Assessment of forest services in Estancia Santa Lucia and silvicultural recommendations

Master thesis

by

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1 Introduction

Forests have to variety of ecosystem services. Mountain forests show a complex combination of services in densely populated regions (Schering 1996; Mayer 1991), where the focus often lays on protection against natural hazards. The ecosystem service concept was developed to quantify and asses the services and their benefits to human kind by the United Nations Millennium Ecosystem Assessment 2005 (further referred to as MEA, 2005). Services thereby are linked to human expectations, thus making them stakeholders. The incorporation of timber production, nature conservation, protection- and welfare services is already part of modern forest management in e.g. Austria (WEP 2012). In Argentina this approach is still lacking. Nevertheless, the Argentinian financial crisis in 2001 has led to a population movement towards Patagonia (Pizzolitto 2006) and hence to an increase of settlement activity in rural areas. As a result, expectations towards the forests have increased, making forests a provider of various services to the residents. While timber production and nature conservation are already defined by forest enterprises and natural park administrations, the protective services of forests have not drawn much public awareness and the local knowledge is still limited. A condition that can also arise conflicts (WSL, 2011). Forest history, in terms of sustainable management, is relatively young in the region, nevertheless some benefits, such as soil accumulation vs. erosion, have been already observed and also assessed (Broquen et al. 2003). Concerning the benefits in rock fall protection and flood control, knowledge is still limited.

During their work on forest monitoring, Hunziker et al. (2012) showed, that although there is no current demand for protective services on behalf of the residents, it may rise over time, when people are affected by natural events. This is one of the reasons that show the importance of service assessments investigations, since profound knowledge can allow avoiding conflicts and mistakes in terms of forest management.

1.1 Objectives

The general goal of this thesis is the assessment of forest services in Estancia Santa Lucia. To achieve this goal the following steps had to be taken.

1) Arrangement and digitalization of aerial photos to enable a field reconnaissance of the research area
2) Mapping of forest stands due to characteristics such as vegetation type, site conditions and management type
3) Assignment of services and expectations towards the forest
4) A comprehensive inventory of representative forest stands to obtain specific key values, and therefore allow an assessment of service provisioning.
5) Verification of the assessed services
6) Comparison of demand and supply of services
7) Suggestion of silvicultural measures to accommodate the forest services

2 Research area

2.1 Location

The Estancia Santa Lucia is located in the region Los Rios, province of Neuquen in northern Patagonia, Argentina. The geographic coordinates are S 42°23’ and W 71°16’. The Estancia is located at altitudes from 900 to 1750 meters.

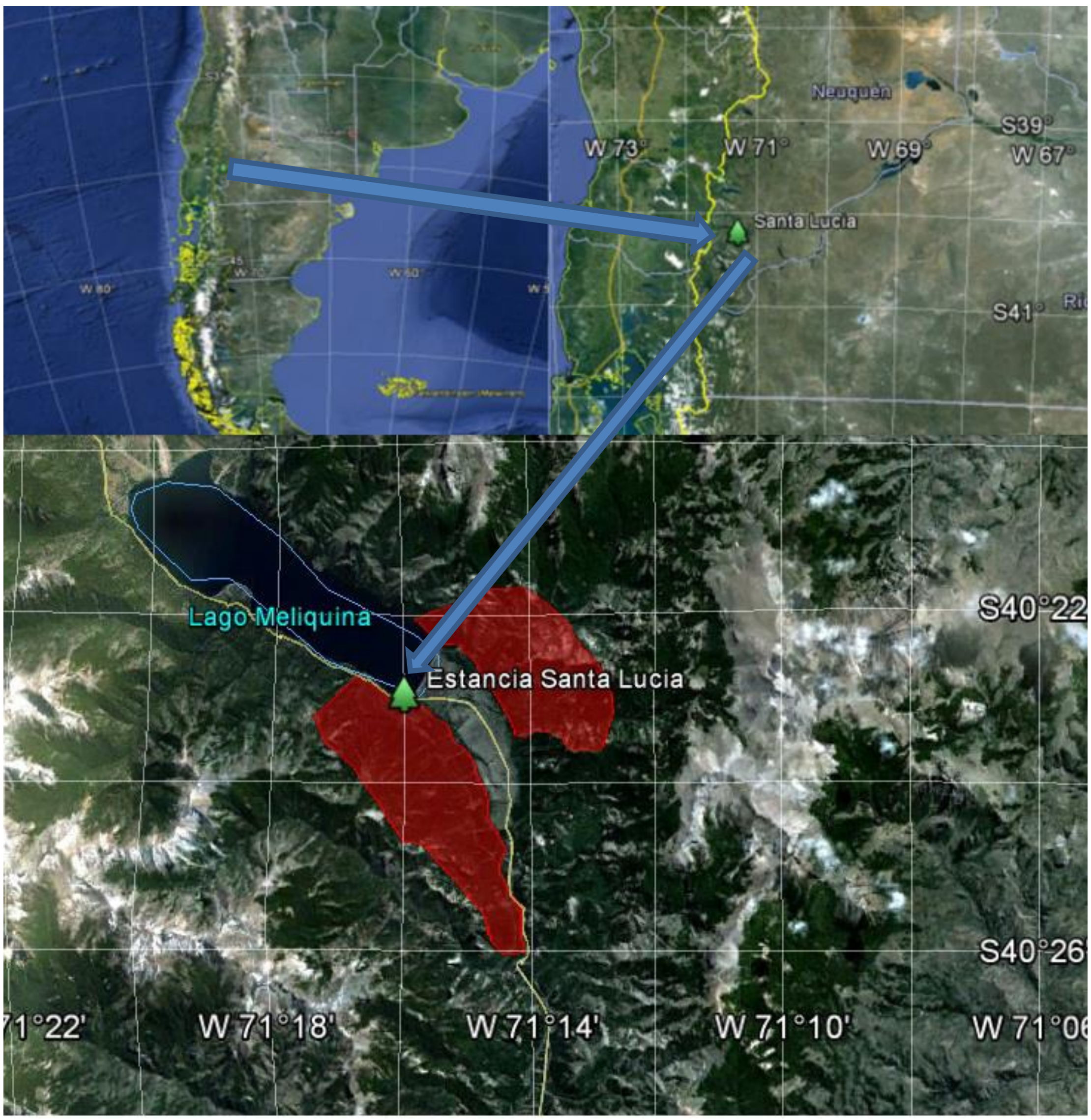


Figure 1: Location of Estancia Santa Lucia (Google Inc.: Google Earth v.7.1.2.2041, 10/7/2013)

The extends of the estancia cover main parts of both hillsides in the Meliquina valley, with a size of approximately 9000 ha, whereas the study area covers about 2000 ha.

The south west part of the Estancia is situated in the National Park Lanin and therefore underlies special regulations. The estancia is divided by the provincial route 63 and the Meliquina valley. The neighboring Estancias are Mil Rosas, Quechuquina, Lemu Cuyen and San Jorge where the last two are also involved in forestry.

2.2 Geology and geomorphology

The region is characterized by the presence of the Andes, which emerged due to pressure of the Pacific Platte after the tertiary. Former glacier meltdown is responsible for the majority of the numerous lakes and rivers in the zone. The lake and valley are formed by glaciers and therefore have a typical U-shape. The north south exposition of the Andes affects the meteorological conditions, leading to an aridity gradient from west to east (cf. meteorological conditions). The study area is situated in the "Cordillera Neuquina", close to the volcanos Lanin and Tronador, which have a big influence to the pedogenesis. Weathering has led to the formation of allophanic clays, which show high water retention potential. The top soil coverage itself is predetermined by volcanic sediments, where Andosols are the only soil type in the study area (see Figure 2). Andosols are dark, fertile and acid soils with good rootability and water storage capability (FAO SOIL).

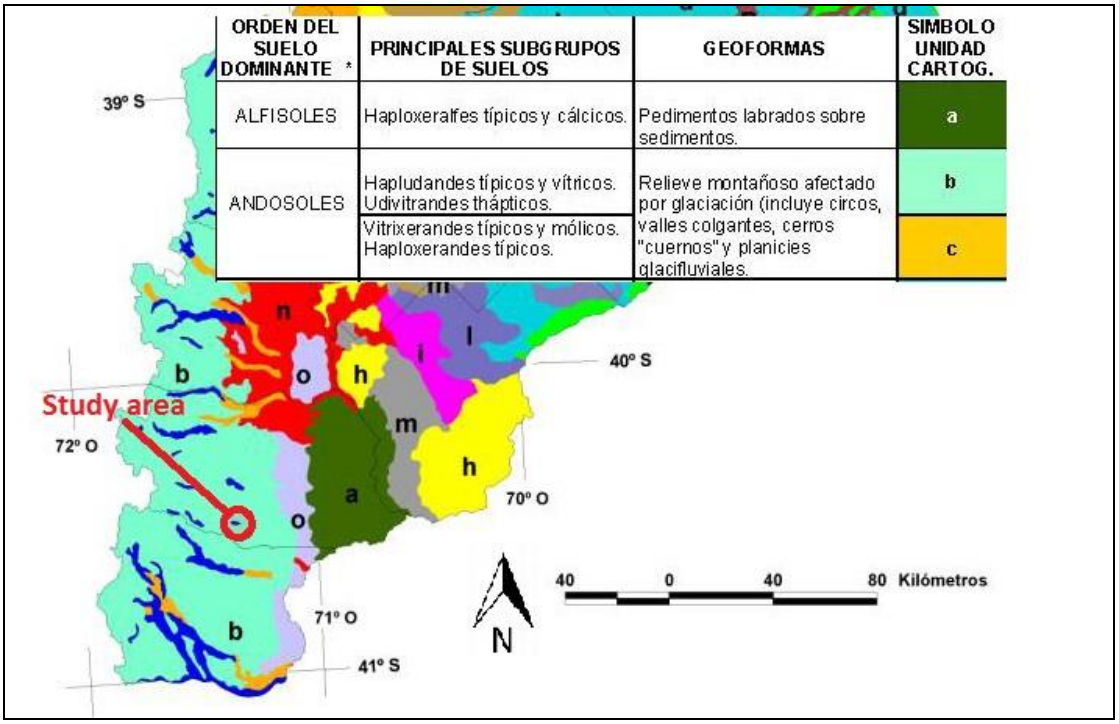


Figure 2: Extract of geological map of Neuquén (INTA, 2011)

2.3 Meteorological conditions

The meteorological conditions in Patagonia are driven by various processes. The two high pressure areas in the Atlantic and Pacific Ocean, the Sub-Polar-Low Pressure Zone and the Innertropical Convergence Zone (ITCZ) as the Andes, which are mainly responsible for the spatial distribution of precipitation on their east side. The annual distribution of precipitation is driven by the moving anticyclones, where higher temperatures over the ocean during the winter months cause a low pressure area and therefore lead to higher precipitation intensity (see Figure 3). The Andes, running in N-S direction, present a great barrier which results in a significant decrease of precipitation from east to west, this phenomena can be observed comparing the meteorological stations of Osorno and San Carlos de Bariloche. The climate in the research area is characterized by dry, warm summers followed by mild, moist winters.

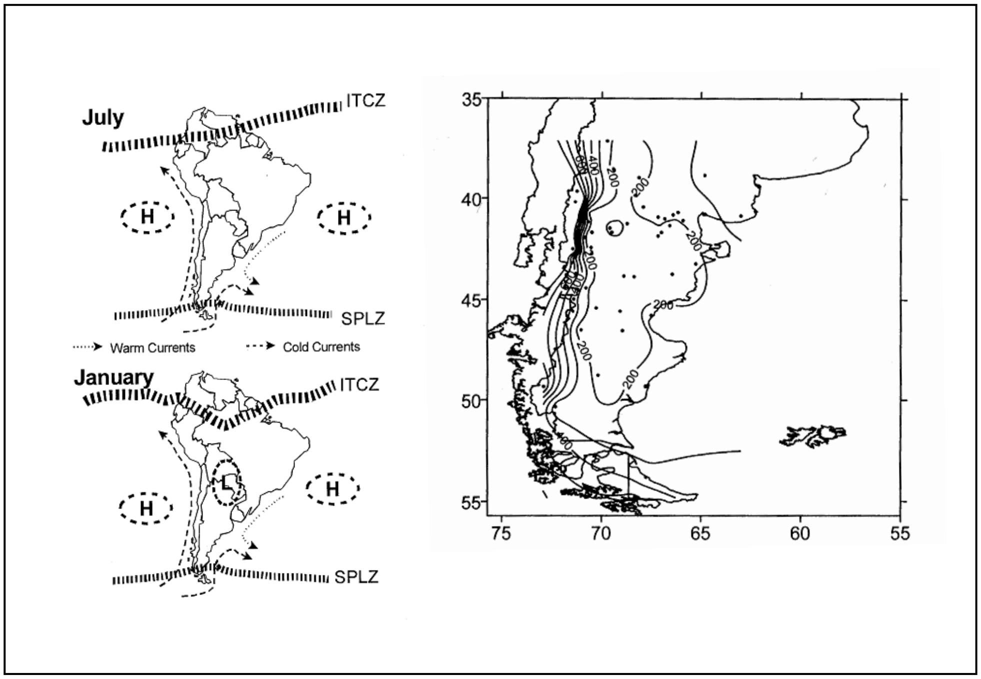


Figure 3: Pressure areas and isohypes over Patagonia (Paruelo et al. 1998)

As there is no official meteorological station in the research area, the data has been interpolated using the FAO CLim2 software. This software allows the display of specific meteorological data for certain coordinates, by interpolating the data of the nearest stations. For this study, the stations of San Carlos de Bariloche and Junin de los Andes where chosen as references because of their geographic vicinity. The figures 5 and 6 show the annual distribution of temperature and precipitation in Argentina and further in Neuquen. The pattern is characterized, as already mentioned above, by warm dry summers followed by mild moist winters.

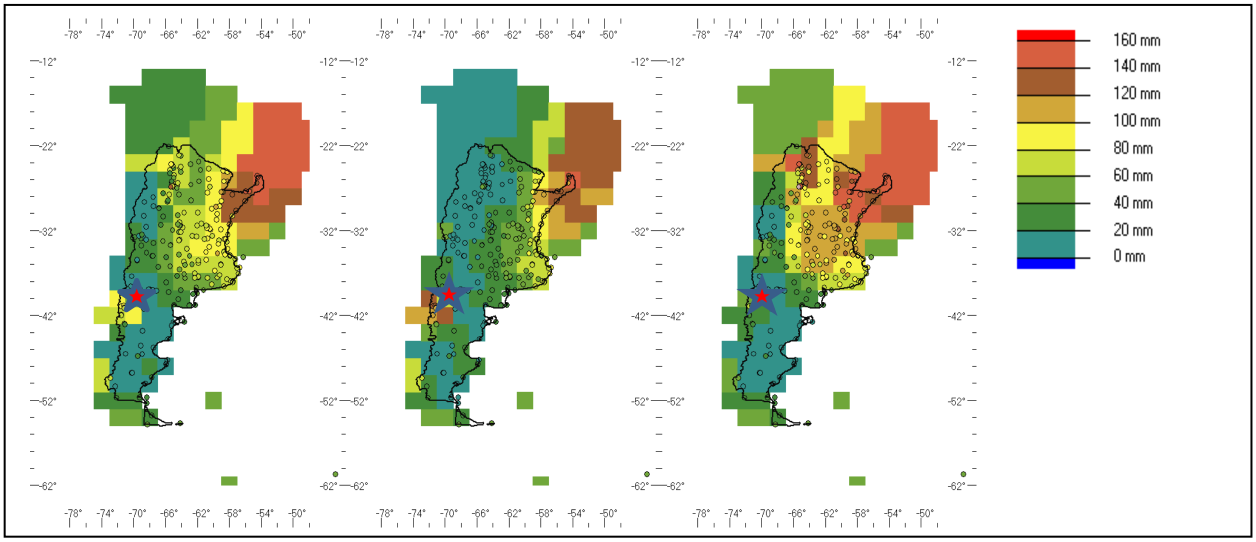


Figure 4: Distribution of stations and precipitation in Argentina, a) annual mean precipitation, b) precipitation in dormant period (April – September) and c) precipitation in vegetation period (FAOCLIM 2 v.2.02)

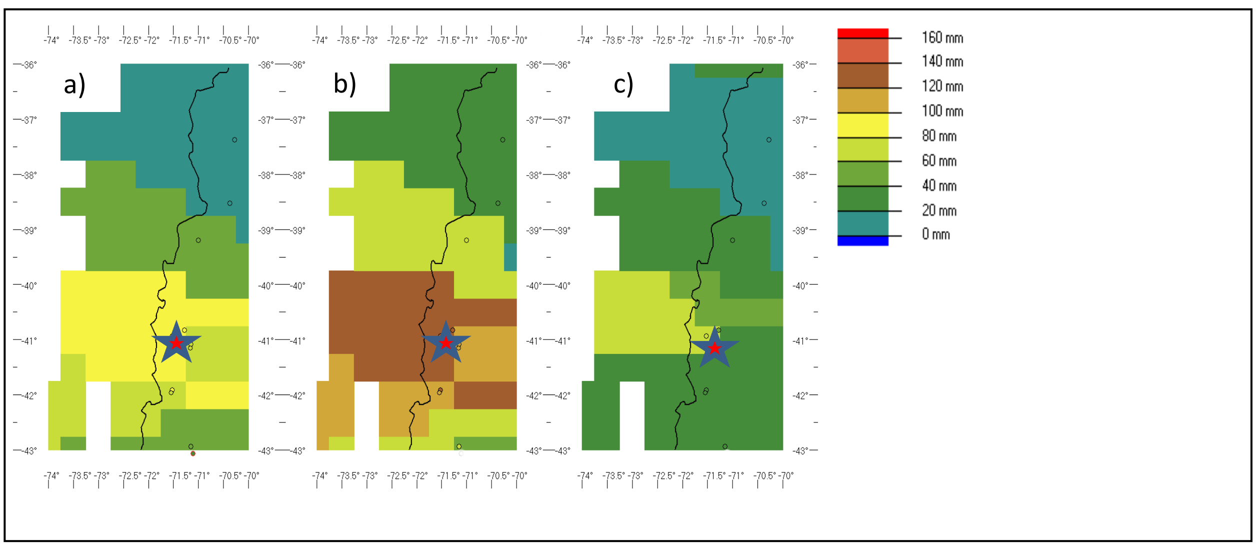


Figure 5: Distribution of precipitation in the research area a) annual mean precipitation, b) precipitation in dormant period (April – September) and c) precipitation in vegetation period (October-March) (FAOCLIM 2 v.2.02)

