THE USE OF LINKING INDICATORS FOR PEATLAND CONSERVATION

A Thesis

by

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ABSTRACT

This research focuses on identifying and quantifying peatland ecosystem services to help inform valuation and conservation efforts. Peatlands worldwide provide food and clean water while also storing large amounts of carbon and supporting biodiversity. They are sites of education and recreation and serve as genetic reservoirs for organisms. However, these services are inherently threatened, as peatland degradation becomes a growing concern, particularly across the tropics. Increasing the resilience of these systems and allowing them to keep serving nature and people require new knowledge and improved local resource management systems.

This thesis uses an ecosystem service framework to identify the main ways in which peatlands benefit nature and people by using examples from around the globe. I then present a list of "linking indicators" connecting peatland stakeholder values with peatland ecosystem services. Using Chilean peatlands as a case study, I use surveys, interviews, and a focus group discussion to understand the unique ways in which different stakeholders use and perceive peatlands and identify which biophysical measurements can be used to help value peatland ecosystem services. The results suggest that linking indicators are a key part of ecosystem service assessments that could serve as an innovative approach to addressing some of our most pressing land management issues in peatlands and beyond.

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Contributors

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NOMENCLATURE

ES	Ecosystem Service
PES	Payment for Ecosystem Service
SES	Social-ecological System
GHG	Greenhouse Gas
GNP	Global Gross National Product
NCSs	Nature-based Climate Solutions
IRB	Institutional Review Board
NNR	The National Nature Reserve
WCS	Wildlife Conservation Society
WFS	Wonderfonteinspruit
GMB	Gerhard Minnebron
PSF	Peat Swamp Forest
NDC	Nationally Determined Contribution
NGOs	Non-governmental Organizations
KNP	Karukinka Natural Park
IUCN	International Union for Conservation of Nature
FAO	Food and Agriculture Organization
MEA	Millennium Ecosystem Assessment
NPP	Net Primary Productivity

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CHAPTER I

INTRODUCTION

Ecosystems worldwide are being impacted by environmental change and human activity. Peatlands, in particular, are threatened by a rapidly changing natural environment (e.g., droughts, fires, sea level rise) and increasing pressure from anthropogenic activities (e.g., logging, draining, harvesting) (Parish et al., 2008). These activities severely impact important peatland ecosystem processes, with effects on the ecosystem services (ES) peatlands contribute to nature and human well-being (Cris et al., 2014).

Peatlands have a wide geographic distribution and are found on every continent (Finlayson and Milton, 2018). They are located across the high latitudes as well as the tropical belt. They are found in the high mountains, along the coasts, and deep into continental regions (Xu et al., 2018). Although peatlands are widespread and contribute to multiple communities' well-being, few studies have used the ES framework and associated valuation methods to help manage peatlands (but see Page and Baird (2016) for an overview).

The ultimate goal of my thesis is to demonstrate how “linking indicators,” which connect stakeholder values with peatland ES (e.g., biodiversity, carbon storage, and clean water provision), can be powerful tools to aid ecosystem valuation and land management decisions. In my thesis, I identify key ES provided by peatlands and review the valuation methods that could apply to these services. Then, using Chile as a case study, I propose several linking indicators that could help bridge the gap between biophysical measurements in peatland ecosystems and the beneficiaries of those services. Overall, this work could inform policy, help community stakeholders appreciate the importance and value of peatland ES, and introduce management solutions that help maintain peatland function. Protecting these ecosystems will reduce carbon emissions into the atmosphere and sustain other important ES that local communities rely on.

Ecosystem Valuation and Conservation

Ecosystem conservation has progressively gained traction over the past few decades due to an increased awareness of anthropogenic impacts on the environment (Canney and Hambler, 2013). Humans have begun to accept their role as contributors and drivers of environmental degradation. Indeed, human civilizations rely on the natural resources and services provided by ecosystems, such as food, clean water, and raw materials. Nature provides these resources and services at no cost to us; this has led to severe alterations and exploitation of ecosystems worldwide, particularly with the advent of industrialization and rapid technological advancements (National Research Council, 1988). To remediate this issue, several methods have been developed to put a monetary value on ecosystems (de Groot, 1987; Costanza et al., 1997), though it has also been argued that nature should remain priceless (McCauley, 2006). As a result of several initiatives, there has been a growing movement aimed at better managing the natural resources we all rely on, with an emphasis on restoring degraded ecosystems, conserving intact ones, and sustainably managing the ones we need. In the following paragraphs, I provide a historical overview of the conservation movement in the context of ES valuation.

Historical overview of the conservation movement

Environmental preservation emphasizes that nature is best when left untouched or unspoiled by human activity. In the USA, this school of thought originated in the late 1800s, in the western mountains, where exploitation of natural resources was rampant on lands out of sight and unprotected by the government. Sir John Muir, known as the father of National Parks, was an early advocate for preservation. Muir, along with other notable conservationists of that time (e.g., Aldo Leopold, Henry David Thoreau, Ralph Waldo Emerson, and former US President Teddy Roosevelt), recognized wilderness as sacred spaces and priceless entities that must remain intact. Early preservationists strongly believed that future generations should be receiving a world that has not been degraded by the current generation (Krutilla, 1967). The Yellowstone model, now considered too protectionist and exclusionary (Schelhas, 2010), once represented a key example of conservation. One of the primary goals of preservation was to “represent a vignette of primitive America" (Leopold, 1963) by setting a baseline conservation goal to help restore and maintain American ecosystems to the conditions they were in at a time before the European settlers arrived. Yellowstone National Park - and many more Parks - were designed to remain pristine wilderness areas, free from human use, except for some tourism (Leopold, 1963).

While attractive, the idea of creating a baseline for Nature is hardly tractable. Baselines can be arbitrary in that it is difficult to pinpoint when the “first” human modification of the landscape took place or what is considered a human modification. For example, it is well known that Indigenous groups have modified their environment for thousands of years and that the use of nature has influenced the unique evolution of those environments (Casson et al., 2007; Hawes and Dixon, 2020). Early preservationists failed to recognize that humans occupied the land and altered the landscape prior to European settlement in the Americas. Likewise, nature itself changes based on climate and other environmental factors, which means that the concept of a baseline is flawed unless one was to let that baseline evolve over time (Jackson et al., 2009). This also brings up the issue of indirect human impact on natural ecosystems, including fertilizers, climate change, pollution, and many others.

While the preservationist movement was gaining traction in the US, conservationists were also developing their perspective on how nature should be managed. This alternative school of thought gave recognition to human-environment relationships. Conservation revolves around the idea that nature is a resource that ought to be sustainably shared among the most people possible (Pinchot, 1910). Critically, it typically revolves around addressing and presenting solutions for preventing the loss of biodiversity. This can include ecosystems, species, populations, and genes (Soulé, 1985). Although the conservation movement has given rise to various platforms to argue for the protection and management of ecosystems, it also drew criticism, particularly due to the way protected areas were historically managed (i.e., without inputs from local communities) (Young and Horwich, 2007). The conservation movement was built upon three foundational principles coined by Gifford Pinchot, the father of American conservation: (1) people have a right to use and benefit from the natural resources provided by the environment. This principle is in response to those who critique conservation in that it is a platform used to withhold resources; (2) conservation should support the prevention of waste. This comes in reference to preventing the loss of natural resources, and (3) natural resources must be developed and preserved for the benefit of the many and not merely the profit of the few (Pinchot, 1910). The world conservation strategy of 1980 provided a definition of conservation that did not deviate much from Pinchot's initial thoughts. They defined conservation as the 'management of human use of the biosphere so that it may yield the greatest sustainable benefit to the present generation while maintaining its potential to meet the needs and aspirations of further generations.' The three main aims of the Strategy were to: (1) maintain essential ecological processes and life support systems; (2) preserve genetic diversity; and (3) ensure the sustainable utilization of species and ecosystems (Canney and Hambler, 2013).

The ideas surrounding conservation kept evolving through the 20th century. Is particularly important that many conservationists do not consider nature a wild and pristine environment free of human interference. Conservationists tend to consider the relationships that already exist within nature and that nature's contribution to people are the driving force behind most current conservation efforts (Sandbrook et al., 2019). This new school of thought also introduces the idea of relational values, which are derived from the relationships and responsibilities between people and nature (Chan et al., 2016). By identifying the importance of those connections, relational values help establish thoughtful solutions associated with each ecosystem and the people that depend on it. Under this framework, local communities have the opportunity to collaborate on setting the value of nature, which may promote collaborative conservation initiatives. For example, the value of protecting biodiversity is based on its importance to people. It, therefore, encourages new approaches to conservation strategies such as partnerships with corporations, the natural capital approach, and the use of market-based tools such as payments for ecosystem services (Sandbrook et al., 2019). Putting a price on ecosystems makes it possible to further identify and define the services provided freely by ecosystems and value those services (see pp. 12-16). Naturally, advocates of the preservation movement and, to some extent, of the more traditional conservation movement reject these newer views, arguing instead for protecting nature for its own sake and emphasizing state-based protected areas and regulation (Sandbrook et al., 2019).

Today, conservation biology is a crisis discipline, as it addresses the most pressing issues of biodiversity loss and seeks to implement immediate action (Soulé, 1985). Conservation biologists are often contracted by government agencies and private organizations worldwide (Soulé, 1985) to address a range of issues, from protecting endangered species and maintaining ecosystem integrity to promoting the sustainable use of ecosystems. In the past 20 years, conservation has also rapidly expanded to include human-environment assessment. The general acceptance that humans are a part of nature instead of independent actors has helped improve local resource management systems across many regions. Scientists who use the social-ecological system (SES) framework to analyze complex problems more holistically have also become an integrated part of conservation (Colding and Barthel, 2019). SES science is well suited to implement adaptable conservation strategies and offer best-practice management solutions for several reasons. SES science recognizes human activity, land use, and biophysical systems as dynamic and highly interconnected systems that depend on a large suite of social, economic, and environmental factors, from market forces and governance to resource needs, community perspectives, sustainable development, and ecosystem resilience (Berkes et al. 2003; Colding and Barthel, 2019). SES science also has the advantage of generating co-produced knowledge by combining ecological knowledge, manager knowledge, stakeholder knowledge, and institutional needs (Berkes and Folke, 1998).

The Ecosystem Service Framework

The ES framework is heavily influential within the field of conservation, as it directly addresses the relationship between people and nature. By definition, ES are anthropocentric: they are the amenities created by natural processes in an ecosystem that are often beneficial to human welfare (Costanza et al., 1997). The ES framework consists of four main types of services: regulating, provisioning, cultural, and supporting (MEA, 2005; Figure 1). ES are composed of flows of materials, energy, and information from natural capital stocks, combined with manufactured and human capital services, to produce human livelihood (Costanza et al., 1997; Laterra et al., 2019). Provisioning services are the products obtained from ecosystems, such as clean water and wood. Cultural services are the nonmaterial benefits obtained from ecosystems, such as education, recreation, heritage, and spirituality. Supporting services are those necessary for producing all other ES and general functioning of the ecosystems, such as nutrient cycling, plant primary productivity, and biological diversity maintenance. Regulating services maintain ecosystem processes that help modulate natural phenomena. This includes climate regulation and flooding control, and air and soil quality (MEA, 2005).

Figure 1. Ecosystem services are nature's contribution to people through provisioning, supporting, regulating, and cultural services.

For example, clean water may be provided to a rural community through the natural filtration processes presented in soil. Soil acts as a sieve and holds back particles that are too large to pass through. In addition, soil microorganisms can often degrade organic chemicals that are considered contaminants if present in drinking water (Pierzynski, 2015). The hydrology of soil, in this case, is a natural process that provides a specific service to a community.

Natural sciences' awareness of the useful services provided by nature to society is not new; the concept gathered momentum in the 1960s and 1970s as a response to resource degradation and pollution. However, the term "ecosystem service" was not coined until Ehrlich and Ehrlich (1981), and it grew alongside the concept of sustainable development. Early research on ES mainly focused on identifying specific services and their relationship with humans.

A foundational and influential - albeit heavily critiqued - example of an ES study is Costanza et al. (1997). These authors looked at 16 biomes and 17 services, and they provided a monetary value for each of these services across those biomes. This study drew worldwide attention to the value of ES due to the reevaluation of their global gross national product (GNP): Costanza et al. (1997) more than doubled the global GNP of ES at that time, from $13T to $33T (Holzman, 2012). However, their results and their methodology were critiqued due to the arbitrariness attached to the framework. While Constanza et al. (1997) assessed ES individually for their capacity to create a commodity, ES can also create joint products and are almost always functionally connected to other services. In addition, the list of services highlighted in Costanza et al. (1997) does not encompass all ES and therefore creates a broad yet limited focus that disregards other important ES. For example, services related to "soil" are not truly acknowledged by these authors, with the only service being “soil formation.” And of course, the arbitrary value that was established for each ES was applied across biomes, foregoing any inputs regarding the localized importance of some of these ES. Since this seminal work, the ES framework has continued to be applied at the global scale. However, it has also been used at local scales, where it can better encompass the uniqueness of ecosystems, the interconnectedness of ES, and the perceived value of those ES. With that said, Constanza et al. (1997) did mention that one ES might be the product of two ecosystem functions or processes, and therefore the interdependent nature of many ecosystem functions must be recognized. While not explicitly used in their ES valuation, this recognition highlights the need to conserve ecosystems in their entirety due to their support of human welfare. However, this message was not emphasized by many of the users of the framework. Of course, preservationists who argue that nature should not be valued have also raised the issue that, once an ES has been priced, it can also be “bought” and destroyed (McCauley, 2006). In other words, putting a price tag on nature could lead to the commodification of nature, which leaves room for misuse of the natural capital system (Chan et al., 2016). In response, pragmatists argued that it may be better to attribute value to ecosystems than none and that this would certainly slow down, if not stop, their degradation. Indeed, the intention of ecosystem valuation is to create an urgent need to protect nature's services, not to “buy out” nature (Daily and Ellison, 2003). Overall, during this time, a growing number of scientists began to attribute value to ES, a new frontier for the field.

Ecosystem valuation and natural capital

The connection between ES and natural capital came to fruition during the 1980s (De Groot, 1986; Barbier, 2019). Capital is defined as a stock of materials or information that exists at a point in time. Capital is broken down into three categories: natural, manufactured, and human. Natural capital consists of physical forms such as vegetation and soil; manufactured capital is represented physically by buildings and technology (machines); human capital is the capital of physical bodies. Costanza et al. (1997) link these concepts together by stating that ES are composed of flows of materials, energy, and information from natural capital stocks that combine with manufactured and human capital services to produce human welfare. However, this idea raises concerns about how a particular form of capital or service is then valued. Valuation methods cannot establish absolute values about an ecosystem (Daly and Farley, 2010). Estimated values are typically thought to constitute lower bounds, as they often only capture the obvious aspect of ES value. In addition, measures of ecosystem goods and services are subjective because of the unique role each service plays in an individual's life. Valuation is a matter of perspective.

Despite these caveats, ecosystem valuation is deemed important, as it calls attention to those natural resources that would otherwise be taken for granted. We know that markets do not directly capture the value of environmental resources. Valuation studies are thus useful for quantifying the economic costs associated with ES losses (habitat or species losses have been particularly impactful). Valuation studies can also guide policy and help create incentives that discourage land management solutions that lead to the degradation of ecosystem function (Daily and Ellison, 2003). There are eight valuation methods: market price, productivity, hedonic pricing, travel cost, cost avoidance, contingent valuation (stated preference), contingent choice, and benefits transfer (Daly and Farley, 2010; Figure 2).

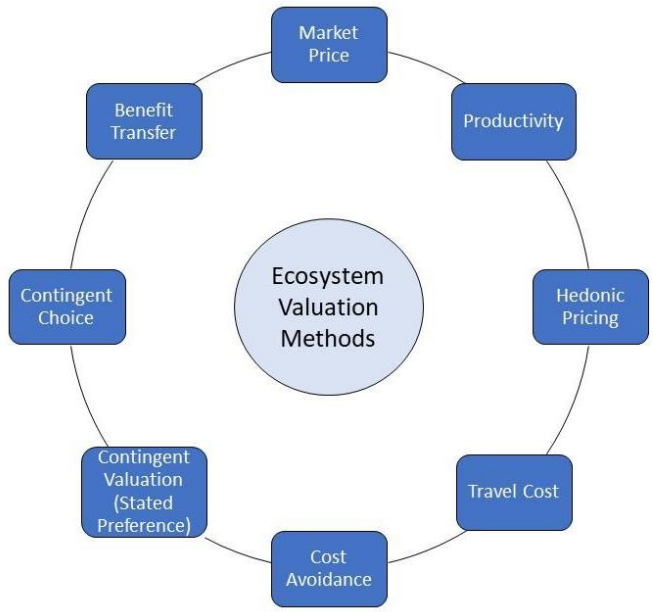

Figure 2. The main ecosystem valuation methods.

The eight ecosystem valuation schemes can be divided into non-monetary vs. monetary assessments, such that ES that hold no monetary value can still be valued. The following paragraphs briefly define those valuation methods; for detailed descriptions, refer to MEA (2005) and Boyd et al. (2016), and Bagnall et al. (2018).

(1) The market price method estimates the economic value of ecosystem goods or services bought and sold in markets. For example, cranberries that naturally grow in peat bogs can be harvested and sold at market price. The market price method

also addresses non-market values, which can be considered “use” and “non-use” values. For example, a hiker in a National Park enjoys a physical use of land to which a market value can be associated. Non-use values are not as straightforward but still deemed powerful to determine the value of an ecosystem. First, the “option value,” for example, the potential for visiting a National Park one day, confers value to a place. Second, the “existence value,” for example, a rare species found in a particular region, even though they may never be seen in nature, gives that ecosystem a value. Third, the “bequest value” focuses on preserving an ecosystem so that future generations may enjoy it. Lastly, the “altruistic value,” such as a non-hiker wanting to preserve a popular hiking trail for hikers, provides nature value through preservation. These concepts within the market price method collectively aid in assessing ES by measuring the economic benefits from marketable goods based on supply and demand estimates.

(2) The productivity method is used to estimate the economic value of ES that contributes to the production of commercially marketed goods. For example, the cost of filtering public drinking water. The economic benefits of improving water quality can be measured by the decreased costs of providing clean drinking water and treating illnesses caused by water-borne diseases. When deciding whether to use the productivity method, the direct effect from an environment's quality level on the cost of producing a marketed good is carefully analyzed. There needs to

be a direct link between the effects of changes in quantity or quality of the resource to consumer or producer surplus changes, which then helps to estimate the economic benefits of a particular environmental service.

(3) The travel cost method calculates people's expenses to reach and experience a location. That information can then be used to estimate the demand for the location, similar to the market price approach. For example, a visit to a National Park may require the purchase of plane, boat, and/or bus tickets. In addition, hotel nights, food, gas, souvenirs, and other expenses generate revenue for various local businesses, which indirectly benefit from the Park.

(4) The cost avoidance method refers to any (free) ES that would otherwise have to be manufactured. For example, flood control, natural carbon sequestration, and water filtration would need to be replaced by engineered solutions involving machinery if not provided freely by nature. The avoided cost associated with replacing those lost ES or the cost of providing substitute services can be valued.

(5) The hedonic pricing method is most commonly applied to variations in housing or land prices that are linked to environmental attributes. It is applied, for example, in cases where the quality of an ES may increase the price of associated goods, like as the water quality of a community increases, so do their housing prices.

(6) The contingent valuation method, also known as the stated preference method, addresses what people would do under hypothetical scenarios. Since most natural resources are not traded in markets and are not closely related to any marketed goods, consumers cannot claim what they are willing to pay for specific ecosystem services through their market purchases or actions. However, within the confines of this method, surveys can be utilized to directly ask what consumers are willing to pay for an ecosystem-based on a hypothetical scenario. Surveys can also be used to question consumers about their willingness to make tradeoffs among various alternatives, which helps to make estimates on their inclination to pay for specific ES. This method is classified as contingent because the consumer is the driving force behind the economic valuation of a particular ES. Valuation is directly affected by the consumers' response because it is solely based on their willingness to pay for a service. For example, some public programs aim to meet the needs of communities where certain infrastructure is lacking, such as sanitation (e.g., toilets, connections to the sewage system, region-wide wastewater treatment). To set the value of the proposed service, public programs may send out surveys to ask community members how much they are willing to pay for improved sanitation (i.e., increase costs in utilities or taxes).

