Alteration of the forest structure in historically impacted *Nothofagus spp.* forests on the Brunswick peninsula.

Recommendations for their protection and management.

Leon Hauenschild

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Alteration of the forest structure in historically impacted *Nothofagus spp.* forests on the Brunswick peninsula. Recommendations for their protection and management.

Leon Hauenschild

Supervisor:	**Lars Östlund, Department of Forest Ecology and Sustainable Management, SLU**
Examiner:	Johnny Schimmel, Department of Forest Ecology and Sustainable Management, SLU

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Swedish University of Agricultural Sciences

Faculty of Forest Sciences

Department of Forest Ecology and Sustainable Management

Abstract

Despite exhibiting a seemingly low degree of human alteration when compared to other types of landscapes, most forest ecosystems in the world have a long history of human use and are product thereof. The southern Brunswick peninsula is no exception to this and has an extensive history of anthropogenic activity, both pre-colonial and modern.

The overall objective of this study was to investigate the historic land use and its impact on natural and cultural values in *Nothofagus spp.* forests along the coastal fringe of the peninsula. Further, my aim was to discuss how these values can be protected and conserved in a holistic way and how restoration can be used as a tool to mitigate historic impacts and restore natural and cultural values.

To broaden my understanding of the land use of the area and the temporal frame during which different land use activities took place, I reviewed various archives and literature published on the history of the area. For the forest structural assessment of the study area, I established transects going inland from three differently impacted sites along the coast of the Brunswick peninsula. Establishing a plot every 100 m, I measured the basal area of live and dead trees, DBH of all trees, height of the dominant trees, dimensions of lying and standing deadwood, and took dendrochronological samples from several representative trees. I also took note of any cultural intervention and sign of logging.

My main findings are that the coastal area was subject to forest exploitation and that there was a significant difference in the forest structure variables between logged and unlogged plots. There were however no statistically significant differences between sites. Rather, I found differences *within* the sites. Considering the patterns of each land use I was able to show that they all left a distinct imprint on the landscape, creating a complex biocultural space.

My recommendations for the area are a combination of visualization of vulnerable cultural artifacts within the forest landscape and their structural protection, as well as active and passive forest restoration to augment natural values and restore a forest structure reminiscent of previous forest landscapes under indigenous land stewardship.

Resumen

A pesar de exhibir un grado aparentemente bajo de alteración humana en comparación con otros tipos de paisajes, la mayoría de los ecosistemas forestales del mundo tienen una larga historia de uso humano y son producto de ello. El sur de la península de Brunswick no es una excepción y cuenta con una extensa historia de actividad antropogénica, tanto precolonial como moderna.

El objetivo general de este estudio era investigar el uso histórico del suelo y su impacto en los valores naturales y culturales de los bosques de *Nothofagus spp*. a lo largo de la franja costera de la península. Además, mi objetivo era discutir cómo estos valores pueden ser protegidos y conservados de una manera holística y cómo la restauración puede ser utilizada como una herramienta para mitigar los impactos históricos y restaurar los valores naturales y culturales.

Para ampliar mis conocimientos sobre el uso del suelo en la zona y el marco temporal en el que tuvieron lugar las diferentes actividades que se realizaron, revisé varios archivos y literatura sobre la historia local. Para la evaluación estructural de los bosques de la zona de estudio, establecí transectas que se adentraban en tres sitios con impactos diferentes a lo largo de la costa de la península de Brunswick. Estableciendo una parcela cada 100 m, medí el área basal de los árboles vivos y muertos, el DAP (diámetro altura pecho) de todos los árboles, la altura de los árboles dominantes, las dimensiones de la madera muerta tumbada y en pie, y tomé muestras dendrocronológicas de varios árboles representativos. También tomé nota de cualquier intervención cultural y signo de tala.

Mis principales resultados son que la zona costera estaba sometida a explotación forestal y que había una diferencia significativa en las variables de estructura forestal entre las parcelas taladas y las no taladas. Sin embargo, no hubo diferencias estadísticamente significativas entre los tres sitios. En cambio, encontré diferencias *dentro* de los sitios. Teniendo en cuenta los patrones de cada uso del suelo, pude demostrar que todos ellos dejaron una huella distintiva en el paisaje, creando un espacio biocultural complejo.

Mis recomendaciones para la zona son una combinación de visualización de artefactos culturales vulnerables dentro del paisaje forestal y su protección estructural, así como la restauración forestal activa y pasiva para aumentar los valores naturales y restaurar un paisaje semejante a las estructuras anteriores bajo la gestión indígena.

Zusammenfassung

Obwohl die meisten Waldökosysteme der Welt im Vergleich zu anderen Landschaftstypen scheinbar nur geringfügig vom Menschen verändert wurden, weisen sie dennoch eine lange Geschichte menschlicher Nutzung auf und sind Ergebnis ihrer. Die südliche Brunswick Halbinsel mit ihrer langen Geschichte anthropogener Aktivitäten, sowohl in der vorkolonialen als auch in der modernen Zeit, stellt hierbei keine Ausnahme dar.

Diese Studie untersucht die historische Landnutzung und ihre Auswirkungen auf die natürlichen und kulturellen Werte von Südbuchenwäldern (*Nothofagus spp.*) entlang der Küstenlinie der Halbinsel. Darüber hinaus untersuche und erörtere ich, wie diese Werte auf holistische Weise geschützt und erhalten werden können und wie Renaturierung zur Abmilderung historischer Walddegradation und zur Wiederherstellung natürlicher und kultureller Werte genutzt werden kann.

Um mein Verständnis für die Landnutzung des Gebiets zu erweitern und den zeitlichen Rahmen, in dem die verschiedenen Arten der Landnutzung stattfanden einzugrenzen, habe ich mehrere Archive aufgesucht und Literatur zur Geschichte des Gebiets gesichtet. Für die waldstrukturellen Erhebungen im Untersuchungsgebiets habe ich Transekte an drei Standorten mit unterschiedlicher historischer Landnutzung angelegt. Diese Transekte verliefen von der Küste der Brunswick Halbinsel ins Landesinnere. Alle 100 m habe ich eine Parzelle angelegt und dort die Grundfläche der lebenden und abgestorbenen Bäume, den Brusthöhendurchmesser (BHD) aller Bäume und die Höhe der dominanten Bäume gemessen. Desweiteren habe ich die Maße des liegenden und stehenden Totholzes aufgenommen und dendrochronologische Proben von mehreren repräsentativen Bäumen entnommen. Außerdem habe ich sämtliche kultuelle Eingriffe und Zeichen von Abholzung aufgenommen.

Meine wichtigsten Ergebnisse sind, dass im Küstenbereich stark abgeholzt wurde und dass ein signifikanter Unterschied in den Waldstrukturvariablen zwischen historisch abgeholzten und nicht abgeholzten Parzellen bestand. Es gab jedoch keine statistisch signifikanten Unterschiede zwischen den drei Standorten. Vielmehr stellte ich Unterschiede *innerhalb* der Standorte fest. Bei der Betrachtung der Muster der Landnutzungen an den einzelnen Standorten konnte ich zeigen, dass sie alle deutliche Spuren in der Landschaft hinterlassen und einen komplexen biokulturellen Raum („biocultural space“) geschaffen haben.

Meine Empfehlungen für das Gebiet sind eine Kombination aus der Sichtbarmachung gefährdeter kultureller Relikte in der Waldlandschaft und deren strukturellem Schutz, sowie aktiver und passiver Waldrenaturierung. Dies dient dem Zwecke den natürlichen Wert des Waldes zu steigern und diesen hin zu einer Struktur zu entwickeln, wie sie unter indigener Landnutzung vorherrschend war.

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Abbreviations

SLU	Swedish University of Agricultural Sciences
DBH	Diameter at breast height, measured at 1.30 m

1. Introduction

The Magellan region had had an extensive history of anthropogenic activity long before the first European explorers started to voyage into the area in the early 16^{th} century in search of a passage to India. At this time, it was home and ancestral land to four nomadic peoples. Two of them were terrestrial peoples, the *Aónikenk*, living in the steppes and more continental regions and the *Selk'nam* inhabiting the main island of Tierra del Fuego. The other two were littoral; the *Kawésqar* people that navigated the Strait of Magellan, its channels, and the shorelines, and the *Yagán* living along the coasts of the southern archipelago and the Drake passage. All of them underwent forceful attempts at assimilation or disappeared almost completely due to introduced diseases, persecution and genocide (de Agostini, 1945; Grebe, 1998; Martinic, 2002; Bustamante Olguín, 2010; Arqueros *et al.*, 2016; Casali, 2017).

What distinguishes the Magellan region from other parts of the Americas is that the far reaching societal and environmental changes of colonization did not take place until the 19^{th} century. There was an early attempt in 1584 at establishing a Spanish settlement in the northern part of the Brunswick peninsula, but it failed so dramatically that no further endeavors were launched for over a century. In fact, none of the attempts at colonization or evangelization were deemed to be successful until the 1840s (Martinic, 2002). By then the Magellan region was not yet formally part of Chile. This changed in 1843 when it was incorporated into the national territory in what is now referred to as the "taking of possession" ("toma de posesión") (Martinic Beros, 2006b; Couyoumdjian, 2019). The antecedents to this were that European powers, particularly England and France showed increasing interest in these territories and regarded them *res nullius*, no man's land (Berguño, 2002; Martinic, 2002; Martinic Beros, 2006b; Couyoumdjian, 2019). Furthermore, with the emerging commercial navigation of the Strait of Magellan in the 1830s, the need to establish presence was felt by Chilean officials. Most prominently Bernardo O'Higgins, arguably the most important figure in Chile's fight for independence, devised plans to colonize the southern Patagonian and "Fuegian" territories (Martinic, 2002; Martinic Beros, 2006b). The first settlement along the shores of the Brunswick peninsula was Fuerte Bulnes (1843), but the colony was quickly moved to Punta Arenas (1848), whose location provided a more favorable climate for the colonizers (Martinic Beros, 2006b; Güenaga de Silva, 2013; Couyoumdjian, 2019).