Table 1: Monthly Precipitation and potential evapotranspiration in Estancia Santa Lucia as interpolated from stations in San Carlos de Bariloche and Junin de los Andes (FAOCLIM 2 v.2.02)

	Best Estimate	Low Estimate	High Estimate	Standard Error
Prec	[mm]	[mm]	[mm]	[mm]
January	29	24,10	33,90	4,90
February	36	26,20	45,80	9,80
March	61	43,04	78,96	17,96
April	75	59,48	80,52	15,52
May	144	36,22	251,78	107,78
June	202	45,23	358,77	156,77
July	169	104,50	233,50	64,50
August	131	46,08	215,92	84,92
September	78	19,21	136,79	58,79
October	44	3,17	84,83	40,83
November	46	22,32	69,68	23,68
December	44	35,84	52,16	8,16
Mean	88,25	38,78	137,72	49,47

	Best Estimate	Low Estimate	High Estimate	Standard Error
PET	[mm]	[mm]	[mm]	[mm]
January	158,3	152,24	164,36	6,06
February	119	116,35	121,66	2,65
March	94	89,9	98,1	4,1
April	59,7	52,56	66,84	7,14
May	30,7	29	32,4	1,7
June	22,9	20,02	25,78	2,88
July	25	21,67	28,33	3,33
August	31,9	27,37	36,43	4,53
September	52,4	48,54	56,26	3,86
October	88,2	82,05	94,35	6,15
November	108,9	108,24	109,56	0,66
December	133,4	131,32	135,48	2,08
Mean	77,03	73,27	80,8	3,76

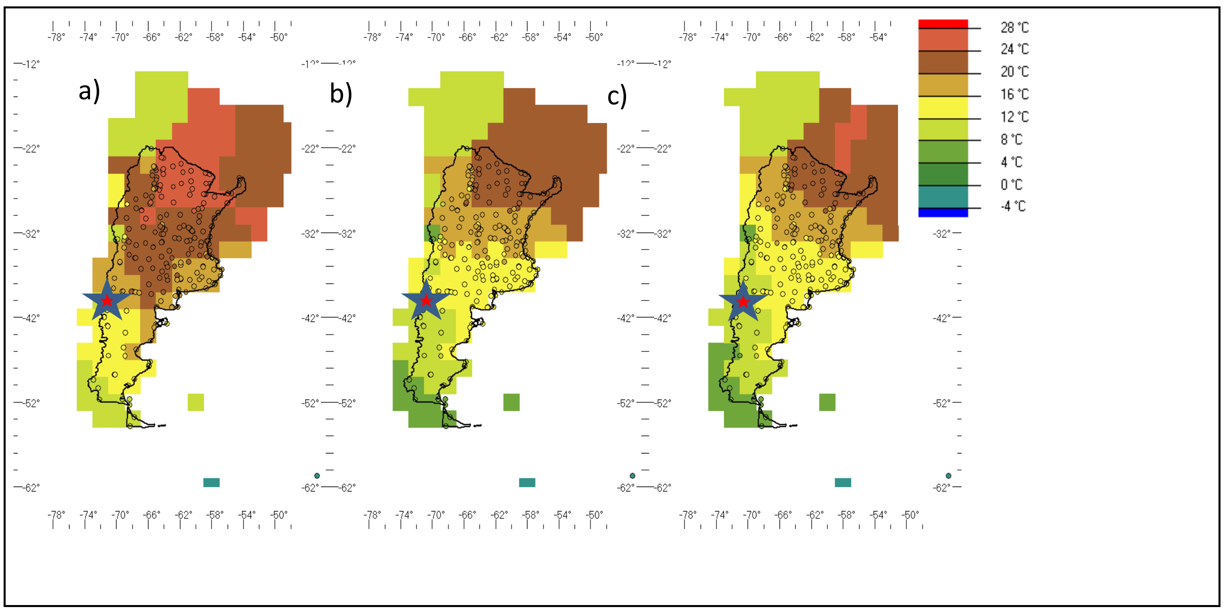


Figure 6:Distribution of temperature in Argentina, a) annual mean temperature, b) temperature in dormant period (April – September) and c) temperature in vegetation period (October-March) (FAOCLIM 2 v.2.02)

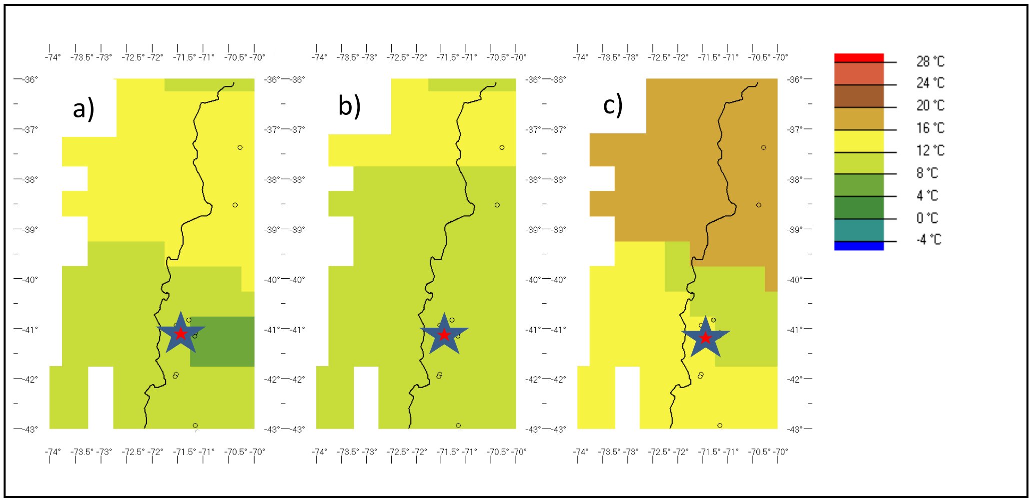


Figure 7:Distribution of temperature in research area, a) annual mean temperature, b) temperature in dormant period (April – September) and c) temperature in vegetation period (October-March) (FAOCLIM 2 v.2.02)

2.4 Forest history and history of estancia

2.4.1 History of the region

The conquest of Patagonia started about 1300 years ago with the Perehuences, a Mapuche tribe. Their impact on forests was small due to their low population density and nomadic way of life. Forests were mainly used for hunting purposes since agriculture and cattle farming were not practiced, a condition that should last for the next 500 years. The crucial impact on forests started around 1850 when natives and immigrants settled down. Forests provided material for the construction of houses, fences, bridges as well as heating. Nevertheless, the main decrease of forested area began with the livestock farming. In order to obtain more pasture areas, vast stretches of timber were burned. After the pastures were grazed, the areas were left to their own, leading to erosion surfaces which still cover a great part of the region. With sinking profitability of cattle farming in the region, new income sources have been discovered. On the one hand forestry, where it still lacks on popularity because of the long return on investment period and on the other hand tourism, which not only promises faster revenues but also imposes new expectations towards nature and the forests

2.4.2 History Estancia

As already mentioned, a wide tract of land was degraded due to extensive human caused forest fires, which also affected the areas of the estancia. The Meliquina valley is surrounded by afforested estancias Estancia Santa Lucia being the largest. It was one of the first private enterprises which invested in afforestations and a sustainable infrastructure, as houses and schools. Afforestations in Estancia Santa Lucia started in 1978, pursuing the goal to establish coherent wooded areas and a sustainable forestry. Different pine species where planted (cf. 2.6.2), unfortunately no accurate records of the provenance plant material exist, only the North - American origin is confirmed. While plantations continued at a regular basis over the years, planting a forest with the size of ca. 9000 ha, a plant nursery was established in 1992, and amplified in 1998. About 800.000 to 1.300.000 plants are sold per year and used for afforestations in neighboring estancias.

Until the year 2000 the afforestations were subsidized by the Argentinian government, afterwards new solutions for the funding had to be found. The idea was to create the production sequence from seedlings to the wooden board. A sawmill, that was built by the association Meliquina S.A., in the years 1998-2001, should have been the solution towards the funding, but it had to be closed due to the economic crisis in Argentina in 2001. Now in 2013 the nursery is the main income source for the estancia, as the economic situation in Argentina is still not stable. The current management activities in the forests are limited to pruning and low thinning.

2.5 Village

The Melliquina Village is located in the basin of the valley, between both sides of the estancia. The terrains in the valley were originally owned by one family, who divided the land into lots in 1977 and is selling them since then. The provincial route 63 an important connection between San Martin de los Andes and San Carlos de Bariloche, the two important touristic centers in the Region, crosses the valley. The route from San Martin de los Andes to the Meliquina Lake, a former gravel road, was paved to almost 13 km near to the valley in 1998. Due to the better traffic connection an increase of settlements has been triggered. Also, the financial collapse in Argentina in 2001 had a great impact on the influx of people in the region, meaning that people left the unsecure cities and chose to live in the countryside (Pizzolito, 2006). Figure 8 shows the population growth in the region. By now 30 families live in the village and 250 houses have been built, both with an increasing trend (cf. Figure 9)

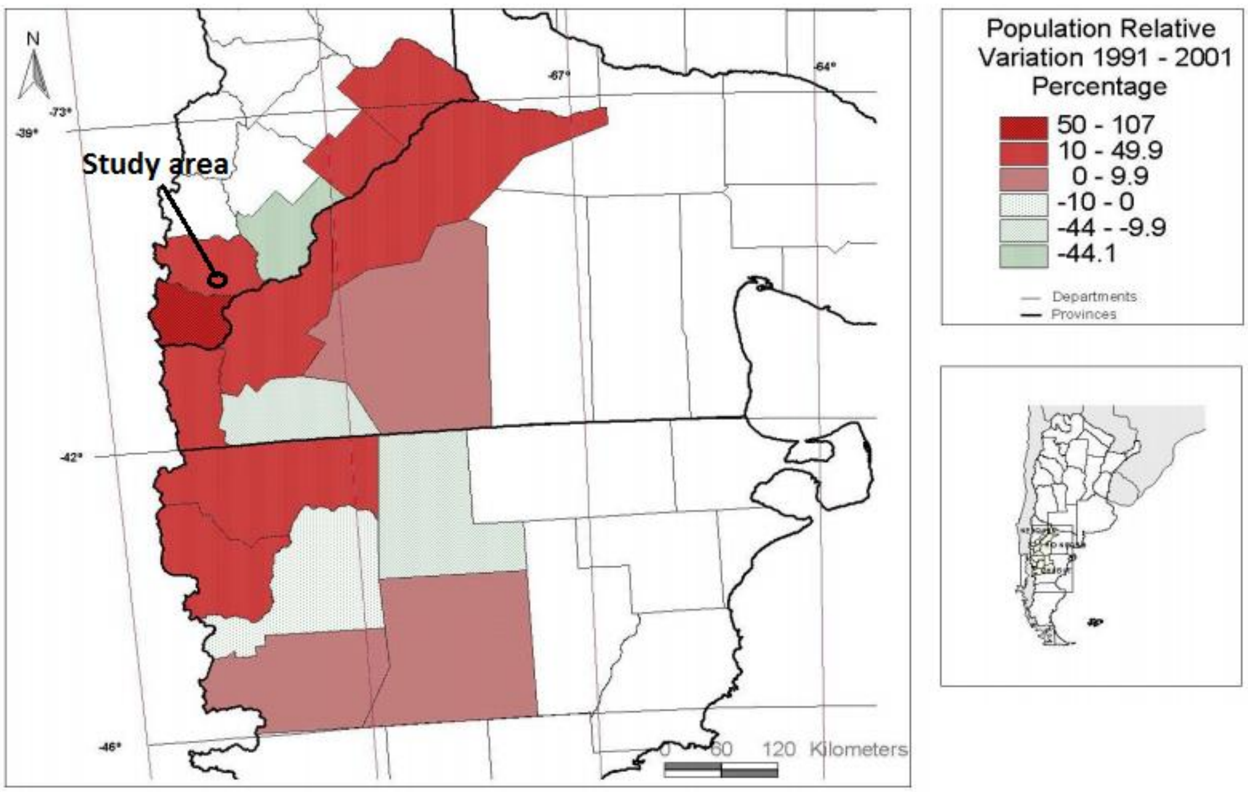


Figure 8: Population relative variation in the study area (Olga et al., 2011)

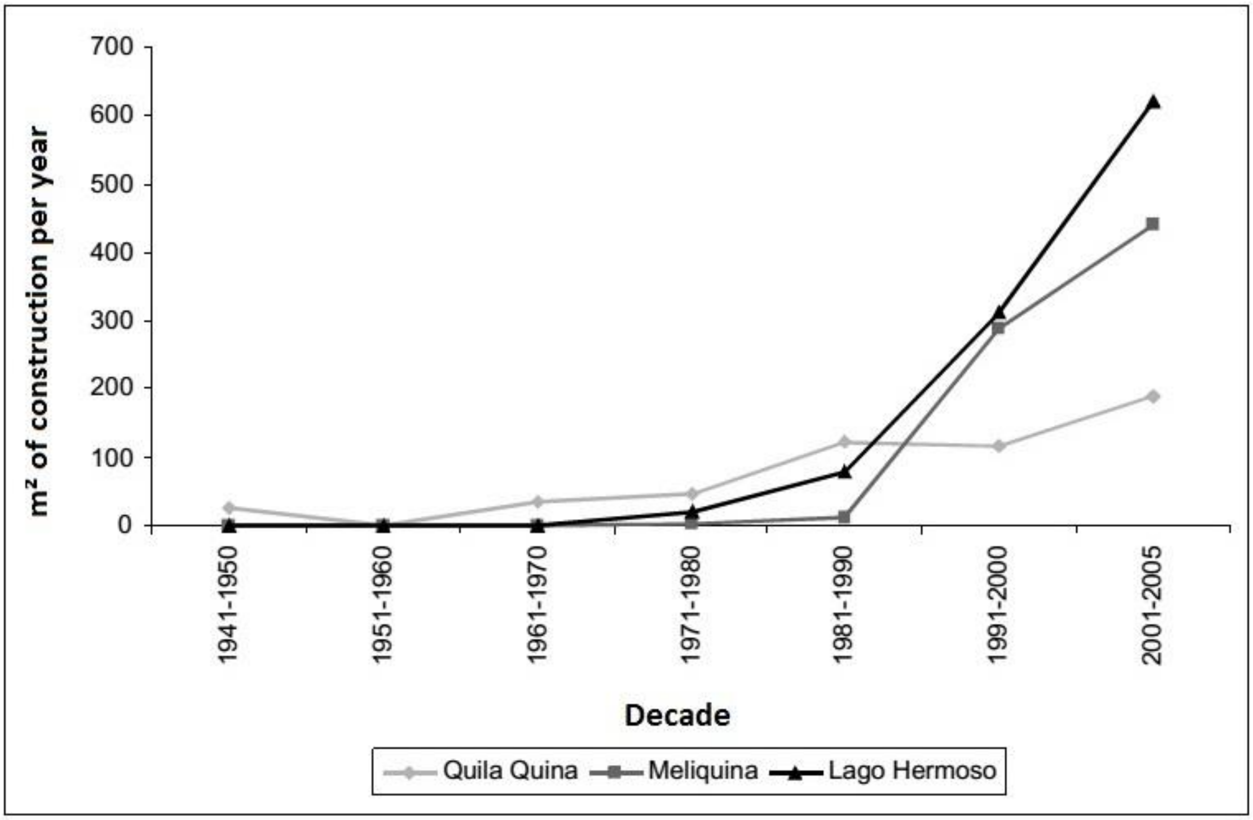


Figure 9: Increment of development in the study area (Funes et al., 2006)

2.6 Vegetation

The vegetation in the region has to be distinguished regarding two types, the natural forest and the afforested forest.

2.6.1 Natural forest

The main vegetation type in the region is the Andino-Patagonian forest, where both, deciduous and evergreen tree species are found. Depending on the altitude different vegetation types resp. forest communities can be found. The naturally occurring species (potential natural vegetation) and resulting forest communities in the study area can be described as follows:

Tree species:

(1) Nothofagus pumilio (deciduous)
(2) Nothofagus dombeyii (evergreen)

(3) Austrocedrus chilensis (evergreen)

The typical scrubs, which cover parts of the Estancia Santa Lucia are:

(1) Nothofagus antarctica
(2) Lomatia hirsuta
(3) Maytenus boaria
(4) Schinus patagonicus (laura)

The pastures in the down slope areas are composed of a few grass species:

(1) Stipa speciosa
(2) Mulinum spinosum
(3) Discaria articulata

Three different natural forest communities can be determined in the study area. In the downer slopes Austrocedrus chilensis dominates, where it can also appear in form of a mosaic with Nothofagus antartica, Mulinum spinosum, Discaria articulate and Stipa speciosa. Also the combination of Austrocedrus chilensis with Lomatia hirsuta can be counted among the typical forest communities in the zone. Wandering uphill Nothofagus pumilio forests in combination with Nothofagus antartica on the more exposed sites are dominant. The other species can be found occasional within the aforementioned communities. Figure 10 shows the actual forest distribution within the national park and the SW-side of the Estancia.

