7548
Right-sided, p-value		**0.0003355**	0.6065	0.7548	0.6065	**3.727e-06**

Table K.15 continued: results of tests for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, for water yield (mm/property), significant results are shown in bold

WATER YIELD α = 0.05		SL 1
Shapiro-Wilk normality test	FSC p value	0.3609
	no FSC p -value	0.2314
Sample number		**36**
	Mean FSC	6494415
	Mean no FSC	-172502.9
	Difference of means	6666917
Two sample t-test		
Two-tailed, p-value		**5.444e-05**
Lower-tailed, p-value		1
Upper-tailed, p- value		**2.722e-05**
Mann-Whitney-Wilcoxon test		
Two-sided, p-value		**2.111e-06**
Left-sided, p-value		1
Right-sided, p-value		**1.056e-06**
Kolmogorov-Smirnov test		
Two-sided, p-value		**1.683e-10**
Left-sided, p-value		**9e-10**
Right-sided, p-value		0.3574

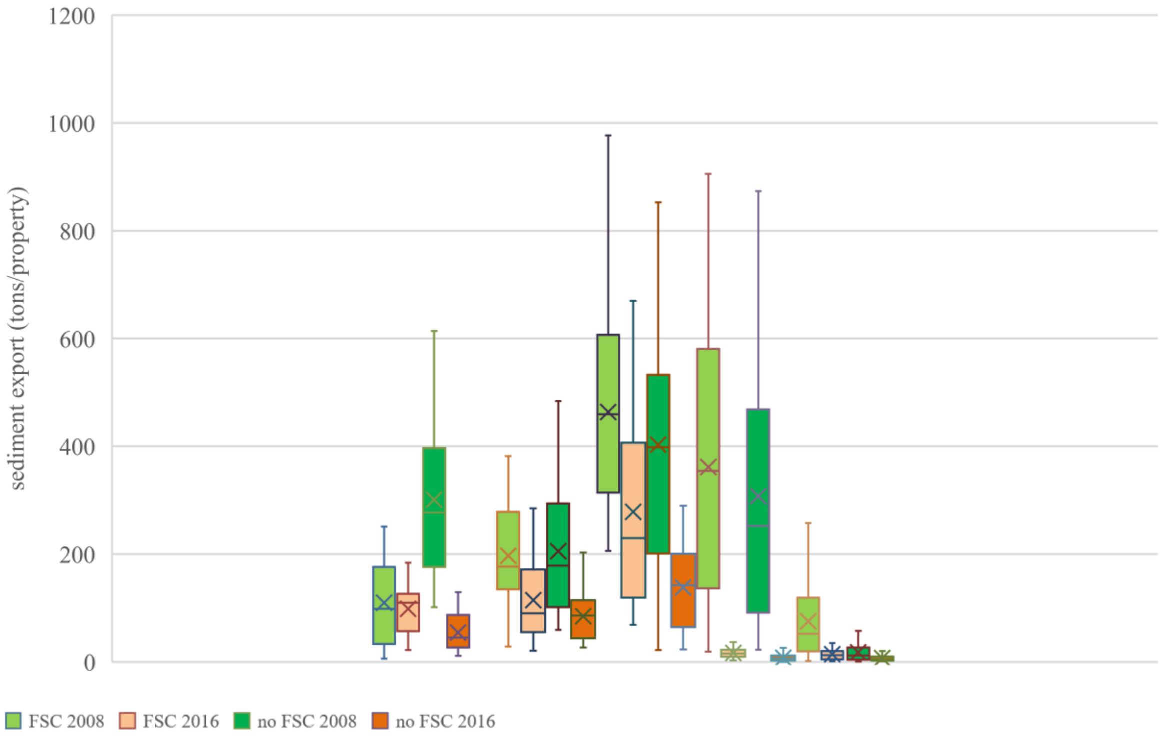

Figure K.1: Boxplots of data for sediment export (tons/property) used for paired statistical tests between 2008 and 2016, in groups of 4 for each SL, left to right of SL 1, 2, 3, 4, and 5