In spite of the considerable alteration of the landscape in the northern part of the peninsula, where coal was mined on an industrial scale from the early 20th century on (Martinic, 2004), high-impact activities in the southern part of the peninsula remained the exception. This is primarily owed to difficult accessibility of the terrain over land (Centro EULA-Chile, 2008), which inhibited rapid colonization and consequently most land use changes. Nevertheless, in recent years, interest in recreational use of the stretch between Punta Arbol, located on the mid-eastern coast of the peninsula, all the way to Cabo Froward, the most southern tip of the South American continent, has been increasing. Especially the coastal fringe is hereby the most frequented.

Despite exhibiting a seemingly low degree of human alteration when compared to other types of landscapes, most forest ecosystems in the world have a long history of human use and are product thereof (Denevan, 1992; Zegers, Arellano and Östlund, 2019; Östlund and Norstedt, 2021). Hence, they qualify as *domesticated landscapes* (Clement and Cassino, 2020; Östlund and Norstedt, 2021) rather than pristine ones. The southern Brunswick peninsula is no exception to this, and anthropogenic activities of different sorts have been influencing and shaping the landscape to different extents for centuries. A variety of anthropogenic activities, both from the pre-colonial and the colonial period, took place precisely within this coastal fringe (Centro EULA-Chile, 2008).

In terms of natural values, the zone lies in the transition zone of coastal and more continental habitats, between evergreen and deciduous *Nothofagus spp.* forests (Ministerio del Medio Ambiente, 2021) and is characterized by a mosaic of different forested and wetland habitats up unto alpine tundra and nival zones (Centro EULA-Chile, 2008; Ruíz and Doberti, 2008). This rich cultural history and natural diversity, as well as the growing pressure originating from tourism (Rosenfeld *et al.*, 2020), call for the elaboration of a conservation and management concept that preserves cultural heritage while promoting and restoring natural values.

Especially, in areas with a long indigenous land use history, the aboriginal influence on the landscape must be made visible and incorporated into management (Östlund and Norstedt, 2021) as not to perpetuate errors of the past. There are prominent examples of conservation efforts around the world that disregarded, in an act of (post-)colonial ignorance, oppression or racism, precisely this influence that made areas worthy of protection (Schelhas, 2001). Instead of conserving a biocultural landscape (Sauer, 1925; Lindholm and Ekblom, 2019) they sought to protect areas for their supposed pristineness (Pickerill, 2008; Östlund and Norstedt, 2021). This was done by excluding indigenous people and their knowledge from the lands, a practice deeply rooted in the US-American tradition of nature conservation (Schelhas, 2001) which serves as an example for conservation around the world.

Denevan (1992) terms this effort to preserve the fictive “original conditions” the “pristine myth”. Deconstructing this myth and including indigenous knowledge and participation can vastly improve conservation outcome and must be the paradigm for nature conservation on ancestral lands.

Although being far from pristine when Chilean and European settlers colonized the area in the 19th century, it was not until the industrial exploitation of the first half of the 20th century, when the impact became much more marked and landscape change far more drastic. Most notable were the activities of logging and whaling (Nicholls Lopeandía, 2010; Ministerio de Bienes Nacionales. Subsecretaría de Turismo, 2020). Although the exact spatial and in some cases temporal extent remains unknown there are archival records that give an unequivocal testimony about the exploitation of the coastal fringe, both marine and terrestrial, and the subsequent transformation its shoreline and forests underwent.

In the light of this long and diverse history of land use, it is imperative to leave behind the artificial dichotomy of nature and culture and embrace both the pre-colonial and modern cultural, as well as the natural heritage of the area. The idea of the “palimpsest” (from Greek “scraped again” referring to a reused parchment) offers both a metaphor to describe the overlapping imprints that varied natural and anthropogenic processes have left on the landscape, and also a new way to think natural and cultural heritage together in one concept (Layne, 2014; Rivera-Núñez and Fargher, 2021). It could serve as a suitable holistic framework to approach conservation in complex biocultural spaces, like the southern Brunswick peninsula.

1.1 Aims of the study

The overall aim of the study is to investigate the historic land use and its impact on natural and cultural values in *Nothofagus spp.* forests along the coastal fringe on the Brunswick peninsula. Further, I aim to discuss how these values can be protected and conserved in a holistic way and how the historic impact can be mitigated through restoration. The specific questions which will be answered are:

1. What is the history of land use in the area?
2. How do forest structure and naturalness indicators broadly differ between study sites and according to historic land use?
3. How do forest structure and naturalness indicators change with increasing distance to the shore?
4. Are there culturally modified trees or other forest historical artifacts present?
5. What could be recommendations for protection and restoration of natural values, and conservation and visualization of cultural heritage?

Lastly, the study seeks to contribute to the conservation and restoration discourse by critically discussing traditional and novel conservation ideas.

2. Material and Methods

2.1 Study area

2.1.1 Biogeographic background

The study area is located at the very southern tip of the South American continent, on the Brunswick peninsula. Administratively it belongs to the municipality of Punta Arenas, Magellan region and comprises parts of the protected area *Bien Nacional Cabo Froward* (*Fig 1*). This concession area stretches from the mouth of Río San Pedro in the North to just 4 km east of Cabo Froward in the South and comprises an area of 8,782.6 ha (Centro EULA-Chile, 2008).

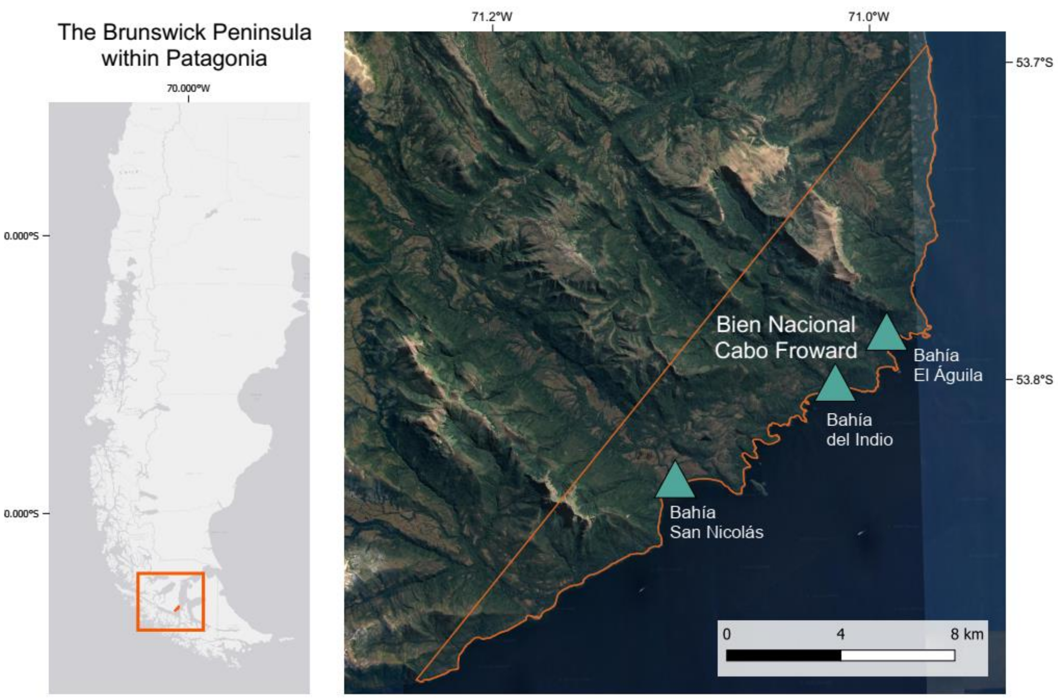

Figure 1 Overview of the Bien Nacional Cabo Froward. The study sites are represented by the green triangles (Source: Esri, Google Satellite).

The western border of the protected area is a straight line, connecting the northern and southern tip, the other is the shoreline of the Strait of Magellan. The north-south extent measures about 38 km, while the maximum width is ca. 4 km. The shoreline in the northern section is relatively even until Cabo San Isidro. In the middle section until Bahía San Nicolás, the widest bay of the area, the shoreline is characterized by mostly smaller bays and exposed beaches. After San Nicolás the shoreline becomes less ragged and continues in a straighter fashion until Cabo Froward.

According to the classification of Fuenzalida (1967) the climate is for the most part trans-Andean with steppe degeneration (Köppen-Geiger ET), with an annual precipitation between 400 and 500-600 mm which is unevenly distributed throughout the year (Pisano, 1973). Only in the northern parts of Bahía El Águila which lies in the shade of the Mount tarn mountain ridge, there is a temperate-cold and rainy microclimate (Köppen-Geiger Cfc) with precipitation exceeding the 600 mm (Departamento de Geografía Universidad de Chile, 2016). The mean annual temperature is 7-8° C (Ruíz and Doberti, 2008). The climate is strongly influenced by the circum-Antarctic low pressure trough (Veblen *et al.*, 1996), and characterized by variations in atmospheric circulations and strong winds coming from the southern Pacific. Seasonal variations in temperature are low (in the magnitude of 5-10° C) (Pisano, 1973; Ruíz and Doberti, 2008).

The landscape within the study area is glacially formed, with rounded hills that do not exceed 800 m.a.s.l. Towards the shoreline, the relief levels off. The hills and mountains are intersected by broad glacial valleys in a fashion perpendicular to the shoreline. The foot of the hillsides is covered in forest, as are the lower slopes until the tree line, which is located between 500 and 650 m.a.s.l. The forest systems in the area are characterized by a high level of humidity, which speeds up above-ground processes of rot and decomposition despite the limiting temperatures. Various environmental gradients make this forest landscape a very heterogenous one. Aside from soil moisture gradients that go from well drained, rocky soils to poorly drained boggy soils, there is a coast-inland gradient and an altitudinal gradient. The nival zone already starts at ~ 700 m.a.s.l. (Ruíz and Doberti, 2008). While most of the area is covered in *Nothofagus spp.* forest of different types, mires make up the most prominent form of open landscape especially in flat areas with poor drainage at the valley bottom. Alpine grasslands occur in some parts above the tree line, but only to a minor extent.

The prominent soils are gleyic and podzolic and belong to the order of Histosols (United States Department of Agriculture Soil taxonomy; Ruíz and Doberti, 2008). Soil processes are slow and soil formation is very limited due to the climatic factors, as well as the presence of rocky substrate of marine, glacial, and fluvial origin, as well as peat. Soils can be either water-logged with a thick organic layer that favors mires, or in similar conditions with better drainage acidic forest soils. All ecosystems of the area are Nitrogen limited (Ruíz and Doberti, 2008).