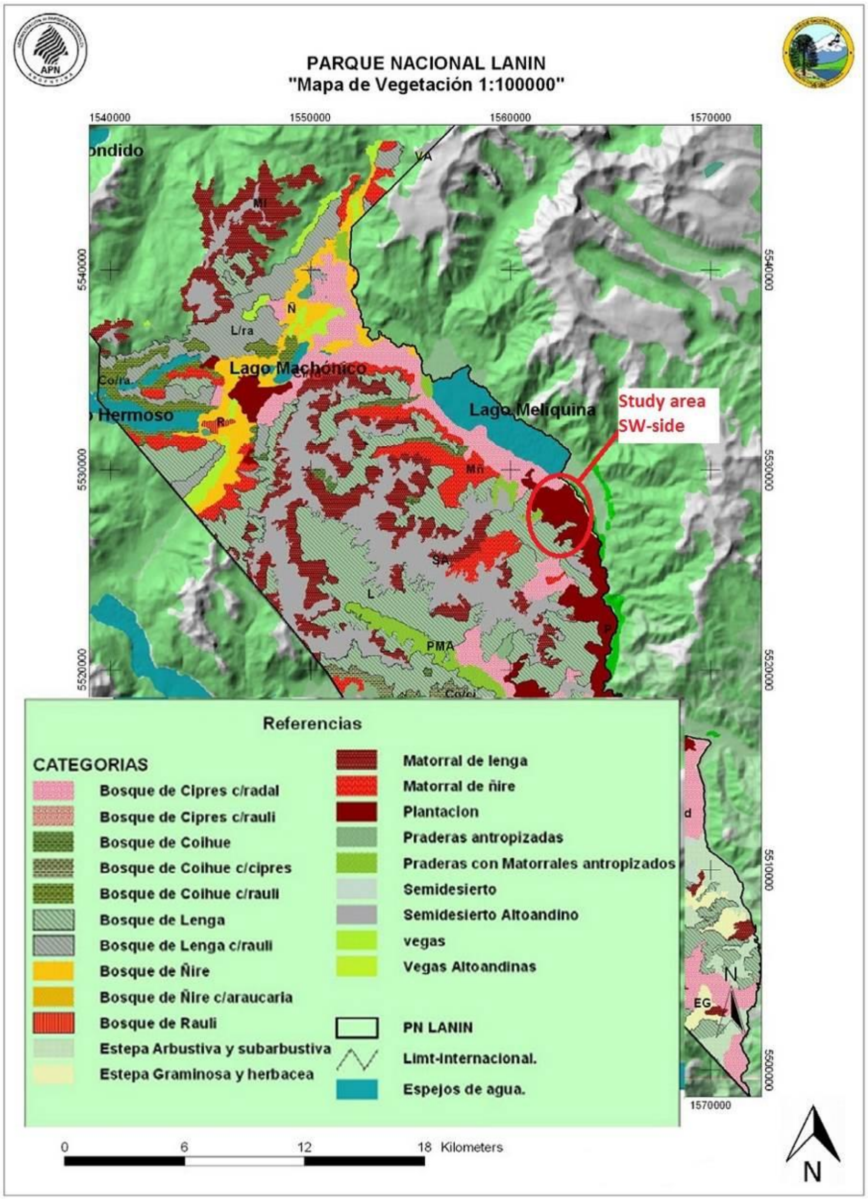


Figure 10: Vegetation map of National Park Lanin in Meliquina valley (Zonificacion Parque Nacional Lanin, 2010)

2.6.2 Afforestations

The first plantations in the zone were established in the mid-1970s testing different plant material. The most successful and promising species were pine species, such as:

(1) Pinus ponderosa
(2) Pinus jeffreyi
(3) Pinus contorta

(4) Pseudotsuga menziesii

Unfortunately no exact records exist concerning the provenances of the used plant material. The only information concerning the first afforestations in 1978, are the northwest American origin of the seeds. The species were chosen due to the similar meteorological conditions in both regions and the successful trials within the first plantations. The main part of the estancia is afforested with Ponderosa pine, followed by Pinus contorta and Pinus jeffreyi. Due to the fact that there was no experience with exotic plant material at the time, the species selection was carried out randomly in the first years. Afforestations in the last decade have been conducted with Pinus oregon. According to the enterprise manager, the growth rate and timber quality outperform those of the other pine species. As already mentioned in chapter 2.4, there is no long forestry tradition in terms of a good infrastructure, sawmills, trade usages or yield tables. Due to the fact that the average age of the forest stands in the estancia is 28 years, the rotation period has not been achieved (50-60 years are aimed) and therefore a lack of experience exists when it comes to possible tree dimensions, prices and transport. Furthermore there are no long term studies concerning the growing behavior of Pinus species in the region.

2.6.2.1 Biotic risk factors

In the year 2008 some areas of the estancia have been infested by Sirex noctilio, a wood wasp, diminishing the wood quality and leading to a dieback of trees. The immigration of Sirex spp. in South America started in Brazil, Chile and Uruguay leading to the first occurrences in Argentina documented in 1985 (Corley et al. 2012). The wasp mainly attacks pine afforestations in the region of Rio Negro, in the estancia, only forest stands with Pinus contorta as main species were affected. Figure 11 shows the infested stand SW-29 of the estancia where all Pinus contorta trees were removed.

Figure 11: Sirex noctilio infestation in stand SW-29 of the estancia

3 Material and methods

3.1 Definition of ecosystem services

As already mentioned in the introduction, ecosystems provide various services such as provisioning-, regulating-, cultural- and supporting services. Stakeholders, in this case the enterprise, federal authorities (national park administration), the villagers in the valley, visitors and hunters have different expectations. Hence preferences on behalf of the stakeholders were assigned to different ecosystem service portfolios. To assess how well current forests support these expectations a set of indicators was generated for every individual service.

3.1.1 Provisioning services

Provisioning services can be seen as goods or products supplied by forests (MEA, 2005). In this study they are defined as industrial roundwood, fuelwood and non-timber forest products such as venison.

3.1.1.1 Roundwood

As already mentioned in chapter 2.4.2, the main goal of the estancia was to establish a sustainable forestry, meaning to use the timber resources for selling purposes. The only legal stakeholder hereby is the enterprise, whose emphasis is the production of industrial roundwood (saw logs and pulp wood). Since it states the main income source, the primary focus of the Estancia lays on a maximum wood harvest of pine species with best possible quality. The indicators used for assessment are the growing stock, site index and stem quality (see ch. 3.6.1.3)

3.1.1.2 Fuelwood

As there is no connection to the public power grid, fuel wood, for cooking and heating is an important supply for the workers families as well as the villagers in the valley. Again, the enterprise is the only legal stakeholder; nevertheless, villagers enter the estancia to collect fuelwood, causing conflicts with the estancia. No records exist on the demand and consumption of fuelwood, therefore no assessment was carried out.

3.1.1.3 Non-timber products

Venison and collecting mushrooms and fruits can be counted among the non-timber forest products, the last two being additional food and income sources for the villagers; nevertheless they are not taken into consideration in this work. Hunting on the other side, is an important factor for the estancia, as it holds the hunting rights and hence provides an additional source of revenue. The estancia offers guided hunting trips, where red deer, puma and boar are the huntable species, deer being the most important. Two different interests are pursued in this case; on the one hand, the establishment of a sustainable game population, requiring good habitat conditions, and on the other hand adequate hunting sites, allowing the harvest of game. Red deer can be seen as a migratory animal, which, depending on the season, can roam up to 100km (Reimoser, 2006). Concerning their habitat, they require a combination of open meadows for foraging and woodlands for cover and calving. According to the local manager, some herds remain or at least return to the grounds of the estancia. Figure 12 illustrates the main factors influencing the habitat quality.

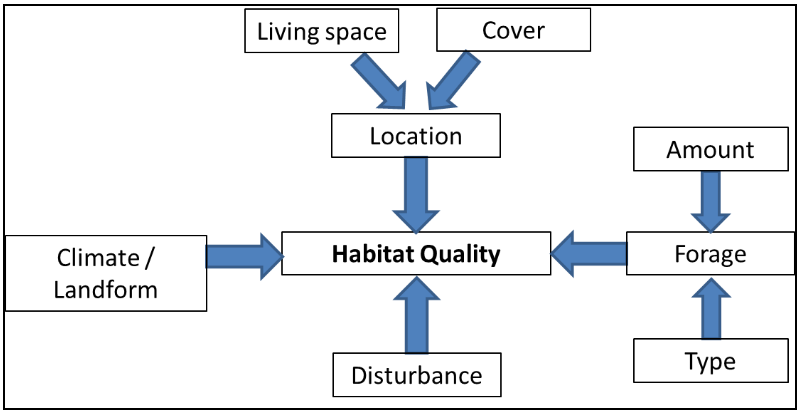


Figure 12: Factors influencing the habitat quality (cf. Reimoser, 2006)

Concerning the aspects of habitat quality, such as location and forage, the development stages were used as indicators (cf. Ch. 3.5.6). The location can be sub divided into living space and cover. Living space can be seen as refuges, which includes features as mobility and a good outlook, mainly found in open spaces and sparse forest stands. The cover from predators and adverse weather requires vertically structured forests with thickets and/or an additional high canopy cover for protection against snow, heat, frostiness and rain. Concerning the forage, red deer can be seen as an intermediate type of consumer, between roughage consumer and selective browser. While in summer its food consists of grass, forbs and herbaceous plants, in winter, grass, shrubs, sprouts and leaves dominate. Witmer et al. (1985) described that deer prefers sites near to cover-forage areas, whereby cover always is more important. Stalking deer is the hunting practice carried out in the estancia; therefore the accessibility of the hunting sites and the visibility are crucial and can be assessed in terms of infrastructure and topography. The increasing settlement activities in the valley have arisen some conflicts with the estancia management. The valley that used to be a game pass between both sides of the estancia is now cut off, restricting the habitat of red deer. Additionally, trespassing and poaching can complicate the implementation of a sustainable and profitable hunt. According to the local manager, not only the hunting sites have wandered uphill but also the natural pass used by game in the valley is no longer existent as a consequence from the disturbance caused by the villagers in the valley.

3.1.2 Regulating services

Regulating services can be seen as services, which result from regulation of ecological processes (MEA, 2003). In this study regulating services consist of protective services, which again are linked to mass wasting processes, such as fluvial, debris flow like, sliding and falling processes. Figure 13 illustrates the classification of mass wasting processes according to Phillips and Davies (1999).

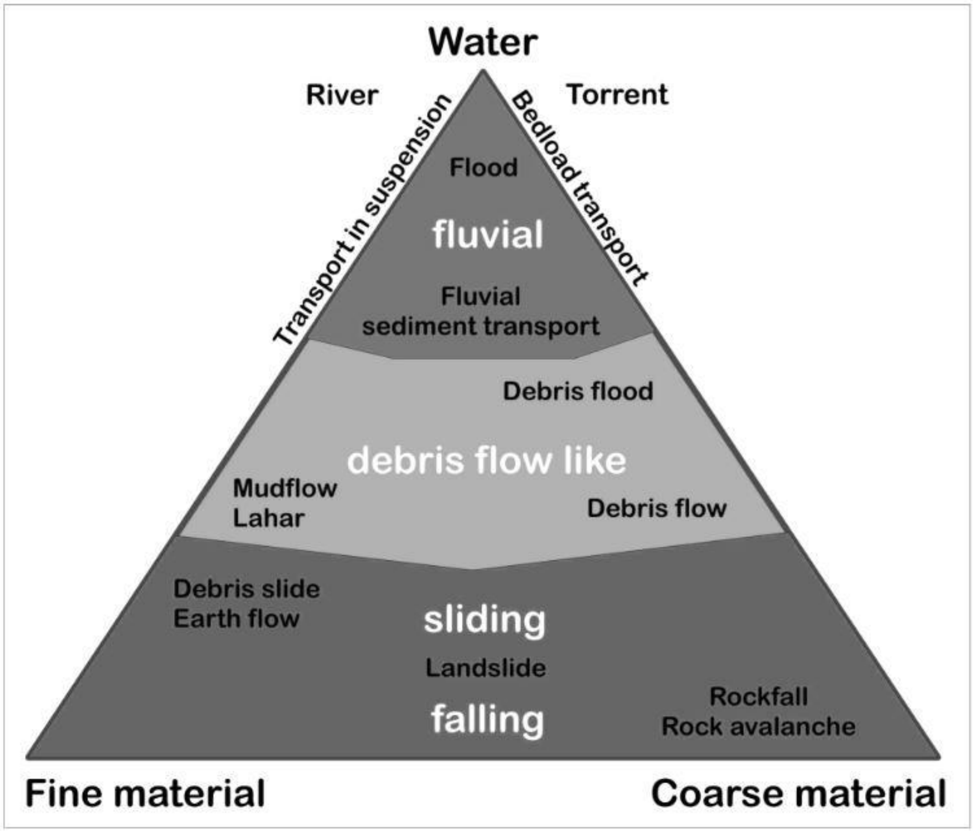


Figure 13: Mass wasting processes (Phillips and Davies, 1999)

Further on the main processes, flood, debris flow (erosion) and rock fall, identified in this work shall be presented

3.1.2.1 Torrential Processes and erosion

In torrent catchments different types of mass wasting processes can occur. They can be classified in fluvial, debris flow like, sliding and falling (ONR 24800). In Austria, for instance, torrential processes are classified in a norm for mitigation measures in torrents (ONR 24800). Four groups of processes in confined channels exist: Water Flood (WFL), Fluvial Sediment Transport (FST), Debris Flood (DFL) and Debris Flow (DF). Water flood is defined as a higher runoff than the average one, transporting only suspended load. The magnitude and frequency of floods and erosion can be diminished by forests since they have a great influence on the hydrologic cycle due to interception, evapotranspiration and root transpiration (Chang, 2003).

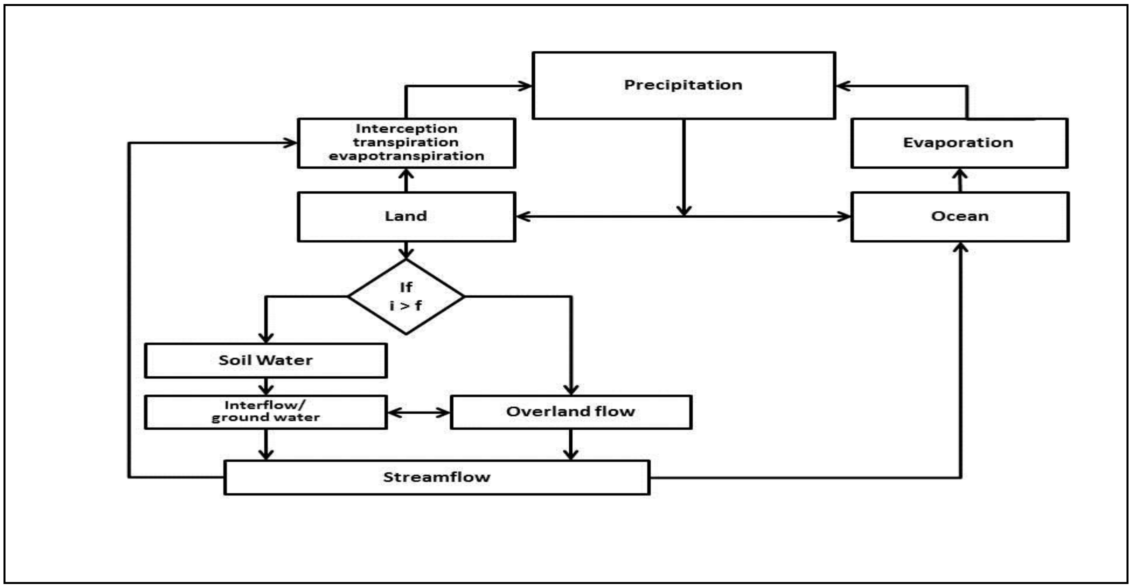


Figure 14: Hydrologic cycle after Chang (2003)

Studies have shown that forests can be seen as the best natural cover for flood prevention and hence are an important tool in flood control (MEA 2005). The benefit gained from flood control through forest management in the study area, is the protection of houses and people living in the valley. Two torrents (Arroyo Pino and Arroyo Maria) stream directly from the NE-side of the estancia to the village in the valley (cf. Figure 21 and Figure 22), making the villagers in the valley the stakeholders with the highest interest on the NE side. In the SW side another important facility is affected - the drinking water supply of the estancia, a basin fed from a small torrent and located at the out of the valley in the south west border of the estancia (cf. Figure 20). A fourth channel which only is perennial in the spring time is situated in the SW side of the estancia. On this side the enterprise is the main stakeholder.

Erosion can be defined as baring of loose material due to water and wind (Frehner et al., 2005). This can lead to further degradation and continuative to landslides and an aggravation of the hydrologic balance in the soil (Chang, 2012). As can be seen in the pictures (Figure 15) erosion is the main degradation process in unstocked areas in the Estancia Santa Lucia. In chapter 2.4.1 it was already mentioned that the primal forest, a substantial part of the estancia, was cleared due to animal farming. Therefore premises for extensive erosion were set (Broquen et al., 2003).

Figure 15: Erosion areas in Estancia Santa Lucia

Experiments have shown that forests are capable of retaining up to 70 % of the precipitation due to interception and evapotranspiration (Markart, 2013). The influence of the root system on the slope stability, solidifying and reinforcing the endangered soil horizons is also of importance is (Rickli, 2004). The afforestations therefore have a dampening effect on the velocity and magnitude of erosion, curbing the impact of winds, overland flow and precipitation. In this section the erosion process is broken down to two main areas, the source and the infiltration area. The Estancia can be seen as the main stakeholder concerning the expectaion of erosion protection.

Since erosion is strongly inked to torrential processes and the requirements to the forest for stabilization are similar the two services were merged. Taking into account that interception, evapotranspiration and root transpiration are the processes responsible for the amount of water available for ground flow, overland flow and eventually stream flow, land coverage and soil conditions were used as indicators to assess the flood - and erosion protection capacity.

3.1.2.2 Rock fall protection

According to Frehner et al. (2005) rock fall can be seen as the movement of falling rocks and their interaction with the surrounding environment. The landslide handbook describes rock fall as an abrupt downward movement of rock or/and earth, that detaches from steep slopes or cliffs (Highland and Bobrowsky, 2008). Figure 16 shows a few examples of detached rock material and the contribution trees can make towards rock fall protection (upper left corner).