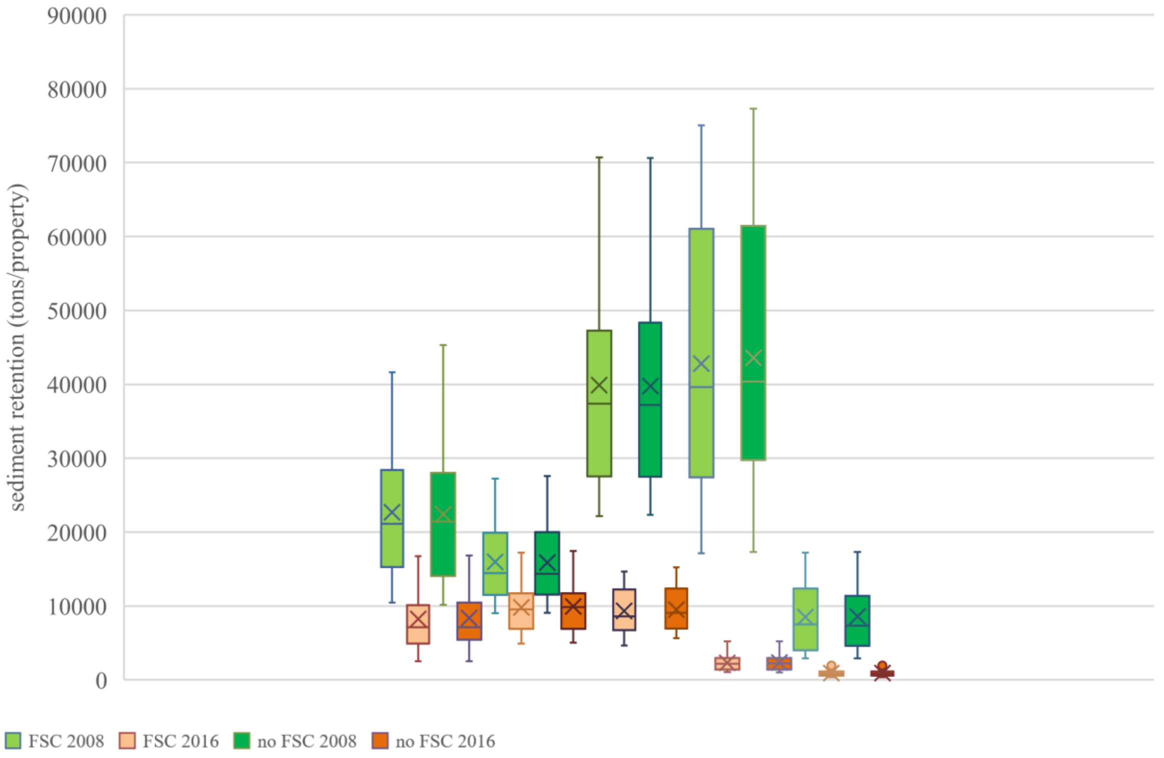

Figure K.2: Boxplots of data for sediment retention (tons/property) used for paired statistical tests between 2008 and 2016, in groups of 4 for each SL, left to right of SL 1, 2, 3, 4, and 5