The area's forests are the product of their unique location in the transition zone between the Magellanic rainforest, and the subantarctic forests (Veblen *et al.*, 1996). Within the forested areas of the Brunswick peninsula there is a transition between mostly deciduous forests, dominated by Lenga (*Nothofagus pumilio* (Poepp. & Endl.)) in the north-eastern part of the peninsula and mostly evergreen Coihue de Magallanes (*Nothofagus betuloides* (Mirb.) Oerst., hereafter Coihue) dominated forests in the southern and western parts (Pisano, 1973). The environmental ministry of Chile refers to this forest ecosystem as mixed temperate-antiboreal Andean forests of *Nothofagus betuloides* / *Nothofagus pumilio* (Bosque mixto templado-antiboreal andino de *Nothofagus betuloides* / *Nothofagus pumilio*) (Ministerio del Medio Ambiente, 2021). According to a finer scale classification by Ruíz and Doberti (2008) there are three distinguished forest types: (1) Coihue - Canelo Forest, where *N. betuloides* forms the dominant layer and the inferior layer is made up by *Drimys winteri* (J.R. Forst & G. Forst), (2) mixed Lenga-Coihue Forest, where *N. pumilio* and *N. betuloides* are codominant, and (3) Lenga Forest, dominated by *N. pumilio.* In the case of our study area, only the first two forest types are present.

2.1.2 Socio-economic and land-use history

Human settlements of littoral hunter gatherer societies were already present between 7440 cal – 6000 uncal years BP, as studies from Punta Santa Ana about 25 km north of the study area show (Morello *et al.*, 2012; Prieto, Stern and Estévez, 2013). The local indigenous people in the study area were mainly the littoral *Kawésqar* who navigated the Strait of Magellan and the adjacent canals by canoes (Fitz-Roy, 1839a; Martinic Beros, 2006a; Zegers, Arellano and Östlund, 2019). The first Europeans to set foot on the peninsula were the members of Fernando de Magallanes' expedition crew, who navigated the entire strait in late 1520. Several expeditions followed, very notable ones being those of Robert Fitz-Roy and Charles Darwin between 1826 and 1830 (Martinic Beros, 2006a). The first permanent colony was established in 1848 in Punta Arenas and from the late 1860s on, Chilean-European settlers started colonizing the wider area, following the discovery of coal-sands. The main early economic activities were trapping and hunting for fur, shepherding, forest exploitation and agriculture. With the increasing European immigration, commercial activities centered around import-export business gained momentum and began reshaping the socioeconomic situation of the colony during the second half of the 19th century. In this period, a small group of mostly immigrant entrepreneurs managed to accumulate the vast majority of the economic wealth. This also had implications on the land tenure rights, which between the late 19th century and the first half of the 20th century were concentrated in the hands of very few financial holdings. Worthy of mentioning are two family groups in particular: the Braun-Hamburger and the Menéndez-Behety. Their unique position in the socio-economic history of the Magellan colony is underlined by historian Mateo Martinic Beros, who coined the term "Magellanic oligopoly" to describe these family clans (Martinic Beros, 2006c). During this time, the indigenous population was increasingly marginalized, displaced, persecuted, and murdered to (near) extinction as it was the case in the Selk'nam genocide, which was authored by members of said oligopoly. Introduced diseases and famine exacerbated the situation and let to the further demise of remnant indigenous populations and to the complete dominance over the territory by Chilean-European colonizers (de Agostini, 1945; Martinic, 2002; Martinic Beros, 2006c; Zegers, Arellano and Östlund, 2019). But even the colonial efforts went into crisis in the 1920s, with the post-World War I recession and the opening of the Panama Canal, which dramatically reduced the importance of the Strait of Magellan as an interoceanic passage. This among other factors led to abandonment and depopulation. Property rights, however did not undergo significant change until the national agrarian reform in the 1960s and 1970s, which is also the time when efforts to protect nature areas gained momentum (Martinic Beros, 2006c; Zegers, Arellano and Östlund, 2019). The *Bien Nacional Protegido Cabo Froward*, where the study area is located, however did not obtain its protection status until 2006 (Ministerio de Bienes Nacionales, 2006). Since then, it has been under short term concession, partially or whole (SEREMI de Bienes Nacionales de Magallanes y Antartica Chilena, 2017)

2.2 Sites

We chose the sites based on their land use history on the one hand and their relative pristineness on the other. Information as to which site could be of historical and cultural importance or of outstanding natural value, was provided by Gabriel Zegers and Benjamin Cáceres which as researchers of the *Museo de Historia Natural Río Seco* have extensive knowledge of the historical background and natural conditions of the area.

2.2.1 Bahía El Águila

We chose the site at Bahía El Águila primarily, because it was perhaps the most prominent scene of early industrial development of the 20th century in the area. Although, it was used for whaling, this marine exploitative activity had implications on the shoreline and the surrounding forests, as well. Furthermore, the whaling station was later converted into a shipyard and then into sawmill, both operating at a minor scale. Aside from these modern uses, there are several shell-middens ("conchales") located on the shoreline which are indicative of indigenous campsites and in consequence possible influence on the surrounding forests.

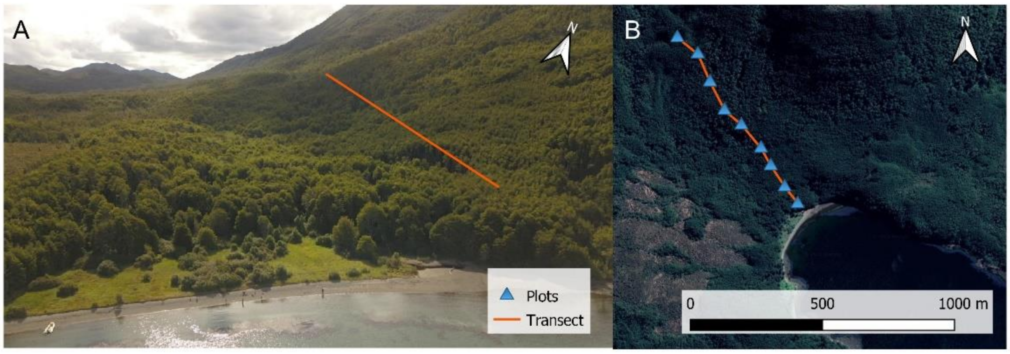

Figure 2 (A) Overview of Bahía El Águila site with transect. (B) Satellite imagery of Bahía El Águila with transect and plots (Sources: Jonathan Poblete, Google Satellite).

The bay is located just 1.5 km west from Cabo San Isidro and the northernmost of the three sites. It is also the most accessible, due to its proximity to Cabo San Isidro, location of the southernmost lighthouse on the South American continent, which is connected to the road by a well-prepared hiking trail (Ministerio de Bienes Nacionales. Subsecretaría de Turismo, 2020). Bahía El Águila is fairly narrow and deep and thus more sheltered than both of the other sites. The beach on the right side of the bay is broader due to the mouth of a stream that is located in this part, and the resulting sedimentation. To the left of the stream there is some forest and an extensive mire, while the right hand-side of the stream is made up by a forested hillside. The transect is located on this hillside (*Fig 2*).

2.2.2 Bahía del Indio

This site was again chosen due to the presence of archeological remains of an indigenous camp in the form of several shell middens ("conchales").

Furthermore, there is a modern recluse's hut and an adjacent campsite. Based on these dates about historic activities on the site, we deemed it likely that the sur-

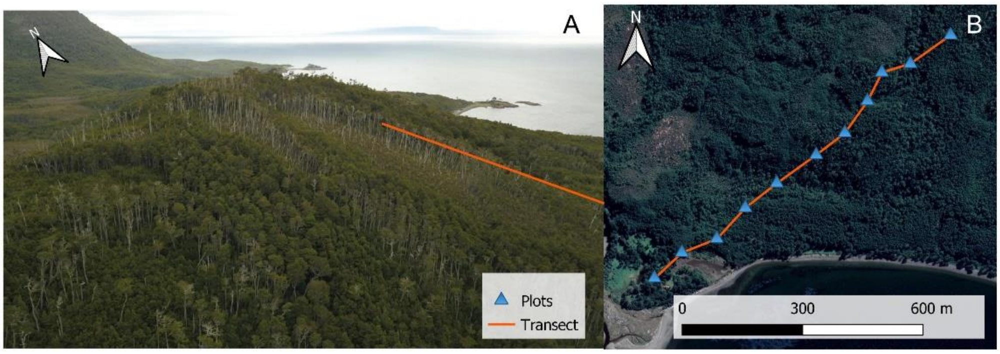

Figure 3 (A) Overview of Bahía del Indio site with transect. (B) Satellite imagery with transect and plots (Sources: Jonathan Poblete, Google Satellite).

rounding forests were subject to some form of use or exploitation.

The shoreline forms a very large and open bay that is much more exposed than either one of the other sites. At the center, the Yumbel river flows into the Strait of Magellan and forms sedimentary deposits at its mouth. To the right of this, there is an open grassland area and then several forest patches surrounding the recluses's hut which show obvious signs of human activity. Another open landscape is formed by a sea-inlet that only temporarily holds water a bit further to the right of the hut. Behind this patchy coastal landscape, there is a hill with permanent forest cover, which the transect traverses (*Fig 3*).

2.2.3 Bahía San Nicolás

Up until the end of the first half of the 20th century, there was a sawmill at Bahía San Nicolás, which operated in the area. Today the site is a popular destination for touristic visits, functioning as a campsite for hikers on their way to Cabo Froward. The site was therefore chosen for its historic and ongoing impact.