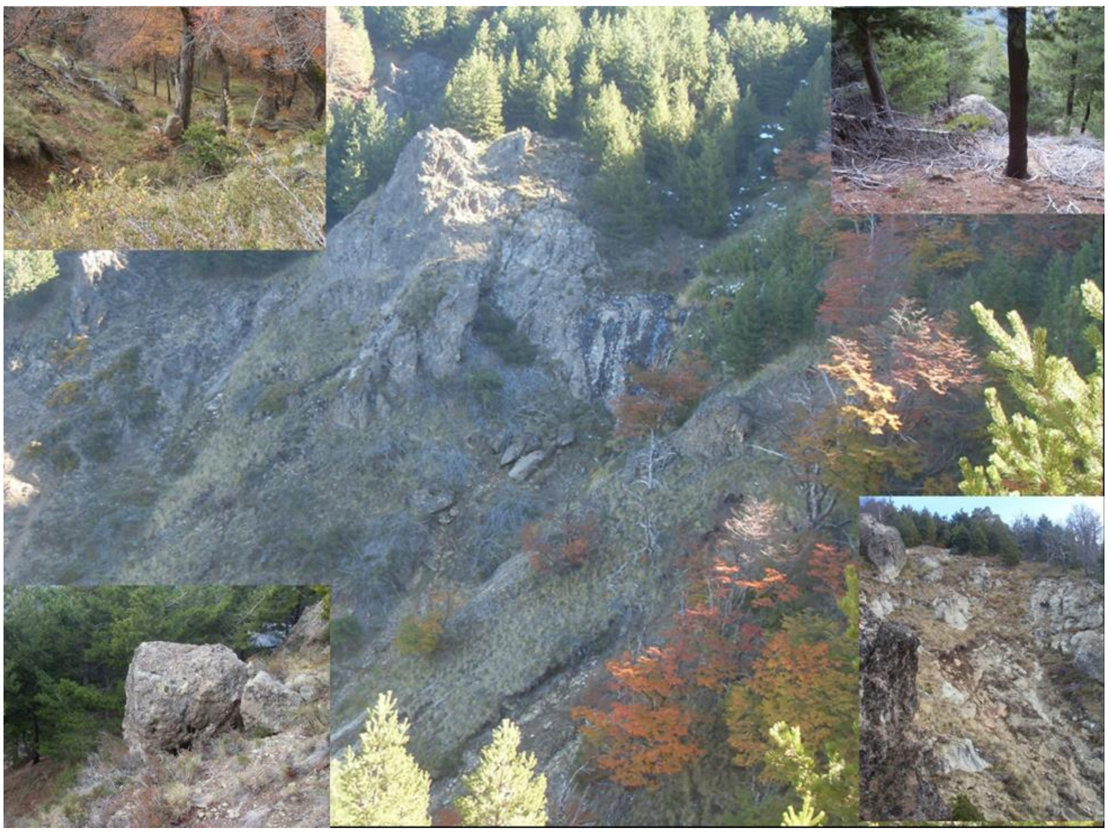


Figure 16: Examples for rock fall in Estancia Santa Lucia

Rock fall can be divided in three zones, the trigger zone, transit zone and deposition zone. Figure 17 shows the position of the zones along the slope.

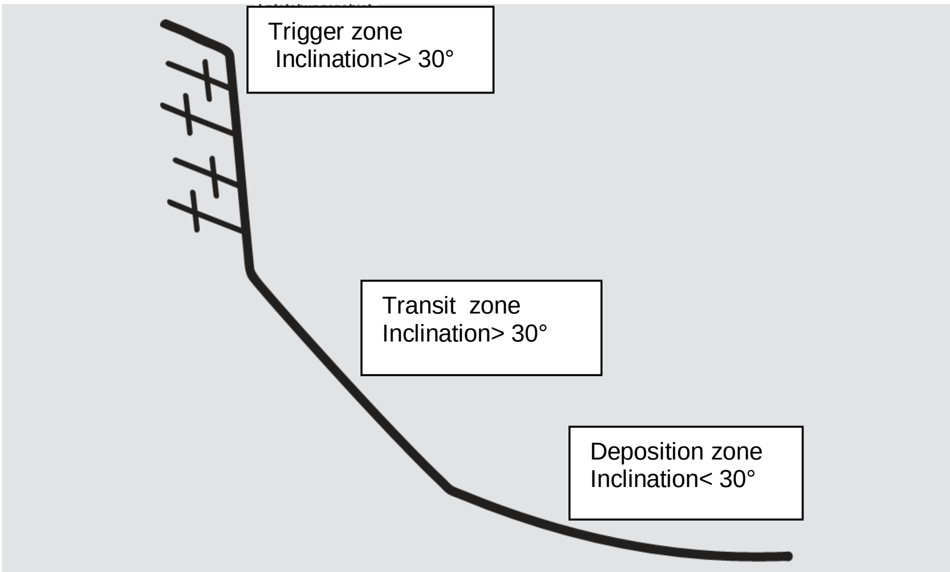


Figure 17: Zones affecting rock fall, and their critical inclination (Frehner et al., 2005)

The zones are characterized as following:

Trigger zone: Area where rocks are detached. The magnitude and frequency of rock fall is influenced by rock type, its stratification, exposition and altitude. The critical inclination is higher than 35°.

Transit zone: rocks roll or slide if the inclination reaches 30° - 35°, above this threshold rocks also can start to jump. In this zone rocks are capable to gain or lose energy depending on obstacles and topography, which can also lead to a change of direction. Rocks that have stopped still can start moving again.

Deposition zone: in this zone rocks normally stop, if no obstacles are available the can even continue moving until the inclination is < 25°.

The definition of protective effects against rock fall can be divided whether the forest site or property and infrastructure are to be protected; both were considered and treated equally in this study. Forests can make a big contribution towards rock fall protection, where stem number and especially the diameter is of crucial importance. Thin trees tend to dodge when hit by rocks whereas thick trees can break and therefore reduce the speed and energy of falling rock material. The indicators used for the assessment were, stem number per hectare, diameter at breast height, slope inclination, rock size and rock distribution. The stakeholders concerning the rock protection service are the Estancia and the village in the valley.

3.1.3 Cultural services

The Millennium Ecosystem Assessment defines cultural services as nonmaterial benefits obtained from an ecosystem such as recreation, aesthetic enjoyment, and spiritual renewal (MEA, 2005).

3.1.3.1 Recreation

The Meliquina valley and therefore the surrounding Estancia Santa Lucia are regionally known and advertised for their landscape beauty. Not only the lake, but also el "cerro de la ventana", an arc shaped rock formation within the estancia, and the natural forests attract many visitors. The Meliquina Valley lies near the "Ruta de siete lagos", a scenic road along seven lakes, allowing short trips to the area. Since cottages, in the estancia and valley, are available for rent and tourists often stay for several days, where the duration of stay varies. People visiting the valley come for many purposes like, trekking, biking, swimming, fishing and hunting, to name a few. Also a variety of restaurants have opened which attract day visitors. For both, the estancia and the village, visitors state an additional source of income. Since no survey has been made on the recreational activities, no data on frequency and duration of tourists is available. Due to the resulting lack of information no assessment of recreational service was carried out.

3.2 Nature conservation

Nature conservation, although not being a service, was also assessed and based on the tree species composition. As mentioned in chapter 2.4 the native forest was cleared in large parts of the region and the areas are now covered by plantations with exotic plant material. Since the SW-side of the Estancia Santa Lucia is located in a national reserve of the national park Lanin (see Figure 18) the national park administration (NPA) has expectations concerning the forest management. National Reserves are areas devoted to the conservation of ecological systems, maintenance of buffer zones to the adjacent National Park, or the creation of independent conservation areas, where the situation does not require or admit the scheme of a National Park (art 9, LEY N° 22.351). Due to the fact that pine forests are not adequate for native flora and fauna, the main interest is to prevent expansion of the exotic plant material and to restore the native vegetation (Plan de manejo Parque Nacional Lanin, 1997). Therefore the NPA exercises the following activities:

(i) Technical control and monitoring of compliance by the owners towards the standards of protection of native forests
(ii) Supervision and control of harvested forest products
(iii) Control of logging- and plantation activities to minimize their impact on the physical environment and landscape values
(iv) Encourage reforestation with native species.

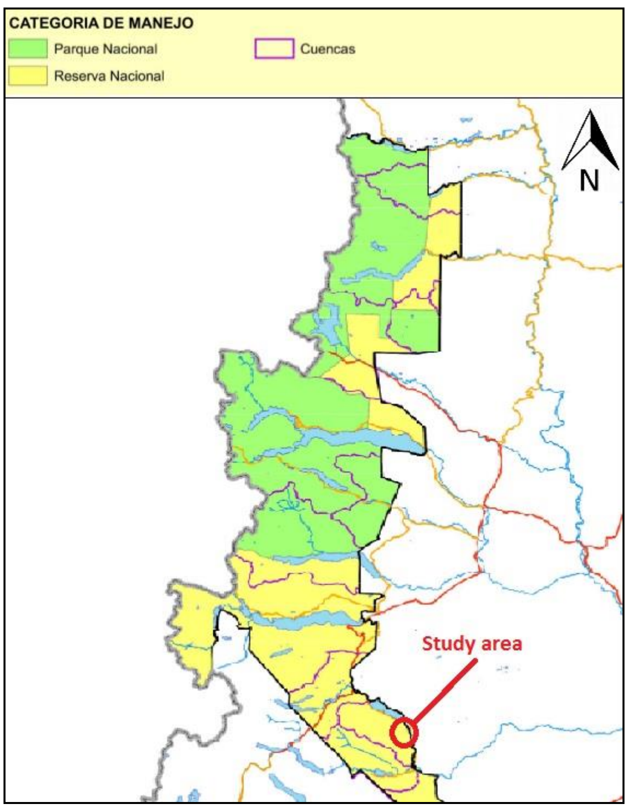


Figure 18: Location of SW-side of Estancia Santa Lucia in National Park Lanin (Zonificacion Parque Nacional Lanin, 2010)

To assess nature conservation the number of native species in the individual stands was used as indicator. The potential natural vegetation (PNV) as described in the management plan of the NPA served as reference in terms of a comparison of the current forest status with a desired forest composition. Tree species composition and regeneration served as indicator for the degree of proximity to the potential natural vegetation.

3.3 Concept of service assessment

To assess the services provided by the forest, the following intermediate steps had to be taken.

The initial situation did not allow an immediate start of the field work due to lack of working material. No forest map respectively forest inventory existed. The only available material was a hand drawn map (see Figure 19), showing a sketch of the afforested areas, and non-georeferenced aerial photos without scale.

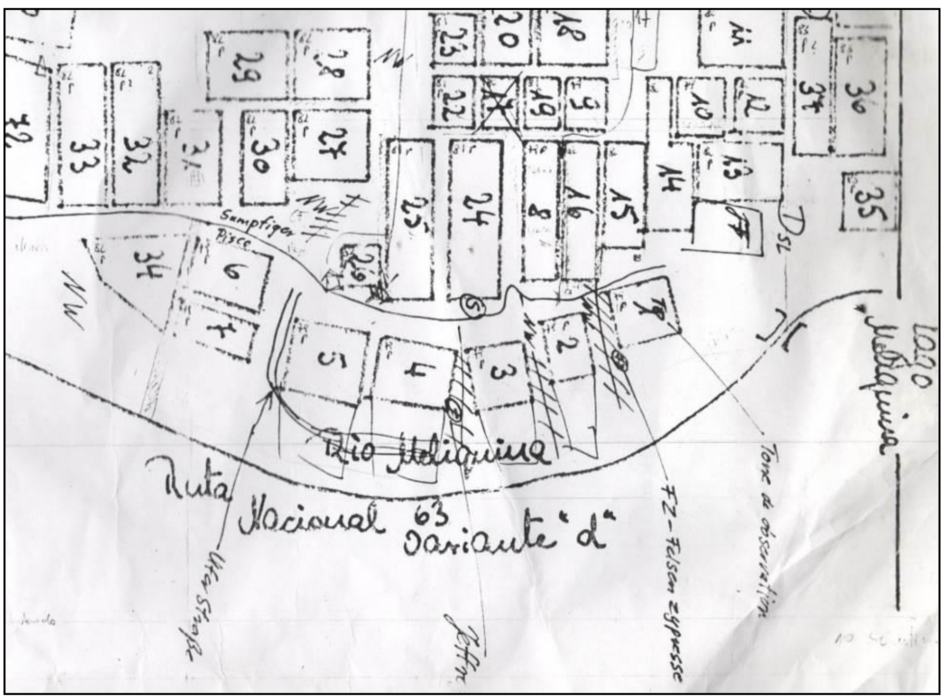


Figure 19: Hand drawn map of afforestations (Archive estancia Santa Lucia)

After arranging and digitalizing the aerial images the mapping was performed by a field reconnaissance, resulting in an identification and delineation of homogenous forest stands. These were classified according to three attributes: the altitude above sea level, the vegetation type and the management type. Having the homogenous stands defined, a matrix was developed to group similar forests stands. Representative stands from each group were chosen for further examination. The assessment of services was indicator based, where data was sampled regarding the indicators of the individual services. The collected data subsequently was compared with corresponding target values for the individual services such as existing guidelines for protective forests.

3.4 Field reconnaissance

The field reconnaissance was the first step taken to obtain an overview of the existing forest stands and site conditions. The main goal was to identify homogenous forest stands and hence derive stand polygons. These stands served as a basis for the assignment of services and further analysis, assessments and eventual silvicultural recommendations. The interim results of the field reconnaissance were maps displaying the polygons (see Figure 20, Figure 21 and Figure 22).