(7) The contingent choice method is similar to the contingent valuation method, as it is also based on the consumers' willingness to pay. However, there are

differences regarding how the results of the respondents are prompted. Essentially, respondents are shown a set of alternative representations of a material good and are asked to pick their most preferred one. Valuation depends upon the consumers' preferred goods, and from there, a price can be applied to said good. For example, a similar scenario as above can be applied, where a survey provides community members with alternative options set at different prices, again in the context of sanitation. Community members choose which service they need and at what price they are willing to pay.

(8) The benefit transfer method estimates the ES value at one place using values from studies that were performed at other locations. For example, this method can be used to attribute admission costs from one National Park to another that is comparable in value and esteem.

Valuation: a matter of perspective

The valuation of nature is audience-specific, meaning how people value nature is subjective and based on individual needs, customs, and experiences (Keenan et al., 2019). Understanding various perspectives attached to the valuation of nature can provide insight that is useful for creating management tools that more accurately capture the perceived value of nature by its stakeholders. Following the new conservation school of thought, recognizing SES as a key component of the conservation movement improves the overall approach to investigating and adapting conservation strategies (Colding and Barthel, 2019; Bouamrane et al., 2016).

Stakeholder perspectives are pertinent for environmental decision-making. However, due to the difficulty of synthesizing potentially conflicting values into a cohesive framework, conservation often omits some stakeholders' perspectives and values (Bouamrane et al., 2016). Consequently, there is often negative pushback from these forgotten stakeholders on resulting frameworks because their needs are not met or, in some cases, not even considered (see Jones and Burgess, 2005; Vogler et al. 2017 for an example).

A lack of co-production of knowledge or perspectives in the peatland conservation process can lead to the imbalance of stakeholders' interests and needs. For example, a government might enable peatland use for hunting, but local residents may rely on those same peatlands as a spiritual site (Guerry et al., 2015). The management of a particular ecosystem depends on specific conservation goals, most often tailored towards an ES of particular interest, which also often influences ecosystem valuation. Stakeholder's management goals could be vastly different from one another if one ES is valued more than another, leading to an unbalanced management plan (Ostrom, 2009). Therefore, stakeholder inclusion is essential to recognize all ES and their interdependence and for developing effective peatland conservation strategies that meet the needs of all stakeholders.

Peatlands' Role in Biogeochemical Cycling, Water Resources, and Biodiversity

Peatlands are carbon-rich wetlands that accumulate organic matter over centennial to millennial timescales. To be considered a peatland, the soil organic layer must have a thickness of at least 30cm and be characterized by organic matter content of at least 30% (dry mass) (Tanneberger et al., 2021). Peatlands are also water-saturated environments that promote anoxic conditions, limiting decay and allowing for a net positive balance between accumulation and decomposition (Mitsch and Gosselink, 2000). For these reasons, peat accumulation can reach depths of several meters (Rydin and Jeglum, 2006); this accumulation will continue as long as water tables are at, or close to, the peat surface throughout the year.

Though they only cover 3% of the global land area (Xu et al. 2018; Figure 3), peatlands are widespread across the world's landscapes. Peatlands come in many sizes and shapes, from small kettle hole bogs to large fen complexes that blanket entire landscapes (Figure 4). Peatlands harbor diverse plant communities, mainly dependent upon location, climate setting, and nutrient status. For instance, fens are sustained by mineral-rich groundwater, and their plant communities are typically dominated by grasses, sedges, or reeds (Mitsch and Gosselink, 2000). Fens typically see high plant productivity and relatively high plant diversity, but their peat deposits also undergo intensive decomposition due to fluctuating water table levels.

Conversely, bogs are acidic peatlands that only rely on atmospheric inputs for their moisture (i.e., precipitation) and nutrients; they are known to support acidophilic vegetation, most notably mosses, as well as an array of carnivorous plants (Mitsch and

Gosselink, 2000). Bogs tend to have lower plant productivity and diversity than fens. However, their acidic conditions and stable water levels further limit peat decay, allowing peat formation and subsequent long-term carbon accumulation. Some swamps and marshes can also be considered peatlands. These systems are both defined as minerotrophic and, like fens, they rely on organic-rich waters that may come from groundwater, overland flow, or a mixture of both (Rydin and Jeglum, 2006). The main difference between fens and bogs vs. marshes is that the latter are either permanently or seasonally flooded, and they often have shallow peat accumulations (Rydin and Jeglum, 2006). Marshes support submergent vegetation, such as reeds and tall sedges (Rydin and Jeglum, 2006).

On the other hand, swamps are forests or thicketed wetlands with various plant life, including tall shrub thickets, herbs, grasses, and mosses (Burton, 2009). The hydrology of swamps is largely determined by the amount, timing, and duration of flooding (i.e., standing water), with flowing water entering the system in pools or channels and subsurface flow (Rydin and Jeglum, 2006). The water table level in marshes is often well below the surface so that the surface layers are exposed to air. For these reasons, swamps can be characterized by shallow or very deep peat deposits (Rydin and Jeglum, 2006).

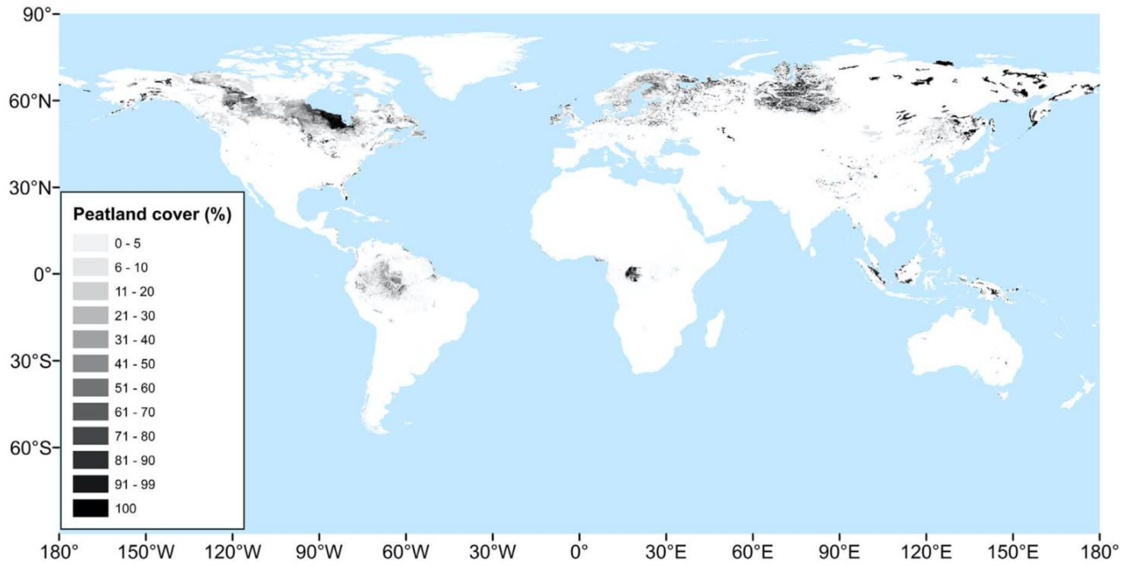

Figure 3. Global peatland map (data from Xu et al., 2018).

Peatlands are primarily known for their role in the global carbon cycle. These ecosystems store up to about one-third of the planet's total soil carbon (Gorham 1991; Yu et al., 2010; Loisel et al. 2014; Ritson et al., 2016). Left undisturbed, stored carbon can remain locked in this organic soil form for thousands of years (Borren et al., 2004). Peatlands' ability to sequester carbon aids in reducing global greenhouse gas emissions; it is now well-accepted that peatlands have contributed to cooling the world's climate throughout the Holocene (Frolking and Roulet 2007; IPCC 2014). For this reason, peatlands have been suggested as a key player in nature-based climate solutions (NCSs) (Bossio et al., 2020; Tanneberger et al., 2021; Humpenöder et al., 2020). NCSs are ways of storing and reducing carbon emissions in the world's forests, grasslands, and wetlands (Griscom et al., 2017). NCSs can help reduce carbon emissions to the atmosphere and store additional carbon in the landscape in the form of soil and biomass (Griscom et al., 2017). This has allowed peatlands to reach the global political arena as an ecosystem of interest for policy making. With that said, these ecosystems also contribute to climate warming through their methane emissions to the atmosphere (Humpenöder et al., 2020). However, those emissions are countered by the net accumulation of carbon dioxide (as organic material) in these soils (Gumbricht et al., 2017), making peatlands' carbon balance a net sink.

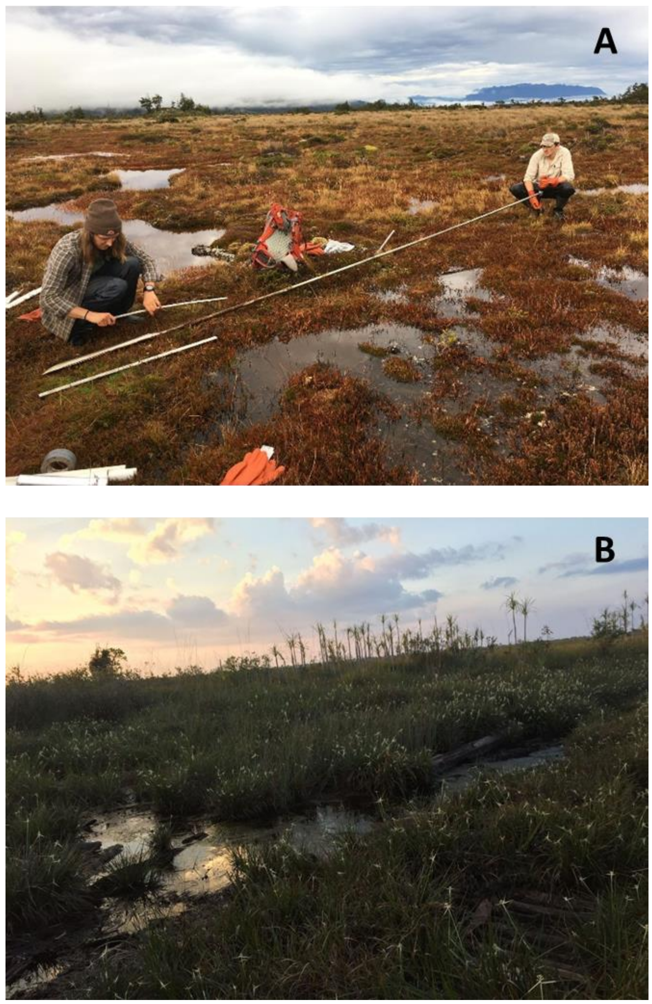

Figure 4. Peatlands are geographically dispersed across the globe. For example, (A) a high-latitude peatland in southern Patagonia, Chile, and (B) a tropical peatland in Central Kalimantan, Indonesia.

In addition to their large carbon store and their capacity to mediate greenhouse gases, peatlands are known for their hydrology, which regulates regional water flow, provides locally sourced water, maintains water quality, and can serve as an economic resource. For example, peatlands are known to contain about 10% of the world's freshwater resources (Joosten and Clarke, 2002). These unique hydrological features are because peatlands are only found where landscapes enable water to collect, i.e., in depressions (Parish, 2008). Their thick and saturated organic layers, combined with their typically flat surface topography, greatly contribute to slowing down water movement across the landscape (Labadz et al., 2010).

Peatlands are known to support several plant and animal species, many of which are unique to these ecosystems. The main peat builder is, without a doubt, *Sphagnum* moss. It is believed that up to about half of the world's peatland carbon stock is made of *Sphagnum* (Rydin & Jeglum 2006). This species is found in most mid- to high-latitude fens and bogs, where it tends to form continuous carpets. *Sphagnum* mosses are known as ecosystem engineers: they acidify their environment by releasing hydrogen ions, making them inhospitable for other plant species (van Breemen, 1995). They also behave like sponges by absorbing much of the atmospheric water inputs and thus limiting the amount of water that percolates down into the rhizosphere, this limiting water uptake by vascular plants (van Breemen, 1995). Peatlands also harbor a myriad of tree, shrub, and grass species, many of which have cultural or commercial value. Fens, swamps, marshes, and bogs are also home to several microorganisms that decompose organic matter under aerobic and anaerobic conditions. As for insects, invertebrates, and fungi, they are abundant near the peat surface, where there is more exposure to oxygen. Lastly, peatlands serve as a habitat for various fauna, many of which are migratory. In particular, a high diversity of birds populates forested peatlands due to the abundance of insects and availability of tree-holes for breeding (Rydin and Jeglum, 2006). Likewise, caribou herds rely on lichen that grows on peatlands for forage. Some fish species nest and feed in the seasonally flooded tropical peat swamps; many of these species are important to the livelihood of local people communities.

Current Knowledge Gaps and Research Objectives

Throughout history, wetlands have often been described as sinister and forbidding. In Dante's Styx of Hell, the final resting place for the wrathful in the Underworld is pictured as a marsh (Dante, 1320); in the Lord of the Rings' Dead Marshes, the reeking swamps contain the dead from battles of long ago (Tolkien, 1954). The swamp also leads to Mordor, where the Dark Lord lives. There is also the "Swamp Thing," a humanoid-plant-monster creature who fights to protect his swamp and the world in general, lives in a scary wetland. In the non-fictional world, similar stories abound: the Urarina indigenous community of the Chambira River Basin in the Peruvian Amazon describes peatlands as "dead lake[s]" filled with powerful and irritable mothers that are known for terrorizing community members (Schulz et al., 2019a). Despite their negative portrayal, wetlands provide numerous services to nature and society worth discussing. Taking Costanza et al. 's (1997) list of ES, wetlands were suggested to contribute 10 different types of ES, and their value per hectare was estimated at $14,785 per year. I would argue that Costanza et al. (1997) underestimated wetlands' ES, as they omitted their role in climate regulation, erosion control, and soil formation. Today, the value of wetlands is estimated at ~$80,000 per hectare per year (Davidson et al., 2019).

Despite their prominent role in the global carbon cycle, regional water cycle, local biodiversity support systems, and their uses and cultural significance for many communities worldwide, a holistic analysis of peatlands' ES remains incomplete. Likewise, the complex linkages between peatland ES and their perceived value by local communities are often not well described. These data and knowledge gaps hinder our ability to improve local resource management systems.

To address these knowledge gaps, I pose the following research questions:

1. What ES have been historically identified as peatland ES by previous literature?
2. How has peatland ES been valuated in the past, and can these frameworks be adapted to ecosystem valuation methods to create effective conservation strategies?
3. How do different peatland stakeholders define conservation? How are peatland ES communicated between stakeholder groups, and what communication barriers exist?
4. What are possible methods for valuating peatland ES that address communication barriers and ES knowledge gaps among peatland conservation stakeholders?

Here, I provide an exhaustive list of peatland ES (Chapter 3). Through a case study, I use the concept of "linking indicators" to connect peatland biophysical measurement with peatland ES and peatland users (Chapter 4). The case study is used to recognize that the value of nature is audience-specific, as nature draws meaning and value from the social constructs we place on it. This contrasts global-scale studies such as that by Costanza et al. (1997), where valuation is done based on a generalized understanding of ES that does not incorporate local stakeholders' perspectives or the unique features of sites being considered. Overall, I argue that, as a new decision-support tool for ES quantification and valuation that could be included in an SES framework, linking indicators can be used to break barriers in conservation discussions.

CHAPTER II

METHODS

A Synthesis of Peatland Ecosystem Services

The sections below describe the way the peatland ES synthesis was developed.

Search strategy

To efficiently synthesize information reported in the published literature, I developed a systematic query using a suite of keywords (Table 1) that were input into Web of Science and Google Scholar search engines. Once found, the literature was examined in the following manner. First, I identified papers and book chapters that discussed “peatland ecosystem services.”. The title and abstract of the selected articles were then screened to confirm the relevance of the papers. Each reference was then screened to identify which ES were mentioned in the full text; those ES were then listed. Second, I searched for examples pertaining to each ES. To do this, articles that specifically addressed peatland “carbon,” “water,” and “biodiversity” services were added to the collection. Words that referred to peatland and “culture,” “art,” “use,” “education,” “tourism,” “nutrients,” etc. (see Table 1) were also used in the search. All these papers were then screened to identify relevant information, and, oftentimes, their reference lists were used to find additional sources of information. The focus was on peer-reviewed literature written in English, but grey literature (also in English) was also considered. The second step yielded numerous case studies that could be tied with the

ES that were previously identified. It also allowed me to recognize additional ES that had not been found during the first step.

Peatland and “culture”	Peatland and “paludification”
Peatland and “art”	Peatland and “flood”
Peatland and “aesthetic”	Peatland and “mitigation”
Peatland and “historical archive”	Peatland and “fire”
Peatland and “use”	Peatland and “mesoclimate”
Peatland and “education”	Peatland and “water”
Peatland and “recreation”	Peatland and “filtration”
Peatland and “tourism”	Peatland and “purification”
Peatland and “nutrients”	Peatland and “GHG cycling”
Peatland and “grazing”	Peatland and “*Sphagnum*”
Peatland and “habitat”	Peatland and “species”

Table 1. Keywords used to complete search

The criterium for my literature review was chosen to focus my study on the sustainable uses of peatlands to help support their conservation. First, the references had to target ES or case studies that were applicable to peatlands (bog, fen, mire, peatland, muskeg, peat marsh, or peat swamp). For example, ambiguous studies (e.g., studies applicable to wetlands, but not necessarily to peatlands) were left out. Second, the analysis focused on “natural” ES; any ES deemed unsustainable (e.g., logging, peat extraction, etc.) was disregarded due to its potential to lead to peatland degradation. Promoting ES that led to degradation would not fulfill the goal of supporting peatland conservation.

Peatland ecosystem service classification

The peatland ES were then split into the four main types of services: provisioning, supporting, regulating, and cultural (MEA, 2005). To be categorized as a regulating service, an ES needed to demonstrate its ability to maintain peatland processes that help facilitate natural phenomena. Provisioning services were sought after in the literature as the goods and materials obtained by peatlands. ES's that assist the production of all other peatland ES and their general function were classified as supporting services. Lastly, cultural services were the non-material societal benefits obtained from peatlands.

To mitigate any overlap between ES categories, I evaluated the interconnected nature of some peatland ES. For example, peatlands are known for their hydrologic properties, especially their ability to store a considerable amount of water. Although water storage is a regulating service (storage and retention), this inherently leads to the provisioning service of peatlands as a water source because communities worldwide rely on peatlands for their abundant source of clean water. In the case above, "water storage" itself was ultimately classified as a regulating service because it does not imply the use of stored water but rather the service of water naturally being stored. Whereas "water source" is deemed a provisioning service because water is referred to as a resource for use.

Linking ES with Valuation Methods

Using an online diagram software called Lucidchart, I designed a figure to show the connection between peatland ES (pp. 39) and ecosystem valuation methods discussed in Chapter 3 (pp. 60). I first listed each of the ES and grouped them according to the type of ES they belong to (i.e., provisioning, supporting, regulating, cultural). Then, I listed each of the ecosystem valuation methods and color-coded each so they could be visually teased apart from one another. I then evaluated which valuation method belonged to which type of ES. Once valuation methods were placed in the appropriate group, I used brackets to draw the connection from types of peatland ES with all applicable ecosystem valuation methods. Naturally, ecosystem valuation methods and their applicability are subjective.

Linking Indicators: Definitions and Use

Ecosystem valuation needs a tool capable of integrating interdisciplinary knowledge while remaining intuitive to use and easy to understand. To do this, I identified "linking indicators," which are described as biophysical measurements that can represent the state of an ecological process that affects human well-being (Bagnall et al., 2018). Linking indicators are measurable in the field (or using a model), and they transform any changes in ES into a measurable value of benefits to people. Linking indicators also facilitate social interpretation of ecological conditions and change (Boyd et al., 2016).