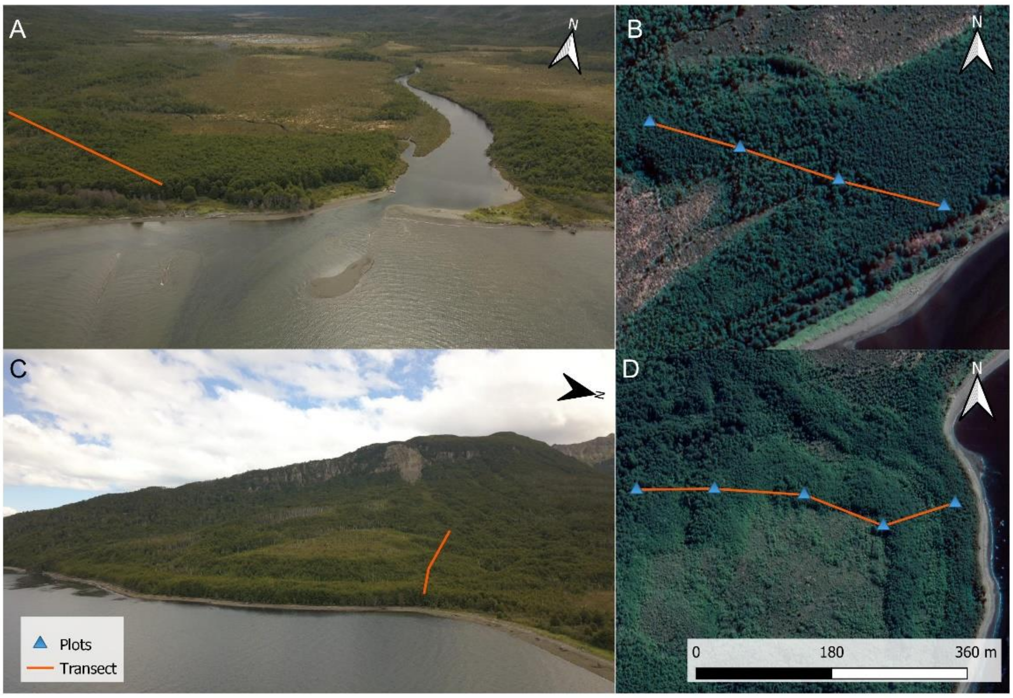

Figure 4 (A&C) Overview of San Nicolás site with transects. (B&D) Satellite imagery with transects and plots (Sources: Jonathan Poblete, Google Satellite).

In terms of shelter from the open sea, the bay is an intermediate of the other two. It is also the southernmost site. At the center of the bay, the large San Nicolás river flows into the Magellan Strait. There are extensive mires on both sides of the river. Directly behind the beach there is a very dense forest belt. Further off to the left, there is a mostly forested hillside, with a gradually increasing slope. The two transects at this site are located on the left hand-side of the river, one in the coastal forest belt and one on the hillside behind the former sawmill (*Fig 4*).

Furthermore, within the macro site of San Nicolás, two smaller sites with one plot each were chosen that seemed promising due to the maturity of the forest indicating a lack of recent human influence and thus a good basis for comparison. These sites are located land-inwards on the far-right side of the large mire on the right hand-side of the river (*Fig 5*).

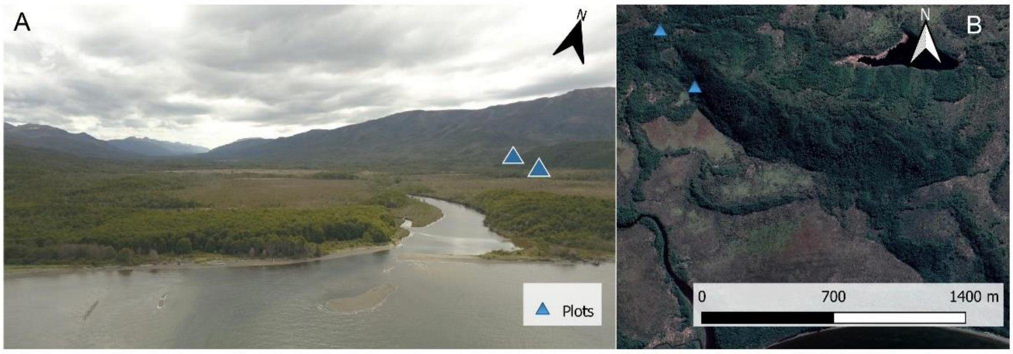

Figure 5 (A) View of the old-growth sites at San Nicolás from the shore with plots. (B) Satellite imagery with plots (Sources: Jonathan Poblete, Google Satellite).

2.3 Archival research and interviews

To broaden my understanding of the land use of the area and the temporal frame during which different industries operated, I reviewed different archives and literature published on the history of the area. For this purpose, Miguel Cáceres, director of the *Museo de Historia Natural Río Seco* provided me with sources and his expert knowledge regarding the whaling station at Bahía El Águila. Furthermore, I consulted the Gabriela Mistral municipal library of Punta Arenas for the archives of the local newspapers. Particularly, I searched the *La Prensa Austral* which has been published from 1942 on, and *El Magallanes,* published starting in 1894. Furthermore, I consulted the photographic archives of the Instituto de la Patagonia and ENAP (Empresa Nacional del Petróleo) for aerial photographs that were taken from the area in a systematical way using the trigometron method. Several flyovers were done in 1945/46, and two lateral and one vertical image were taken at each site along different transects, thus covering the majority of the area from different angles. Rodrigo González Vivar, curator and investigator at the Instituto de la Patagonia assisted me in locating the archives and also provided me with expert knowledge regarding further possible sources about the area. I conducted all of the historical research in January and early February 2022.

2.4 Forest structural and natural value assessment

We conducted our fieldwork in early February of 2022. For the forest structural assessment, we established transects going inland from each coastal site. We determined the exact length of each transect in the field based on the conditions at each site. The longest one was 1000 meters (Bahía del Indio) and the shortest 400 meters (Bahía San Nicolás). Every 100 meter, we established a sample plot. Only locations within forests were considered, evading mires, as they do not comprise part of the study object. We established the first plot about 50 meters from the shore (being the basis of impacting activities) inside of the forest. The last plot, i.e., the end of the transect was reached when there were no more signs of human intervention in the forest for at least two consecutive plots. We chose circular plots over rectangular ones to reduce bias (Paul, Kimberley and Beets, 2019). The radius of a plot was set to ~17.84 m so that each plot would cover an area of 0.1 ha. For reasons of practicality and time constraints in this very difficult terrain we chose to sample a quarter of each circular plot. At each site we also created satellite relascope plots as a quick way to measure the basal area and to get a reference of the adjacent areas to each plot. We described all plots and satellite plots, focusing on their site-specific ecological characteristics and the presence or absence of any sign of cultural modification. Within each of the quarter plots, we recorded the height of the two tallest trees, as well as the diameter at breast height (DBH>10cm). From the center of each plot, we recorded the total basal area and the basal area of each living tree species and standing and lying deadwood using a relascope. To approximate the stand age, we cored between 2 and 6 randomly chosen specimen of both present dominant/co-dominant *Nothofagus* species as well as of *Drimys winteri* (Östlund *et al.*, 2020). To assess naturalness of each plot, we measured the volume of deadwood within the quarter plot (Lassauce *et al.*, 2011; Kunttu, Junninen and Kouki, 2015). For this purpose, we took the dimensions (length, mid-diameter/DBH) of lying and standing deadwood.

2.5 Data analysis

I conducted the data analysis in R studio version 1.2.5019 (R Core Team, 2019).
For the calculation of the standing volume of Coihues, I used a species specific allometric formula from the Peninsula Antonia Varas, Magellan region (Marquéz, 2011):

$$V = 0.000388643 * (DBH^{1.28365}) * (H^{0.929743})$$

For the calculation of the standing volume of Canelo, I used an equation specific to the species from Isla Navarino (Quiroz 1990 in Drake, Emanuelli and Acuña, 2003):

$$V = 0.401 + 0.0000318 * DBH^2H$$

For the calculation of the standing volume of Lenga, I used the following species specific equation (Mosqueda 1995 in Drake, Emanuelli and Acuña, 2003):

$$V = 0.001863 * DBH * H – 0.015086 * D$$

In all equations V is the volume, DBH is the diameter in centimeters measured at 1.30 m of height, and H is the height of the tree.

To calculate the deadwood volume, I used different formulas according to the type of deadwood:

I calculated lying deadwood using the following equation (Lombardi *et al.*, 2011):

$$V_{lying} = \pi/4 * D^2_{0.5L}L$$

Where V_{lying} is the volume, $D_{0.5L}$ is the diameter at half length, and L is the length.

For stumps, I used Huber's formula (Teissier Du Cros and Lopez, 2009):

$$V_{stump} = \pi/4 * D^2H$$

Where V_{stump} is the volume, D is the top diameter, and H is the height.

The means for all forest structural variables per hectare with their respective standard errors were calculated using the following extrapolation factor:

$$F=10000/((\pi r^2)/4)$$

To search for interrelations between the different variables, I performed several statical tests. Where normality was given, I used a *Welch's T test* to test for differences in structural variables between logged and unlogged plots. In the absence of normality, I performed a *Mann Whitney U test*. To test for any differences in variables between sites and to test for differences in basal area between main and satellite plots, I conducted t*wo-way analyses of variance (ANOVA)*. In the absence of normality, I used a *Kruskal Wallis test* as the non-parametrical alternative.

To test for any relation between the structural variables and the distance to the shore, I performed *Pearson* and *Spearman correlations*. The choice was based on the previous visual assessment of scatterplots. In doubtful cases, I performed and reported both correlations. I also tested correlated variables for their suitability to fit a linear model, which would provide further predictive qualities. For the significance of all statistical tests, I assumed a probability of 95% or higher ($p < 0.05$).

3. Results

3.1 Historical activities

All three sites were both the scene of indigenous activities and modern exploitative activities in the 20th century. The details of the land use history however differ from site to site.

3.1.1 Bahía El Águila

Although data on the history before the Chilean-European colonization is scarce, there are at least five indigenous archeological findings in the bay that give us an idea about the historical use of the area in the past 1000 years and in prehistoric times. All remains are shell-middens, heaps made up of mollusk shells that indicate the presence of an indigenous campsite (“campamento de pasaje”) (Laming-Emperaire, 1972; Morello, 2008; Prieto, 2008; Morello and San Román, 2012). In contrast to more permanent settlements such sites are thought to have been used in a temporary way in relation to hunting activities and were usually located along frequented travel routes (García-Piquer *et al.*, 2021).