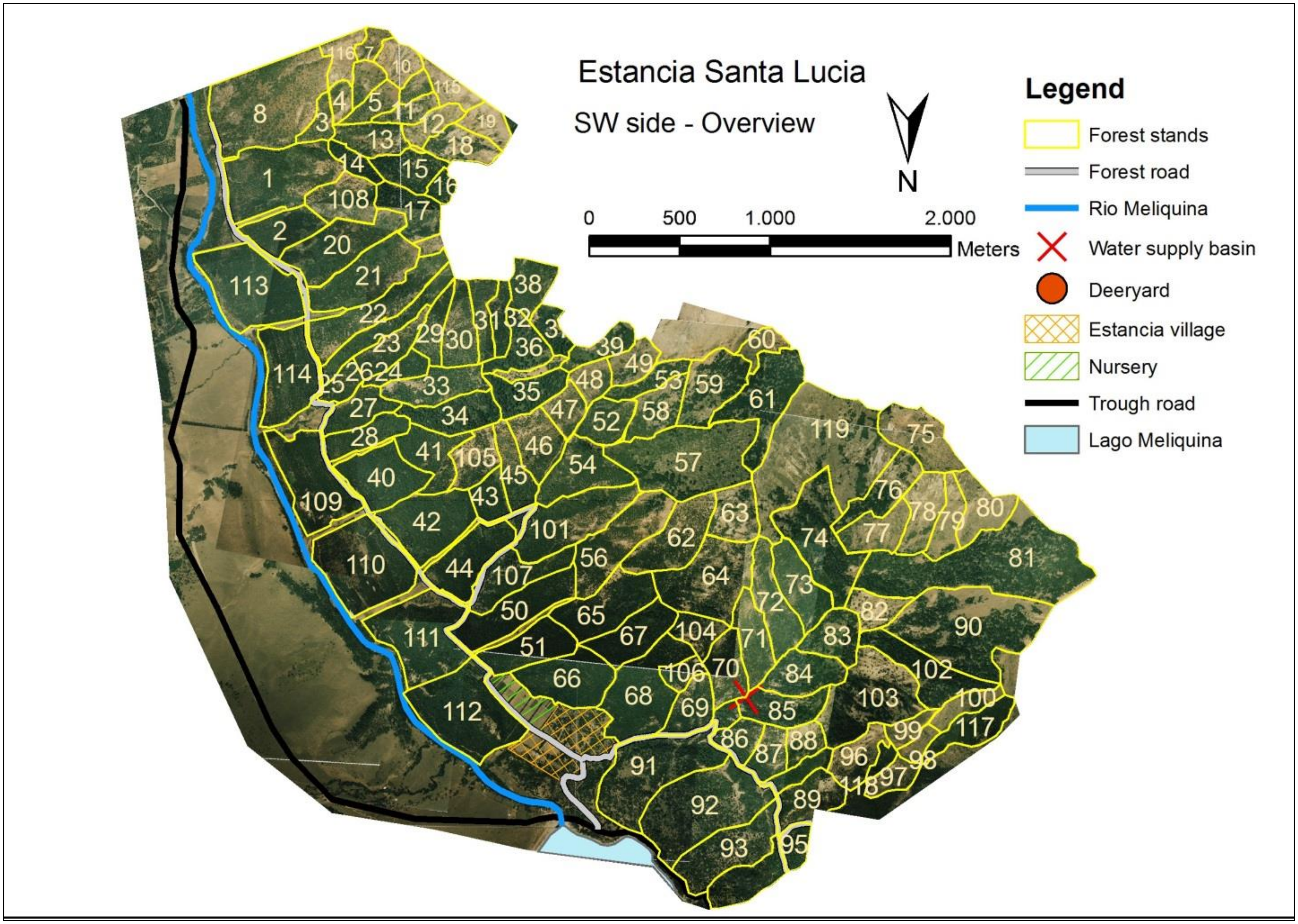


Figure 20: Overview forest stands SW side

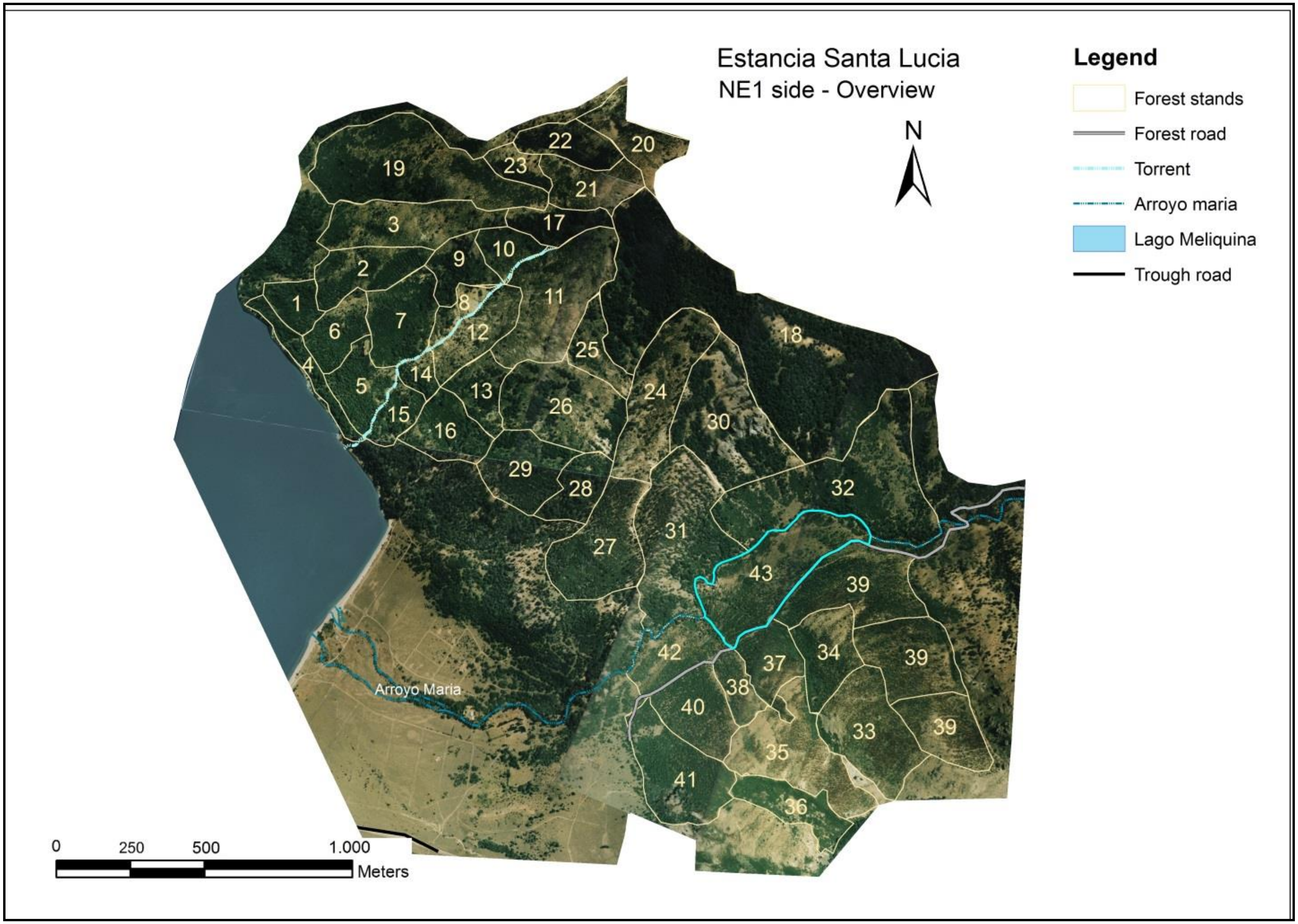


Figure 21: Overview forest stands NE side pt. 1

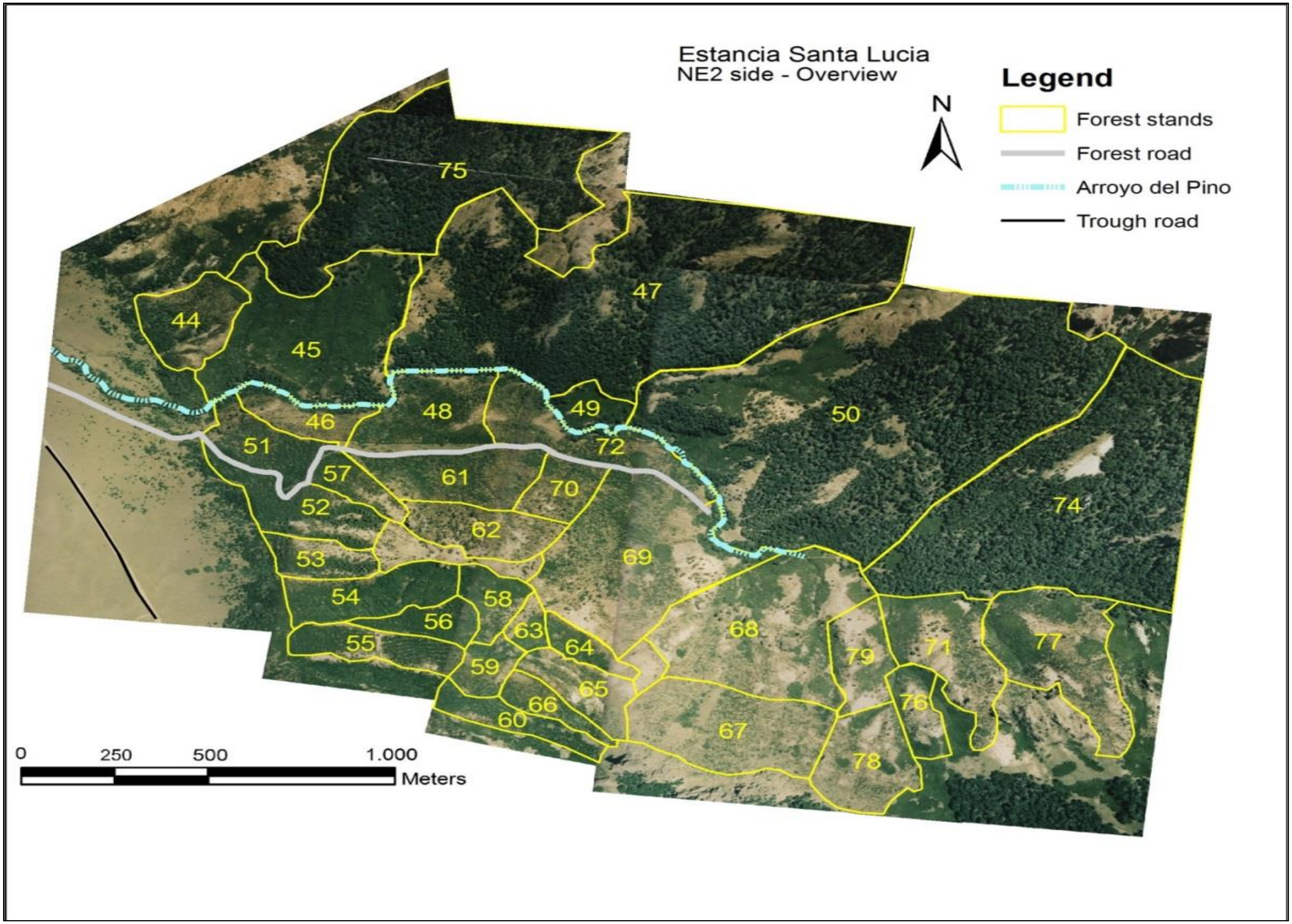


Figure 22: Overview forest stands NE side pt.2

The first step was to create a matrix where the survey area in the Estancia was divided into the southwest (SW) and northeast side (NE). In the second step the forest stands were defined due to similar properties such as: tree species, sea level, exposition, and management type, such as such as pruning and thinning. The stands were numbered consecutively in both sides (SW-n° and NE-n°). The attributes are listed in Table 2.

Table 2: Attributes measured for the individual forest stands

Nr	Attribute	Unit	Instrument
1	Stand number	-	-
2	Sea level	m	Altimeter (GPS)
3	Exposition	°	Compass (GPS)
4	Inclination	°	clinometer (Vertex)
5	Tree species	-	-
6	Management type	pruned, thinned, none	-
7	Relief	Ridge, upper slope, middle slope, bottom slope, graben, hollow, plain (class 1-7)	-

The goal was to examine stands representing all tree species compositions, ages, and management types in the planted forests. The field reconnaissance revealed the following intermediate results.

Table 3: Abbreviations of tree species

Species	
Pp	Pinus ponderosa
Pc	Pinus contorta
Po	Pinus oregon (Pseudotsuga menziensii)
Ac	Austrocedrus chilensis
Np	Notofagus pumilio
Na	Nothofagus antartica
Lh	Lomatia hirsuta

119 stands were defined in the SW-side and 17 were chosen for further examination whereas 79 stands were defined respectively 19 examined in the NE-side. Table 4 shows the identified tree species compositions and corresponding stand numbers.

Table 4: Stand frequency according to tree species composition in SW-side and NE-side of Estancia

SW-Side			NE-Side		
Species	frequency	selected	Species	frequency	selected
Pp	36	7	Pp	18	6
Pc	3	2	Pc	1	1
Pp, Pc	41	4	Pp, Pc	32	9
Pp, Po	9	2	Pp, Ac	2	1
Pp, Ac	3	1	Pp, Po	5	2
Pp, Pc, Lh, Ac	3	1	Ac	1	0
Np	22	0	Ac, Na	1	0
Np, Na	1	0	Np	5	0
			Np, Na	12	0
			Na	2	0

Table 5 shows the altitudes of the stands where the majority is located at altitudes between 1000m and 1300m.

Table 5: Stand distribution in SW-side and NE-side in the Estancia according to altitude. Natural forest stands are written in brackets.

SW- Side			NE-Side		
Altitude	Frequency	selected	Altitude	Frequency	selected
900 – 1000 m	11	2	900 – 1000 m	4	0
1000-1100m	31	3	1000-1100m	16	3
1100-1200m	23	4	1100-1200m	22	10
1200-1300m	28	5	1200-1300m	23	4
1300-1400 m	19	1	1300-1400 m	13	2
1400-1500 m	7	2			

Table 6 shows the breakdown of forest stands due to the management type, as can be seen most stands are pruned whereas thinning only was carried out in 8 stands in the SW-side. 10 stands were not managed, 8 on the SW-side respectively 1 on the NE-side.

Table 6: Management types of Estancia in SW-side and NE-side (natural forests are written in brackets)

SW- Side			NE-Side		
Management type	Frequency	selected	Altitude	Frequency	selected
None	10 (23)	2	None	1 (24)	0
Pruned	78	13	Pruned	54	19
Thinned	8	2	Thinned	0	0

The third step of the field reconnaissance consisted of assigning services to the individual stands were a binary code was used to determine whether the services applied (1) or did not apply (0). Table 7 shows the assigned forest services and the resulting combination.

Table 7: Assigned forest services

	TP	NC	RP	TP/EP
	Timber production	Nature conservation	Rock fall protection	Torrential processes & Erosion protection
Stand code	1000	0100	0010	0001

This approach leads to a service combination (target type) in terms of a code. Stands with the same code where assembled in groups. The grouped forest stands due to the target type are listed in Table 8 and Table 9, (the stands highlighted red where chosen for further examination).

Table 8: Service target types in NE-Side

Code	Stands (NE)	Number	Elected
0000	1, 4, 5, 16, 18, 36, 60, 74, 75	8	0
0001	9, 14, 15, 17, 30, 31, 32, 45, 47, 49, 50	7	0
0011	24, 34	1	0
1000	2, 3, 6, 13, 19, 20, 21, 22, 23, 41, 44, 57, 67, 71, 76, 77, 78, 79	18	1
1001	7, 10, 11, 12, 35, 37, 38, 39b, 39c, 40, 42, 43, 46, 48, 51, 61, 62, 69, 70, 72	20	13
1010	27, 28, 29, 52, 53, 54, 55, 56, 58, 59, 63, 64, 65, 66	14	2
1011	33, 25, 26, 39a	4	3

Table 9: Service target types in SW-Side

Code	Stands (SW)	Number	Elected
0100	34, 35, 117, 118	4	0
0100	36, 37, 39, 58, 59, 61	6	0
0101	52, 85	2	0
0101	53	1	0
0100	14	1	0
0101	15, 16, 17, 81, 82, 83, 84, 90, 102	9	0
0111	76	1	0
1100	1, 2, 3, 4, 5, 6, 7, 8, 10, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 38, 39, 40, 41, 42, 42, 43, 44, 50, 55, 57, 60, 62, 65, 69, 89, 91, 92, 93, 94, 95, 97, 98, 99, 100, 101, 105, 107, 108, 109, 110, 111, 112, 113, 114, 117, 118	59	6
1101	54, 56, 70, 71, 72, 73, 74, 86, 87, 88, 96, 103, 119	13	5
1110	9, 11, 12, 13, 18, 19, 51, 63, 64, 66, 67, 68, 104, 106, 115, 116	16	3
1111	45, 46, 47, 48, 49, 75, 77, 78, 79, 80	10	2

In the selected stands a comprehensive inventory was performed to gather the necessary data for further assessment.

3.5 Comprehensive inventory design

The main goal was to collect data on service relevant forest parameters, to create a data basis, which allows an objective evaluation of the demanded forest ecosystem services.

As already described in chapter 3.1, the fulfillment of services was verified by using indicators, which were derived from field data. The data was gathered both, in randomly distributed sample points within the stands and as a survey over the entire polygon. Tree data, soil records and regeneration samples were acquired in sample points, located every 50 m on transects through the polygons. The number of sample points varied between 4 and 8, depending on the size of the examined stands. Data concerning gravitational hazards, lying dead wood and the forest development stage were assessed over the entire polygon.

3.5.1 Tree data

To gather the biometric data, angle count sampling was carried out using a Bitterlich relascope. In the course of the angle count sampling, tree attributes, such as DBH, height, damages and height of the live crown were gathered for further calculations (see ch.3.6.1). The basal area factor 4 was chosen and the callipering limit was DBH >5 cm. All recorded tree attributes are listed In Table 10.

Table 10: Tree/forest attributes

Nr	Attribute	Unit/Classes	Instrument
1	ID	-	-
2	Species	-	-
3	living/dead	1/0	-
4	DBH	cm	Caliper
5	Tree height	m	Vertex
6	Height of the live crown	m	Vertex
7	Damages	Rock fall, management, game, biotic (insects)	-
8	Stem form	forked stem, crooked stem	-
9	Branch diameter	Class 1-3	-
10	Branch number (<5m bole length)	-	-
11	Branch angle	Class 1-3	-

The species of the individuals were determined; standing dead wood was considered and registered only if the height exceeded 1.3 m. The DBH was measured with a caliper and adjusted downwards to full cm. Three heights were measured per species. First, the height of the median tree was measured to allow an application of a uniform height curve and hence calculate the residual tree heights (see Chapter 3.6.1.2). By listing the trees with ascending DBH, the median tree was found by striking off the trees pairwise, starting from the thinnest. Second, the top height was approached by measuring the height of the second thickest tree (According to Pollanschütz (1970), it represents the average height of the strongest 12 m^2 per ha with basal area factor 4). Lastly, the height of the second thinnest tree was measured to obtain a data basis over the entire diameter range. Furthermore the height of the live crown was determined simultaneous with the height measurements. All recorded individuals were checked for damages from harvest, rock fall, insects and game. Stem form was considered and classified by forked stem and crooked stem. Concerning the stem quality, the number, diameter and angle of branches were measured on the first 5m log. The qualitative description of the forest structure was performed over the area of the individual stand (polygon) where the tree species composition, referring to the ratio of deciduous trees to conifers and the crown coverage (%), was estimated.

Lying dead wood also was recorded holistically in the individual polygons. The minimum threshold was set to a mean diameter of 25 cm and a length of 2 m, the classification is shown in Table 11.

Table 11: Lying dead wood classification

Class	Amount
Very little	< 1 piece per stand
Little	1 – 3 pieces per stand
Middle	3 – 10 pieces per stand
High	> 10 pieces per stand

3.5.2 Soil properties

To get the necessary information on soil parameters, pits with ideal dimensions of 30x30x30 cm were dug near the center points of the angle count samples. The obtained soil profile served to determine the humus type and –depth. Soil texture and coarse fraction were recorded using the standards of Englisch and Killian (1998) (cf. Table 13). The finger test was used to define the proper soil texture. The soil depth was measured and divided into three classes. The soil type was specified according to the keys to soil taxonomy as provided by the USDA (2010). As already mentioned in chapter 2.2, the soil type is classified as Andosol. The main differences between the soil records within the Estancia, are found in soil depth and soil fraction. The attributes recorded are listed in Table 12

Table 12: Recorded soil attributes

Nr	Attribute	Unit/Classes	Instrument
1	Humus	Mull, Mold, Raw humus, other	-
2	Humus depth	cm	Pocket ruler
3	Soil type	Andosoles	-
4	Depth	0-30 cm, 31-50 cm, >50 cm	Pocket ruler
5	Soil (coarse)fraction	% of soil volume 5 classes	-
6	Soil texture	Sand, silty sand, loamy Sand, clayey sand, sandy silt, silt, loamy silt, sandy loam, loam, silty loam, sandy clay, loamy clay, clay	Finger test

The coarse fraction >2 mm was quantified as percentage of the soil profile, first using the sketch showed in Figure 23 and then classified as shown in Table 13 b).

Table 13: a) main soil texture classes and b) estimation of soil fraction classes (Englisch & Killian, 1998)

a)

Class	Description	Size [mm]
1	Coarse sand	0,2-2
2	Fine sand	0,02-0,2
3	Silt	0,002-0,02
4	Clay	>0,002

b)

Class	Description	% of top soil volume
1	Slight coarse amount	0 – 10
2	Moderate coarse amount	10 – 20
3	High coarse amount	20 – 40
4	Very high coarse amount	40 – 80
5	Mainly coarse amount	> 80

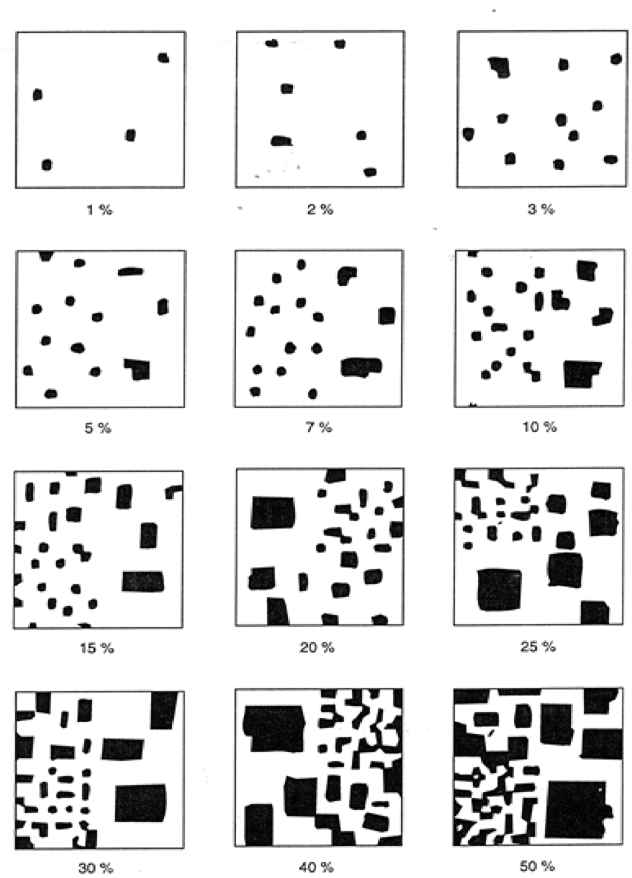


Figure 23: Sketch to assess the coarse fraction >2 mm in % of top soil volume (Englisch & Killian, 1998)

3.5.3 Torrential processes and erosion

During the comprehensive inventory, the catchment areas for the torrents (channels) were identified. The limits of the catchment area were set within the watershed, meaning that all stands within the watershed were assigned the flood protection service. Ground vegetation and soil properties were collected in the assigned forest stands. Existing erosion areas were identified during the field reconnaissance where the magnitude was measured as presented in Table 14. Erosion areas were classified into sheet wash-, gully- and ravine erosions as proposed by the FAO (2011).