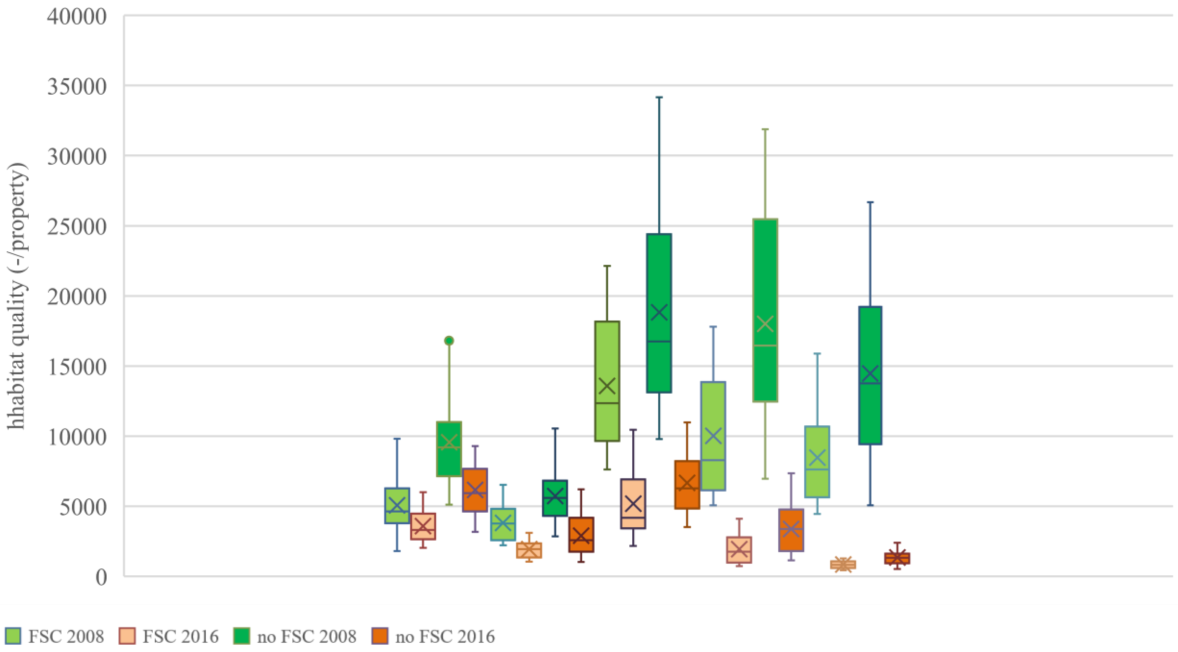

Figure K.3: Boxplots of data for habitat quality (-/property) used for paired statistical tests between 2008 and 2016, in groups of 4 for each SL, left to right of SL 1, 2, 3, 4, and 5