The industrial history of the site began with the opening of a whaling station in 1905. Operating under the name “Sociedad Ballenera de Bruyne, Andersen y Cia” it established its headquarters at Bahía El Águila. There were a processing plant for the whale fat, a smithy, a barrel factory and several other administrative and residential buildings for the workers. Furthermore, there was a landing dock built to haul the caught whales ashore. Some of the remnants, such as the ruins of building structures, the posts from the dock, and parts of the machinery are still present at the site (Morello and San Román, 2012). Most of it however, was auctioned off when the whaling business plunged into a crisis due to the first World War and additionally, more southerly waters of the Antarctic were ventured in (Nicholls Lopeandía, 2010; Quiroz, 2011). What was left of the whaling station was later transformed into a small shipyard and in 1947 into a small sawmill that operated in the area until 1966 (Asociación de Investigadores del Museo de Historia Natural Río Seco, 2017).

Regarding the results from the aerial photographs, the site did not lie immediately below the course of the 1940s flights, therefore the lateral photos from further north had to be considered. Due to the mountain ridge of Mount Tarn that passes just north of the transect at Bahía El Águila, the direct view of the transect was impeded and only the adjacent areas were visible. The coastal fringe on the southern half of the bay, all the way to Bahía del Indio shows signs of heavy logging, probably in form of clear cuts (Film 457, R 203-205, United States Air Force, 1949).

3.1.2 Bahía del Indio

There are at least two registered archeological sites in the northern part of the bay. Both are shell-middens, which are indicative of temporary indigenous campsites (Ruíz and Doberti, 2008).

Furthermore, there are records of a recluse living in the cabin at the site until he had to vacate the premises due to property rights issues in the 1980s (Ministerio de Bienes Nacionales. Subsecretaría de Turismo, 2020). He also kept livestock at the site (Cáceres, oral communication 2022).

While there are no records about industrial forest exploitation of the area that I know of, the aerial photos show obvious signs of high impact logging activities already in the 1940s. At this site there is no immediate flyover available, thus I analyzed the lateral images. Clouds covered parts of the transect, therefore I considered the immediately adjacent forests. The coastal forest cover was much more open than it is nowadays. Also, it was much more open than the forests further inland (Film 457, R 203-205, United States Air Force, 1949).

3.1.3 Bahía San Nicolás

During the morning hours of December 17, 1949, an earthquake with the epicenter in Tierra del Fuego triggered a landslide on the hillside above the sawmill of Bahía San Nicolás. It hit the administration building and pushed it into the sea resulting in the death of three people and the consequent abandonment of all logging operations (La Prensa Austral, 1949). There were no further records found of industrial scale forest exploitation at the site.

The aerial photos from 1945/46 (Film 461, V 21, United States Air Force, 1949) reveal alterations of the forest landscape, especially on the hillslope behind the former sawmill building. The forests canopy is much lighter there, which is indicative of a heavy logging impact.

3.2 Forest structure

3.2.1 General forest structure

The forest structural variables varied considerably between plots. Among the dendrochronologically sampled trees, the youngest one was 17 (Coihue) and the oldest 314 years old (Lenga, DBH > 10cm). The mean age of trees was 104. Only 13 % of all cored trees predate the colonization of the Brunswick peninsula in 1843. The DBH of all trees within the plots ranged from 10 cm to 120 cm with a mean of 20 cm. The basal area of living trees ranged from 20 m^2ha^{-1} to 120 m^2ha^{-1} with a mean of 50 m^2ha^{-1}. The basal area of deadwood ranged from 2 m^2ha^{-1} to 36 m^2ha^{-1} with a mean of 19 m^2ha^{-1}. The standing volume ranged from 142 m^3ha^{-1} to as much as 1141 m^3ha^{-1}, with a mean of 479 m^3ha^{-1}. The volume of deadwood ranged from 39 m^3ha^{-1} to 743 m^3ha^{-1} with a mean of 331 m^3ha^{-1} (*Table 1*).

3.2.2 Logging activity and forest structure at Bahía El Águila

We sampled 8 plots along a transect that was directed from the shore inland. The plots were 100 m apart, with the first one being inside the coastal forest, 50 m from the beach. The first 4 plots close to the beach showed signs of logging, while the latter 4 further inland did not. Dendrochronological analysis showed that the trees at the site were aged between 17 and 270 with an average of 101 years. The DBH of all trees on the plots at the site ranged from 10 cm to 82 cm with a mean of 21 cm. Around 27% of the cored trees at Bahía El Águila predate the establishment of the whaling station in 1905. However, it has to be noted that we found the vast majority of those trees on the unlogged plots further inland and only one individual on a logged plot close to the shore. Ca. 59% of all trees at the site predate the installment of the sawmill in 1947, but less than one third of those are located on logged plots. The basal area of living trees measured at the center of each plot ranged between 23 m^2ha^{-1} and 64 m^2ha^{-1} with a mean of 45 m^2ha^{-1}. The basal area of deadwood ranged between 2 m^2ha^{-1} and 27 m^2ha^{-1} with a mean of 15 m^2ha^{-1}. The standing volume calculated from the DBH and height of all trees within a quarter plot ranged from 142 m^3ha^{-1} to 816 m^3ha^{-1} with a mean of 455 m^3ha^{-1}. The deadwood volume calculated from the dimensions of all pieces of deadwood within the quarter plot ranged between 39 m^3ha^{-1} and 370 m^3ha^{-1} with a mean of 218 m^3ha^{-1} (*Table 1*).

Table 1 Means with standard errors and ranges for the most important forest structural variables, measured at four different sites in the protected area Bien Nacional Cabo Froward.

Variable	Site	Mean[f] ± SE	Range[g]
Tree age[a]			
	Bahía El Águila (n=8)	100.8 ± 10.4	17 – 270
	Bahía del Indio (n=11)	104.3 ± 8.9	17 – 290
	Bahía San Nicolás (n=9)	93.5 ± 8.0	28 – 234
	Old-growth San Nicolás (n=2)	124.5 ± 27.2	24 – 314
	total (n=30)	103.6 ± 5.2	17 – 314
DBH[b]			
	Bahía El Águila (n=8)	20.8 ± 0.8	10 – 82
	Bahía del Indio (n=11)	19.9 ± 0.5	10 – 68
	Bahía San Nicolás (n=9)	18.2 ± 0.4	10 – 68
	Old-growth San Nicolás (n=2)	28.8 ± 3.7	15 – 120
	total (n=30)	19.9	10 – 120
Basal area[c] living			
	Bahía El Águila (n=8)	45.3 ± 4.9	23 – 64
	Bahía del Indio (n=11)	54.9 ± 9.4	20 – 120
	Bahía San Nicolás (n=9)	47.4 ± 4.5	31 – 63
	Old-growth San Nicolás (n=2)	48 / 53	
	total (n=30)	49.7 ± 3.8	20 - 120
Basal area[c] dead			
	Bahía El Águila (n=8)	15.4 ± 3.0	2 – 27
	Bahía del Indio (n=11)	25.8 ± 9.4	5 – 36
	Bahía San Nicolás (n=9)	12.1 ± 2.5	7 – 27
	Old-growth San Nicolás (n=2)	25 / 40	
	total (n=30)	18.9 ± 2.2	2 – 36
Volume[d] standing			
	Bahía El Águila (n=8)	455.3 ± 95.8	142 – 816
	Bahía del Indio (n=11)	526.4 ± 70.6	142 – 876
	Bahía San Nicolás (n=9)	600.0 ± 88.0	329 – 993
	Old-growth San Nicolás (n=2)	348.8 / 1141.4	
	total (n=30)	479.0 ± 46.1	142 - 1141
Volume[d] dead			
	Bahía El Águila (n=8)	217.5 ± 40.2	39 – 370
	Bahía del Indio (n=11)	433.8 ± 62.0	127 - 743
	Bahía San Nicolás (n=9)	305.9 ± 56.9	93 – 512
	Old-growth San Nicolás (n=2)	210.7 / 545.0	
	total (n=30)	331.5 ± 33.8	39 – 743

[a] in years

[b] in cm measured at 1.30 m

[c] in m^2ha^{-1}

[d] in m^3ha^{-1}

[e] no mean, two individual values of the two old-growth plots

[f] arithmetical mean of each site and in total

[g] variation within a site and in total

3.2.3 Logging activity and forest structure at Bahía del Indio

We sampled 11 plots, from the hut close to the shore, uphill into the forest. The first 5 plots showed clear signs of logging, while the latter 6 plots did not. The DBH of all trees on the plots at the site ranged from 10 cm to 68 cm with a mean of 20 cm. The age of trees at this site as a whole ranged between 17 and 290 with a mean age of 104. However, there are stark differences within the site. At the plots adjacent to the recluse's hut, only one of the trees that we cored, predates the 1980s, the decade when the inhabitant was forced to abandon the area. On the remainder of the plots with signs of logging, the mean age was 98 and on the plots without signs of logging 137. I did not test these differences statistically, due to insufficient sample sizes. Basal area of living trees at the site as a whole ranged from 20 m^2ha^{-1} to 120 m^2ha^{-1} with a mean of 55 m^2ha^{-1}. The basal area of deadwood ranged from 5 m^2ha^{-1} to 36 m^2ha^{-1} with an average of 26 m^2ha^{-1}. The standing volume ranged from 142 m^3ha^{-1} to 876 m^3ha^{-1} with a mean of 526 m^3ha^{-1}. The volume of deadwood ranged from 127 m^3ha^{-1} to 743 m^3ha^{-1} with a mean of 434 m^3ha^{-1} (*Table 1*).

Aside from logging scars and a few bark peelings, we found charcoal on trees towards the plateau of the hillside, which are indicative of clearing by burning.

3.2.4 Logging activity and forest structure at Bahía San Nicolás

At the site, we sampled two transects: One with 4 plots inside the fringe of coastal forest, and one with 5 plots going uphill behind the former sawmill building. Out of the 9 plots, 7 showed signs of logging. The DBH of all trees on the plots at the site ranged from 10 cm to 68 cm with a mean of 18 cm. The trees were between 28 and 234 years old with the mean age being 94. More than half of the cored trees (55%) can be dated to the period after the abandonment of the sawmill in late 1949. Further cultural modifications were charcoal on one trunk and several bark peelings one of which was very large (Fig 6). The basal area of living trees ranged from 31 m^2ha-1 to 63 m^2ha-1 with a mean of 47 m^2ha-1. The basal area of deadwood ranged from 7 m^2ha-1 to 27 m^2ha-1 with a mean of 12 m^2ha-1. The standing volume ranged from 329 m^3ha-1 to 993 m^3ha-1 with a mean of 600 m^3ha-1. The volume of dead-wood ranged from 93 m^3ha-1 to 512 m^3ha-1 with a mean of 306 m^3ha-1 (Table 1).