Fundamentally, a linking indicator is a measurement of an ES that makes the most sense to the target audience (Figure 5). It links the science to the needs of the stakeholder. This is useful when trying to convey the costs and benefits found from a valuation method in addition to, or in the absence of, price (Bagnall et al., 2018). Linking indicators are crucial because they act as points of contact between ecological and social systems and their analysis (Boyd et al., 2016). To build linking indicators, one must first identify and listen to the stakeholders and learn how they use, value, or perceive the ecosystem. Next, the ecosystem processes that make those ES possible must be identified and measured. This scientific aspect of the work may be meaningless to the stakeholder; for instance, a farmer may be interested in knowing how much she needs to irrigate her fields to maximize yield. The scientist can measure water retention rate and water-holding capacity in her soil, which would then need to be renamed and transformed to better address the stakeholder's needs. In other words, linking indicators provide a common language between all stakeholders; it also facilitates education. In this thesis, I am developing linking indicators using surveys, interviews, and a focus group discussion held with peatland stakeholders from Chilean Patagonia (see below).

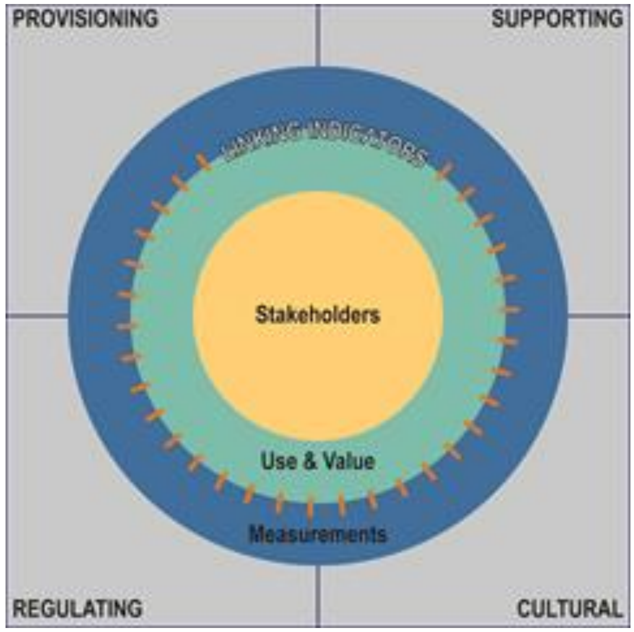

Figure 5. A conceptual model representing "linking indicators". The orange dashes represent linking indicators, which lie at the interface between scientific biophysical measurements (blue ring) and the unique ecosystem use by a stakeholder (green and yellow rings). Linking indicators allow us to integrate peatland ES (provisioning, supporting, regulating, cultural; grey squares) into valuation schemes (e.g., market price, cost avoidance, contingent choice, benefits transfer).

Study Region - The Peatlands of Chilean Patagonia

Chile is a country rich in natural resources, primarily when it comes to mineral deposits and water. The importance of environmental protection has gained significant traction over the past few years, as a growing number of local, national, and international initiatives have been aimed at bringing Chilean environmental protection to the spotlight. Notably, the foundation of the Ministry of the Environment in 2010 has made it more difficult to degrade the country's natural resources (Mansilla et al., 2021). For instance, there is a new law that protects "areas of scientific interest" from exploitation.

This law requires special permits to access those protected lands. Any commercial development or natural resource extraction requires a large amount of paperwork, including a letter signed by the President of Chile's cabinet (Mansilla et al., 2021). This law has been an effective tool to deter land-use change. An example of a grassroots movement, "Patagonia Without Dams," rallied environmental activists and local community members across Chile to protest the construction of five hydroelectric dams in the Chilean Patagonia region (Vince, 2010). Lastly, several private conservation Parks have been developed across Chile, including Karukinka (WCS, 2012), Tompkins (Wakild, 2009), and Pumalín (Wakild, 2009; Hora, 2018).

Many of the peatland resources of Chile are threatened by land-use change. This is particularly the case in southern Patagonia (Figure 6), where peat drainage and extraction for horticultural use are widespread, and extractive activities have increased exponentially over the past few years (Saavedra and Figueroa 2015; Gobernio de Chile, 2019). Peat is considered a concessional mineral under Chilean mining law (Hoyos-Santillán et al., 2019), and its extraction is permitted regardless of existing land tenure. As for peat moss harvesting, the regulatory framework changed a few years ago; since 2019, the 'Servicio Agricola ganadero' can supervise the harvest and carry out training on sustainable harvesting practices. However, it remains to be determined how training will be carried out; in addition, there is no distinction between moss harvested from 'pomponales' (anthropogenic peatlands) or natural peatlands (Mansilla et al. 2021). These conditions pose a threat for all peat in Chile, on public or private land, and even within Protected Areas (Landry et al. 2010), with the narrow exception of those "areas of scientific interest."

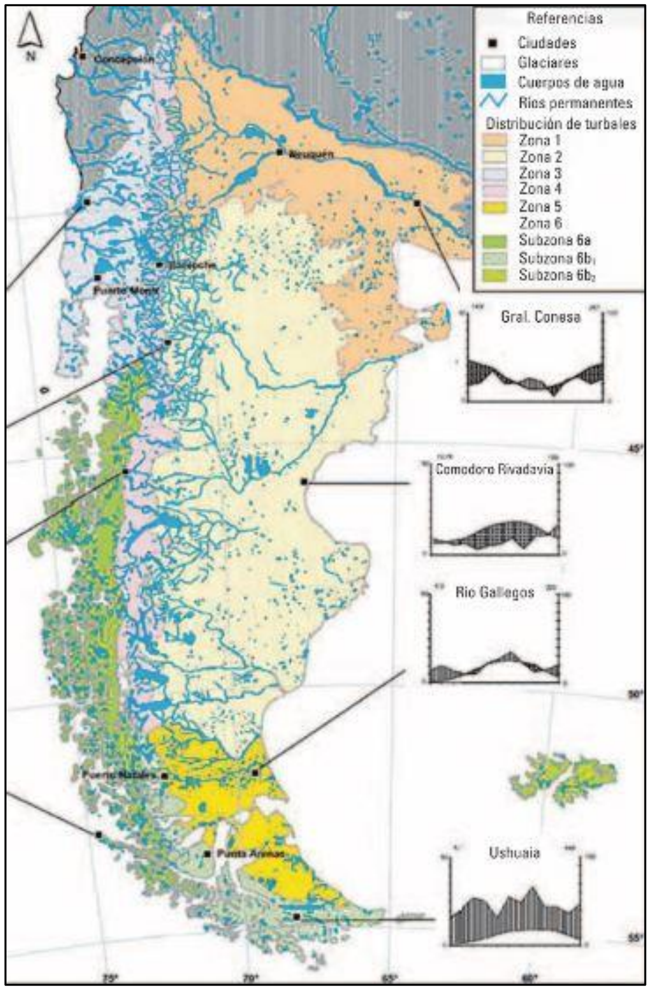

Figure 6. Peatland map of Patagonia
(data from Dominguez and Vega-Valdes, 2015)

In my thesis, the focus is on the high-latitude peatlands of Chilean Patagonia. Many stakeholders are active in conservation in this region, as the Chilean high-latitude peatlands are considered one of the main peatland regions in the world (Keddy, 2005). The case of Chilean Patagonia is thus ideally suited for this study on peatland linking indicators. There is much to be gained from a holistic view of the importance of peatlands for the local communities and nature. In addition, our research team at Texas A&M University has long-lasting relationships with a few peatland stakeholders from this region. I leveraged this existing network to test my hypotheses.

Gathering information about peatland stakeholders

Once stakeholders are identified, getting insight into how they understand peatland processes and perceive the value of their ES is a complex task. In this study, I use a three-pronged approach to document these facts: (1) develop and deploy an online survey, (2) interview the respondents, and (3) lead a focus group discussion on peatland ES. Below, I briefly describe how these steps were achieved.

Identify respondents

To identify the most appropriate participants for this study, a set of criteria was created. Each participant needed to be between the ages of 18-80, live in Chile, and experience working and/or volunteering with peatlands in Chile within three possible sectors: academic, conservation, or government. I targeted professionals working or volunteering in science, conservation, and sustainable development for this proof-of-concept project. Due to the COVID-19 pandemic, critical peatland stakeholders considered vulnerable populations, such as local and indigenous populations, were not included in this study, as community engagement was not possible. Future research should include these stakeholders. Participants that matched these criteria were selected and identified through an existing professional network. Recruitment emails were then sent to this network. I employed snowball sampling, in which subjects were asked to share the recruitment email with other professionals who fit the criteria.

Develop and deploy survey

The goal of the online survey was to get an idea of each peatland stakeholder's perspective with respect to peatland use and ES knowledge and then compare those perspectives. Specifically, the survey gathered information on how participants perceive peatland ecosystems, how they use them (or resources provided by them), how they might measure their use, how they value them, and whether they believed peatlands are important for sustaining Chilean livelihood. The survey contained a total of 13 questions (Appendix A). Before sending the survey to potential respondents, the study underwent a review by the Institutional Review Board (IRB) at Texas A&M University to establish the project's validity and ensure the safety of potential participants. My project was ultimately deemed "exempt," signifying that it is no more than "minimal risk" and fits one of the exempt review categories as defined by federal regulation 45 CFR 46. The recruitment email, which included the online survey, was disseminated on December 1, 2020, to 12 people. The survey was presented using Qualtrics. Candidates had until January 31st, 2021, to complete the survey.

Interviews

The goal of the individual interviews was to connect individually with participants and allow them to elaborate more on some of the themes that were touched on in the survey. The interview questions themselves were split into two different categories. The first half of the interview pertained to a more general view of conservation in Chile. The second half of the interview centered on participants' perspectives of peatland conservation in Chile. Each interview was semi-structured and set to last approximately one hour. Each interviewee was asked questions pertaining to known conservation efforts in Chile, communication barriers in conservation, their familiarity with peatland ES, and potential ways to measure and value those ES (Appendix B). Interviews were held via Zoom between March 1, 2021, and March 25, 2021. I interviewed each participant. A total of 4 interviews were completed.

Lead a focus group discussion with the respondents

The goal of the focus group was to facilitate a 'meeting of the minds.' The participants took part in a group exercise that would eventually lead to the development of linking indicators. During the first part of the discussion, I asked the participants to identify whom they considered to be peatland stakeholders in Chilean Patagonia. In the second part of the exercise, I asked them to name all the measurements that scientists perform in the field regarding peatland ES. Afterward, I asked the participants to build bridges between peatland stakeholders and ES measurements (i.e., develop linking indicators), but we did so without mentioning the concept of linking indicators. This way, the respondents reported unbiased, original examples of ecosystem uses and how they could be measured in the field. After listening to their examples, I described the concept of linking indicators, showed them the conceptual model (Figure 5), and explained that I would utilize our conversation to build linking indicators, which I would then report back to them for further inputs. The focus group discussion took place on March 26, 2021 and lasted a total of one hour. A total of three respondents took part in the discussion. I led the discussion; also present were Drs Julie Loisel and Courtney Thompson, who assisted with note-taking and documenting focus group observations.

Follow-up emails were sent out a week after the focus group to thank participants and to share an example of a linking indicator from the information they provided. I encouraged participants to respond with any feedback or suggestions they might have. Some participants responded with additional linking indicator ideas, which are included in my linking indicator results.

Qualitative data analysis of collected data

The survey data were analyzed using the Qualtrics survey software. After downloading the survey data and carefully reviewing the responses, I highlighted common themes from their responses. The survey results were aggregated into four main themes to ameliorate their analysis: conservation, ES priorities, ES valuation methods, and communication barriers in conservation. Detailed survey results can be found in Appendix A. Note that words or phrases were manually transcribed to ease text legibility are shown between brackets.

I completed a content analysis using concept coding to analyze the interview transcriptions in Atlas.ti, a qualitative data analysis software (Atlas.ti 9, 2020). Content analysis is a research tool used to determine certain words, themes, or concepts within some given qualitative data (i.e., text). Using content analysis, researchers can quantify and analyze the presence, meanings, and relationships of certain words, themes, or concepts (Bengtsson, 2016). A concept code assigns meso- or macro levels of meaning to data or data analytic work in progress. In other words, concept codes are used to suggest the 'bigger picture' from qualitative data (Miles, Huberman, and Saldana, 2020). Codes were specifically developed to focus on themes targeted by the interviews: conservation, people in conservation, ES and valuation, and communication barriers in conservation. A total of 19 qualitative codes resulted from the content analysis (Table 2). The interview results were aggregated into two main themes: conservation in Chile (general) and peat conservation in Chile (specific).

General	Specific
• Conservation Meaning	• Peat Conservation Meaning
• Conservation Role	• Peat Conservation Priority
• Conservation Priority	• Peat Conservation Non-Priority
• Conservation Non-priority	• Peat Conservation Efforts
• Conservation Efforts	• Peat Conservation Issues
• Conservation Issues	• Peat Conservation Success
• Conservation Success	• Peatland ES and Value
• Communication Barriers in Conservation	• Peatland Stakeholder
• Communication Successes	
• ES Measurements	
• Valuation Scheme Perspective	

Table 2. The 19 qualitative codes developed from the interview transcripts. They are presented as conservation in Chile ("general") and peat conservation in Chile ("specific").

Lastly, the information gathered during the focus group discussion was used to construct linking indicators. Peatland stakeholders and biophysical measurements that the respondents identified were tabulated. I used these lists and information provided during the second portion of the group discussion (where respondents were asked to build bridges between stakeholders and ES measurements) to construct a total of 6 linking indicators.

CHAPTER III

SYNTHESIS

It is well known that peatlands provide many benefits to mankind and nature. However, these ecosystem services have often been undervalued or overlooked (Parish et al, 2008). Ecosystem services and valuation frameworks have seldom been applied to peatlands. First, I synthesize the existing literature and provide an exhaustive list of services provided by peatlands (see pp. 38-59). I then apply market-based and non-market-based valuation schemes to peatland ecosystem services (see pp. 60-64). Addressing ES and associated valuations schemes highlights peatlands as natural capital (i.e., natural assets to humans) and the monetary or nonmonetary value of those assets.

Identifying and Defining Peatland Ecosystem Services

The ecosystem service framework has become an integral part of valuing and protecting various ecosystems across the globe. ES are the amenities created by natural processes in an ecosystem that are often beneficial to human welfare (Costanza et al. 1997; MEA 2005; see pp. 7-10). The ES framework has been applied to peatlands in a few specific cases (e.g., Harrison, 2013; Saarikoski et al., 2019; Schulz et al., 2019a). For example, tropical peat swamp forests in Indonesia have been factored into conceptual models that link human impacts and peatland ecosystem functions and services (Harrison, 2013). Likewise, a recent study in Southern Finland used participatory multi-criteria decision analysis to address the trade-offs related to peatland

ES (Saarikoski et al., 2019). In the Peruvian Amazon, implications for peatland conservation are addressed by considering peatland uses, cultural significance, and management (Schulz et al., 2019a). Here, definitions are proposed for each peatland ES and presented into the four broad categories of provisioning, supporting, regulating, and cultural services. Specific examples for each ES are also provided (Table 3). The reader should note that the analysis below focuses on "naturally-occurring" ES (e.g., carbon storage) and on those ES that are considered sustainable or low-intensity (e.g., sustainable fruit harvesting). While peatlands can provide additional services when they are intensively used (e.g., peat harvesting for energy), those ES typically lead to peat degradation and loss of ecosystem integrity (Bonn et al., 2016). They are therefore not considered in this review.

Table 3. Peatland ecosystem services (ES), presented into the four broad categories of provisioning, supporting, regulating, and cultural.

Peatland ES	Example
Provisioning	
Food Gathering	The Urarina indigenous nation of the Peruvian Amazon gathers the aguaje palm fruit (*Mauritia flexuosa*), found in local peatlands, for their consumption (Schulz et al., 2019a).
Water Source	Cayambre-Coca Ecological Reserve has a large concentration of wetlands and is an important ecological region in Ecuador because it is the major source of drinking water for Quito (Troya & Curtis 1998; Chimner & Karberg, 2008)
Livestock Grazing	A study conducted at the Teagasc Hill Sheep Farm in Co. Mayo, Ireland, demonstrated that sheep grazing could be sustainably managed using a stocking density based on the habitats that are most likely to be used (Williams et al., 2010)
Wood and Fiber Production	The Urariana women also use the aguaje palm tree fiber to produce traditional textiles (Schulz et al., 2019b). To protect this resource, the community formed a set of regulations including (1) climbing, rather than felling aguaje palm trees for harvesting the fruit; (2) planting of aguaje seedlings to restore depleted areas; (3) identification of alternative monetary income strategies (Schulz et al., 2019b).
Other Raw Materials	Peat moss biomass was traditionally used as a wound dressing in World War I (Varley and Barnett, 1987). Due to *Sphagnum* moss's ability to acidify its environment, it can act as an antiseptic as it keeps a balanced pH level around the wound site and inhibits the growth of bacteria (Stalheim et al., 2009).

Supporting	
Nutrient Cycling	In ombrotrophic *Sphagnum*-dominated peatlands, wet and dry atmospheric deposition of nitrate and ammonium are regarded as the main external sources of reactive N, providing 13–80 % of the nutrient requirements of plants (Damman, 1988; Urban et al., 1988).
Genetic Reservoirs for Organisms	Mongolian peatlands harbor over 400 species of vascular plants, which represent about 18% of all plant species recorded in the country (Minayeva et al., 2016; Parish et al, 2008).
Soil Formation	Paludification is reported to be the most prevalent peatland initiation type in west-central Canada at 71%, with terrestrialization representing the remaining 28% (Ruppel et al., 2013; Kuhry and Turunen, 2006)
Habitat for Endemic Species	Indonesia's peatland rivers produce a habitat for unique assemblages of fish species that often exhibit high endemism (Ng et al. 1994; Noor et al. 2005; Thornton et al., 2020). According to Thornton et al., (2018), the results of their study found a total of 55 endemic fish species from 16 different families, such as *Pristolepis grootii* and *S. osphromenoides*.
Regulating	
Carbon Storage	In the tropical region, peatlands store approximately 10 times more carbon per hectare than adjacent ecosystems on mineral soil (Parish et al., 2008). Page et al. (2011) estimated that peatlands in Southeast Asia stored at least 68.5 gigatons (billion tonnes) of soil carbon
Greenhouse Gas Cycling	A study in a permafrost peatland in subarctic Sweden shows the peatlands as a net annual sink of CO2 (55.77 gCm^{-2}), but the spring, fall, and winter seasons as sources (-4.9, -9.5, -6.1 gCm-2, respectively) (Olefeldt et al., 2012).
Water Storage	Tropical peat swamp forests serve as overflow areas in flooding periods, while in the dry season the stored water is slowly released (Klepper, 1992). The same study estimated long turnover times for peat water, with water ages over 1000 days old (Klepper, 1992).
Flood Mitigation	Lowland fen peatlands typically form in large-scale depressions in the landscape, often on floodplains or directly connected to river channels, and therefore offer substantial water storage during high flow events (Mitsch and Gosselink, 2000).
Fire Resistance	In high-latitude peatlands, high surface moisture content due to high porosity means that water table variability is minimized and often too wet to sustain smoldering. Even if surface peats dry out and become flammable, the wet and dense organic layers that occur deeper in the peat profile typically serve as an additional fire barrier (Turetsky et al., 2015)
Water Purification	A 2011 study on uranium (U) - contaminated karst systems in South Africa, examines peatlands as filters for polluted mine water. Findings show that over three tons of waterborne uranium is lost annually from the Wonderfonteinspruit (WFS), a river in South Africa, into underlying karst aquifers that feed the Gerhard Minnebron (GMB) peatland (Winde, 2011).
Mesoclimatic Conditions	Some peatlands can regulate local climates; in tropical regions, through evapotranspiration and associated alteration of heat fluxes and moisture conditions (Crump, 2017).
Cultural	
Historical Archives	Analyses of peat sequences from European bogs have produced reconstructions of atmospheric lead deposition linked to mining activity and evidence for deforestation in associated pollen records (de Vleeschouwer et al., 2010)

Spirituality	The Dieng Plateau in Central Java, Indonesia is a mysterious remote area of high-altitude peatland that at one time housed 400 temples and whose name was originally meant ‘Adobe of the Gods’ (Michell, 1977; Bonn et al., 2016)
Aesthetic Use	Art has often emerged from the aesthetic features of peatland landscapes. Notably, the Nobel Prize winning poet and author Seamus Heaney has been influenced by Irish peatlands directly, as in poems ‘Digging’ (1966) and ‘Bogland’ (1996) (Bonn et al., 2016)
Educational Use	The National Nature Reserve (NNR), Blawhorn Moss, UK, is part of a themed study that is taking place across Scotland, where teachers at local schools have integrated peatland themes into their Curriculum for Excellence. Students learn about a range of peatland topics, such as, the different types of peatlands (i.e., bogs and fens), threats to peatlands (i.e., drainage, afforestation, fires), management techniques (i.e., raising water-table and condition assessment), and the biodiversity of peatlands (i.e., plants, insects, birds) (Scottish Natural Heritage, 2016).
Recreational Use	Every August, in the small Welsh town of Llanwrtyd Wells, competitors must complete two laps of a 180-foot lane carved into the Waen Rhydd peat bog, aided by nothing but flippers and a snorkel. As a yearly contest, the event is used as a platform to raise awareness of the environmental importance of peat bogs, which harbor a multitude of wildlife (Grundhauser, 2014).
Ecotourism	The Qinghai Tibetan Plateau is home to 5,086 km2 of peatlands (Yang et al., 2017) and is an important region for ecotourism. For tourists who travel in the upper reaches of the Yellow River, they can see endangered species, such as the Black-necked crane (G. nigricollis); and landscapes in the region notably exhibiting Tibetan culture, such as folk costumes, cultural cuisine, and famous temples like the Maiwa Temple, which is the biggest Tibetan Buddhist temple in northwestern Sichuan Province, as well as the history of the Long March (Mei, 2003).