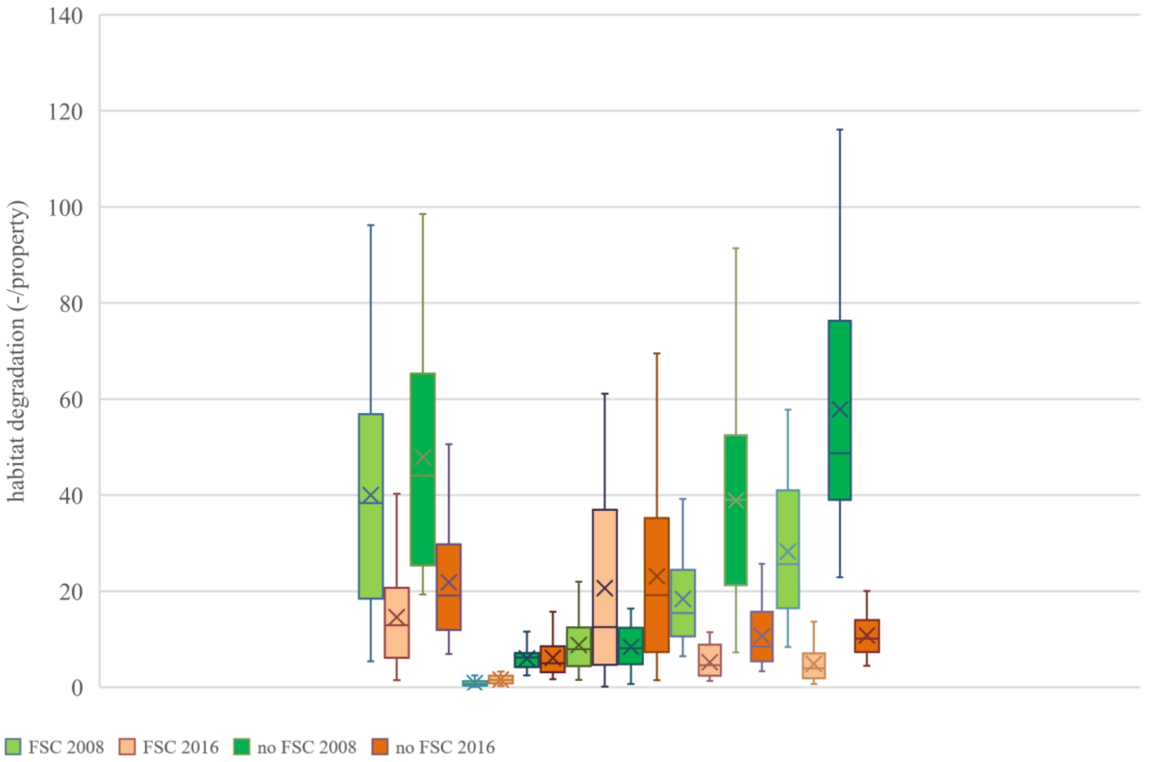

Figure K.4: Boxplots of data for habitat degradation (-/property) used for paired statistical tests between 2008 and 2016, in groups of 4 for each SL, left to right of SL 1, 2, 3, 4, and 5

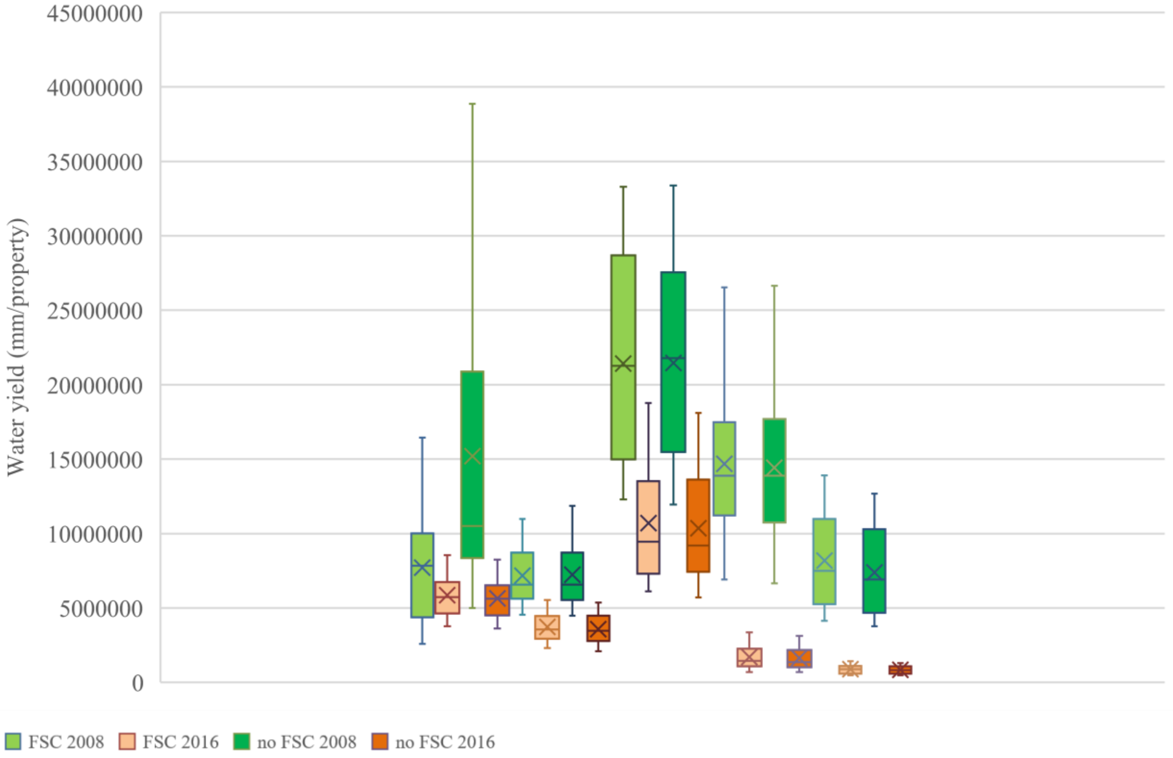

Figure K.5: Boxplots of data for water yield (mm/property) used for paired statistical tests between 2008 and 2016, in groups of 4 for each SL, left to right of SL 1, 2, 3, 4, and 5