Figure 6 Field aide Sebastián Oyarzún next to huge and very decomposed bark peeling (Photo: Lars Östlund).

The trees at the old-growth sites, upstream and inland of Río San Nicolás ranged from 24 to 314 years of age with an average of 125. The DBH of all trees on the two plots ranged from 15 cm to 120 cm with a mean of 29 cm. The basal area of living trees in the first plot was 48 m^2ha^{-1} and in the second plot 53 m^2ha^{-1}. The basal area of deadwood was 25 m^2ha^{-1} in the first plot and in the second plot 40 m^2ha^{-1}. The standing volume varied strongly, with the first old-growth plot having a volume of 349 m^3ha^{-1} and the second one 1141 m^3ha^{-1}. The dead wood volume also varied between 211 m^3ha^{-1} at the first plot and 545 m^3ha^{-1} at the second plot. There were no signs of logging or other human intervention found at either one of the plots (Table 1).

3.2.5 Differences in structure along the transects

Among all sites, the main influencing factor on forest structural variables was the logging activities of the last century. This impact was manifested on the sites in form of remnant logging stumps, which I used as an indicator if the site had been subject to logging or not. The presence of stumps was strongly correlated to the distance of a plot to the shore (-0.79 Spearman, - 0.72 Pearson). Logged plots were located significantly closer to the shore than unlogged (Mann Whitney U, W=1, $p < 0.001$) and after approximately 500 meters inland there were no more plots with signs of logging (*Fig 7*).

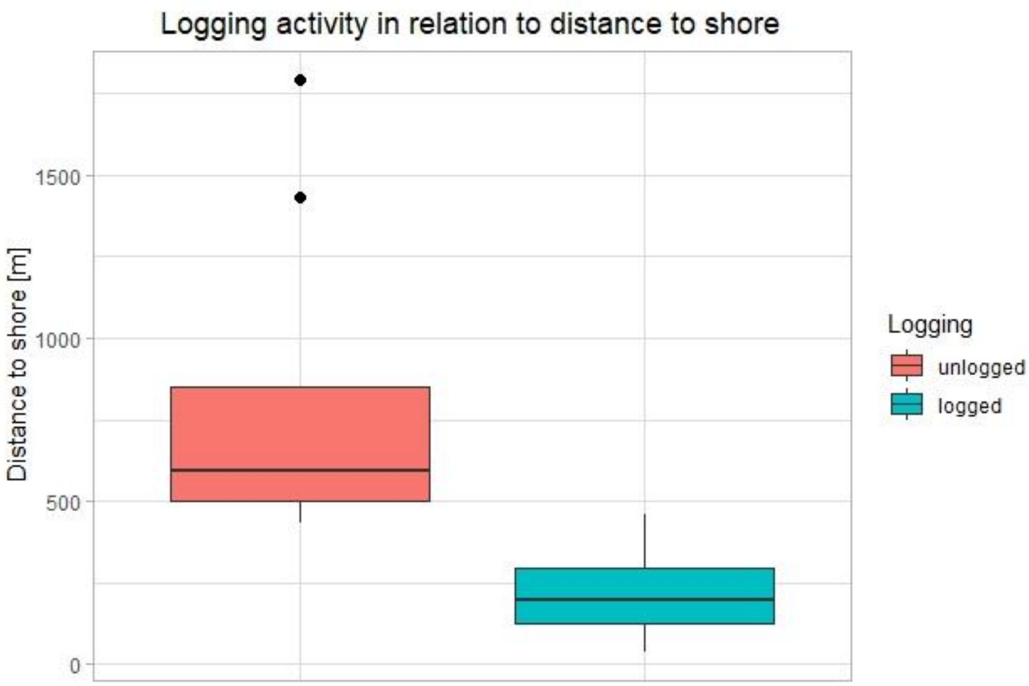

Figure 7 Distance to the shore in logged and unlogged plots. The orange box shows the interquartile range of the distance to shore on unlogged plots, the blue box that of logged plots. The median distance to shore is shown by the bold line in the center of the boxes. Outliers are indicated by black dots.

Between the logged and unlogged plots, there were significant differences regarding the tree diameter - (Mann-Whitney U, W = 90128, $p < 0.001$) and age distribution (Mann-Whitney U, W=1480, $p < 0.001$). While previously logged plots had a more even-aged and even-sized structure with mostly younger and smaller diameter trees, the unlogged plots had a broader spectrum of diameters and ages (*Fig 8*). This is also reflected by the means of age (logged = 95.2 years, unlogged = 130 years) and diameter (logged = 18.5, unlogged = 23.5) which were moderately correlated with the distance to the shore (0.48 and 0.45 Pearson). It is important to note that these variables were also weakly correlated among one another (0.35 Spearman). Although mean deadwood volumes were not significantly different in logged and unlogged plots (logged = 297.3 m^3ha^{-1}, unlogged = 336.9 m^3ha^{-1}, $p=0.57$), there was a weak correlation between lying deadwood and the distance to shore (0.32 Pearson and Spearman).

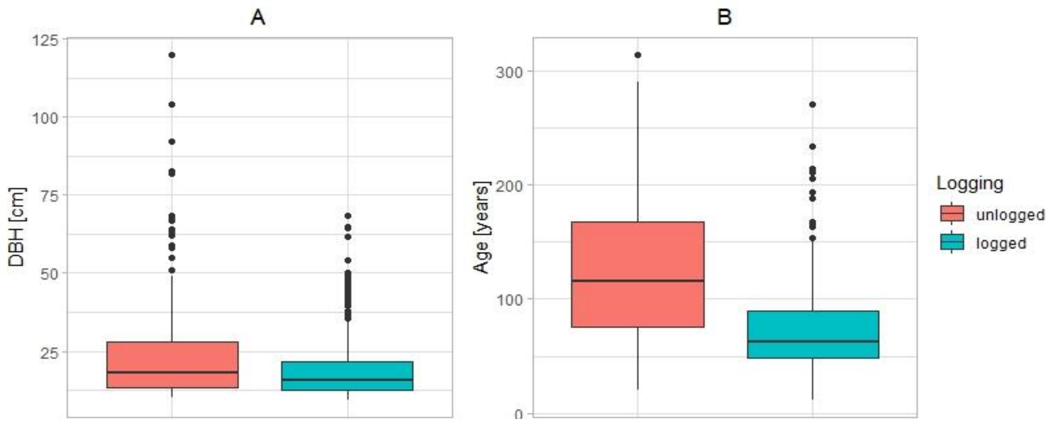

Figure 8 (A) DBH and (B) age in logged and unlogged plots. The orange box shows the inter-quartile ranges of the DBH and the age on unlogged plots. The blue box those on logged plots. Medians are displayed by the bold lines in each box. Outliers are indicated by black dots.

Stronger responses gave the tests for basal area of both lying and standing dead-wood: Lying deadwood had a significantly higher median basal area on unlogged than it did on logged plots (logged = 6 m^2ha^{-1}, unlogged = 14 m^2ha^{-}1, Mann Whitney U, W=42.5, $p=0.04$). The same was true for standing deadwood (logged = 2 m^2ha^{-1}, unlogged = 8 m^2ha-1, Mann Whitney U, W= 25.5, p=0.003). Both Coihue (logged = 16.1 m^2ha^{-1}, unlogged = 20.5 m^2ha^{-1}, Mann Whitney U, W = 47918, $p < 0.001$) and Canelo (logged = 13.2 m^2ha^{-1}, unlogged = 14.9 m^2ha^{-1}, Mann Whitney U, W=8047, $p = 0.001$) showed significant differences in the median basal area between logged and unlogged plots. Again, the basal area was higher in unlogged than in logged plots. The correlations for the basal area with the distance to shore show a similar result: Lying deadwood had a moderately positive correlation of 0.55 (Pearson). Standing deadwood was almost the same with 0.54 (Spearman). The basal area of Canelo in relation to the distance to the shore was the most strongly correlated one with 0.65 (Pearson). There were no significant differences found between the basal area counts of the main plots and the satellite plots.

Lastly, none of the interrelations was strong enough to allow for a well-fitted linear model that could be used to predict the forest structural situation further inland.

4. Discussion

While all three sites statically showed similar forest structural conditions and also patterns of exploitation, there are some particularities at each site that are only explicable when taking a closer look at their varied land use histories.

4.1 The forest at Bahía El Águila

Out of all of the three sites, Bahía El Águila is probably the one with the longest and most varied history of modern land use (Nicholls Lopeandía, 2010; Morello and San Román, 2012; Asociación de Investigadores del Museo de Historia Natural Río Seco, 2017). But one thing that the whaling station, the shipyard and the sawmill all have in common, is that their installation and operation required wood, which was harvested from the adjacent forests. The fact that there are very few trees that predate these activities and even fewer on plots that show signs of logging, is clearly indicative of intensive logging in the past. Although the aerial photos do not allow for a judgement of the area of the transect that would support these findings, the forest structure, and the observations that we made during the fieldwork paint a picture of a heavily altered forest landscape, to a point where the logging activity is strongly manifested in today's forest landscape. Therefore, it does not come as a surprise that we did not find any signs of indigenous forest use during the fieldwork, as they were likely erased during this period of industrial exploitation.

As to which part of the forest was exploited when, or better by which activity is not clearly discernible in the data. In any case it is likely that the coastal areas were exploited first, i.e., by the whaling station. Hence, forest workers from the sawmill and the shipyard probably had to venture further inland to extract wood for their purposes. However, the areas that were exploited at each time and by each activity probably also overlapped, as each type of forest use required different types of trees. While the workers from the sawmill and the shipyard were probably high grading the forest in an attempt to only extract the most valuable timber, the whaling station's main requirement was likely firewood for the processing of the whale products. Thus, the qualitative standards for the wood were lower.

4.2 The forest at Bahía del Indio

Based on the records about the recluse and the aerial photographs from the 1940s we can assume that there were both industrial scale exploitation and later logging on a small scale in the form of clearing land for pastures and harvesting wood for construction and firewood. Therefore, there are at least two levels of impact on the forests of the site from different times and on different spatial scales, but that also overlap.