Table 14: Characteristics of erosion areas

Nr	Attribute	Unit/Classes	Instrument
1	Form	1 Round 2 Elliptic 3 Slit shaped	-
2	Length	[m]	-
3	Width	[m]	-
4	Orientation	[°]	compass
6	Type	1 Sheet wash 2 Gully 3 Ravine	-

3.5.4 Rock fall

To get information about the possible rock fall potential, parameters such as rock size, spatial distribution, number, shape of rocks and slope inclination were measured respectively observed in the polygons. The rock size was classified in three diameter classes; the distribution of rocks was seen as individual, areal or clotted. The spatial distribution and shape of rocks was estimated ocular, regarding three different shapes: round, angular and flat. The attributes concerning rock fall are shown in Table 15.

Table 15: Attributes to characterize rock fall potential

Nr	Attribute	Units/Classes	Instrument
1	Microrelief	1 concave 2 convex 3 even	-
2	Rock diameter resp. Rock volume	1 0 – 40 cm ≈ 0,05 m3 2 41 – 60 cm ≈ 0,05 – 0,20 m3 3 61 – 180 cm ≈ 0,20 – 5 m3	Tapeline
3	Rock shape	1 Round 2 Angular 3 Flat	-
4	Zone	1 Source 2 Transit 3 Deposit	-
5	Spatial distribution	1 Individual 2 Areal 3 Clotted	-

3.5.5 Nature conservation

The ratio of the tree species composition was based on the basal area (cf. 3.6.1.1) expressed as a percentage of total basal area per stand. The regeneration was examined in circular sample plots located three meters (3m) in north direction (0°) of the center points of the angle count samples. The regeneration was structured into three height classes (<10 cm, 10-50 cm, 51-130 cm) and two DBH classes (<2 cm, 2-5 cm). The lowest height category was recorded with a 1 m radius, the other classes within a 3 m radius. Additionally the coverage of the regeneration was estimated per polygon.

Table 16: Recorded regeneration attributes

Size class	Condition
<10 cm (1m radius)	Browsed Unbrowsed
11-50 cm (3m radius)	Browsed Unbrowsed
50-130 cm (3m radius)	Browsed Unbrowsed
<2 cm DBH (3m radius)	Browsed Unbrowsed
2-5 cm DBH (3m radius)	Browsed Unbrowsed

3.5.6 Hunting

The stand development stages after Mayer (1991, Table 17) were assessed during the comprehensive inventory to obtain an overview of possible habitat conditions.

Table 17: Development stages after Mayer and Ott (1991)

Managed forest, development stages	**Natural forest, development phases**
Clearing (C)	Young growth phase (YG)
Young growth (YG)	Initial phase (IP)
Thicket (T)	Optimal phase (OP)
Pole wood (PW)	Terminal phase (TP)
Young timber (YT)	Decay phase (DP)
Middle timber (MT)	Regeneration phase (RP)
Aged timber (AT)	Natural forest phase (NP)
Selection forest (SF)	
Disturbed area (DA)	

The development stages are divided into managed forests and natural forests. The differences are due to tree species and mainly due to the fact of existing anthropogenic influences such asmanagement, roads etc.

The development stages in managed forests can be defined as follows:

(1) **Clearing**: a development stage without any growing stock after exploitation
(2) **Young growth**: the development period between the stage of germ buds from natural regeneration, sowings and/or plantations till the height of shrub layers (2m). Utter causes are responsible for strong first selection.
(3) **Thicket**: Height <2m, DBH <10 cm
(4) **Pole wood**: accessible sub canopy space/area with a DBH 10-20 cm
(5) **Young timber**: DBH 20–35 cm
(6) **Middle timber**: DBH 36-50 cm
(7) **Aged timber**: DBH > 50 cm

(8) **Selection forest**: all development stages (young growth – timber wood) are represented in one stand
(9) **Disturbed area:** can be defined as areas with dead wood and/or windthrow area with or without growing stock

The development stages of natural forests are defined as following:

(1) **Young growth phase:** Growth or regrowth after natural decay or calamitous decay of the old growth also repopulation of erosion areas with a high stem number.
(2) **Initial phase:** Characterized by a high stem number and a well-developed structure (thicket to pole wood). Mortality and development of layers increase showing a maximum grow rate.
(3) **Optimal phase:** Still showing a high stem number with good growth rates, decreasing stratum and good stability.
(4) **Terminal phase:** Lower stem number of old timber wood with a maximum stock of timber wood. Decreasing stratum and vitality and increasing mortality of the top layer. Beginning decay of the forest stand.
(5) **Decay phase:** Very low stem number, irregular structure with a strong decreasing vitality, stock of timber wood. Formation of gaps in which the regeneration starts filling in.
(6) **Regeneration phase:** Emergence after deficiency of the top layer, if enough shadow tolerant species are available to form a new top layer of trees.
(7) **Natural forest phase:** Can exist as a quasi-permanent phase if low growing rates lead to a conservation of the structure. Depends on the site (growth conditions)

In terms of hunting, possible hunting sites and their distance to forest roads were estimated.

3.6 Service assessment and derivation of Indicators

Based on the presented indicators, the assessment was performed by rating the examined stands for the degree of fulfillment of services. A traffic light approach was followed in order to display whether the ideal conditions are met (green), minimal requirements are met (yellow), or minimal requirements are not met (red). Due to fact that some services require more than one indicator for assessment, they have been aggregated and sorted according to the preferences of the stakeholders. In the following the comparative values and the corresponding grades are presented.

3.6.1 Roundwood production

Timber production was assessed first, by determining the growing stock of the examined stands and second by the quality, meaning the ratio of saw timber and pulp wood. To calculate the growing stock, the following calculations were required.

3.6.1.1 Basal area

The basal area of an individual tree was calculated with equation 1

$$g_i = \sum_{i=1}^{n} \frac{\pi * DBH^2}{4} \qquad [m^2] \qquad \text{(eq. 1)}$$

and the representative stem number per hectare of an individual tree by using equation 2

$$N_{rep} = G/g_i \qquad [N/ha] \qquad \text{(eq. 2)}$$

where G = 4

3.6.1.2 Tree height

The missing tree heights were calculated using the height equation and coefficients after Knieling (1994) (eq. 3-5)

$$\ln\left(h_{[m]} - 1{,}3\right) = a + \frac{b}{DBH\,[cm]} \qquad \text{(eq. 3)}$$

where:

$h_{[m]}$ = height of tree of mean basal area

b = -8,10 (Pine sp.) and therefore

$$a = \ln\left(h_{[m]} - 1{,}3\right) - \frac{b}{DBH\,[cm]} \qquad \text{(eq. 4)}$$

resulting in:

$$h_{[m]} = e^{a - \frac{b}{DBH_{[cm]}}} + 1{,}3 \qquad \text{(eq. 5)}$$

3.6.1.3 Site index

Due to the young age of afforestations, no accurate site index (SI) tables resp. curves exist for the region (interview with local manager, 2013). To assess the productivity of Pinus ponderosa, the site index was estimated by applying the site index curves provided by Meyer (1938). The site index curves by Meyer where chosen due to the origin of the plant material in the estancia and because they were designed for even aged Pinus ponderosa stands and cover a broad spectrum of site conditions. The total height of tree of average diameter at breast-height and age of the stands were used to assign the stands to the corresponding site index curve. The tree of average diameter at breast height was obtained by dividing the total basal area of the trees by their number and converting the quotient to diameter. The provided site index curves range from 40, being the poorest sites, to 160, being those with highest productivity and reference 100 years of age. Figure 24 displays the site index curves for Pinus ponderosa.

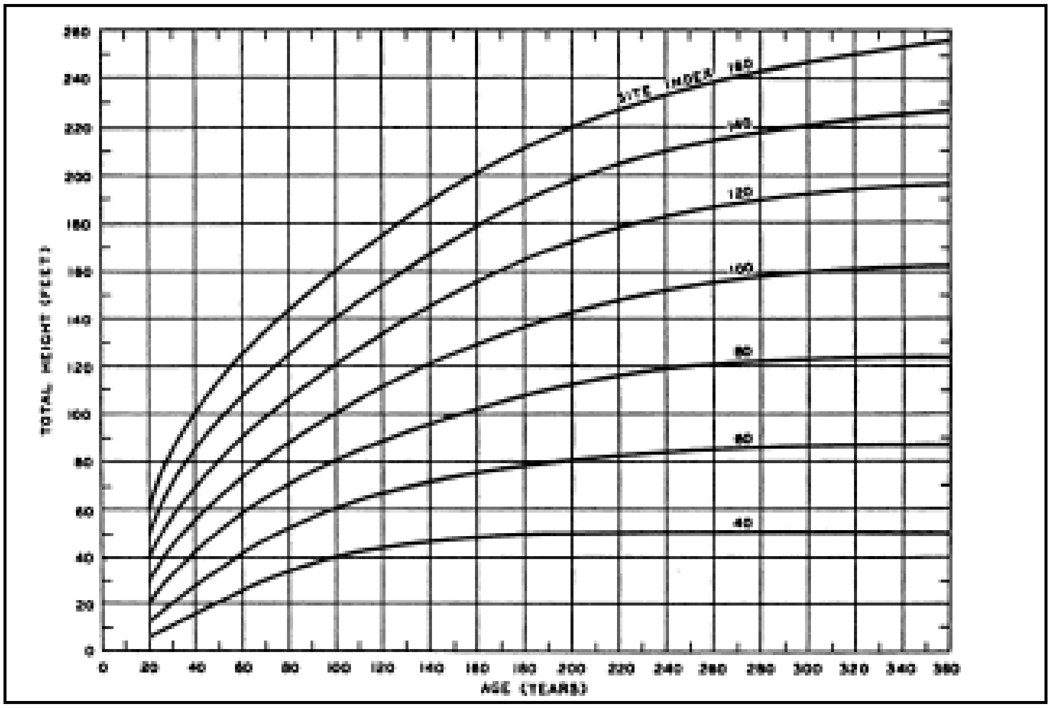


Figure 24: Site index curves for Pinus ponderosa (Meyer, 1938)

The site index for Pinus contorta and Pseudotsuga menzienzii were estimated using the site index curves provided by the Ministry of Forests in British Columbia, Canada (Hegyi et al. 1979). The site index curves given by the ministry were calculated for reference age 50, therefore they were considered comparable. Four classes are determinated concerning the site index; low, poor, medium and good. The thresholds for both species are shown in Table 18.

Table 18: Site index classes for Pinus contorta and Pseudotsuga menziesii

Class	Threshold	
	Pinus contorta	Pseudotsuga meinziensii
low	≤12,2	≤12,2
poor	≤18,9	≤21,3
medium	≤24,4	≤27,4
good	>24,4	>27,4

The site index was approached by assigning the total height and age of the stands to the corresponding curve. The used curves are shown in Figure 25.

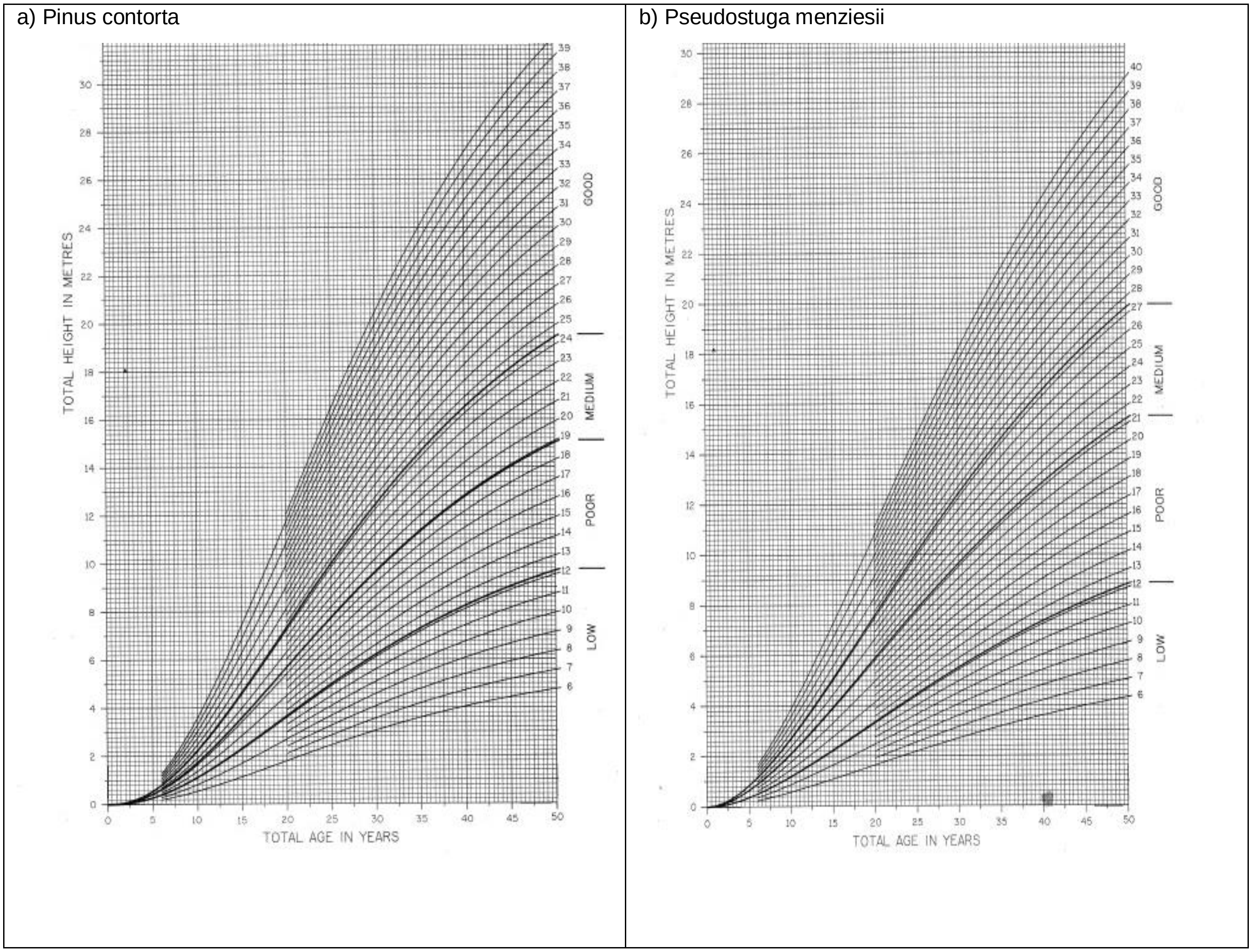


Figure 25: Site index curves for a) Pinus contorta and b) Pseudotsuga menziesii (Hegyi et al., 1979)

3.6.1.4 Volume

Having obtained all tree heights, two different approaches were used to calculate the volume. The first one is the method after Pollanschütz (1974) using the equation with the corresponding coefficient values for Pinus spp. (cf. equations 6 and 7). The local manager confirmed that this approach leads to too large values, hence a second method was chosen. The method after Gonda (1998) (cf. equation 8) which on the other hand underestimates the actual volume. Nevertheless, both calculations were used for comparison.

$$f_{SmR} = b1 + b2ln^2DBH + b3\frac{1}{h} + b4\frac{1}{DBH} + b5\frac{1}{DBH^2} + b6\frac{1}{DBH*h} + b7\frac{1}{DBH^2*h} \qquad \text{(eq. 6)}$$

Table 19: Coefficients for Pinus spp. after Pollanschütz (1974)

Coefficients	**Value**
b1	0,43595
b2	-0,01491
b3	5,21100
b4	0,00000
b5	0,02870
b6	0,00000
b7	0,00000

the volume resulting of:

$$V = f_{SmR} * g * h \qquad [\mathrm{Vfm}] \qquad \text{(eq. 7)}$$

Volume after Gonda (1998)

$$V_{Gonda} = \alpha + \beta * DBH^2 * h + \gamma * DBH \qquad [m^3] \qquad \text{(eq. 8)}$$

where the coefficients are:

α = 0,000214
β = 0,000030
γ = 0,000538

The saw mill requires a minimum top diameter of 16 cm. Therefore the usable stem length was calculated additionally with the following equation:

$$h_{us} = h - ((16 * (h - 1{,}3))/DBH \qquad [m] \qquad \text{(eq. 9)}$$

The calculated heights were then inserted in the equations 7 and 8 to obtain the usable stem volume.

Two categories were allocated to describe the stem quality; saw timber (ST) and pulp wood (PW). The quality parameters were determined in consultation with the local manager as presented in Table 20 and applied on the lower 3 m of the stem.