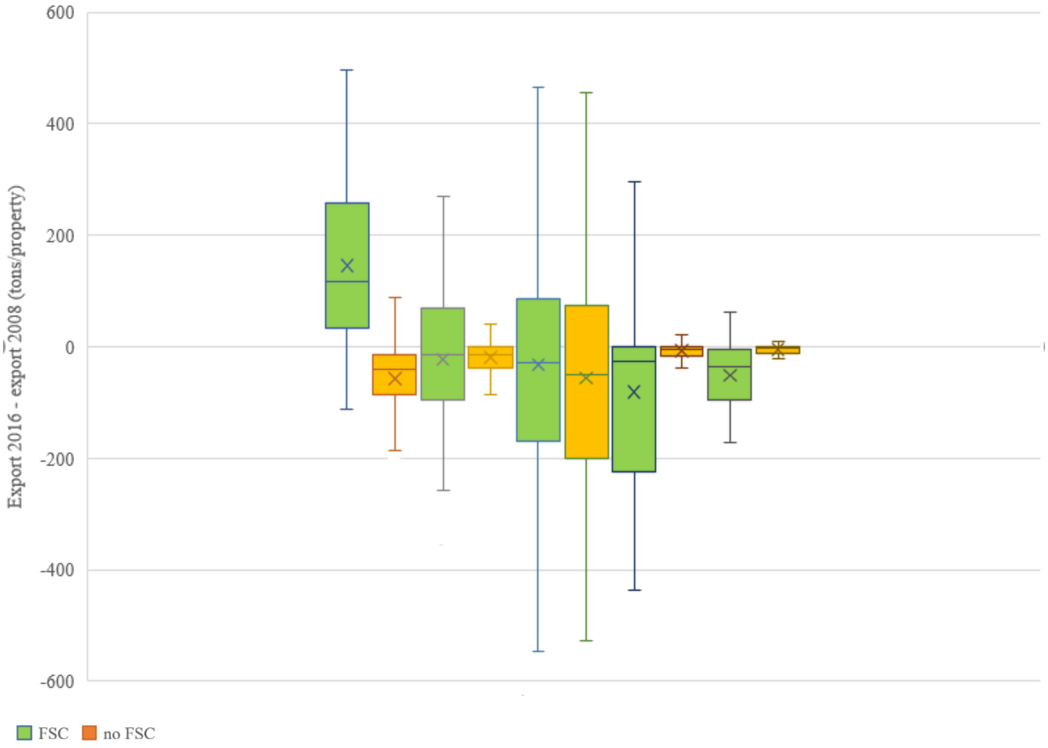

Figure K.6: Boxplots of data for sediment export (tons/property) used for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, in groups of 2 for each SL, left to right of SL 1, 2, 3, 4, and 5