Provisioning services

Provisioning services are the products obtained from ecosystems, such as clean water and wood (MEA, 2005). Peatlands are being used as provisioning systems worldwide, with their flora and fauna being widely used for food, construction, medicine, etc. The water they harbor can also be an important resource locally (Harrison et al., 2013). The following provisioning peatland services have been identified:

(1) Food gathering: often referred to as foraging, consists of collecting naturally occurring seeds, berries, or roots (Somnasang and Moreno-Black, 2000; FAO, 2020; Uda et al., 2020). Peatlands are important food sources for several local community

members. For example, South America's largest peatland complex, located in the Loreto Region of the Peruvian Amazon, is home to the Urarina indigenous nation and the *mestizo* communities. The Urarina indigenous nation gathers the aguaje palm fruit (*Mauritia flexuosa*) for their consumption. They also trade the plant and use it for textile production (Schulz et al., 2019a). This particular species grows in or near swamps and other wetland areas in tropical South America (Kahn, 1991). Likewise, high-latitude peatlands such as those in southern Finland, where peatlands cover around 25% of the land surface, are often cited for their foraging services (Saarikoski et al., 2019). In this region, berry picking is common amongst local community members and is described as an outdoor activity that maintains physical and mental health (Saarikoski et al., 2019).

(2) Water source: peatlands serve as reservoirs and suppliers of fresh water for local communities and regional water systems worldwide (Harrison et al., 2013; Harrison et al., 2019; Xu et al., 2017). Peatlands' ability to store and filtrate water creates opportunities for communities with access to local peatlands to benefit from a plentiful and clean water supply. Cayambre-Coca Ecological Reserve has a large concentration of wetlands and is an important ecological region in Ecuador because it is the major source of drinking water for Quito (Troya and Curtis 1998; Chimner and Karberg, 2008). At the heart of the Maluti-Drakensberg Transfrontier Park between Lesotho and South Africa, immediately adjacent to South Africa's Quathlamba-Drakensberg World Heritage and Ramsar sites, numerous mires occur at higher altitudes. These mires contribute not only to local biodiversity but also to the importance of this region as the principal water

reserve in southern Africa (Grundling et al., 2015; Nel, 2009). The mires and wetlands occurring in this alti-montane zone or alpine region form the headwaters of the Senqu River (known as the Orange River in South Africa). The headwater tributaries also feed the Katse Dam, part of the Lesotho Highlands Water Project (Grundling et al., 2015; Nüsser, 2003), which will generate hydroelectricity for Lesotho and transfer water to South Africa's most densely populated industrial heartland in Gauteng Province (Grundling et al., 2015; Quinlan, 1995). Likewise, approximately 85% of all drinking water delivered directly from peatlands is consumed in the United Kingdom and the Republic of Ireland, meaning that peatlands play crucial roles in the water security of these nations (Xu et al., 2018).

(3) Livestock grazing: although intensive grazing on peatlands can lead to ecosystem degradation (Joosten, Tapio-Biström, and Tol, 2012; Worral and Clay, 2012), many communities have developed low-intensity grazing methods that do not compromise ecosystem integrity (Cris et al., 2011; Joosten, Tapio-Biström, and Tol, 2012; Gardiner and Miller, 2020). Grazing is the act of using livestock to consume wild vegetation, which gets converted into meat, milk, wool, and other animal products (Vallentine, 2001; Williams et al., 2010). For example, peatland vegetation is a good food source for sheep, and in return, sheep are important commodities for several communities. A study conducted at the Teagasc Hill Sheep Farm in Co. Mayo, Ireland, demonstrated that sheep grazing could be sustainably managed using a stocking density based on the habitats that are most likely to be used (Williams et al., 2010).

(4) Wood and fiber production: ecosystems provide a great diversity of materials, including wood, biofuels, and fibers from wild or cultivated plant and animal species (Sampson et al., 2005; FAO, 2020). Wood and fiber production are prominent provisioning services recognized in peatlands. The woody materials produced from peatland forests have various unique characteristics that make them commercially valuable (Saito et al., 2016). For example, ramin *Gonystylus bancanus* and agathis *Agathis dammara* are commercial tree species found in Indonesia's tropical peat forests that yield some of the most valuable tropical timbers (Finlayson and Milton, 2018). Here again, while timber harvest has been responsible for the degradation and deforestation of massive areas of tropical peat swamp forests (Saito et al., 2016), sustainable solutions for peatland wood and fiber production have been created. For example, the Urarina indigenous community in the Peruvian Amazon has found low-intensity uses of peatland wood and fiber. As previously noted, peatlands are the source of the aguaje palm tree fiber in the Peruvian Amazon. Urarina women use the aguaje palm tree fiber for the production of traditional textiles (Schulz et al., 2019b). To protect this resource, the community formed a set of regulations including (1) climbing, rather than felling aguaje palm trees for harvesting the fruit; (2) planting of aguaje seedlings to restore depleted areas; (3) identification of alternative monetary income strategies (Schulz et al., 2019b). Additionally, only community members are permitted to harvest the aguaje palm tree fiber several months out of the year; outsiders caught harvesting timber in their region face penalties such as verbal warnings, fines, and temporary detention (Schulz et al.,

2019b). Albeit mixed compliance, local community members have also agreed to limit their use of natural resources through the local governance system. For example, a former local authority of the Urarina community brokered a temporary agreement among community members during his tenure to stop all commercial timber harvesting activities to let trees regrow. According to Schulz et al. (2019b), local community members seemed to be in compliance with this particular agreement.

(5) Other raw materials: ecosystems provide raw materials that have been used for a myriad of purposes (Allen et al., 2009). In peatlands, *Sphagnum* (peat moss) found in high-latitude and temperate peatlands has and still is, harvested (Kumar, 2017). The sustainability of this practice largely depends on the method used to grow and harvest the *Sphagnum* biomass (Blievernicht et al., 2012). For example, *Sphagnum* farming is the cultivation of *Sphagnum* mosses to produce biomass of non-decomposed *Sphagnum* fibers on a cyclic and renewable basis (Pouliot et al., 2015). *Sphagnum* can be farmed on various degraded and drained peatlands of former lands used for agriculture, forestry, roads, oil pad, energy, or horticultural substrates. Non-decomposed *Sphagnum* fibers have the advantage of being harvested on a cyclic and renewable basis compared to peat moss conventionally harvested from natural peatlands. According to Pouliot et al. (2015), *Sphagnum* farming gave higher *Sphagnum* cover, biomass, and similar productivity than peatland restoration projects and *Sphagnum* biomass increased year after year in many production cycles all done mechanically, it can thus be considered as a potential option for reclamation in degraded peatlands. *Sphagnum* farming is deemed a

sustainable practice for the following reasons, (1) it reduces the human pressure on the remaining natural peatlands in the surrounding areas by providing renewable *Sphagnum* biomass with multiple possible uses, (2) the development of partnerships with local companies able to transform the raw material coming for *Sphagnum* farming basins into other products such as pots and growing substrate or with companies using *Sphagnum* biomass as shipping material would create new niche markets, and (3) *Sphagnum* farming could diversify the activities and incomes of peat companies (Pouliot et al., 2015). Peat moss biomass was traditionally used as a wound dressing in World War I (Varley and Barnett, 1987). Today, peat moss is mainly sold as a growing media. Due to its cell structure, *Sphagnum* moss has a high capacity for fluid uptake and retention (Varley and Barnett, 1987; van Breemen, 1995). This feature is useful for soaking up blood, pus, and other bodily fluids as *Sphagnum* moss absorbs liquids more rapidly, about three times as fast, and in amounts three to four times as great as cotton (Varley and Barnett, 1987; Porter, 1918). Due to *Sphagnum* moss's ability to acidify its environment, it can also act as an antiseptic as it keeps a balanced pH level around the wound site and inhibits the growth of bacteria (Stalheim et al., 2009). Blocks of *Sphagnum* peat have also commonly been used throughout the northern UK and Ireland to insulate homes; peat blocks have also been, and continue, to be burnt as fuel to provide heat (Rotherham, 2011). As for the previous ES, *Sphagnum* moss harvesting and peat-block cutting have often been done in unsustainable ways (Labadz et al., 2010), but this is changing, and post-harvest site restoration is becoming the norm around the world

(Ferland and Rochefort, 1997). The *Sphagnum* cover can be back within a few years following harvest (Pouliot et al., 2015).

Supporting Services

Supporting services are those that are necessary for the production of all other ecosystem services (MEA, 2005). The supporting services found in peatlands include:

(6) Habitat for endemic species: are often geographically isolated making it difficult for species to spread to other areas, or it has unusual environmental characteristics to which endemic species are uniquely adapted (Burlakova et al., 2011; Isik, 2011; Coelho et al., 2020). Due to these limitations, endemic species are especially vulnerable to human invasion and destruction. For example, the blackwater aquatic habitats associated with tropical peat swamp forest (PSF) (i.e., high acidity, high content of dissolved organic matter and low nutrient content) makes Indonesia's peatland rivers a habitat for unique assemblages of fish species that often exhibit high endemism (Ng et al. 1994; Noor et al. 2005; Thornton et al., 2020). According to Thornton et al., (2018), the results of their study found a total of 55 endemic fish species from 16 different families, such as *Pristolepis grootii* and *S. osphromenoides*.

(7) Nutrient cycling: the flows and exchanges of organic and inorganic elements (e.g., nitrogen (N), phosphorus (P), potassium (K), sulfur (S) cycles) within and between the various biotic or abiotic pools across an ecosystem and beyond (Brady and Weil, 2017).

Nutrient cycling is an essential part of the production of matter; it includes the recycling and transformation of elemental species (Bormann and Likens, 1967; Atlas, 1998; Lavelle et al., 2005). In ombrotrophic *Sphagnum*-dominated peatlands, wet and dry atmospheric deposition of nitrate and ammonium are regarded as the main external sources of reactive N, providing 13–80 % of the nutrient requirements of plants (Damman, 1988; Urban et al., 1988). This example demonstrates the importance of the Nitrogen cycle, where the N gets assimilated by the plants and reduced to nitrite ions, when the plants degrade, this N gets metabolized by microbes in which it forms ammonium.

(8) Genetic reservoirs for organisms: most ecosystems make up habitats for fauna and flora (Crump, 2017). Different ecosystems host a range of genetically diverse species that are not only crucial to a given biomass but contribute to the overall global biodiversity (Begon, Harper, and Townsend, 1986; Schulze and Mooney, 2012). For example, Mongolian peatlands harbor over 400 species of vascular plants, which represent about 18% of all plant species recorded in the country (Minayeva et al., 2016; Parish et al, 2008).

(9) Soil formation: peat soil (e.g., histosols and gleysols) most commonly form through a process called paludification (Gorham, 1957; Glaser 1987), in which peat forms on previously drier, vegetated habitats on inorganic soils and in the absence of a body of water, generally due to regional water table rise and associated climatic moderation

(Buol et al., 2011; Vitt and Fath, 2013). Peatlands form in waterlogged conditions when the rate of peat accumulation is greater than the rate of decomposition (Parish et al., 2008). Peat formed through paludification is underlain by organic material originating from the preceding vegetation communities, such as forest or heath; often macroscopic charcoal particles are present and indicate peat formation after a local fire (Tuittila et al., 2007). On rare occasions paludification has occurred on bare ground, e.g., on moraines that have been exposed for centuries or millennia, and cannot, therefore, be classified as primary mire formation (Ruppel et al., 2013). For example, paludification is reported to be the most prevalent peatland initiation type in west-central Canada at 71%, with terrestrialization representing the remaining 28% (Ruppel et al., 2013; Kuhry and Turunen, 2006).

Regulating Services

Regulating services control, moderate, or maintain the rate of processes that take place within the ecosystem. These services include air and soil quality, flood and disease control, as well as climate and water regulation (MEA, 2005). Peatland ecosystems provide several key regulating services, including:

(10) Carbon storage: the process of capturing and storing carbon dioxide in a reservoir of organic material (Sparks, 2003; Mitsch and Gosselink, 2000; Mitsch et al., 2013). Peatlands are large carbon sinks, making them integral to the global carbon cycle (Bossio et al., 2020). Peatlands sequester carbon from the atmosphere through plant photosynthesis; as the plants die, they partly decompose and accumulate over long

periods of time as peat (Rydin and Jeglum, 2006). Carbon is thus held in the living vegetation as well as in the shallow litter and deeper peats that have built up over time (Mitsch et al., 2013). In the tropical region, peatlands store approximately 10 times more carbon per hectare than adjacent ecosystems on mineral soil (Parish et al., 2008). Page et al. (2011) estimated that peatlands in Southeast Asia stored at least 68.5 gigatons (billion tonnes) of soil carbon.

(11) Greenhouse gas cycling: the process of greenhouse gas exchange is an important feature of Earth's biogeochemical cycles and a critical element of Earth's climate regulation (Brusseau, 2019). Peatlands play an important role in CO_2 and CH_4 gas exchanges with the atmosphere: while they are net CO_2 sinks on an annual basis at the global scale, they also emit large amounts of CH_4. On the global scale, it was estimated that peatlands sequester 0.37 Gt CO2 and emit 500–600 Tg CH4 annually (Cris et al., 2014; Abdalla et al., 2016). That said, a closer look reveals that peatlands can also be CO2 sources on a seasonal basis and/or on a regional basis. For example, a study in a permafrost peatland in subarctic Sweden shows the peatlands as a net annual sink of CO2 (55.77 $gCm^{-2)}$, but the spring, fall, and winter seasons as sources (-4.9, -9.5, -6.1 gCm-2, respectively) (Olefeldt et al., 2012).

(12) Water storage: some ecosystems naturally store large amounts of water (Weiler and McDonnell, 2004; Girotto et al., 2019). The mean residence time of water in peatlands is much longer than in other ecosystems; this is because peatlands are characterized by the

high porosity of their surface layers that can slow down surface water flow, the low hydraulic conductivity of their deep peat layers, and their low hydraulic head (i.e., their low-lying to flat topography) (Charman, 2009; Rezanezhad et al., 2016; Lennartz and Liu, 2019). Peatland bodies are thus effective water reservoirs over seasonal timescales; they contribute to regulating both the local surface and groundwater regimes. By slowing down water flow, peatlands help mitigate droughts and floods (Allot et al., 2019). For example, tropical peat swamp forests serve as overflow areas in flooding periods, while in the dry season, the stored water is slowly released (Klepper, 1992). The same study estimated long turnover times for peat water, with water ages over 1000 days old (Klepper, 1992).

(13) Flood mitigation: the control or management of flood water movement is an important attribute of many ecosystems worldwide (Ming et al., 2007; Wingfield et al., 2019). Peatland catchments provide a place for overspill of water (Bonn et al., 2016). For example, lowland fen peatlands typically form in large-scale depressions in the landscape, often on floodplains or directly connected to river channels, and therefore offer substantial water storage during high flow events (Mitsch and Gosselink, 2000). At a smaller scale, surface water storage also takes place in micro-topographic variations across peatland surfaces, for instance, in small hollows or shallow pools (Allot et al., 2019).

(14) Fire resistance: an ecosystem's natural ability to withstand fire hazards (Lead et al., 2005; de Groot et al., 2010). In high-latitude peatlands, high surface moisture content due to high porosity means that water table variability is minimized and often too wet to sustain smoldering (Wösten et al., 2008). Even if surface peats dry out and become flammable, the wet and dense organic layers that occur deeper in the peat profile typically serve as an additional fire barrier (Turetsky et al., 2015). In addition, many high-latitude peatlands are treeless, which greatly limits the propagation of canopy fires from adjacent forests. In the tropics, abundant rainfall combined with a humid climate ensures that water inputs usually exceed evapotranspiration losses from peatlands, maintaining high peat moisture. As a result, tropical swamps in their natural state are thought to be fire-resistant (Turetsky et al., 2015). Prior to large-scale settlement and agricultural conversion of peatlands, only occasional fires were detected on peatlands in Southeast Asia, which tend to take place during droughts. There was enough time between fires to allow recovery of forest cover (Turetsky et al., 2015).

(15) Water purification: an ecosystem's ability to improve water quality by filtering and removing sediments, pollutants, and other elements (MEA, 2005; Díaz et al., 2015; La Notte et al., 2019). Purification can either be achieved through mechanical, biological, or chemical processes. Peatlands trap sediments and excess nutrients from surface water run-off before it reaches open water, acting as a natural filter in maintaining water quality (Ritson et al., 2016). For example, a 2011 study on uranium (U) - contaminated karst systems in South Africa examines peatlands as filters for polluted mine water.

Findings show that over three tons of waterborne uranium is lost annually from the Wonderfonteinspruit (WFS), a river in South Africa, into underlying karst aquifers that feed the Gerhard Minnebron (GMB) peatland (Winde, 2011). They found that the decrease in Uranium movement in the peat is due to two different types of processes, namely immobilization, and remobilization (Winde, 2011). The processes of immobilization and remobilization demonstrates the effectiveness of the peatland at purifying its water.

(16) Mesoclimatic conditions: distinct regions within a general climate zone that have their own climatic conditions (Gruza, 2009). Some peatlands can regulate local climates; in tropical regions, through evapotranspiration and associated alteration of heat fluxes and moisture conditions (Crump, 2017). In areas with extensive peatlands, the regional climate is cooler and more humid (Parish et al., 2008). Whereas other wetland ecosystems, such as mangrove forests, will experience a loss of species at temperatures below 16 degrees C (~60 degrees F) (Beserra de Lima and Galvani, 2013).

Cultural services

Cultural services are the nonmaterial benefits obtained from ecosystems, which include education, recreation, heritage, and spirituality (MEA, 2005). On a community basis, ecosystems provide services that span outside the construct of provisioning, supporting, and regulating services. A community may value their land as a cultural resource more than anything else. They may also have their own thoughts about the services they believe their home provides. With this said, it is important as a researcher to respect and acknowledge the specific interactions between a particular ecosystem and the people inhabiting that environment. Peatlands are known to hold significant cultural value amongst individual communities worldwide, including:

(17) Historical archives: a repository of archaic remains (Walsh, 2019; Historic England, 2021). Peatlands contain important information on environmental conditions and cultural history (Bonn et al., 2016). For example, analyses of peat sequences from European bogs have produced reconstructions of atmospheric lead deposition linked to mining activity and evidence for deforestation in associated pollen records (de Vleeschouwer et al., 2010).