One example is the forest immediately behind the cabin. Due to its easy accessibility close to the shore and with relatively plane terrain, it was likely the first to be industrially exploited. A look at the aerial images confirms this notion and it is a pattern that repeats all along the coastline of great parts of the southern Brunswick peninsula. However, the same forest was later kept open or further cleared for pasture by the recluse. Nowadays, this can still be appreciated when looking at the very dense forest structure and the remnants of fencing and gates, which hint towards the use as an animal pen. The very dense present forest can be explained by fertilization of the ground that occurred through droppings from the animals that were kept there. The influence of former agricultural practices on current secondary forest is well studied and in some cases remains detectable after millennia (Craddock *et al.*, 1985; Dambrine *et al.*, 2007). Furthermore, there is a log storage yard, immediately adjacent to the cabin where we found 32 logs, each with a diameter of ca. 60 cm and 4 m long (Fig 9). Based on the dendrochronological data (oldest cored tree from 1984) and the very low diameters (mean 14.6 cm DBH) of all the trees present at the plot, I can date at least the clearing of the area to the 1980's, the time of the recluse. Whether the logs were cut during the same time could be confirmed by analyzing the logs themselves with dendrochronological methods.

Another testimony of former deforestation is given by the large diameter stumps that line the beach east of the cabin. Based on the aerial photographs and the large scale of the impact, I can infer that this was likely the result of the industrial logging and not the recluse's work. Further analysis of the stumps is needed to confirm this conclusion.

Figure 9 Log storage yard next to the cabin (Photo: Lars Östlund).

Lastly, the immediate surrounding forests of the cabin might also be impacted by recent gatherings of firewood, since they are very close to the campsite that is frequented by hikers on their way to Cabo Froward.

4.3 The forest at Bahía San Nicolás

At San Nicolás the only recorded land use activity that I know of, is the sawmill that existed and operated there. The accident of 1949, when a landslide triggered by an earthquake took two lives and destroyed key infrastructure of the logging business, instigated the abandonment of the sawmill. These events were tragic, but they provide us with important contextual information that allow for two assumptions. First, that there was a high degree of deforestation which facilitated the landslide that hit the sawmill building. And second, that the forest of the area has been following a mostly natural development with little to no human intervention for over 70 years now, since there are no records of later exploitation that I know of. Regarding the first assumption, although landslides can be triggered in intact forests as well and there is a myriad of factors influencing slope stability, deforestation is generally considered to have a destabilizing effect that facilitates mass movements (Hack *et al.*, 2007; Reinhold *et al.*, 2009). Furthermore, another sawmill at Caleta María in Tierra del Fuego was also partially destroyed by a landslide caused by the same earthquake (García, 2013), which underlines the connection between unsustainable forest exploitation and increased vulnerability in the case of seismic or extreme weather events. Regarding the second assumption, it is likely that small scale interventions in the form of e.g., collecting deadwood for firewood, especially around the campsite occurred periodically, and also increased in recent years due to the increased pressure from tourism, however at a minor scale.

Although there are no records of archeological findings at the site that I know of, we did find several bark peelings and one very large one which proves that there was indigenous land use of the area, even though most of the traces were erased by logging and the natural processes over time.

The old-growth sites further inland have to be seen from a different point of view. Judging from the rather far distance to the shore (ca. 1800 m), it is not surprising that there were no signs of logging, but also no signs of other human intervention, since the Kawésqar were a littoral people and usually did not venture that far inland due to the difficult conditions of the Magellanic forests (Acuña, 2013). Therefore, we have to regard these inland sites as examples for long, un-intervened natural development, rather than a reference of what the coastal forests might have looked like before the industrial exploitation. Yet, we also see differences between the two un-intervened old-growth sites. While one was at least reminiscent of the unlogged coastal plots with Coihue being dominant and Canelo inferior, the other one was a much older forest with a co-dominance of Lenga and Coihue. An explanation for this could be their location and the resulting difference in growing conditions. While the former site is located at the foot of a hill and adjacent to a mire, the latter lies in the meander of a river. Thus, soil conditions, climatic conditions and the natural disturbance regime are likely different which manifests itself in the forest structure.

4.4 The impact of historical forest exploitation on coastal Magellanic forests

Unsustainable forest harvesting practices are well known to have far reaching implications for the ecosystems they are performed in and can affect them for decades and centuries to come. This is especially evident for clear cutting , but also selective logging may drastically alter the forest structure and influence forest ecosystems in a negative way (Pollmann, 2002; Josefsson, Olsson and Östlund, 2010; Lie *et al.*, 2012; Albrich *et al.*, 2021). The data of this study suggest that sites where forestry took place in some parts more than 100 years ago, still differ in structure with regard to standing biomass, and also deadwood (based on basal area, not volume) from their old-growth counterparts.

In the case of clear-felled patches, the differences were very easily palpable. The resulting forests were one-storied and dense, made up of small diameter trees, with very few *Nothofagus spp.* saplings in the understory and only small amounts of large diameter deadwood (*Fig 10*).

Figure 10 Above: Secondary forest after clear cut with logging trail in the center (Photo: Leon Hauenschild).

But also, in selectively cut parts, the diameter distribution was skewed towards the lower diameters with the few larger diameter trees often being crooked and disformed (Fig 11).This is a sight not uncommon in formerly high graded forests, as only the big, straight and thus valuable trees were harvested, leaving behind poorer specimen (from an economic point of view) or those located on unfavorable sites, which made harvesting difficult (Salas et al., 2016). The results of this practice are an impoverished diameter distribution with a diminished tree species diversity, and a lack of important habitats that large trees offer, which together reduce the overall ecosystem health (Donoso, 1996; Vásquez-Grandón, Donoso and Gerding, 2018). Josefsson, Olsson and Östlund (2010) found that the long term effects of high grading on deadwood and old-growth dependent species in boreal forests can surpass the mark of a century. Albrich et al. (2021) even found a significant difference in the number of downed logs and tree diameter distribution comparing old growth forests and forests that have been unmanaged forests for 220 years. Adequate protection and restoration, however, may help to recover some of the old-growth values more quickly.

Figure 11 Above: High graded forest (Photo: Lars Östlund) Below: Un-intervened old-growth forest (Photo: Jonathan Poblete).

Aside from these strictly ecological impacts there are also some cultural impacts to be named, most importantly the erasure of evidence of indigenous land use. The shaping influence of the Kawésqar had been present in the area for the past six to seven millennia and on nearby sites was described to have altered the forest structure in such a significant way that it resembled an “English Park” (Fitz-Roy, 1839a). Due to successional processes that have been changing the structure since Kawésqar times, in their study at Río Batchelor on the western part of the Brunswick peninsula, Östlund *et al.* (2020) were not able to locate an area that still looked just like that. However, they did find a significant difference in forest structural variables in the proximity of former Kawésqar settlements that indicate that the forest landscape had been much more open in former times They also found a large number of indigenous bark peelings, whose occurence was very limited in my study area. In the case of this study, such alterations of the forest landscape that were likely also present on the sites along the southern Brunswick peninsula were unfortunately overwritten by modern exploitative forestry. Östlund and Josefsson (2011) described a similar phenomenon of cultural erasure in the case of Sami heritage in exploited boreal forests of northern Sweden.

4.5 Spatial patterns of exploitation

Contrary to initial expectations, the difference in forest structural variables was not very evident between the different sites. Although we had chosen the three sites for their differing land use history, the results show, that they all witnessed intense logging at some point and that the differences are rather to be found in the spatial pattern *within* the sites. In fact, distance to the shore was found to be a more important explanatory variable than historic land use, as it was directly correlated with the logging pattern. Parameters such as the diameter and age distribution were significantly different, and basal area of deadwood was significantly higher in forest plots that showed no sign of intervention than they were in their logged counterparts. Aside from this binary distinction of logged or not, the way in which forests were logged also seems to have changed with increasing distance to the shore and up the hillslope. While there were no trees present on coastal plots that predate the logging activities, there were remnant ancient trees further inland on plots that otherwise showed clear signs of logging. From this I can infer that logging along the shoreline followed a clear-cut model, while high grading, was the preferred method further inland. This is supported by historic photographs of the area around Cabo San Isidro, just north of Bahía El Águila and aerial photos from the entire study area, that show clear signs of very heavy logging and in many cases complete deforestation of the shoreline, while further inland the forest cover remained intact.

Figure 12 One of many large stumps that line the beach at Bahía del Indio (Photo: Lars Östlund).

Furthermore, in *Figure 12* we can appreciate the immediate impact, clear cutting still has on the landscape. The location of the stumps on what is today the beach give a clear testimony about the previous extent of the forest border and how the loss of the structural support through the root system favored erosion. The exact dating of the logging events and the apparent changes in the shoreline however should be the subject of further studies.

4.6 Contextualizing the shoreline

The epicenter of high-impact extractive activities of the 20th century was the shoreline. This does not come as a surprise when we consider the historical descriptions of impenetrable forest and hostile climate that did not invite one to explore (Fitz-Roy, 1839b) and even deterred the indigenous Kawésqar from venturing far inland (Acuña, 2013). Looking for an explanation to this pattern, it seems important to also consider the position of the study area within a regional context. Punta Arenas at the time of the exploitative events was already a prospering city, and also Chile's gate to Europe with the most important harbor of the time, and one of the main connections to Argentine Patagonia (Martinic Beros, 2006c; Nicholls Lopeandía, 2010). Yet, there still were no larger settlements on the southern Brunswick peninsula, a situation that has not changed since then and is certainly due to a multitude of factors, such as unfavorable terrain or climate. Thus, it can be assumed that the area's principal function at this time was to provide resources for a growing local, national, and international economy. The Strait of Magellan as the main waterway of the region connected the sawmill or the whaling station to Punta Arenas, from where resources could be sold to southern Argentina for fence-posting on one of the large ranches of Magellanic business magnates (Martinic Beros, 2006c) or across the Atlantic to power lanterns in Europe's cities (Nicholls Lopeandía, 2010).