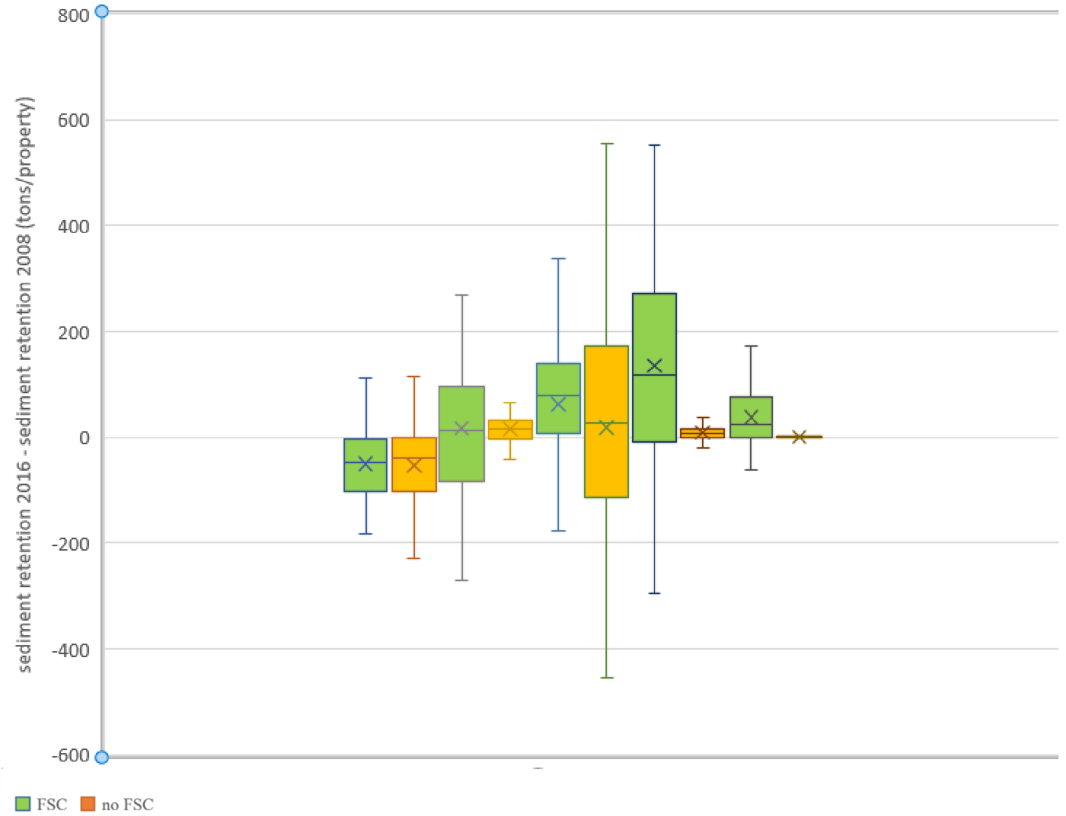

Figure K.7: Boxplots of data for sediment retention (tons/property) used for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, in groups of 2 for each SL, left to right of SL 1, 2, 3, 4, and 5