(18) Spirituality: often experienced in nature when there is a belief that the natural world is an embodiment of divinity or sacredness (Tacey, 2004; Sheldrake, 2009). Peatlands hold a unique place in many indigenous communities who live in their proximity (Parish et al., 2008; Joosten and Clarke, 2002). The Chambira River basin is a peatland-rich area of the Peruvian Amazon and is home to the Urarina indigenous community. The palm species *Mauritia flexuosa* (locally known as aguaje) is native to this area and is pertinent in the Urarina Creation myth (Dean, 1994; Schulz et al., 2019a; Schulz et al., 2019b). Along those lines, high-elevation mountain peatlands are often associated with spiritual traditions, as their remote nature is often associated with deities (Bonn et al., 2016). For example, the Dieng Plateau in Central Java, Indonesia, is a mysterious remote area of high-altitude peatland that at one time housed 400 temples and whose name was originally meant ‘Adobe of the Gods’ (Michell, 1977; Bonn et al., 2016).

(19) Artistic use: artists of all types use the natural environment to influence their work often owing to something striking that essentially catches the attention of said artist (Kastner and Wallis, 1998; Grande and Smith, 2012). Environmental artists, in particular, seek to work in tandem with the natural environment rather than disrupt it. Rydin and Jeglum (2006) so eloquently state that “an important effect of peatlands is that they add mosaic diversity to the landscape in areas with otherwise quite uniform areas of agriculture or forestry.” With that said, peatlands frequently occur in folklore, literature, paintings, and other art forms (Bonn et al., 2016). Art has often emerged from the aesthetic features of peatland landscapes. Notably, the Nobel Prize-winning poet and author Seamus Heaney has been influenced by Irish peatlands directly, as in poems ‘Digging’ (1966) and ‘Bogland’ (1996) (Bonn et al., 2016). Without peatlands as a creative influence, cultures that are embedded in peatland aesthetics and history may face deprivation.

(20) Educational use: nature is an incredible source of education, where students of all backgrounds can gain insight into a particular environmental subject matter by taking part in a tangible approach to learning (Hungerford and Volk, 1990; Hutcheson, Hoagland, and Jin, 2018). Peatland sites can serve as educational centers. Blawhorn Moss, UK, has received a National Nature Reserve (NNR) designation (Cris et al., 2011). It is an area of land set aside for nature, where the main purpose is the conservation of habitats and species of national and international significance. In the

case of Blawhorn Moss, access to the peat bog is granted to visitors, who can experience the unique nature of peatlands first-hand through an immersive experience, which may lead to improved awareness of the importance of these ecosystems (Cris et al., 2011). Blawhorn Moss is also part of a themed study that is taking place across Scotland, where teachers at local schools have integrated peatland themes into their Curriculum for Excellence. Students learn about a range of peatland topics, such as the different types of peatlands (i.e., bogs and fens), threats to peatlands (i.e., drainage, afforestation, fires), management techniques (i.e., raising water-table and condition assessment), and the biodiversity of peatlands (i.e., plants, insects, birds) (Scottish Natural Heritage, 2016).

(21) Recreational use: although recreational use of the environment can also lead to degradation, utilizing certain ecosystems for sporting events, leisure activities, hobbies, etc. (e.g., fishing, hiking, biking) can also bring awareness about the importance of protecting said ecosystem (Buckley, 1991; Hurd, Anderson, and Mainieri, 2021). The unique biophysical features of peatlands, in combination with their cultural and aesthetic values, offer high potential for recreation. For example, activities that can only be conducted in a peatland, such as bog snorkeling, have gained in popularity (Connolly, 2011). Every August, in the small Welsh town of Llanwrtyd Wells, competitors must complete two laps of a 180-foot lane carved into the Waen Rhydd peat bog, aided by nothing but flippers and a snorkel. As a yearly contest, the event is used as a platform to raise awareness of the environmental importance of peat bogs, which harbor a multitude of wildlife (Grundhauser, 2014).

(22) Ecotourism: intended to support conservation efforts and observe wildlife, ecotourism provides an opportunity for tourists to visit exotic, often threatened, natural environments (Fennel, 2009; International Ecotourism Society, 2015; Santarém, Saarinen, and Brito, 2020). Peatlands are known to promote ecotourism due to their unique physical characteristics (van Hardeveld et al., 2018). Peatlands are home to lush forests in the tropics, tranquil landscapes in high latitude regions, and remote getaways set high in the mountains. Owing to its unique natural and culturally important landscapes, the Qinghai Tibetan Plateau, which is home to 5,086 km2 of peatlands (Yang et al., 2017), is an important region for ecotourism. Developed by local communities over the past several decades, some of the most favorite areas to visit in this region include the natural landscapes comprising grasslands, rivers, and snowcapped mountains. For tourists who travel in the upper reaches of the Yellow River, they can see endangered species, such as the Black-necked crane (*G. nigricollis*); and landscapes in the region notably exhibiting Tibetan culture, such as folk costumes, cultural cuisine, and famous temples like the Maiwa Temple, which is the biggest Tibetan Buddhist temple in northwestern Sichuan Province, as well as the history of the Long March (Mei, 2003).

Summary

This literature review of peatland ES shows the importance of those services to people across all four categories, and across various regions of the globe. This review also documents and justifies the growing interest in peatland conservation, including by prominent international groups such as the United Nations' Environmental Program

(Global Peatland Initiative) and the United Nations' Food and Agriculture Organization (Mitigation of Climate Change in Agriculture Programme). Although there is debate surrounding sustainable uses of peatlands, there is major progress in developing low intensity uses of peatland ES as a solution for peatland degradation (Bonn et al., 2016).

Peatland Valuation

Each of the eight valuation methods (see pp. 11-16) can be applied to peatland ES (Figure 7). In this section, I relate the peatland ES (and associated examples) that were identified in the previous section to the different valuation methods. Note, that although this study focuses on intrinsic (i.e., nature has value independent of people) and instrumental values (i.e., protecting nature for human's sake), there are alternative valuation methods such as, relational values (i.e., value is not present in things but derivative of relationships and responsibilities to them) and eudaimonic (i.e., values associated with a good life) (Chan et al., 2016).

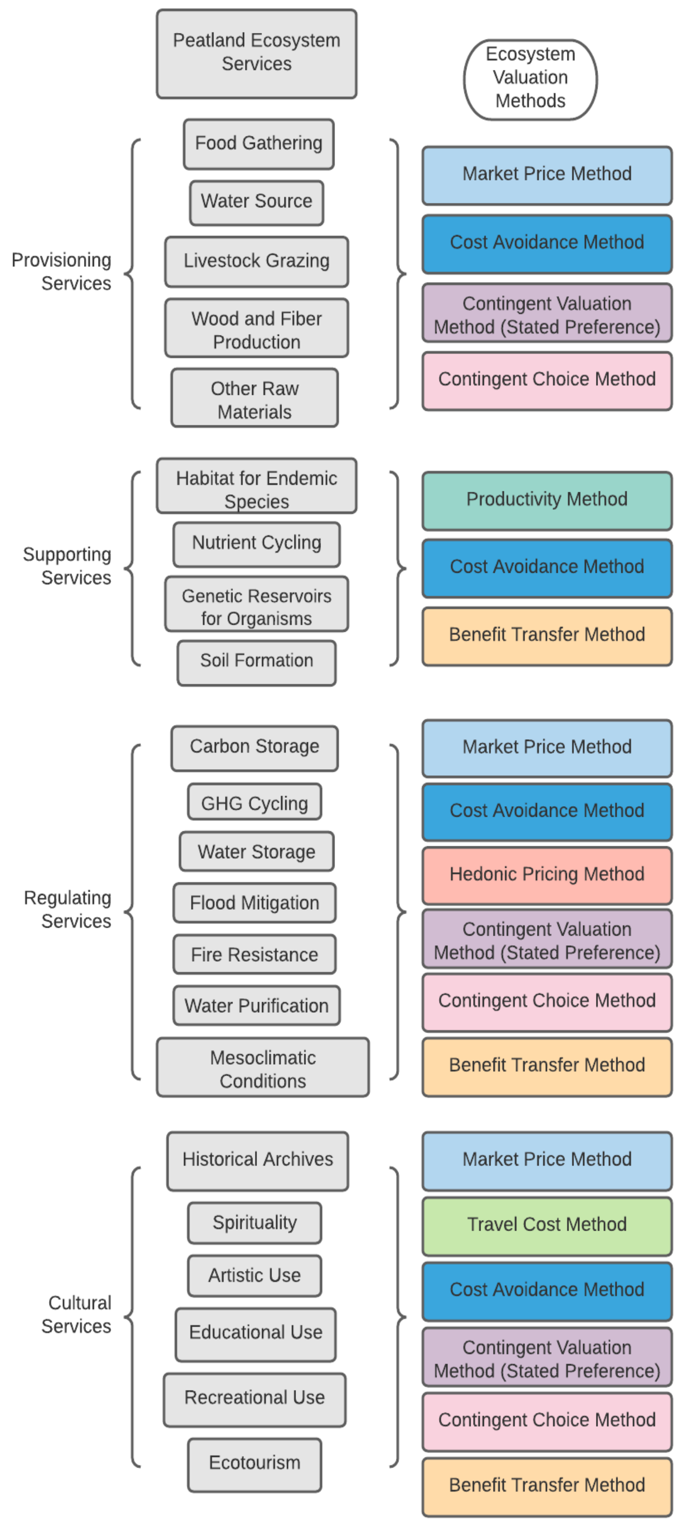

Figure 7. Applicability of each ecosystem valuation method to different types of peatland ES.

(1) Market price method: in the United States, peat moss can be purchased as a growing substrate for gardening from a local home improvement store (e.g., Lowes, Home Depot, Walmart). Consumers will spend anywhere between $3.78-$13.48 on a bag of peat moss fertilizer. Consumer demand can not only inflate the cost of peat moss but encourage rapid extraction, leading to peatland degradation. However, consumer demand for peat moss as a growing substrate is in a constant state of flux as consumerism evolves. In recent years, substitutions have been introduced into the market (e.g., coconut coir, compost, bark or wood fiber, pine needles, leaf mold), which can decrease the value of peat moss as a fertilizer upon the consumers' willingness to pay for the alternative. In this case, market forces can indirectly discourage the extraction of peat moss if alternative products are preferred. Market forces can also encourage sustainable practices of peat moss extraction as there is a growing trend among consumers to purchase more eco-friendly products.

(2) Productivity method: peatlands provide several ecosystem services that can be economically valued for their contribution to the production of commercially marketed goods (e.g., wood, fiber, food, etc.). For example, berry picking is common amongst local community members in the peatlands of southern Finland, and these berries can then be consumed or sold for profit (Saarikoski et al., 2019). As community members harvest berries, they rely on the net primary productivity (NPP) of the cranberry plants. The NPP of the cranberries can be calculated scientifically by measuring the amount of carbon taken up by the plants and subtracting carbon lost via respiration, and the

economic valuation works in tandem and can be measured by methods such as the number of berries harvested, the size of the berries, or the berry quality. Placing value on the productivity of natural goods, like wild cranberries, can therefore lead to the practice of sustainable management of peatlands.

(3) Travel cost method: due to the remote nature of some peatland ecosystems, the accessibility to reach these locations is challenging. To reach these destinations, several modes of transportation may be required, which can be quite costly. For example, the Sabangau National Park in Borneo is a known educational site due to its unique peat swamp forest ecosystem. Young students and researchers travel across the world to learn about the biodiversity and land-use management of the Sabangau National Park. A visitor traveling from Los Angeles to Borneo needs three flights, followed by a bus trip from the airport to a boat dock, a traditional canoe-like fishing boat (*kelotok*) to reach an outpost in the Sabangau River, and a small train (*lori*) to travel to the final destination. The extensive means of transportation inadvertently assigns a high cost or value to the location.

(4) Cost avoidance method: most peatlands around the world store more carbon than they release (i.e., they have a positive carbon balance). Peatland degradation destroys these natural carbon sinks; in a world where peatland GHG would be calculated in national accounting schemes, these lost sinks would need to be counteracted using alternative solutions, which could include man-made carbon sequestration. On a related

note, peatland degradation releases large amounts of CO_2 to the atmosphere (from the stored carbon), amplifying climate change (Leifeld et al., 2019). Adapting to climate change is expected to be costly (Stern, 2007), particularly when compared to "leaving the peatlands alone."

(5) Hedonic pricing method: a peatland's ability to naturally mitigate disasters, such as a flood or fire, in tandem brings up the overall value of that land. However, due to unsustainable peatland uses, these natural mitigation measures are threatened. For example, drainage of peatlands can lead to land subsidence (1–2 cm yearly), which results in greater flooding risks, and ultimately, loss of productive land (Tenneberger et al., 2021). On the other hand, communities may be willing to pay more to live near or protect a peatland ecosystem if they know flood mitigation is a direct benefit. In fact, natural flood mitigation could also cut down costs of living since homeowners may have to pay less in damages when a natural disaster occurs (i.e., hurricanes, tsunamis, monsoon). Regardless, a peatland's ability to mitigate floods likely has a direct impact on the economic value of the area (Tenneberger et al., 2021).

(6) Contingent valuation method (stated preference): a mining company might be interested in utilizing a remote peatland site that is on public land. However, peatlands are known as genetic reservoirs for a number of fauna and flora (i.e., endemic plants, birds, insects) that owe to the beautiful diversity that tourists are willing to travel far distances to visit. By extracting peat, the mining company will be compromising the

biodiversity of the area. In a survey, visitors that frequent the site can be asked how much they are willing to pay to maintain the biodiversity of this area to deter the mining company from using the land.

(7) Contingent Choice: the contingent choice method can be applied to peatlands water quality service; how much is someone willing to pay for clean water. In countries such as the UK, most potable water is received through the extensive peatland complexes in the region (Xu et al., 2018). Their natural ability to filter water is highly coveted and important for sustaining human welfare. Although clean water can naturally occur in nature, it still holds a market value, and since water is a basic human necessity, people are willing to pay for this invaluable service.

(8) Benefit transfer method: due to the inaccessibility to some tropical peat swamp forests in Borneo, researchers may apply some of the same benefits resulting from studies done in the Amazon rainforest (Bourgeau-Chavez et al., 2018). These are two similar environments that possess many of the same ecosystem services. However, while the benefit transfer method is useful when deciding the valuation of an ecosystem in need of conservation efforts, like the forest in Borneo, not all ecosystems are exactly the same. Therefore, results from the benefit transfer method must be examined liberally.

CHAPTER IV

CASE STUDY

It is well known that the peatlands of Chilean Patagonia are under threat due to land-use change. Several studies argue that a large fraction of the local population benefits from peatland ES, though many individuals are not aware of it (Grunewald and Bastian, 2015). Peatland degradation is costly to those communities, yet little information exists to educate the public and communicate the importance of peatlands to local and regional stakeholders. This section presents the results from a survey, individual interviews, and a focus group discussion surrounding peatland conservation that were held with several peatland stakeholders from Chilean Patagonia.

Survey Results

A total of four participants responded to the survey questions (response rate of 33%), all of whom fit the participant criteria (see p. 34). The participants were composed of two stakeholders from a conservation group (Participants 2 and 4), one member of the Chilean government who works for the Ministry of the Environment (Participant 1), and one academic scholar from a Chilean University (Participant 3).

Conservation and ES priorities

Participants were asked to share their thoughts on what conservation means to them. Most responses were similar between participants; they all expressed that conservation connects people and nature by establishing a goal of protecting nature for the benefit of people. However, participants framed their responses differently. For example, **Participant 4** elaborated on the importance of minimizing and/or eliminating the threats to biodiversity. In contrast, **Participant 2** described conservation as “a way of life, hoping to redeem our wrongs with the rest of nature.” **Participant 1** focused on the pragmatic aspect of conservation, stating that it is “a management of the resource to [secure] the future [availability] of them, [their ecosystem] functions and [their ecosystem] services.” While the responses were framed differently, the underlying concept of ES was innately used in the definitions provided.

Next, participants were asked to identify the ES they value the most in Chilean ecosystems. To do so, participants listed and ranked their top three valued ES (Table 4), and then they briefly explained their reasoning. Three participants ranked regulating ES, particularly with regards to water, clear air, and GHG emissions/climate, as their top choice. The maintenance of biodiversity (supporting ES) was the other top choice. Other ES that were mentioned include recreation (cultural ES) and water (provisioning ES). Pertaining to the latter, **Participants 2 and 4 (conservation)** described water as a provisioning ES rather than a regulating one, as they described water provision as “key in a city with [a] great population” and recognized water as a key resource in Chile by stating there is a “presence of massive ice fields and glaciers along the Andes ranges.” However, neither participant ranked water provisioning as number 1; this service was ranked either 2nd or 3rd.

Table 4: Participant ES ranking from surveys.

	Rank 1	Rank 2	Rank 3
Participant 1: Government	regulation (water and gas)	habitat provision	economics
Participant 2: Conservation	biodiversity maintenance	water provision	recreation
Participant 3: Academia	climate regulation	gas regulation	cultural
Participant 4: Conservation	clean air	recreation	water provision

Peatland ES and valuation

For questions regarding peatland conservation specifically, participants were provided with three key peatland ES: carbon storage, water storage, and biodiversity. Participants were asked, "Which do you value the most?" and prompted to rank the ESs and explain their reasoning (Table 5). Biodiversity was the top-ranked ES for all participants, as it is viewed as a "key ES, as it maintains and regulates many others indirectly" and "the basis of our well-being." Carbon and water were either ranked second or third (2 respondents ranked carbon as their second priority, while the other 2 ranked water as their second priority). Explanations for these rankings included: "carbon storage and water storage (or regulation), [is] the principal function of [these] areas." For carbon storage specifically, "the need of [maintaining] healthy ecosystems" was a key reason for its ranking. **Participant 4** deemed water as "one of the most scarce resources in the [planet] and with ongoing growth of population and climate change, it will become even more scarce."

Table 5: Ranking of ES by number of participants.

	Rank 1	**Rank 2**	**Rank 3**
Carbon	-	2	2
Water	-	2	2
Biodiversity	4	-	-

Participants were then asked whether they used valuation methods to measure the value of peatland ES. Only **Participant 1 (government)** indicated that they use or have used productivity, hedonic pricing, travel cost, and benefit transfer methods as part of their job function. The other three participants have not used these methods.

Communication barriers

When asked about any communication difficulties between peatland stakeholders, the participants unanimously stated this was a frequent issue. Participants mentioned that stakeholders with conflicting interests (e.g., use vs. protection) view and value peatlands differently, which causes confusion in terminology. For example, scientists' use of technical terms is not the same as those used by farmers. **Participant 3 (academia)** also introduced "economic interests" as a difficulty. This was corroborated by **Participant 2 (conservation)**, who indicated that "some of [the stakeholders] value peatlands as an economic resource and others as key for providing ecosystem services and [are, therefore,] worth being protected." Incidentally, each participant alluded to differences in use and value as a barrier to communication among peatland stakeholders, and some suggested this barrier as an argument for conservation.

Participants then listed up to five terms regarding ES terminology frequently used in their peatland conservation efforts. The following terms were identified: wetland, biodiversity, carbon storage, extraction, nature-based solutions, sustainability, protection, mitigation, conservation, water supply, mining, and conservation target. "Mitigation" and "carbon storage" were the only terms mentioned more than once. However, most terminologies were analogous. For instance, the terms "extraction" vs. "mining" could describe a similar process, as mining is a form of natural resource extraction. Comparable terminology indicates that stakeholders may report different terms to describe the same general concept when identifying key ES terms for peatland conservation.