Table 20: Branch parameters and potential timber grading in Estancia Santa Lucia (Interview with local forest manager, 2012)

Branch parameters				Grading
class	diameter [cm]	angle [°]	Amount per whorl	
1	0-3	≤ 45°	< 6	Saw timber
2	3-6	90°-45°	> 6	Pulp wood
3	> 6	≥ 90°		

3.6.1.5 Regeneration

The extrapolation of the collected regeneration data to hectare values (n/ha) was performed as described in Zöhrer (1980):

$$\frac{Y}{ha} = \frac{1}{an} \sum_{j=1}^{n} \sum_{i=1}^{zj} y_{ij} \qquad \text{[n/ha]} \qquad \text{(eq. 10)}$$

where

Y/ha = amount per ha
a = sample area size in ha
n = amount of sample areas
z_j = amount of plants in sample area j
y_{ij} = feature of individual plant i in sample area j (e.g. browsing)

3.6.2 Torrential processes and erosion

As already mentioned in chapter 3.1.2.1 stream flow, in this work especially the surface flow, is the main process that can lead to hazardous conditions in terms of erosion and flooding. Since there is no precipitation or run off data available for the research area, the SCS-CN method was chosen as the most appropriate. The Soil Conservation Service (SCS) provided a method which was developed by the USDA (United States

Department of agriculture). It is an empirical approach based on the flow-producing precipitation (h_A) as a service of the precipitation height (h_N) and an area characteristic variable CN. CN is influenced by the soil type and land coverage. The basic assumption is that the runoff starts after certain duration of precipitation, and with increasing precipitation the runoff approaches asymptotically a 45° line. At the same time the difference between runoff and increasing precipitation heads towards a constant value. The difference between precipitation and runoff corresponds to the potential retention which is based on soil- and land coverage. This relation is shown in equation (10). Figure 26 shows the relation between the different CN-values and the resulting effective precipitation, which leads to runoff. A CN-value of 100 would be a plane surface without any retention effects, 100 % of the precipitation leads to runoff.

$$\frac{Current\ retention}{Potential\ retention} = \frac{Current\ runoff}{Potential\ runoff} \qquad \text{(eq. 11)}$$

$$\frac{h_N - h_A}{S} = \frac{h_A}{h_N} \qquad \text{[mm]} \qquad \text{(eq. 12)}$$

$$h_{N,eff} = h_A = \frac{h_N{}^2}{(h_N + S)} \qquad \text{[mm]} \qquad \text{(eq. 13)}$$

where:

h_N: total rainfall [mm]
h_A: rainfall excess [mm
$h_{N,eff:}$ direct runoff [mm]
S: potential maximum retention [mm]

Due to the fact that not the entire rainfall results in runoff, the rainfall is reduced by initial subtractions (interception, infiltration etc.).

$$\frac{(h_N - h_{N,Av}) - h_{N,eff}}{S} = \frac{h_{N,eff}}{h_N - h_{N,Av}} \qquad \text{(eq. 15)}$$

$$h_{N,v} = h_N - h_{N,eff} \qquad \text{[mm]} \qquad \text{(eq. 16)}$$

Leading to:

$$h_{N,eff} = \frac{(h_N - h_{N,Av})^2}{S + h_N - h_{N,Av}} \qquad \text{[mm]} \qquad \text{(eq. 17)}$$

$h_{N,Av}$: initial subtraction [mm]
$h_{N,v}$: continuing subtraction [mm]

The analysis of various experiments showed that the initial subtractions correspond to 20 % of the retention capacity.

$$h_{N,Av} = 0{,}2 \cdot S \qquad \text{[mm]} \qquad \text{(eq. 18)}$$

Resulting in:

$$h_{N,eff} = \frac{(h_N - 0{,}2 \cdot S)^2}{h_N + 0{,}8 \cdot S} \qquad \text{[mm]} \qquad \text{(eq. 19)}$$

Since the retention capacity of soils is not always known, the parameter CN (run off curve number) is introduced.

$$S = \frac{25400}{CN} - 254 \qquad \text{(eq. 20)}$$

Respectively:

$$h_{N,Av} = \frac{5080}{CN} - 50{,}8 \qquad \text{[mm]} \qquad \text{(eq. 21)}$$

The CN is based on the hydrologic soil group (HSG) and the coverage as presented in Table 21 and Table 22.

Table 21: hydrologic soil groups (U.S. Department of Agriculture, Soil Conservation Service, 1993)

HSG	Soil textures
A	Sand, loamy sand or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay or clay

Table 22: CN values dependent on cover type and soil group (U.S. Department of Agriculture, Soil Conservation Service. 1993)

Cover Description		Curve number for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, - continuous forage for grazing (1)	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Woods - grass combination (2)	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods (3).	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30	55	70	77

Where:
(1)
Poor: <50 %) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75 % ground cover and lightly or only occasionally grazed
(2)
50 % forest and 50 % grass
(3)
Poor forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair woods are grazed but not burned, and some forest litter covers the soil.
Good:woods are protected from grazing, and litter and brush adequately cover the soil

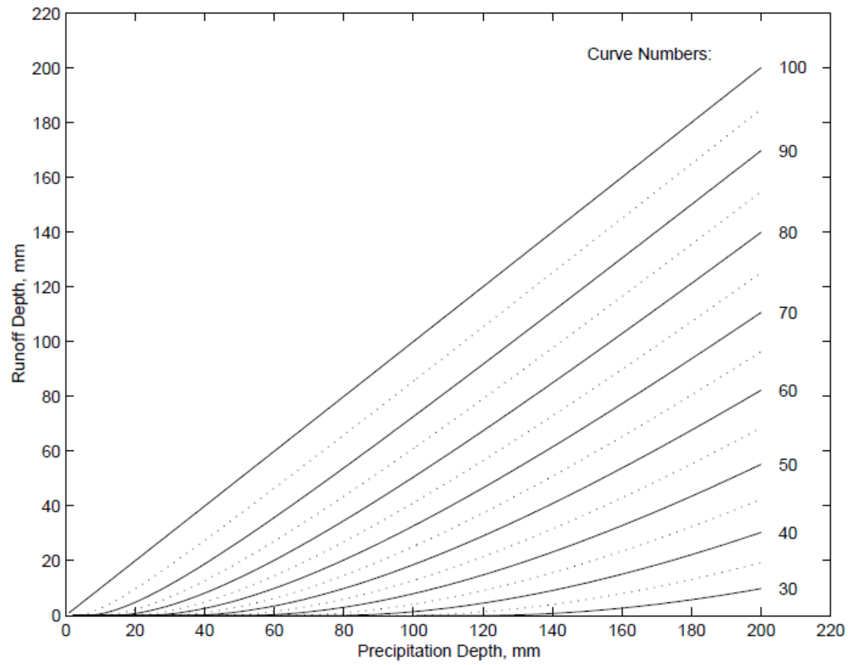


Figure 26: Curve number assuming an initial subtraction of 20 %. The runoff can be read out depending on the precipitation depth. (U.S. Department of Agriculture, Soil Conservation Service. 1993)

Having the proper curve number chosen, the effective (rainfall) runoff results in:

(20 % initial subtraction)

$$h_{N,eff} = \frac{\left(h_N - \frac{200}{CN} + 50{,}8\right)^2}{h_N + \frac{20320}{CN} - 203{,}2} \qquad [mm] \qquad (eq.\ 21)$$

(5 % initial subtraction)

$$h_{N,eff} = \frac{\left(\frac{h_N}{25{,}4} - \frac{50}{CN} + 0{,}5\right)^2}{\frac{h_N}{25{,}4} + \frac{950}{CN} - 9{,}5} \cdot 25{,}4 \qquad [mm] \qquad (eq.\ 22)$$

For comparison h_N was chosen as 84,9 mm/24h as it can be seen as the threshold for heavy rainfall (Wussow in Gao et al., 2000). The stocking and the amount of ground vegetation were chosen as indicators where the rating is carried out by calculating the potential surface runoff and comparing the benefit of stocked- with unstocked areas.

3.6.3 Rock fall

The main parameters influencing rock protection by forests are mentioned in Table 23. To rate the degree of fulfillment, diameter distribution and stem number were chosen as parameters. The stem number per hectare was determined by the arithmetic average of representative stem number per hectare (eq.2) of the angle count samplings per stand. The assignment of rock fall protection service was based on the main factors influencing the detachment of rocks, as existing rock material and slope inclination. The fulfillment of the protection service was evaluated by comparing the actual forest composition to the minimal/ideal composition as shown in Table 23. For each zone forests can provide protective services, depending on the raw rock material and the structure of the forest.

Table 23: Requirements on rock protection (cf. Frehner et al., 2005)

Zone	Potential contribution of forests	Minimal demands on forests according to hazard	Ideal demands on forests according to hazard
Trigger zone	**High**	Stabilizing support No instable, heavy trees	
Transit zone	**High** Rocks < 0,05 m^3	Horizontal structure Min. 400 trees /ha DBH > 12 cm	Horizontal structure Min 600 trees/ha DBH > 12 cm
		Event. stumpshoots	
		Vertical structure Adapted to diameter	
	Rocks 0.05 to 0.20 m^3	Horizontal structure Min. 300 trees /ha DBH > 24 cm	Horizontal structure Min. 400 trees /ha DBH > 24 cm
		Vertical structure Adapted to diameter	
	Rocks 0.20 to 5.00 m^3	Horizontal structure Min. 150 trees /ha DBH > 36 cm	Horizontal structure Min. 200 trees /ha DBH > 36 cm
	Additional for all rock sizes:	Horizontal structure Distance between trees in line of dip < 20 m Lying wood and high stools as addition to standing trees	
Deposition zone	**High** The effective tree diameter is clearly smaller than in the transit zone. Lying wood is always effective	Horizontal structure Min. 400 trees /ha DBH > 12 cm	Horizontal structure Min. 600 trees /ha DBH > 12 cm
		Distance between trees in line of dip < 20 m Event. stumpshoots	
		Vertical structure Adapted to diameter Lying wood and high stools as addition to standing trees	

The combination of rock size and zone leads to the requirements on stem number and diameter as shown in Table 24.

Table 24: Rating of rock fall protection (Frehner et al., 2005)

Zone → / Rating ↓	Trigger Zone	Transit Zone: Rocks < 0,05 m^3	Transit Zone: Rocks 0.05 to 0.20 m^3	Transit Zone: Rocks 0.20 to 5.00 m^3	Deposition Zone
1	No instable, heavy trees	Min 600 trees/ha DBH > 12 cm	Min. 400 trees /ha DBH > 24 cm	Min. 200 trees /ha DBH > 36 cm	Min. 600 trees /ha DBH > 12 cm
2		Min. 400 trees /ha DBH > 12 cm	Min. 300 trees /ha DBH > 24 cm	Min. 150 trees /ha DBH > 36 cm	Min. 400 trees /ha DBH > 12 cm
3		if < 400 trees /ha DBH < 12 cm	if < 300 trees /ha DBH < 24 cm	if < 150 trees /ha DBH < 36 cm	if < 400 trees /ha DBH < 12 cm

3.6.4 Nature conservation

The assessment of nature conservation was carried out by comparing both, the species composition of the canopy and the regeneration in the examined stands, with the potential PNV. The PNV forest communities in the study area are defined described as shown in Table 25.

Table 25: PNV - forest communities and dominance of species

Sea level	Dominant species (>50 %)	Subdominant species (25 %-50 %)	Occasional species (0-25 %)	Ground vegetation
900~1150	Austrocedrus chilensis	Nothofagus antartica Lomatia hirsuta	Nothofagus alpine Maytenus boaria Nothofagus dombeyi	Mulinum spinosum, Discaria articulate Stipa speciosa Schinus montanus
1150 ~1500	Nothofagus pumilio	Nothofagus antartica	Nothofagus alpine Maytenus boaria Nothofagus dombeyi Lomatia Hirsuta	Stipa speciosa Schinus montanus

The composition of the current forest canopy was determined by calculating the ratio of the basal area per species in the examined stands. The coverage of the individual species in regeneration was estimated in tenths and classified as described in Table 26. Three classes were defined in order to determine whether the observed species are dominant (1), sub dominant (2), admixed (3) or non-existent (0). The classification of coverage was based on the Braun-Blanquet scale and is shown in Table 26.

Table 26: Coverage classes of individual species

Class	Representation	Percentage basal area
1	Dominant species	> 50 %
2	Subdominant species	25 % - 50 %
3	admixed species	1 % - 25 %
0	non existent	0

To rate the naturalness of the individual stand, the matrix presented in Table 27 was used. The actual vegetation composition (canopy and regeneration) was compared with the PNV communities presented in Table 25. The amount of PNV species lead to the rating as shown in Table 27, where 1 is the highest and 3 the lowest naturalness.

Table 27: Rating of naturalness

Canopy \ Regeneration	1	2	3	0
1	1	1	1	1
2	2	2	2	2
3	2	3	3	3
0	1	2	3	0

3.6.5 Hunting

Due to the fact that deer requires large territories as habitat (Bützler, 1986) the assessment of the hunting service was not performed at the level of stands. The SW- and NE-side were chosen as possible assessment unit. To assess the habitat quality of both sides the development stages were identified as presented in Table 17. The advantages and disadvantages which individual stages can have on deer habitat are described in Table 28. Patton (1992) (in Holland et al. (2005)) stated that food and cover requirements and management practices vary according to the habitat conditions that the local deer population has adapted to. Nevertheless, Patton provides a few general guidelines that can be applied for local deer habitats (Figure 27):

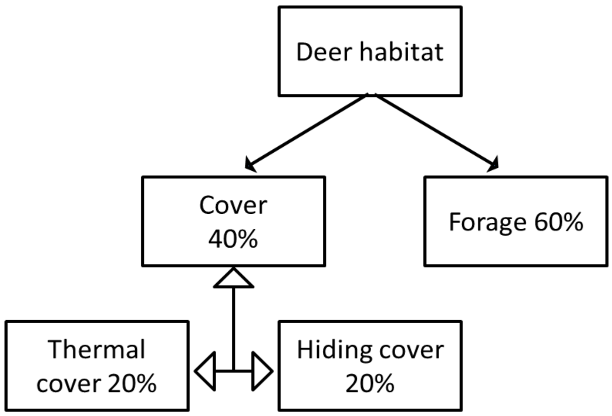


Figure 27: Deer habitat composition where 40 % of the habitat should consist of cover, where 20 % is thermal cover and 20 % hiding cover. The remaining 60 % should be open areas for forage (Patton, 1992)

These three attributes were assigned to the observed development stages. Concerning forage, clearings and young growth provide good conditions, whereas pole wood, young-, middle- and aged timber only provide good forage in stands with low density. Table 28 shows the individual development stages and their influence on the habitat quality.

Table 28: Development stages and influence on habitat quality

		Forage	Thermal cover	Hiding cover
Clearing, unstocked areas		+	-	-
Young growth		+	-	+
Thicket		-	-	+
Pole wood Initial phase	Dense	-	+	+
	Low density	+	-	-
Young timber Initial phase	Dense	-	+	+
	Low density	+	-	-
Middle timber Optimal phase	Dense	-	+	+
	Low density	+	-	-
Aged timber / Optimal phase	Dense	-	+	+
	Low density	+	-	-
Terminal phase		+	+	-
Decay phase		+	-	+
Selection forest		+-	+-	+-

The threshold for density was set at 25 m²/ha in the afforestations and estimated in the natural forest stands. The sum of the individual development stages as percentage of the total stands in both sides of the Estancia was used for comparison with the aforementioned values provided by Patton (1992).

The quality of hunting sites was assessed due to their quality and accessibility. There is one forest road on the bottom of the SW-side and two forest roads in the side valleys of the NE-side. Hence, the distance from the next forest road was chosen as indicator where three classes were defined whether the site was accessible within a 10 minutes walk (1), a 30 minutes walk (2) or >30 minutes (3) walk. The second indicator was the quality of the hunting site in terms of visibility. Three classes were formed, where 1 means optimal visibility conditions (open spaces), 2 is barely to medium stocked areas with lower visibility and last, fully stocked areas with worst visibility which were classified 3. The matrix displaying the rating is displayed in Table 29.

Table 29: Rating of hunting site quality

		Distance from next road		
		1	2	3
Hunting site quality	1	1	1	2
	2	1	2	3
	3	2	3	3

4 **Results**

4.1 Site

The exposition of the two valley sides differs; the main exposition being north to east on the SW side and south to northwest on the NE side (Figure 28).

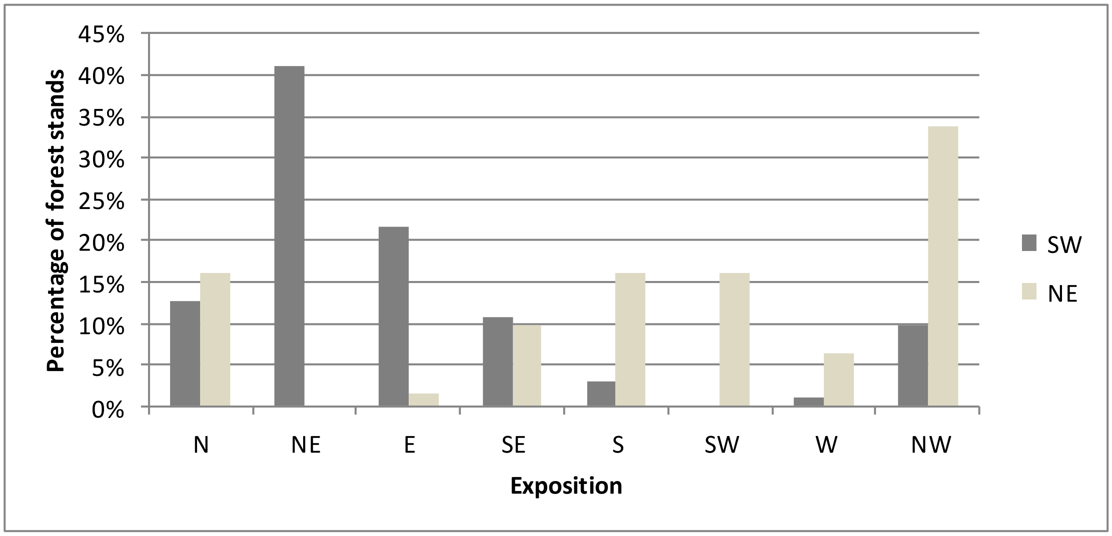


Figure 28: Exposition of forest stands in SW and NE side

The overall inclination differs between both sides while the stands on the SW side are more or less evenly distributed over the inclination classes, the stands on the NE side show a peak of 48 % in the inclination class of 25 -30°. The majority of the stands of both sides show an inclination between 21-35° (Figure 29).

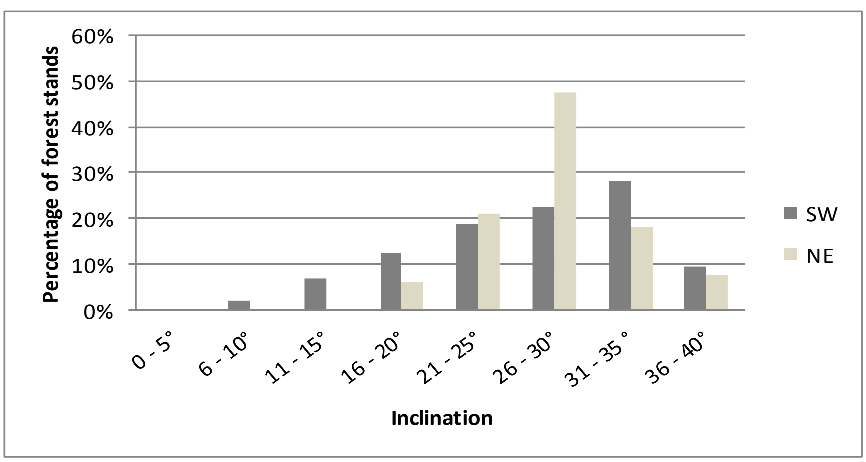


Figure 29: Inclination of stands in SW and Ne side

Concerning the soil properties, two humus types dominate in the examined stands on both sides. Mold with 6 % on the SW- respectively 11 % on the NE side and raw humus with 94 % on the SW side and 89 % on the NE side (Figure 30).