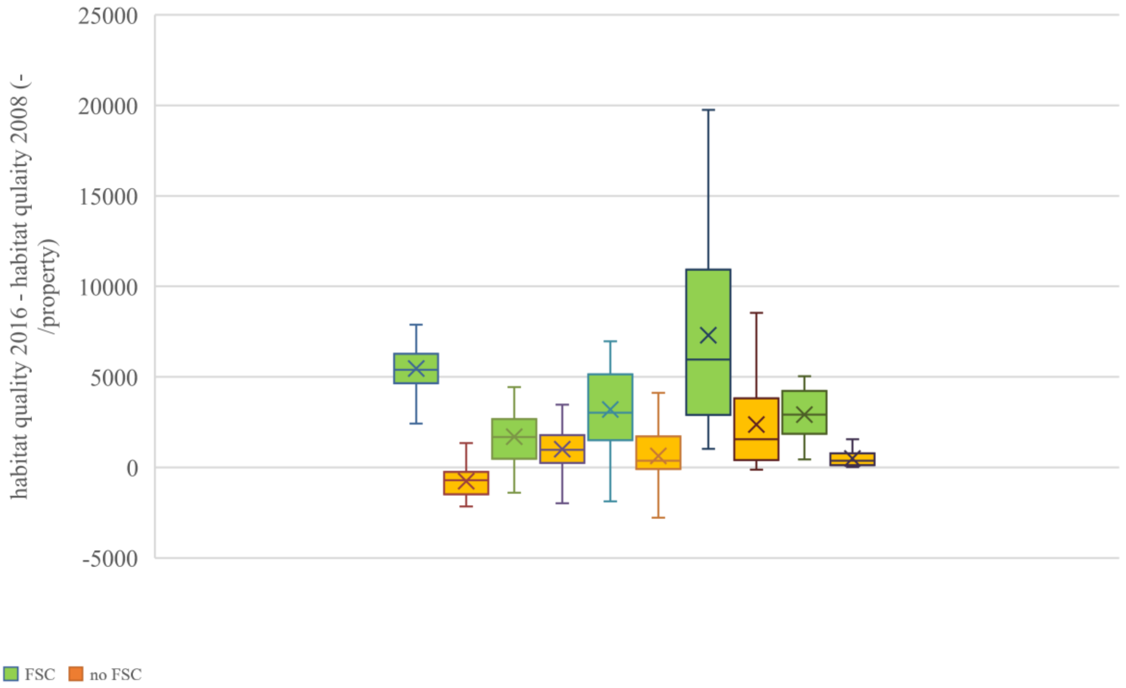

Figure K.8: Boxplots of data for habitat quality (-/property) used for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, in groups of 2 for each SL, left to right of SL 1, 2, 3, 4, and 5