To further attest to the similarities or differences in the respondents' terminology, participants were then asked to define the following key terms: "intact ecosystems," "linking indicators," and "stakeholder" (Table 6) and describe whether they were commonly used in peatland conservation. Results show that "intact ecosystems" and "stakeholder" are terms that at least one participant uses and can define. As for "linking indicators," only **Participant 1 (government)** mentioned being familiar with the term but provided no definition, making it difficult to assess how this person defines, uses, or understands the term. These results show that the concept of linking indicators has probably not reached this group of stakeholders before.

Table 6: List of common terminology in conservation and the familiarity participants have with each term.

Term	% Respondent who use the term	General meanings
Intact Ecosystems	75%	minimal disturbance; preventative principles
Linking Indicators	25%	No definition provided
Stakeholder	75%	users with some degree of influence; all types of people

Interview Results

The same four participants who responded to the survey also agreed to an individual follow-up interview. The following sections describe the results from the individual interviews.

Conservation

First, participants were prompted to declare if they view conservation as a means to either manage land sustainably or to preserve untouched lands, as both serve as different approaches to conservation (see pp. 3-7). Interestingly, **Participant 3 (academic)** indicated that the main goal of conservation in Chile is to leave important ecosystems untouched, whereas the others described conservation in Chile as a means to manage and safeguard resources. However, without prompting, **Participant 2** also discussed how different organizations have different approaches to conservation. Therefore, the concept of conservation in Chile is expanded to include protected areas as a form of management.

When asked if conservation is considered a priority in Chile, the responses were mixed. Content analysis of the interview transcripts shows that conservation in Chile was tagged more often as a 'non-priority' than a 'priority.' **Participant 3** claimed that conservation is not a focus in Chile. Three out of four participants mentioned marine ecosystems as the main national conservation focus in Chile; only **Participant 1** mentioned wetlands as an equally important conservation focus. Each participant noted that their disclosures reflected their perception of the overall conservation disposition of Chile, which differs from their personal position.

Peatland conservation in Chile

When participants were asked to describe the meaning of peatland conservation, some of their responses diverged from their initial explanations of conservation in general. **Participant 3 (academic)** discussed sustainable uses of peatlands, while **Participant 2 (conservation)** insisted peatlands are better off untouched. Recall that **Participant 3** had initially mentioned conservation in Chile as leaving ecosystems untouched, while **Participant 2** had acknowledged conservation in Chile as a diverse set of approaches. **Participant 2** claimed that "it's hard to sustainably use something without understanding timelines" and that "[peatlands] can be sustainable when we are aware of the time frames for them." **Participant 2** expressed the critical need for scientific information that would inform "timing for [peatland] recovery," which refers to the need to better integrate physical measurements and ecosystem dynamics when developing and implementing management and conservation efforts. The other stakeholders did not deviate much from their initial responses (i.e., conservation is a means to manage natural resources), except to say that peatlands are an opportunity for conserving important ES (i.e., clean water provision and regulation, and climate regulation).

As participants recalled *successes* in peatland conservation in Chile, they noted what made those efforts effective. Each participant spoke about the importance of stakeholder inclusion and how it has improved conservation in Chile. For example, **Participant 2** described a roadmap project designed to include an inventory of GHG emissions from peatlands in the Nationally Determined Contribution (NDC), a report that highlights Chile's climate objectives. **Participant 2** discussed how stakeholder inclusion was critical to the success of this roadmap. While the different stakeholders (e.g., companies that extract peat, municipalities, academics, etc.) spoke about peatland conservation in different terms, it was mentioned that "when people feel heard, they are more willing to listen." The roadmap project gave everyone a chance to speak and understand different conservation perspectives., **Participant 3** substantiated this statement in their separate interview by saying the current success of peatland conservation is owed to the improved communication between policymakers and academics. These testimonies provide evidence that conceptual frameworks that consider stakeholder perspectives are a successful approach to conservation.

Peatland conservation stakeholders

Each participant was asked to list several stakeholders that are directly or indirectly tied to peatland conservation in Chile. Their responses included: non-governmental organizations (NGOs), local residents and landowners, farmers, tourists, academics, and members of the Ministries of the Environment, Mining, Agriculture, and the National Forestry Commission. Although some stakeholders (i.e., local and indigenous) are not always at the forefront of environmental decision-making, participants acknowledged that their input to community conservation efforts is invaluable because they are directly involved in peatland use. **Participant 1 (government)** asserted that it is a disservice to omit local and indigenous stakeholder knowledge when developing peatland conservation strategies. Likewise, **Participant 2 (conservation)** suggested that some local residents are actively aware of peatland degradation, stating that "when someone has the information [a]nd the difference of explaining… what the changes…[are] in the short and long term. People understand." While such responses emphasize the importance of a bottom-up approach (i.e., starting with local and indigenous input) for successful conservation practices, **Participant 4 (conservation)**, in contrast, suggests a top-down approach where influential stakeholders should be responsible for bringing everyone else together to conserve peatlands. **Participant 4 (conservation)** stated that "there needs to be a strong conviction of influential people to really drive conservation efforts and to be [...] successful." No matter the suggested approach (top-down or bottom-up), all participants highlighted the different power dynamics of stakeholder influence in peatland conservation and how they affect the success of any conservation effort.

Peatland conservation ES frameworks

Another theme that emerged from the responses about peatland conservation was how SES frameworks, specifically the ES framework, serve as a major component in conservation strategy development and implementation. When asked if they use the ES framework to help justify peatland conservation, all participants responded yes. **Participant 4** further stated that "when you want to create a protected area, I would guess you really need to make the connection of the value for people."

According to participants, the ES framework and associated measurements also include looking at peatlands as major climate regulators and water provisioners. Each participant discussed a new law in Chile (2017) that decreed that peat extraction from a Protected Area with "scientific importance" requires a complex approval and permitting process. Previously, no such restrictions existed. In the case of Karukinka (a Private Natural Park in Patagonia, Chile), this law was seen as a huge success by the participants to halt the rapid degradation of peatlands and safeguard ecosystem integrity. Indeed, a Park designation is insufficient to protect peat resources from mining. To be granted this special status, stakeholders utilized the ES framework and measurements of ES to justify conservation efforts in this region. According to **Participant 4**, it took evidence, experience, and partners backing the cause to get the government to pay attention. In fact, **Participant 2** indicated that a new goal for safeguarding peatlands' carbon storage

ES is to develop a methodology for carbon measurements in order to ensure their inclusion in the GHG emission inventory in Chile's NDC for climate objectives. That being said, it is apparent that the ES framework and associated measurements are indeed utilized in supporting peatland conservation efforts in Chile.

Language and communication barriers in peatland conservation

The final interview question asked participants to discuss any communication barriers in peatland conservation between different stakeholders. Some participants said there is a disconnect between stakeholders, while others did not acknowledge any barriers. For example, **Participant 3 (academic)** did not acknowledge any major communication issues. In contrast, **Participant 1 (government)** feels as though there is a disconnect and claims the information/research in academia is not being passed along to government stakeholders. Inconsistently, **Participant 3 (academic)** admitted that when stakeholders first meet, everyone seems to have a good understanding of peatland conservation, but that communication seems to deteriorate or get misinterpreted later in the process. People need to start conservation efforts with the same general level of understanding, which may require, as stated by **Participant 2 (conservation)**, "[going] in and mak[ing] people [be] prepared for this to get that scientific information into a level that really everyone can understand." That level of knowledge must also be fostered throughout the conservation effort to ensure that communication does not deteriorate over time.

The government also uses standardized terminology that other stakeholders may not know or use regularly. **Participant 4 (conservation)** mentioned that “a lot of the environmental regulation lies in different institutions, ministries, and services.” **Participant 4 (conservation)** goes on to explain that “[government officials] speak their own language, so when you approach the Ministry of Agriculture, you really need to tell them why these conservation objectives or challenges that you have [to] affect them in particular.” **Participant 4 (conservation)** also stated that they “really need to know [the] connection with them and then when you go to [someone else], [for example], the Water Agency, you really need to know why, and then you need to sort of study a lot and you need to change your language.” These responses highlight the types of communication barriers between stakeholders and that they require some solution to enhance conservation effectiveness, most notably a common language.

Linking Indicators

Based on the results from the survey and interview, it is evident that there is a common understanding of the meaning of conservation and the way the ES framework is applied to peatland ecosystems. However, the linkages between ES and stakeholders (i.e., the fundamental connection that makes ES a useful tool to help assess ecosystem importance) are still lacking due to communication barriers. A focus group was conducted with three of the four previous participants to identify potential peatland stakeholders and common linking indicators. **Participant 3 (academia)** could not attend the focus group discussion but offered feedback and suggestions in subsequent emails.

The following sections describe the results from the focus groups and **Participant 3's** email contributions.

Focus group

During the focus group, three participants created a list of peatland stakeholders in Chile (Figure 8) and a list of the biophysical measurements that can be used to measure peatland ES (Figure 8).

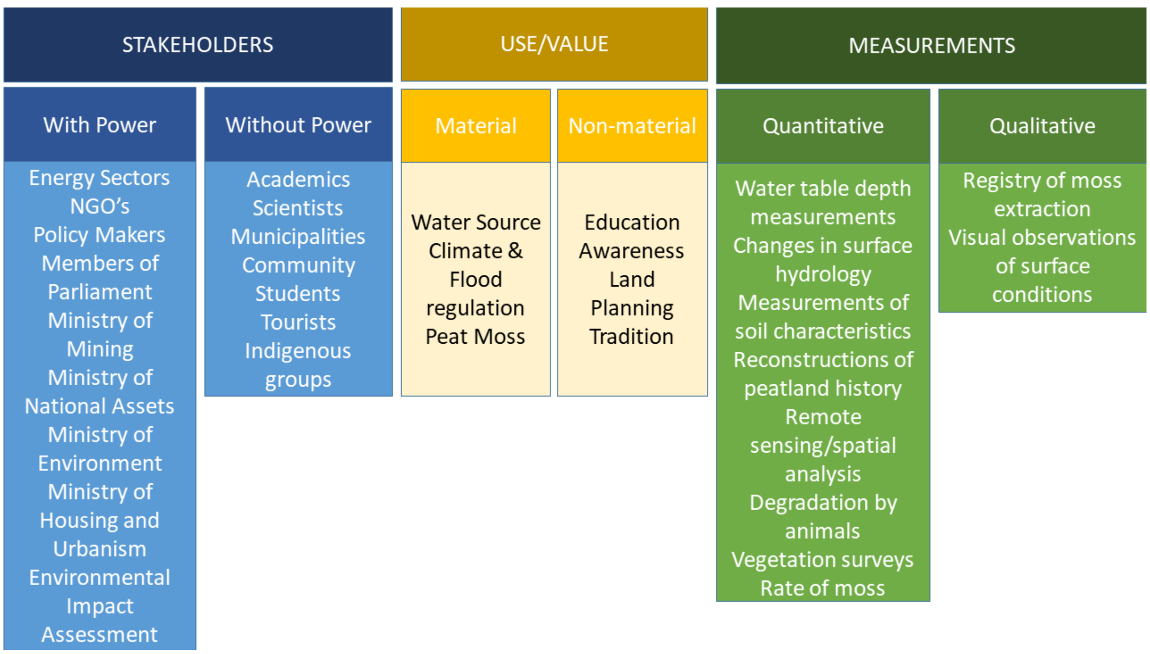

Figure 8. List of Chilean peatland stakeholders, peatland use/value, and peatland measurements identified from focus group discussion.

During the discussion, participants made distinctions between peatland stakeholders. They deliberated on which stakeholders held more power with regards to environmental decision-making of peatland conservation. While participants were discussing the various peatland stakeholders in Chilean Patagonia, they also identified the uses and values of peatlands. Participants then listed qualitative and quantitative measurements of peatland ecosystems (shown in Figure 8).

Identified linking indicators

As a result of the focus group and subsequent email correspondence with the participants, many linking indicators for peatland conservation were identified. Below, I present six linking indicators that pertain to provisioning, regulating, and cultural services. This study emphasizes proximal indicators for ecosystem assessment as they are more closely tied to human use (Boyd et al., 2016). Supporting services are not identified in this study as they are considered distal indicators (i.e., they serve as a catalyst for other ES to exist).

Provisioning

Water

In Isla Grande de Chiloé, a region in Patagonia, peatlands could serve as a natural and sustainable source of clean water. Unfortunately, the peatland complexes in Isla Grande de Chiloé have been facing rapid degradation due to land-use change (i.e., peat mining), which is detrimental to peatlands' water storage capacity. As a result, communities rely on trucks to haul in clean water for consumption at a high monetary cost. Scientists have the tools to quantify a peatland's water budget based on peat volume, porosity, and evapotranspiration and can estimate the mean residence time of water and flow rates within the system (Peichl et al., 2013). However, scientific terminology and measurements do not directly speak to the community's needs, which are more broadly interested in clean water.

Based on the focus group discussion, I identified "**volume of drinkable water**" as a linking indicator to assess sustainable clean water sources (Figure 9).

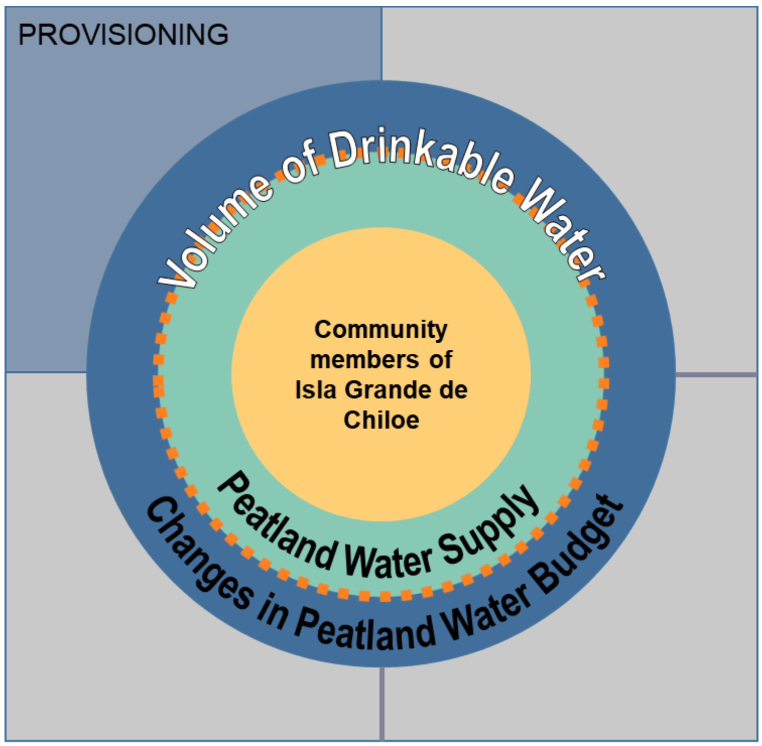

Figure 9. Linking Indicator for Community members of Isla Grande de Chiloe. The Linking Indicator is presented as Volume of Drinkable Water.

This indicator clearly informs the public about the current amount of accessible drinking water from the local peatland ecosystem and is directly related to the community's well-being. The volume of drinkable water from the local peatland system can also be used in monetary assessments. For example, current measurements can be compared with past measurements to assess how much groundwater has been lost over time and how much the community could have saved in costs (i.e., water transportation and road maintenance) had the local peatland been sustainably managed. Overall, in Isla Grande de Chiloé, sustainable use of local peatland resources would ensure a cost-effective supply of drinking water while also restoring the local peatlands, thus making the natural water supply a sustainable one. This is in addition to several other peatland ES (e.g., carbon storage, habitat) that would be restored and add further economic value to any restoration effort.

Resource Extraction

In Chilean Patagonia, peat extractors hold unprecedented power as peatland stakeholders since their industry provides a significant source of household income for commercial extractors and regional income through the export of peat moss for home gardening (Iturraspe, 2016). Local residents also conduct peat extraction as a second source of income when their primary ventures are impaired (i.e., livestock, fishing). Although peat moss extraction contributes directly to their livelihood, it also leads to degradation of the peatlands ecosystems on which these extractors rely. Degradation jeopardizes the integrity of all peatland ES and drastically reduces the volume and quality of peat available for extraction. Peat volume has been tied to significant environmental indicators such as carbon storage and water regulation (MEA, 2005; Mitsch et al., 2013; Dargie et al., 2017). Scientists can measure and predict past, present, and future peat volume using ground-penetrating radar surveys, peat core data, as well as peat density and carbon content measurements (Hooijer et al., 2011; Chimner et al., 2014).

Based on the focus group discussion, I identified **“availability of peat”** as a linking indicator for economically feasible, sustainable mining operations (Figure 10).

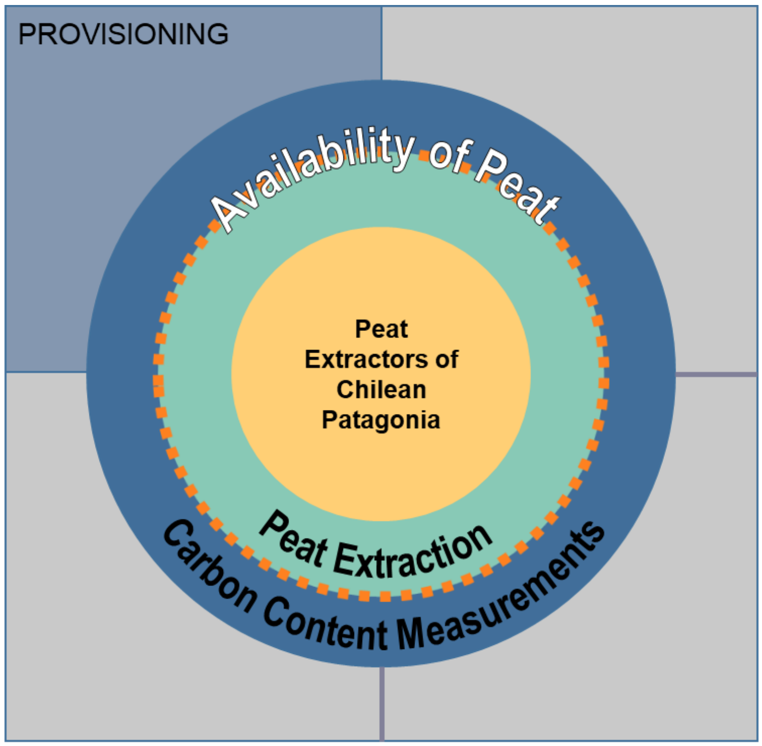

Figure 10. Linking Indicator for Peat Extractors of Chilean Patagonia. The Linking Indicator is presented as Availability of Peat.

Peatlands are characterized by slow growth (e.g., one mm a year on average, according to Borren et al. (2004) and are sensitive to environmental change (Loisel et al., 2021). Peat is considered a non-renewable resource (Hooijer et al., 2011). As such, if peat extraction in one area exceeds peat formation (either from natural processes or from restoration) from other areas, the peat extraction business will be limited. If peatland extractors want to maintain the integrity of these systems in the long term, they must develop sustainable ways to harvest peat and ensure the maintenance of peat moss quality in the future. Programs that provide incentives are likely a necessity to make this scenario a reality. Without funding to encourage sustainable use and discourage mass extraction, locals who rely on peat moss for a portion or all of their income will continue extraction to meet their livelihood needs.

Regulating

Flood management regulation

Punta Arenas is located in a complex topography created by the limits of the Last Glacial Maximum (Hauser, 1996), which encouraged the development of peat bogs over the last several thousand years (Hauser, 1996). This has resulted in the city being encircled by natural bogs dominated by *Sphagnum* (i.e., peat moss). As the city has grown, development has been implemented in predominantly peat bog areas, whose soft soil can cause major structural housing issues over time (Mahmod et al., 2016). As a result, the western side of the city has undergone serious structural problems for some homes. Despite these known complications, construction companies still carry out Earth-fillings on peat bogs to continue building homes and other infrastructure, further encouraged by the government's policies to subsidize home building for low-income families (Peri, 2021). In addition, Punta Arenas has a history of river flooding (examples provided by a focus group member include 1945, 1990, and 2012). The most recent flood (2012) resulted in a major loss to both the city center and people without housing. The flooding has been attributed to several causes, including deforestation, alterations in the river meander bends, and construction along the river. Peatlands serve as a natural flood management strategy (Allot et al., 2019). During a flood or high water, peatlands naturally absorb water. After the event ends, water is slowly released as water recedes. Thus, peatlands can help serve as a flood mitigation strategy, as they slow peak discharge, reduce erosion, and reduce downstream flooding (Joosten, Tapio-Biström, and Tol, 2012). However, of all the factors mentioned, peatlands have never been identified by local stakeholders as a technique to mitigate flooding. Although scientists can assess peatland hydrology, peatland catchment areas, and surface oscillation to determine effective mitigation strategies, these measurements are not a proximal benefit related to the local people of Punta Arenas (prime stakeholder), who arguably suffer the most from flooding incidents.