Another fact that frames the logging history of the area is that while in Europe and the central parts of Chile the principles of modern forestry, especially the ensuring of regeneration, were already naturalized (Camus, Castro and Jaksic, 2014), in the southernmost parts of the country silvicultural methods seemed to have been of no importance. An explanation for this could be the relatively late integration of the southern Patagonian territories into the Republic of Chile which helped to uphold the colonialist exploitative view of the region for a longer time. The logging pattern, but also the whaling activities of the area suggest that the southern Brunswick peninsula was seen as a mere well of resource that was to be exploited and then left behind in search of other places rich in resources. Following this narrative, the exclusive focus on a narrow coastal fringe of the logging operations seems logical.

4.7 Restoration and conservation

Even though, the exploitative activities of the past century had a very strong impact on the forests of the southern Brunswick peninsula, they are only part of a far longer landscape history. Today's landscape is the product of millions of years of natural processes, millennia of indigenous land use and more than a century of modern activities. Each process and action left and continues to leave its shaping marks on the landscape making it an "unceasingly remodeled space" (Corboz 1983). With this in mind, conservation and management might seem like an impossible riddle of how to combine it all in one concept that encompasses the manifold cultural and natural particularities of the area, but proponents of the "palimpsest theory" argue that this complexity bears an opportunity to overcome conceptual challenges. The palimpsest metaphor refers to a parchment in ancient Greece, that was scraped off and used over and over again. With time, past scriptures would reappear faintly, creating a coexistence of different scriptures from different times. Applying this concept to the management and conservation of the Brunswick peninsula's forests, permits us to preserve and foster the natural values of the area while respecting and embracing its long and diverse cultural history as something that makes this a unique biocultural space (Layne, 2014). Furthermore, this concept allows us to leave behind the "pristine syndrome" (Robbins and Moore, 2013; Rivera-Núñez and Fargher, 2021) and start discussing concepts based on "anthropogenesis" the idea that not all human influence is intrinsically bad and that the shaping hand of traditional indigenous management practices can be in fact beneficial to conservation and restoration efforts (Rivera-Núñez, Fargher and Nigh, 2020). Embedding the palimpsest concept into restoration means to read the imprints previous sustainable land-uses left on the landscape and integrate them into new management practices that respect the challenges of new conditions and global change. Concretely this can be done through different "human-mediated disturbances" which allow us to restore (sensu Zerbe, 2019, p.25) and manage the ecosystem (Rivera-Núñez and Fargher, 2021). The underlying view of this is one that perceives humans as an actor within nature that dramatically alters its ecosystem: *Homo sapiens* as a keystone species (Sinclair, Moen and Crumley, 2017; Rivera-Núñez and Fargher, 2021). The palimpsest not only serves as a metaphor to understand the multileveled nature of landscapes processes, but also to allows for older and newer approaches and approaches stemming from different disciplines to coexist in their own right (Layne, 2014). This makes it very open to compromises in increasingly complex conservation debates, and also adaptable to paradigm shifts, that undoubtably will occur in the future. In the context of rapid global change this flexibility will prove an invaluable quality.

In this theoretical framework, I ground the following recommendations for the management of the area: The structurally impoverished and very dense even-aged forests of the coastal fringe should undergo various thinnings to allow for regeneration of shade-intolerant *Nothofagus spp.* and nurturing of dominant trees and thus stimulate the development towards a state in which the forest is much more open and has a more diverse age and diameter structure. Captain Fitz-Roy likened the forests under Kawésqar land stewardship to an "English park" in 1831 (Fitz-Roy, 1839a), an analogy that gives us a reference of what the forest of the area could have looked like before the industrial exploitation and thus provides important data for the establishment of restoration goals. Such a management serves two purposes: On the one hand does it increase landscape heterogeneity and forest biodiversity by creating new niches and habitats (Rivera-Núñez and Fargher, 2021), and on the other hand does it revitalize the indigenous manifestation in the landscape that was lost by high-impact activities following the colonization of the 19th century (Zegers, Arellano and Östlund, 2019). Furthermore, such a management would allow for some wood harvesting, although at the current stage of predominantly small diameter trees, it would hardly be of commercial value. Nevertheless, the wood could be provided e.g., as firewood at the campsites at San Nicolás or Bahía del Indio, so as to demotivate uncontrolled cutting by hikers. Practitioners should be careful in thinning in a way that promotes the few Lengas and other inferior tree species, such as *Embothrium coccineum* or *Maytenus magellanica* that are present in the forest, thus fostering not only a multi-storied forest, but also a multi-species one. This will undoubtedly make it more resilient in the face of global change. As for reference forests, some of the plots close to the shore that did not show signs of logging but otherwise had comparable conditions, could be used, always considering the now advanced successional state and the lack of indigenous intervention over the past 70+ years.

Regarding the time that has already passed since the last intervention in the high-graded forests and the comparatively low impact the selective cutting had on the forest structure and ecological qualities, the forests further inland are provided with a unique chance to recuperate a contiguous forest with valuable old-growth qualities at a large geographic scale. Therefore, I recommend a passive restoration, i.e., refraining from silvicultural interventions. It is doubtful if a possible gained value of active restoration would justify the costs – ecological and economic – and if continuity without intervention and protection of natural processes would not be more beneficial at this stage (Zerbe, 2019).

Most important in the face of any of these restoration efforts is not to damage any cultural heritage in the forest, which is why extensive archeological surveys of the area must precede any future intervention. An archeological baseline can then also be used to integrate findings into the conservation plan. All culturally modified trees must be registered and included in management plans and excluded from any harvesting activities (Josefsson *et al.*, 2012). Past archeological surveys have already identified various shell-middens (“conchales”) and also proposed management measures to protect them. Morello and San Román (2012) propose boardwalks in the sensitive “conchal” areas which are usually found on the upper ends of the beaches and are thus very exposed to accidental trampling. These structural measures in combination with educational initiatives such as informative boards and symbols on hiking maps could help to create protection and awareness of the cultural value of these rather inconspicuous remains, while at the same time visualizing the indigenous history of the landscape.

Similar educational measures should be taken to inform about the ruins of the whaling station at Bahía El Águila and the remnants of the sawmill at Bahía San Nicolás, if they are to be left in situ and not exhibited e.g., at the nearby museum at the San Isidro lighthouse.

Lastly but most importantly, all restoration and conservation efforts should involve participatory processes. Although to my knowledge there are no members of the Kawésqar people that consider the southern Brunswick peninsula their ancestral land, it could be fruitful to include and consult people from other Kawésqar groups to solicit their help and input on the planning and execution of the project.

5. Conclusion

In this study I was able to show the impact historical exploitative activities had on the coastal forests of the southern Brunswick peninsula and how it is manifested in today's forest structure. There was a clear difference in various structural variables between logged and unlogged forests. The type of exploitative activity however did not have any significant statistical influence on these variables. Rather, I found differences *within* the sites. Considering the patterns of each land use I was able to show that they all left a distinct imprint on the landscape, creating a complex biocultural space, which needs to be protected and partly restored.

Notwithstanding the mark, exploitative activities have left on the forest landscape, the time that has elapsed since the logging, the limited spatial extent, and the comparatively low-impact intervention in all but the immediate coastal fringe provide us with a unique opportunity for the conservation and restoration of some of the world's most southern broadleaf forests. Furthermore, there are still vast zones of the peninsula that have seen little to no intervention in the past centuries, which holds the potential for an extensive protected forest landscape with a high degree of ecosystem contiguousness. Furthermore, there are historical sources and studies from similar areas that give us an idea of what the coastal forests could have looked like under indigenous land stewardship. These provide us with a baseline for restoration to help visualize the cultural heritage of the Kawésqar ancestral lands. All of this is possible within a holistic conservation approach that also encompasses the modern historical artifacts of the area. This study helps to grasp the cultural and natural complexity of the southern Brunswick peninsula and with the concept of the "palimpsest" suggests a way to approach the conservation and restoration of it.

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Supplementary material

Lack of differences between the sites

There were no differences found between the coastal sites. A possible explanation for this could be that all three sites were subject to forest exploitation in the last century. While we had been aware of the sawmill at San Nicolás and the whaling station, turned shipyard, turned sawmill at Bahía El Águila, the presence of a timber storage yard at Bahía del Indio came as a surprise while conducting the fieldwork. Due to the high impact of the logging activities on the landscape, the subtle traces of low-intensity indigenous forest use that might have existed before at Bahía El Indio or even Bahía El Águila with its several indigenous archeological remains, were overwritten by high impacting activities.

Restoration of high graded sites. Active or passive?

In the context of the goal of restoring a former state of forest under indigenous management, thinning or girdling could also be considered at the high graded sites, if the forests in question are thought to still have been within the coastal zone under Kawésqar influence. Although my data shows that the logging operations reached about 500 m inland, I do not have any data about how far inland Kawesqár cultural activities reached. Therefore, the decision for or against active restoration would have to be based on further dendrochronological and archeological assessments to determine a baseline for these forests.

Limitations of methods

The hardly accessible terrain with lots of deadwood, sometimes a dense understory and generally dense forests, posed some difficulties and limiting factors on the methods that were applied in the fieldwork of this study. These then later had implications on the processing of the data and their analysis. For example, the volume calculations that I performed seem to be slightly over-estimated, when compared to other studies of the area (see e.g. Lencinas *et al.*, 2008; Pastur *et al.*, 2011). This is likely due to the fact that we had to estimate the height of trees in most plots, since measurements of the height with the instruments that we had at our disposal were not possible due to the density of the forest. Also, we only estimated the height of the two dominant trees, since in many cases the forest was mono-storied.

Forest density also posed a challenge to making precise relascope counts, since it was difficult to see larger trees that were further away but would have entered the count.

Regarding the archival work, I performed a priority-based search which by no means claims to have been exhaustive. Due to time constraints and the sole availability of archival records at the local archives in Punta Arenas, it was not possible to dig deeper into the land-use history of the area. Perhaps a more thorough archival research would unveil facts and circumstances that could enrich the historical context this study was performed in.

As valuable as the aerial photos were to give an indication about how much the forests of the area were impacted during the time of modern activities, some particularities of the way they were taking posed limits to the usefulness. Often there was no direct flyover available, which is why I had to analyze the lateral image. In some cases, the distance from the plane to the site was rather high so that an exact distinction of logging impact is difficult. In other cases, clouds covered important areas and I had to make inferences based on the conditions of the adjacent forest patches.

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