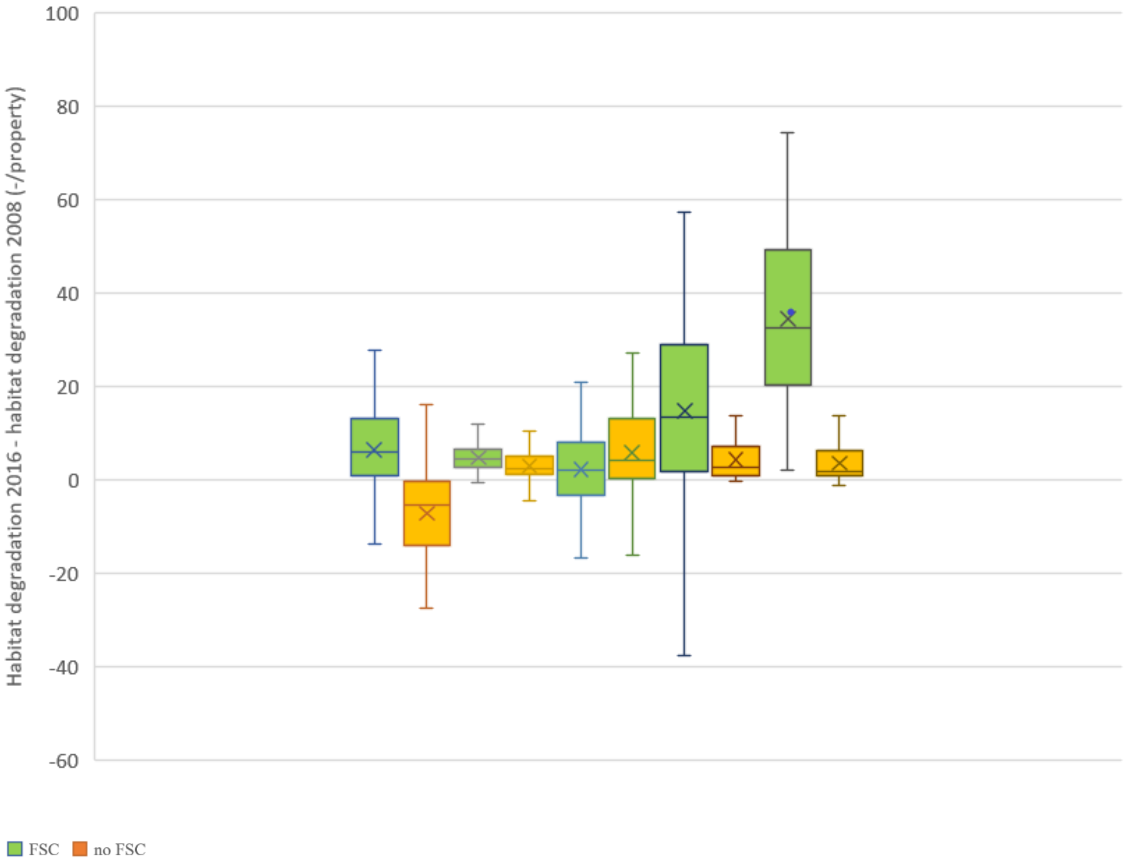

Figure K.9: Boxplots of data for habitat degradation (-/property) used for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, in groups of 2 for each SL, left to right of SL 1, 2, 3, 4, and 5

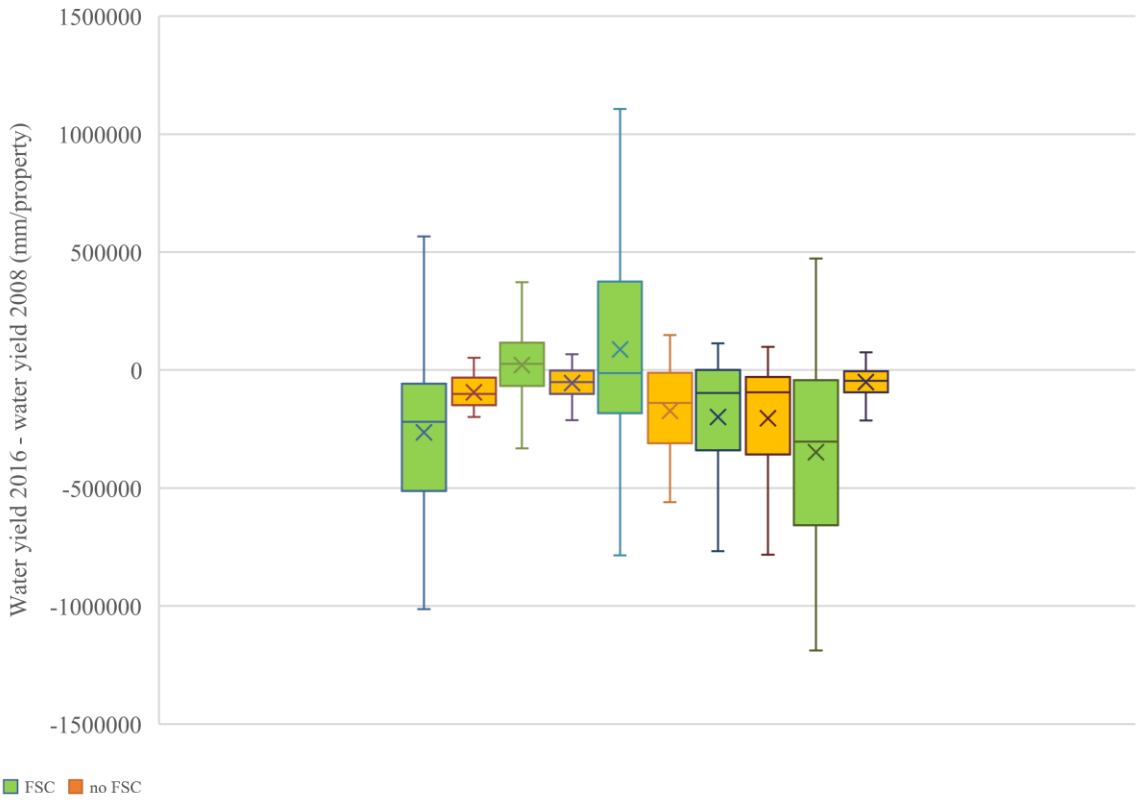

Figure K.10: Boxplots of data for water yield (mm/property) used for comparing temporal differences (2016 minus 2008) between FSC certified and uncertified areas, in groups of 2 for each SL, left to right of SL 1, 2, 3, 4, and 5