Based on the focus group discussion, I identified **“flood management”** as a linking indicator for cost-effective flooding regulation (Figure 11).

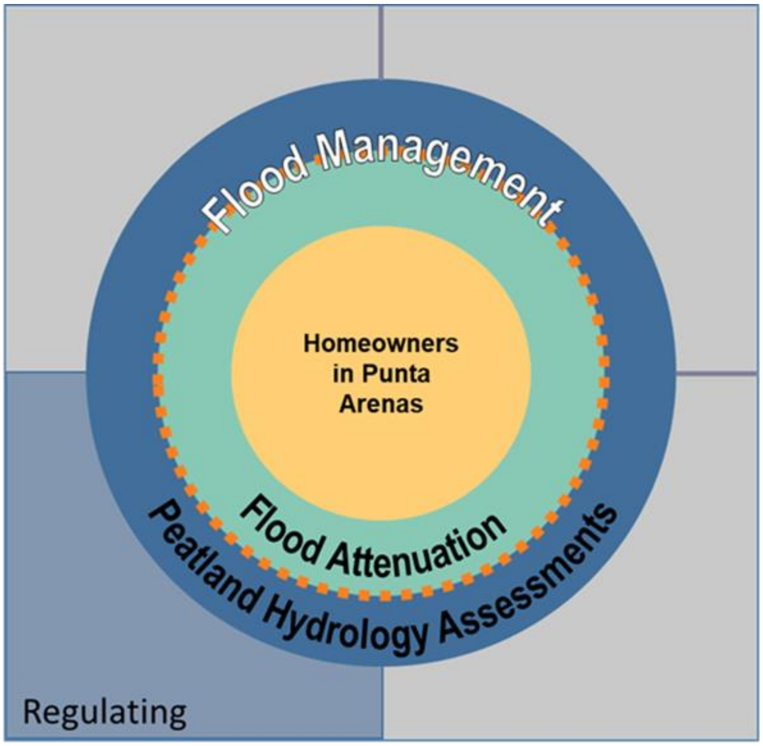

Figure 11. Linking Indicator for Homeowners in Punta Arenas. The Linking Indicator is presented as Flood Management.

There are known ways to assess losses from flood events through different flood impact analyses (Pattison-Williams et al., 2018). For example, municipalities' overall costs associated with flooding damage are typically calculated soon after the disaster has struck. The degree, extent, and frequency of flooding can also be directly correlated to areal extent and degree of peatland destruction or degradation. Discussing flood impacts in terms of damages is something stakeholders already understand and could be used to demonstrate how peatlands could influence the degree and extent of flooding in their homes. Identifying the economic benefits of peatland conservation could also be appealing to stakeholders, as it is possible to assess how much they could be saving by using peatlands as a flood mitigation tool. This is because peatlands provide this natural

ES at no cost, compared to costly existing projects to reduce flooding, like building floodwalls and other mitigation tactics. The question of using peatlands as a flood mitigation tool then becomes how much stakeholders could be saving if they ensured they were sustainably managing and restoring the peat bogs on which they live.

Climate regulation

Currently, there is a move amongst governmental agencies and NGOs in Chile towards integrating peatlands into their GHG inventory for the country's NDC (Germani, 2020). Peatlands are known as nature-based climate solutions due to their longstanding carbon pools, aged up to several thousand years. However, there is local and foreign pressure to continue peatland extraction for raw materials (e.g., peat moss), which reduces peatlands' ability to sequester and store carbon, and by extension, their ability to regulate climate. The recent creation of Karukinka Natural Park (KNP) in Tierra del Fuego, Chile, is a model of a conservation-based protected area. KNP was established to safeguard regional biodiversity (including rare plant communities and fauna) as well as the vast carbon stores in the region, the latter being a coveted ES vital to climate regulation. In addition, the extraction law in Chile provides additional legal protections to this land, preventing unchecked extraction, a step towards alleviating economic pressures to extract. It has been established in previous economic studies (Bossio et al., 2020) that peatlands are worth more if left intact due to both the market value of carbon and their integral contribution to climate regulation. Scientists can assess the value of carbon and its contribution to global GHG emissions by using ground-penetrating radar surveys, peat core data, as well as peat density and carbon content (Hooijer et al., 2011; Chimner et al., 2014).

Based on the focus group discussion, I identified "**climate cooling potential**" as a linking indicator for regulations impacts of climate change when communicating with government stakeholders (Figure 12). The direct degradation of peatlands within the region would contribute to global climate warming due to the loss of their carbon stores. By listing peatlands in Chile's NDC and protecting these ecosystems, they reduce the risk of adding them as contributors to climate change and help reduce the increasing future risk that global climate change poses to Chileans.

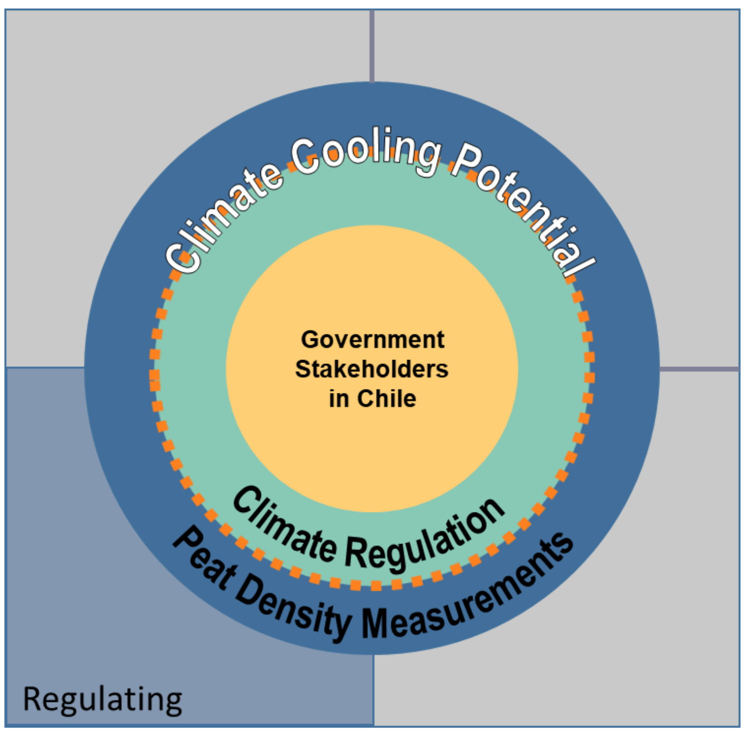

Figure 12. Linking Indicator for Government Stakeholders in Chile. The Linking Indicator is presented as Climate Cooling Potential.

For example, as global temperatures rise and precipitation decreases, agriculture in Chile could become one of the country's most vulnerable economic sectors as crops are subject to harsher conditions (Ponce et al., 2014). Financial benefits can also be accrued from conserving peatlands by participating in market-based solutions that aim to address climate change, ecosystem degradation, and other critical environmental issues (Zhang, 2013). These efforts include developing a carbon budget (Houghton, 2007), implementing a carbon tax (Barbier et al., 2020), and participating in carbon credits or markets (World Bank, 2016). Payment for ecosystem services (PES) is another market-based solution that uses an economic incentive to encourage conservation by offering beneficiaries (e.g., farmers or landowners) of environmental services a subsidy or market payment to safeguard or maintain natural ecosystems (Guerry et al., 2015). Ultimately, government stakeholders must be educated on potential future financial losses and environmental effects of global climate change due to current peatland degradation to make well-informed environmental policy decisions.

Cultural

Indigenous cultural traditions

From the mid-Holocene until the 19th century, the western configuration of the Fuego-Patagonia region provided marine and terrestrial resources, settlement, and shelter for the first maritime hunter-gatherers called the Kaweskar and Yamanas (de la Fuente et al., 2015). These indigenous groups relied heavily on local natural resources (i.e., *Nothofagus betuloides* trees and *Marsipospermum* spp sedges) found in surrounding peat bogs. *Nothofagus betuloides* trees and *Marsipospermum* spp sedges are traditionally used to construct canoes and baskets as they are highly resistant and can easily be repaired with hydration (Promis et al., 2008). Today, only a small population (i.e., 20-30) of both indigenous groups remain. However, some of their practices remain a large influence in Chilean art, culture, and heritage as they continue to make baskets sold as souvenirs for tourists. This learned weaving technique is passed down from generations and has gained outside attention from local community members of Fuego-Patagonia. Using *Marsipospermum* spp, artists have adopted the Kaweskar and Yamana weaving technique in crafts and current fashion trends where clothes and accessories have linked the community to peatlands. The indigenous weaving technique has put a cultural value on Fuego-Patagonian peat bogs, as they not only provide the raw materials required for this tradition but are owed to for its origin. Without the peat bogs, a generational tradition will be lost. Though scientists and conservationists may have greater concerns about losing raw materials from the peat bogs, people who still practice the Kaweskar and Yamanas weaving technique will be missing out on a generational tradition that, for them, means losing a part of their identity.

Based on the focus group discussion, I identified the "**traditional weaving technique**" as a linking indicator for measuring impacts on indigenous cultural traditions (Figure 13).

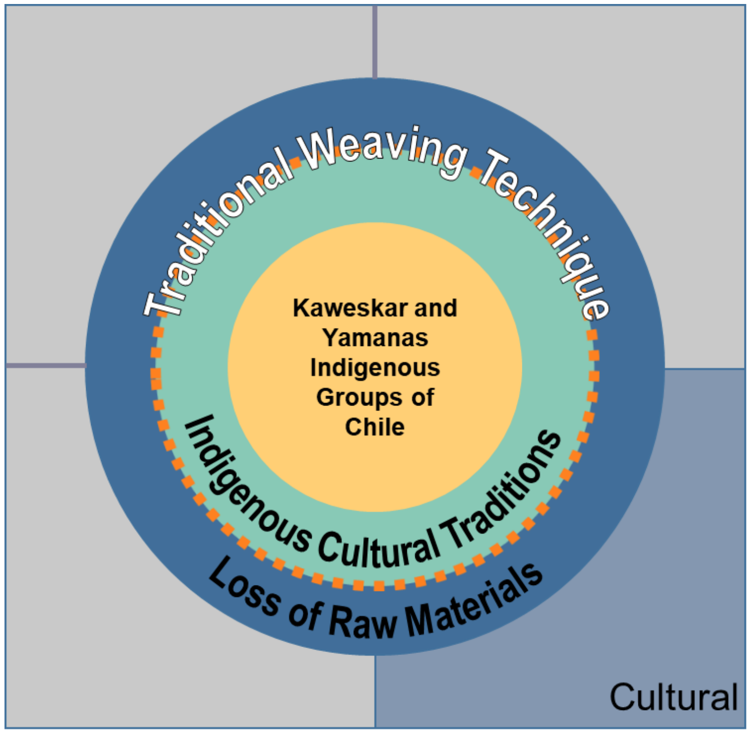

Figure 13. Linking Indicator for the Kaweskar and Yamanas Indigenous Groups of Chile. The Linking Indicator is presented as Traditional Weaving Technique.

This indicator expresses the importance of safeguarding its raw materials to those who utilize the peat bogs for this tradition. Ultimately, the peat bogs must remain intact to preserve the tradition and the raw materials used for the weaving technique. These resources are critical for this indigenous tradition, as the technique would not exist without the raw materials from the peat bog. The question then becomes how local community members can advocate for peat bog protection and management to ensure their cultural traditions are not lost and that the raw materials remain intact. This indicator can be quantified by assessing how many people benefit from the learned weaving technique. This refers to those who use the technique themselves and anyone who purchases items linked to the traditional weaving technique (e.g., indigenous people, locals, and tourists).

Ecotourism

The region of Magallanes serves as an attractive ecotourism location owing to its unique ecosystems and close proximity to world-class National Parks (e.g., Torres del Paine). Ornithophiles, or bird enthusiasts, specifically travel to the Magallanes region to observe the 207 species of birds (Matus and Jaramillo, 2008; Venegas and Sielfeld, 1998) found here throughout the year. The native bird population, specifically birds like the Royal Penguin (i.e., *Eudyptes schlegeli)*, Chilean Flamingo (i.e., *Phoenicopterus chilensis*), and the black-chested buzzard-eagle (i.e., *Geranoaetus melanoleucus*), are flagship species of this region due to their significant popularity among eco-tourists and their ability to generate income. Many ecotourists seek bird guides or register for bird tours to observe rarer species within the region for recreation and education purposes. However, extraction sites among neighboring peatlands to Magallanes are a source of biodiversity degradation and directly impact some of these flagship species and many other ones. Aesthetic features known to attract tourists are often negatively impacted, most notably flagship species habitats, which are often used to generate social and financial support for local biodiversity conservation. Extraction sites are loud and hazardous and cause widespread ecosystem destruction, deterring birds from inhabiting or migrating to these locations. To mitigate biodiversity degradation in Magallanes peatlands, scientists can evaluate species richness by measuring latitudinal gradients, species–energy relationships, relationships between local and regional richness, and taxonomic covariance to calculate biodiversity loss and potentially incite mitigation strategies (Gaston, 2000). They can also look at historical perturbation, environmental stability, and habitat heterogeneity (Gaston, 2000). Ecotourists also hold power to aid in mitigation as they are integral to generating funds necessary for conservation action.

Based on the focus group discussion, I identified the "**number of flagship bird species**" as a linking indicator (Figure 14). Though some ecotourists may not relate to the biophysical measurements' scientists assess in the field, tourists are likely to identify with the number of flagship species that attract ecotourists. Since flagship species are internationally identifiable and directly associated with the Magallanes region, this allows the income drawn by ecotourism to generate financial support for local environmental management and conservation efforts.

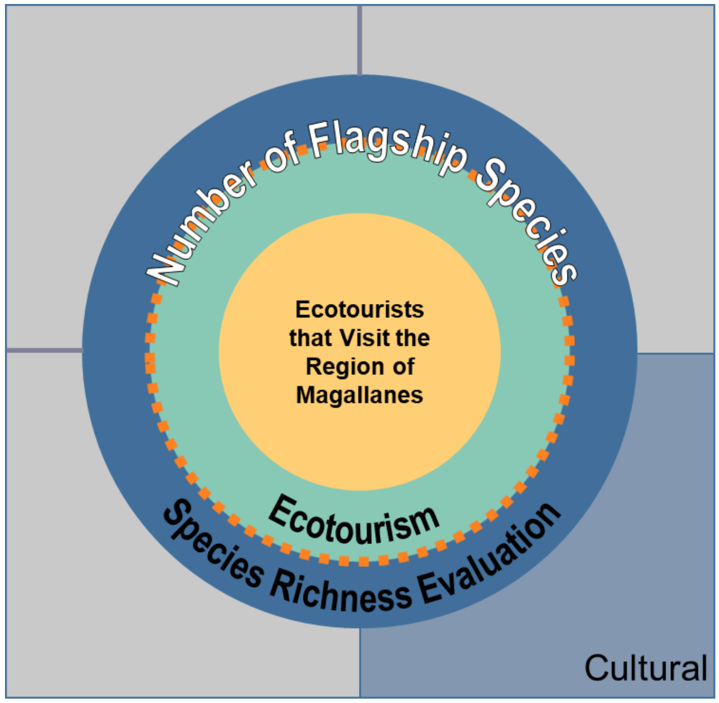

Figure 14. Linking Indicator for Ecotourists that Visit the Region of Magallanes. The Linking Indicator is presented as Number of Flagship Species.

Identifying and advertising the number of flagship species unique to the region allows ecotourists to drive the market value for ecotourism, as consumer demand directly drives market values. The more accessible and apparent the number of flagship species in the region, the more ecotourism income generated. The resulting income can then be used to fund conservation efforts to protect said species. Money generated to support these flagship species' protections inadvertently conserves other ecosystem functions needed to support all biodiversity.

CHAPTER V

DISCUSSION: CONNECTING LINKING INDICATORS TO VALUATION METHODS

While peatlands foster many ES for the benefit of people, they face degradation at an alarming rate (Parish et al., 2008). To reduce peatland degradation and encourage sustainable use of peatland ES, stakeholders need better ways to socially interpret the ecological conditions and changes in peatland ecosystems to establish the best conservation methods. Peatland stakeholders are collectively working towards creating and implementing conservation strategies to safeguard peatland ES, but lack of communication, or differences in vocabulary, are barriers in this process. For example, different ES may be perceived and valued differently between stakeholders.

This research sought to identify linking indicators representing common peatland ES that might be described differently between stakeholder groups. I identified several linking indicators that can help bridge the gap between biophysical measurements in peatland ecosystems and ES beneficiaries. These linking indicators can then be coupled with several valuation methods to provide a tangible product designed to measure ecosystem value.

Conservation Definitions and ES Priorities

While conservation is known to take on different approaches and meanings (see Chapter 1), the survey and interview participants each framed their definition of conservation around the benefits of nature to people, known as ES. They also mainly discussed conservation through the lens of sustainable use of nature rather than the strict protection of nature from use. The responses were feasibly equivocal in nature, and direct connections between the provided definitions were inferred (see pp. 75-76, 80-81). These findings suggest that although stakeholder rhetoric surrounding conservation differed, there was a *general* consensus on conservation's overall definition and goal, which may facilitate the integration of different stakeholders to create and implement common conservation goals.

However, a general definition does not fully address differences in ES priorities. In my case study, conservation of regulating vs. provisioning services were perceived and approached differently, suggesting that their classification can impact how they are valued. For example, when participants ranked ES based on their perceived value, water and carbon *regulation* were identified as among the most important ES's. However, when participants were asked to rank water, carbon, and biodiversity services, all stakeholders ranked biodiversity first due to its *support* of all other ES (Table 5). This contrasts with the previous question's findings (Table 4), where regulating services were perceived as most important.

These results support existing literature suggesting that ES frameworks based on individual perspectives are critical for conservation success. By allowing stakeholders to make individual distinctions on what they particularly value in nature, ES frameworks can assess and incorporate what constitutes a benefit to local stakeholders (Boyd et al., 2016, Breyne et al., 2021, Bouamrane et al., 2016). The findings surrounding how stakeholders list different ES priorities and frame ES function and definition differently show a broad consensus of what conservation means and how it varies between individuals (Sandbrook et al., 2019; Md. Nadiruzzaman and Rahman, 2020; Breyne et al., 2021). Indeed, it is expected that, as a foundational concept, conservation definitions overall will be similar in any ES framework; however, frameworks are typically adapted to meet stakeholder needs, leading to differences between different ES, which may take on different meanings.

As stated by Pinto et al. (2014), frameworks should recognize all ES as individual structures or parts within a system, as most ES cannot exist without others. This is most notably true for biodiversity (Table 4), as it serves as a catalyst for the existence of all other ES (Pinto et al., 2014). Water can also be identified as a foundational ES. Without water purification (a regulating service), there would not be natural clean drinking water (a provisioning service); those water ES are closely linked to the vegetation communities, which are themselves linked to the animal and microbial communities, which are connected to biogeochemical cycling, and so on. Therefore, identifying specific ES that are important to the stakeholders provides a mechanism to advocate for, or even link, all ES in a single framework. Linking ES all together to emphasize the holistic support of human welfare by ecosystems is also important to account for potential misalignments between stakeholders.

Overall, ES frameworks must include a general definition of conservation on which they are built, while remaining flexible enough to acknowledge and incorporate ES definitions that speak to the stakeholders and link different ES together to emphasize the holistic support of human welfare. The importance of an ES to a specific audience must also be effectively conveyed.

Peatland Stakeholder, Conservation, ES, and Valuation

The case study highlights the recurring theme of connecting people to the land. To effectively protect peatlands and the ES they support, stakeholders must understand the inner workings of the land they rely on. This concept is not new and is often reflected in SES frameworks (Olander et al., 2018). As such, educating stakeholders to recognize the importance of individual ES and the way they are connected is a building block of any ES framework. Then, building the connection between peatland ES and the value to people can be used as an assessment tool that highlights the holistic benefits people receive from peatland ecosystems (e.g., clean water, clear air, tourism). ES also help communicate why peatland conservation is important for human welfare.

While the ES framework is an important tool to advocate for the importance of conservation and communicate to specific stakeholders, determining which stakeholders to engage with can be challenging. In the case study, participants identified a wide array of peatland stakeholders, which emphasizes that anyone who is related, either directly or directly, to the peatland of interest can be considered a stakeholder (e.g., residents, municipalities, NGO's, worldwide consumers, see Figure 8). Therefore, an approach to conservation that helps to integrate the various stakeholders' perspectives is needed.

Stakeholder inclusion is a crucial part of creating and implementing sound environmental decisions and policies (Bouamrane et al., 2016). It ensures that critical ecosystems, such as peatlands, are being addressed from every possible angle. Stakeholder inclusion ensures that all ES are considered, even those that might provide exclusive benefits to specific groups. Such a framework would recognize peatlands for all their ES contributions and the co-dependencies between those ES.

Stakeholder inclusion must also come with the understanding that the involvement of large groups of people from a variety of backgrounds requires a user-friendly approach to conservation that can be adapted to the needs as well as the knowledge of the stakeholder. The approach must be accessible to any stakeholder to ensure their participation in, use of, and benefit from the ES framework. The linking indicator approach makes this possible (see pp. 28-30).

SES frameworks can also allow for a web of ES to accumulate and connect so that decision- and policymakers can assess the bigger picture of ecosystem benefits. According to our participants, SES frameworks play a role in current peatland conservation efforts in Chile, with known successes. For example, participants discussed the roadmap project for Chile's NDC, Chile's new mining law (2017), and Karukinka (a Private Natural Park in Patagonia, Chile). Reasons for their success included the use of the ES framework to advocate the benefits peatlands provide to human welfare and stakeholder inclusion to allow for all peatland ES to be considered and better communication among stakeholders. SES frameworks were also found to help build common values, which can stimulate a common goal of conservation. These frameworks emphasize the benefits of nature to people, which is why we see this shift in the general meaning of conservation (Sandbrook et al., 2019).

These results support previous studies that state ES valuation is subjective (Costanza et al., 1997; Daly and Farley, 2010). The results also support the notion that the ES framework can help communicate the importance of peatlands to different stakeholders (Boyd et al., 2016). Similar conclusions have been reached by Breyne et al. (2021) and Pinto et al. (2014), who both found that socio-cultural values must be considered in ES valuation methods to ensure that resulting ES valuation measures address the services and concerns for different stakeholder groups. Having valuation systems that account for multiple perspectives and priorities is critical for peatland conservation. Our study further supports the need for developing valuation methods that address different stakeholder needs, particularly through linking indicators.

Communication Barriers

Communication barriers were clearly identified in the surveys, interviews, and focus group results. The case study showed that, while conservation holds similar meanings to stakeholders, it can be framed differently by different stakeholders, in line with findings by previous studies (e.g., Keenan et al., 2019). Different rhetoric used by stakeholder groups can serve as communication barriers when discussing and addressing conservation issues, even if stakeholders share the same general concerns. For example, although similarities can be drawn between the peatland ES terminology identified by the participants, different words were presented for similar concepts. The terms "extraction" and "mining" were both identified by different participants as peatland ES. Though the terminology itself is different, both terms refer to the removal of natural resources (e.g., peat moss and peat soil). Other terms used to designate ES included “mitigation” and “nature-based climate solutions.” Technically, mitigation refers to a broader idea than an ES, and it implies reducing the impact of something typically seen as a negative impact. The use of such words can quickly become a matter of contention in a conversation with other stakeholders, who may be responsible for the impact in question. For example, if someone proposed to mitigate the effect of peatland drainage ditches on carbon storage, other stakeholders in the room may take offense, as they may see the value of drainage ditches. But in this case study, “mitigation” referred to a peatland’s ability to serve as a carbon sink, which mitigates anthropogenic greenhouse gas emissions, similar to the concept of natural climate solution. Though the ES terminology differs between stakeholders and different services (i.e., mining and extraction), their core meanings do not.

Participants also identified the type of terminology used in peatland conservation as another potential communication barrier. For example, scientists tend to use more technical terms when describing socio-ecological changes or conditions. Although this type of rhetoric is formally used, it can be problematic when communicating peatland ES and conservation strategies to local peatland residents, leading to miscommunications. The scientist may be trying to discuss something that is of direct benefit to the community, but community members may assume it is simply to the benefit of the scientist. Therefore, not only does the use of technical jargon impedes community members from understanding the matter at play, it also does not effectively advocate the stakeholder's needs (i.e., residents). Therefore, residents may not show interest in the conservation strategy proposed by the scientist, even if it may serve them.

In this case, informal language can be more appropriate. To make environmental decisions, studies support the need to find a way to link or translate the differences in ES communication among stakeholders (Wright et al., 2017).

Participants also identified peatland use and value as contributing to communication barriers in peatland conservation. For example, participants described peatland conservation by different management styles (i.e., use vs. protection). Peatlands were also valued as either a source of ES or more so as an economic resource. By learning to speak to the stakeholder's needs, we can identify which conservation strategy (use vs. protection) makes the most sense based on what exactly is being valued by the beneficiary.

Participants also acknowledged that peatland conservation efforts are managed through different sectors with varying degrees of power. Oftentimes, information is not percolated through all sectors; likewise, some participants suggested that it should be the responsibility of influential stakeholders to unify all stakeholder groups in thoughtful peatland conservation discussions. On the other hand, other participants proposed peatland conservation to start at the grassroots level, with local and indigenous knowledge serving as the foundation. Nevertheless, participants recognize that information must be extended to all stakeholder groups to eliminate communication barriers in peatland conservation.

From the results, I can conclude that different meanings or approaches to conservation are not the major issues in conservation management; it is *how* such approaches are communicated between stakeholders. Language and communication are critical because different words can mean different things to various people, which is where communication barriers develop and require remediation. While peatland stakeholders have different rhetoric about the same concern, linking indicators can help make the connections between ES, valuation, and stakeholder, in addition to easing communication, bridging knowledge gaps, and reducing confusion stemming from language miscommunication. Linking indicators is a way of translating and comparing stakeholders' interests.

Linking Indicators to Address Communication Barriers

As identified from the results, only one of the four participants indicated their familiarity with linking indicators; however, they did not provide a definition (Table 6). From this result, I conclude that this ES framework may not have reached this group of stakeholders before this study. Still, all the participants described several communication barriers in peatland conservation, ranging from a lack of transfer of information among stakeholders to differences in terminology.

Based on the case study results, I know that the ES framework is considered an important and successful conservation strategy. However, the need for better integration of physical measurements and ecosystem dynamics when developing and implementing management and conservation efforts was recognized. This suggests that the connection between science and stakeholder's needs is critical to developing relevant ES frameworks (Oudenhoven et al., 2018).

Such a need can be addressed via linking indicators; this model uses the ES framework while also explicitly identifying connections between people and nature, which are ‘linked’ through biophysical measurements of ES. According to Oudenhoven et al. (2018), linking indicators are pertinent in informing environmental decision making as they are user-centered; meaning, they take into consideration direct beneficiaries of an ecosystem and associated services. Linking indicators, therefore, lay at the interface between ES and ecosystem valuation.

As a newer concept, linking indicators may prove useful when valuing and assessing ES in peatland ecosystems. Linking indicators are designed to acknowledge how different stakeholders perceive different ES. Ultimately, linking indicators serve as a universal way to discuss ES, determine ecosystem priorities, and find common ground for communicating and valuing ES.

Policy Implications and Moving Forward: Applying Linking Indicators in Ecosystem Valuation Schemes

This research has several implications for policy that involve peatland ES conservation. Foremost, linking indicators uniquely inform policy development in a way that meets different stakeholder groups’ needs, resulting in management solutions that are clear to everyone, well documented, and that should ultimately maintain peatland function. The results from the survey and interviews build a case for why linking indicators could provide a solution for peatland conservation in Chile. As discussed throughout this thesis, communication barriers were often described by the participants;

linking indicators would help stakeholders gain an appreciation for the different perceptions other stakeholders might have in terms of the importance and value of peatland ES. Linking indicators can also enable broad participation in peatland conservation. Lastly, linking indicators can be coupled with valuation methods. Here, the value of focus remains instrumental and intrinsic, although other values (i.e., relational and eudaimonic) can be applied. The following paragraphs provide a few examples of such connections.

Cost avoidance method

The “cost avoidance” valuation method could be applied to a peatland’s “**volume of drinkable water**” (linking indicator, see p. 80). This value is then translatable in monetary terms that can be compared with the current cost of trucking in water, maintaining roads for the heavy truck traffic, and environmental costs from emissions released during the operation of the trucks and repair of damaged roads (Duthu and Bradley, 2017). I argue that the cost avoidance method is the most appropriate valuation model for examining this peatland ES valuation for several reasons.

First, the cost avoidance method can accurately incorporate market valuation, an economic indicator emphasized by participants in the survey, interviews, and focus group. Second, this model is the only one explicitly brought up by the survey, interview, and focus group participants. Finally, the cost avoidance method is the only valuation metric that focuses on potential losses, not simply cost benefits. A key discussion point consistently brought up by participants was: "what do you stand to lose?" The idea of loss is an important concept to consider for ES valuation. Identifying what stakeholders would be losing (or how much the loss would cost them financially) if they do not conserve or protect certain ecosystems is more impactful than emphasizing the benefits (Boyd et al., 2016).

While other valuation methods could easily be applied to specific ES services, these do not account for losses of ES services that are critical to the existence of others. For example, a travel cost-benefit analysis could be used to valuate ecotourism. Birders will often travel long distances to enjoy local bird sightings. However, suppose there are no birds to see. In that case, birders will not visit, leading to no money being contributed to the ecotourism sector, resulting in economic loss. Ultimately, the cost avoidance method may well be the most universal ES valuation scheme.

CHAPTER VI

CONCLUSION

This thesis sought to characterize data and knowledge gaps that hinder our ability to improve local peatland conservation and resource management systems and identify complex linkages between peatland ES that can represent perceived peatland ES value from different stakeholders. To address these knowledge gaps, I posed four research questions.

Research Questions

What ES have been historically identified as peatland ES by previous literature?

To answer the first research question, I conducted a synthesis of peatland ES and valuation schemes. According to the literature, peatlands provide several ES. In Chapter 2, I provide 22 sustainable ES's found across the globe. The synthesis results build the case for investing in the conservation of peatland ecosystems.

How has peatland ES been valuated in the past, and can these frameworks be adapted to ecosystem valuation methods to create effective conservation strategies?

To answer the second research question, I drew connections between peatland ES and ecosystem valuation methods, found in Chapter 3. My findings ultimately show how to adapt the ES framework to peatland ecosystems and apply ecosystem valuation methods to ensure effective conservation strategies.

How do different peatland stakeholders define conservation? How are peatland ES communicated between stakeholder groups, and what communication barriers exist?

To answer the third research question, I conducted a series of surveys, interviews, and focus groups with different peatland stakeholder groups (Chapter 4). The results demonstrate that though conservation may hold the same general meaning among stakeholders, it is their approach to conservation that acts as a barrier.

What are possible methods for valuating peatland ES that address communication barriers and ES knowledge gaps among peatland conservation stakeholders?

I applied the ES framework to propose a new peatland ES valuation metrics and valuation scheme to answer the fourth research question, using linking indicators. The results suggest that linking indicators could help improve communication about peatland conservation. Linking indicators can provoke a sense of urgency to conserve certain ES by highlighting what stakeholders risk losing from integral ecosystems. The cost avoidance method was particularly useful for understanding both the monetary and non-monetary values of peatland ES.

Study Limitations

This study does have limitations. First, while a small sample size (four participants) afforded the opportunity to conduct individual interviews with each participant, it is still small. As such, the results may be skewed because the survey, interviews, and focus group results represent perspectives from a few people. Therefore, though valuable and integral to this study, the participants' perspectives and opinions may not apply to the broader view of peatland stakeholders in Chile.

Likewise, the sample did not include inputs from more vulnerable populations, such as local and indigenous stakeholders. Therefore, the information provided by participants regarding local and indigenous perspectives is anecdotal, as their personal testimony is lacking; rather, it is the narrative of whom can be considered ‘professional’ stakeholders. Fortunately, each participant had experience working with local and indigenous stakeholders, in addition to being local residents themselves.

The discourse regarding linking indicators and cost avoidance method suggests that an ES must be lost, or at risk of being lost, for stakeholders to care about protecting it. As this research serves as a platform for protecting intact ecosystems (before they are threatened or degraded), it is becoming clear that acknowledging “what can be lost from intact peatland ecosystems” must be thoroughly addressed.

Summary

The future of linking indicators is endless. This approach can be applied in any region, as it is stakeholder specific. Though this study focused on proximal indicators, addressing distal indicators could serve as a valuable tool for peatland ES assessment. The cost avoidance method is arguably the most universal valuation method to use and is most appropriately tied to valuing linking indicators; however, further studies could be dedicated towards comparing the applicability of valuation methods to linking indicators.

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APPENDIX A

SURVEY QUESTIONS AND RESULTS

Participant: Questions:	Participant 4	Participant 3	Participant 2	Participant 1
1. Do you have any experience working or volunteering with peatland ecosystems?	Yes	Yes	Yes	Yes
2. Which of the following three sectors are you apart of? (check all that apply)	Conservation	Academia	Conservation	Government
3. What does conservation mean to you?	It's a discipline whose main objective is to minimize and/or eliminate the threats to biodiversity. It requires efforts at differente scales and levels, as well as commitment of various sectors to be achieved effectively. Conservation means safeguarding life on earth and human	Means protecting, managing sustainably, and restoring	Conservation for me is a way of living, hoping to redeem our wrongs with the rest of nature.	It's a management of the resource to asegurate the future disponibility of them, his ecosystems functions and his ecosystems services.

	health and wellbeing.			
4. Which ecosystem services in Chile do you value the most? Please list and rank your top three valued ecosystem services. Write the name of service in the corresponding textbox and briefly explain your answers. Place your most preferred item on top.	1) Clean air 2) Recreation 3) Water Provision	1) Climate Regulation 2) Gas Regulation 3) Cultural	1) Biodiversity: maintenance, as it is also key for our wellbeing 2) Water provisioning: as it is key in a city with great population and a Mediterranean climate 3) Opportunities for recreation: I feel blessed for the landscapes I can enjoy in Chile	1) Regulation (water and gas) 2) Habitat provi 3) Economics (low impact activities)
5. Of the following ES in Chile, which do you value the most? Please rank the following services (most preferred item on top). Please explain answer.	1) Biodiversity: its integrity allows the existence of all others. For example, well conserved peatbogs and forests allows water storage and water quality. 2) Water Storage: it's one of the most scarce resources in the planet and with ongoing growth of	1) Biodiversity: is a key ES, as it maintains and regulates many others indirectly 2) Carbon Storage 3) Water Storage	1) Biodiversity: the basis of our wellbeing 2) Water storage: prime necessity and climate change adaptation possibilities 3) Carbon Storage: important, but not enough if we don't manage our carbon emissions	1) Biodiversity: If the climate change it's probably .the most relevant topic, the conservation of biodiversity helps the preservation of this landscapes, and the carbon storage can be possible 2) Carbon Storage: The carbon storage and water storage (or

	population and climate change, it will become even more scarce. 3) Carbon Storage: I value this one in relation to biodiversity and the need of maintaining healthy ecosystems.			regulation) it's the principle function of this areas. 3) Water Storage: the carbon storage and water storage (or regulation) it's the principle function of this areas.
6. A part of your job or position, do you use valuation methods or metrics to measure the value of ecosystem services in peatlands?	No	No	No	Yes
7. Which method do you use to value peatland ecosystem services? (check all that apply)	….	….	….	**Use Currently**: travel cost method, benefit transfer method **Have used in the past but not currently:** productivity method, hedonic pricing method **Have never used:** market price method

				I do not know: Damage cost avoidance method, contingent valuation method, contingent choice method
8. Are there communication barriers between different peatland stakeholders? If so, what are they?	Yes. Some of them value peatlands as an economic resource and others as key for providing ES and worth to be protected.	Yes. Economic interests.	Yes. Different interests between them, specially conflicting between use and protection	Yes. Probably, in Chile some stakeholders are technicals, and others are more users, farmers may be.
9. What are some terms that are frequently used in your work environment when involved with peatland conservation? (List terms to the best of your knowledge)	1) Carbon storage 2) Nature Based Solutions 3) Mitigation 4) Mining 5) Conservation target	1) Biodiversity 2) Carbon Storage 3) Water Supply 4) Conservation	1) Wetland 2) Extraction 3) Sustainability 4) Protection 5) Mitigation	1) pompom
Of the provided terms, which do you use in peatland conservation? Please briefly describe what they mean to you?	1) *Intact Ecosystems*: ecosystems that have had minimum or null disturbance. 2) *Stakeholder*: people that are	1) *Intact Ecosystems*: Preventative and precautionary principles	2) *Stakeholder*: all type of people, institutions, governments related (positively or negatively) to peatlands. Identifying	1) *Intact Ecosystems*: in Magallanes, it’s more relevant but in Aysen or Los Lagos this ecosystems are perturbated

	key to reach the conservation goals proposed *linking indicators was not selected	*linking indicators and stakeholder was not selected	them, their personal and institutional views and goals and motivations is KEY on developing long term effective peatlands conservation initiatives. *Intact Ecosystems and Linking indicators were not selected	2) *Linking Indicators*: I don't know 3) *Stakeholder*: local users with some degree of influence *Linking Indicator was selected but participant said they did not know the meaning

APPENDIX B

INTERVIEW QUESTIONS

1. What does conservation mean to you? What does conservation mean in Chile? Is it untouched or managed lands?

2. Is conservation a priority in Chile? Are there particular ecosystem(s) and/or animals that governments, non-profits, and residents prioritize with their conservation efforts?

3. What are your conservation focuses in your line of work? What are you interested in conserving?

4. Which past, present, and future conservation efforts in Chile are you aware of? How successful or unsuccessful were/are these efforts? To your knowledge, what leads to successful conservation efforts, and what limits such efforts?

Transition to Peatland Conservation, Specifically

5. What does peatland conservation mean to you?

6. Can you name at least one example of a successful peatland conservation effort in Chile? What makes it successful? Where (in Chile) are existing or new locations for continuing peatland conservation efforts? What makes these locations appealing to you?

7. Are there any areas of peatland conservation interests in Chile, where people live?

8. Who do you consider to be peatland conservation stakeholders? Why?

9. How are peatland conservation efforts met by local community members? Are all stakeholders supportive? In what ways?

10. Do you take into consideration local and indigenous stakeholder knowledge when developing peatland conservation strategies? Why are these stakeholders interested in peatland conservation?

11. Would there be mechanisms to facilitate peatland conservation?

12. Do you use an ecosystem service framework to help justify peatland conservation? Which ecosystem service do you think peatlands play in Chile?

13. How do you measure these services?

14. Do you take into consideration physical properties of the environment you're trying to conserve? (i.e., how has it changed overtime?)

15. What proxies do you look at for valuing peatland ecosystems in Chile? What do you take into consideration when creating a protected area?

16. How do you perceive the use of valuation schemes to set the value of peatland ecosystem services?

17. Have there been any barriers in communicating peatland conservations strategies between peatland stakeholders (policy makers, government, locals, etc.)? What are they? (i.e., what difficulties do you encounter when communicating with other stakeholders)