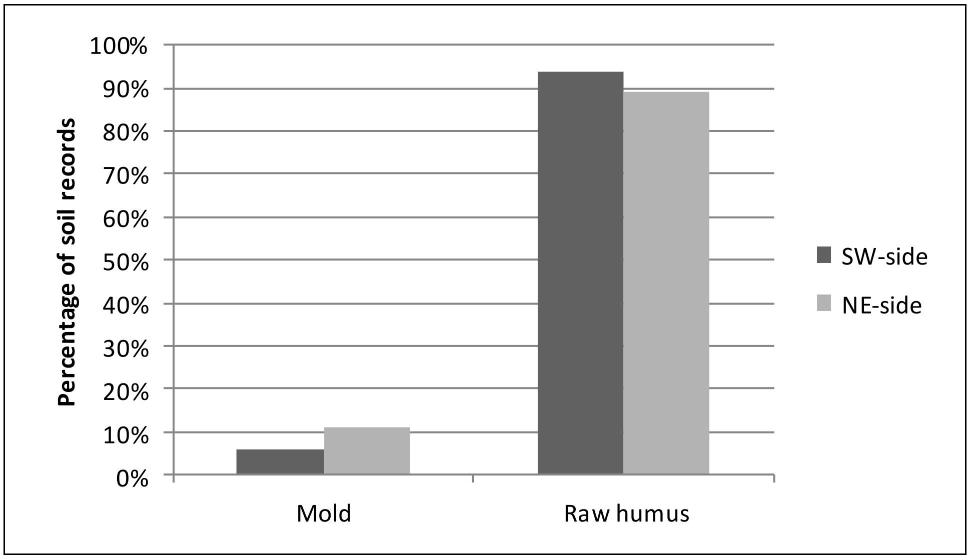


Figure 30: Recorded humus types in SW- and NE-side

The humus depth varies between 3-12 cm on the SW side and 4-15 cm on the NE side (Figure 31).

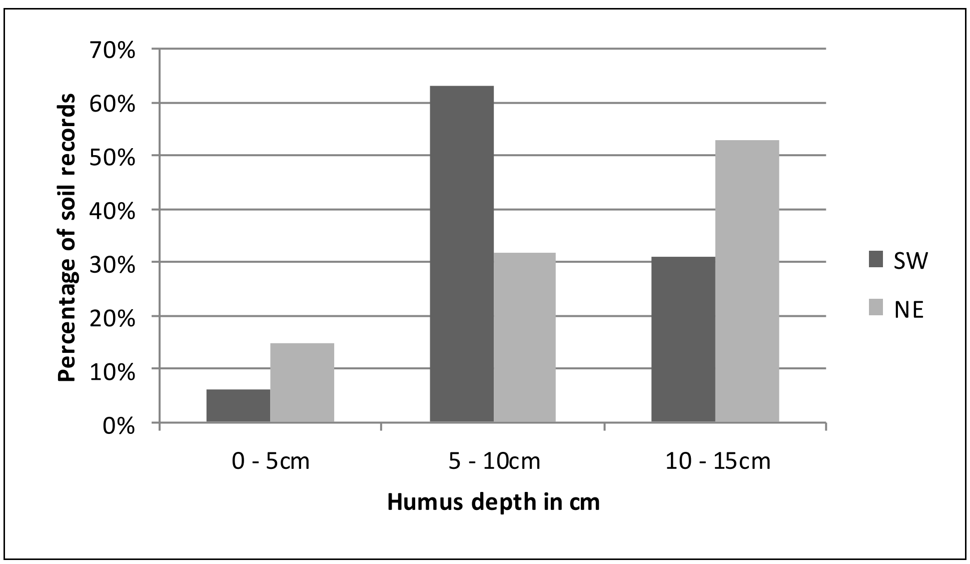


Figure 31: Recorded humus depths in SW- and NE-side

The top soil depth of the examined stands is shown in Figure 32. As can be seen in a) shallow soils dominate with 50 % in the SW side and even 74 % in the NE side. The more profound soils amount to 19 % (31-50 cm) and 31 % (>50 cm) on the SW side whereas on the NE they only reach 16 % (31-50 cm) and 11 % (>50 cm).

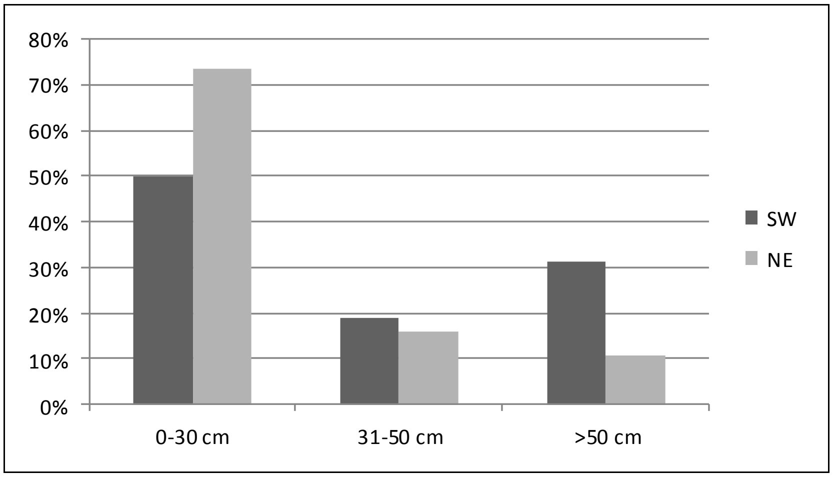


Figure 32: Top soil depth on SW- and NE-side

Two soil textures where found during the inventory; sand and silty sand, the distribution is illustrated in b). The SW side reveals a ratio from 69 % (sand) to 31 % (silty sand) and an almost equal distribution of 47 % (sand) and 53 % (silty sand) in the NE side (Figure 33).

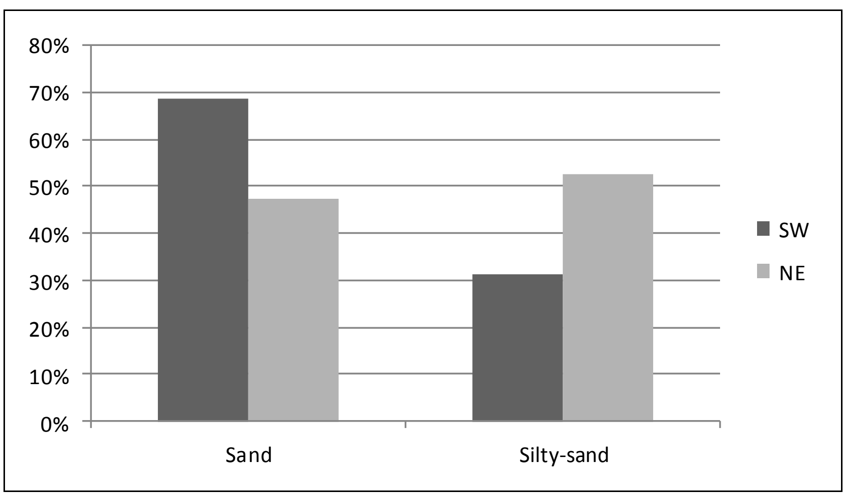


Figure 33: Top soil texture on SW- and NE-side

The topsoil fraction distribution is displayed in Figure 34. All fraction classes are represented, having a peak of 38 % (10-20 % of coarse fraction) and a second one at 25 % (41-80 % of coarse fraction) whereby the other classes reach values from 13 % (0-10 %) over 19 % (20-40 %) to 6 % (>80 %) in the SW side. The examined stands on the NE side show a more evenly distribution with the maximum value of 32 % (20-40 % of coarse fraction) and a minimum of 11 % (>80 %). The other classes are represented with 21 % (0-10 %), 21 % (10-20 %) and 16 % (40-80 %).

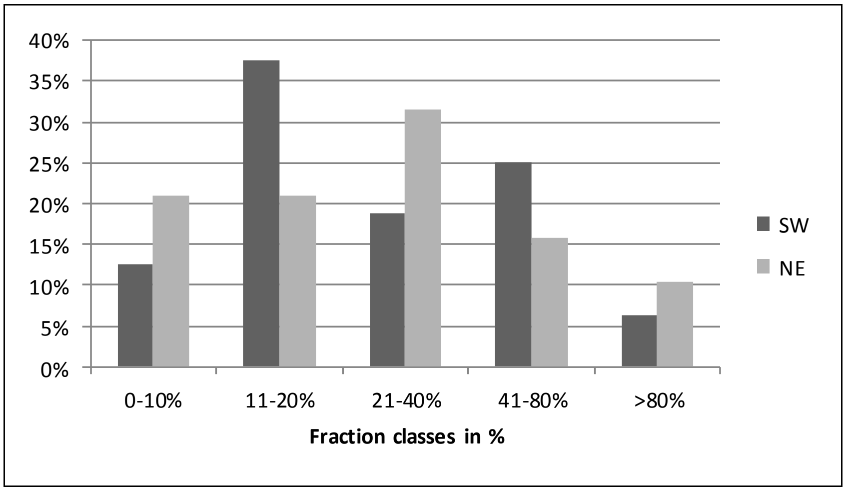


Figure 34: Top soil fraction on SW- and NE-side

4.2 Forest

According to the plantation records of the Estancia, the age of the afforested stands varies between 18 to 32 years on the SW side and 25 to 30 years on the NE side. The inventory showed that on both sides the natural forests represent 24 % of the overall area. The afforested forests in the SW side cover 73 % of the stocked areas whereas in the NE side 66 % of the stands are afforested. The rest of the area on both sides is covered by shrubs, rocks and/or ditches (see Figure 35).

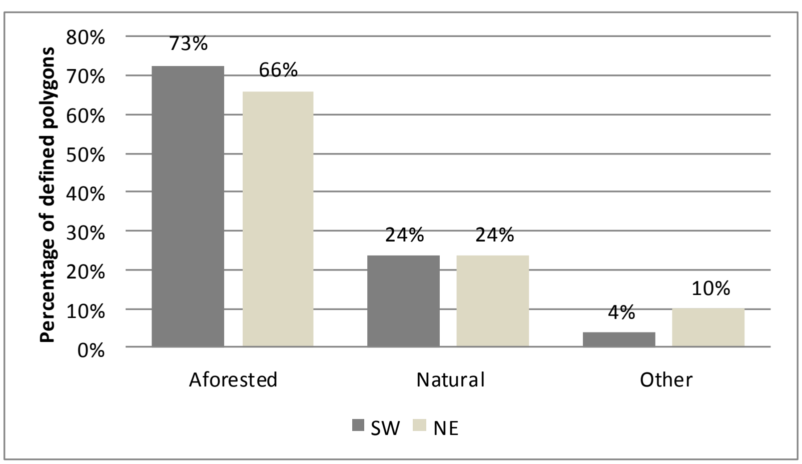


Figure 35: Forest types in the SW and NE side

1847 trees were examined during the comprehensive inventory, where 806 trees were located in the SW-side and 1041 trees were located in the NE-side respectively. Table 30 shows the tree species distribution in the examined stands. The main tree species used in former afforestations is Pinus ponderosa with 78 % in the SW-side resp. 76 % in the NE-side. Pinus contorta follows second with 16 % and 17 %. Pinus oregon represents 3 % of the afforested species. The autochtonous species only cover 1 % to 3 % of the examined stands where Austrocedrus chilensis is the most abundant species with 3 % on the SW-side and 2 % on the NE-side.

Table 30: Overall species distribution in examined stands in SW- and NE side

Species ->	pp	pc	po	ac	Lh	np	na	mb
SW- Side	78 %	16 %	3 %	3 %	0 %	0 %	0 %	0 %
NE-Side	76 %	17 %	3 %	2 %	1 %	1 %	0 %	0 %

The results of the regeneration records are displayed in Figure 36, where the overall species distribution of regeneration within the examined stands shows a difference between both sides. While on the SW side only four species are represented, seven species are represented in the NE side. Pinus ponderosa is the dominant species with 69 %, fact that had to be expected concerning the distribution within the old growth, Pinus oregon follows with 25 %, Lomatioa hirsuta with, 5 % and Pinus contorta with negligible 1 %. The situation in the NE-side is different with a more evenly distribution. Pinus oregeon is the dominant species with 30 % followed by Pinus contorta (24 %) and Pinus Ponderosa (17 %).The autochtonous species represent 29 %, subdivided into Lomatia hirsuta (12 %), Maitenus boaria (8 %), Nothofagus pumilio (5 %) and Nothofagus antartica (4 %).

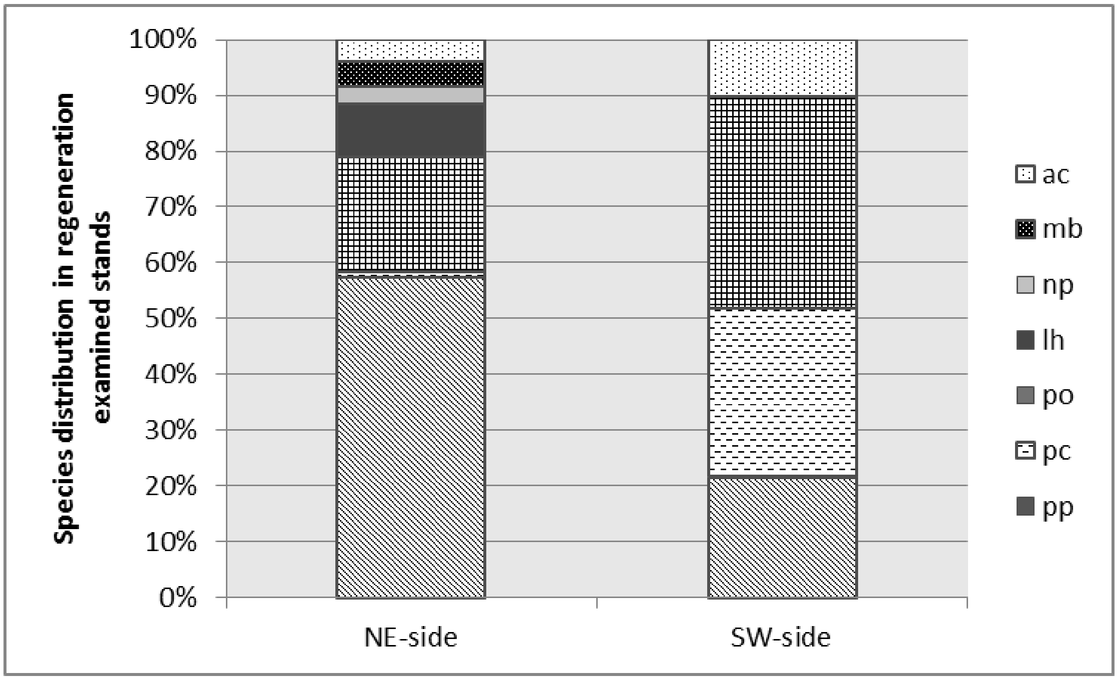


Figure 36: Species distribution in regeneration examined stands (ac=Austrocedrus chilensis, mb=Maytenus boaris, np=Nothofagus pumilio, lh= Lomatia hirsuta, po=pseudotsuga menziensii, pc=Pinus contorta, pp=Pinus ponderosa).

The inventory revealed the following results concerning damage types and stem deformations (Table 31).

Table 31: Damage types and stem deformations in % of measured trees in SW-side and NE-side

Damage type ↓	SW-side	NE-side
Dead wood	1 %	2 %
Damage rock fall	1 %	2 %
Damage due to harvest	1 %	1 %
Damage game	2 %	1 %
Damage insects	0 %	1 %
Forked trees	6 %	5 %
Sweep of the bole	8 %	17 %
Broken tops	0 %	0 %

The growth habit reveals an amount of 17 % of swept trees in the NE side and 8 % in the SW-side. 6 % respectively 5 % of the measured trees are forked. Only 1 % to 2 % of the trees show damages, game damages being the most abundant in the SW-side (2 %) and rock fall in the NE-side (2 %). 1 % resp. 2 % of the measured trees were classified as standing dead wood.

4.3 Roundwood production

The basal area in the examined stands on the SW-side varies from 21 m²/ha in (SW-63) to 77 m²/ha (SW-63) at an average of 48 m²/ha. (Figure 37)

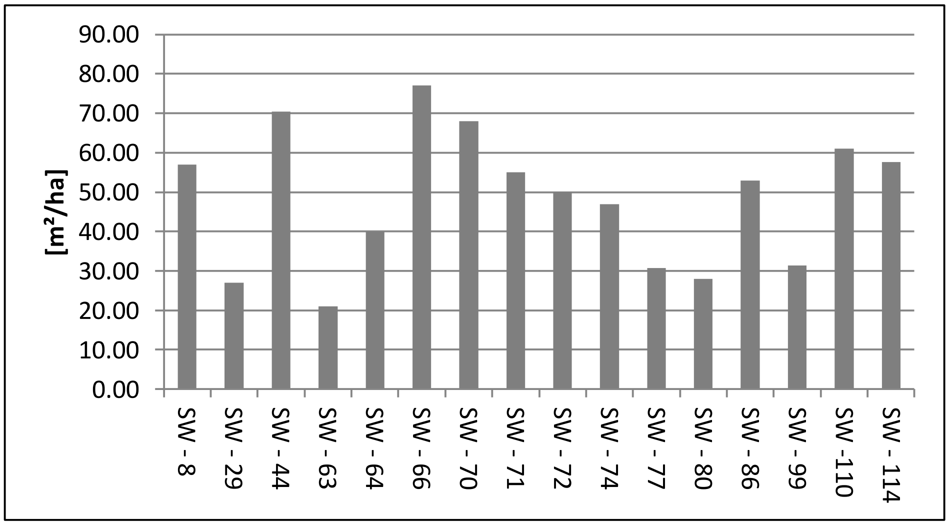


Figure 37: Basal area in examined stands at SW-side

In the NE side on the other hand the average basal area lays at 54 m²/ha, reaching a minimum at 33 m²/ha (NE-27) and a maximum at 73 m²/ha (NE-48) (Figure 38).

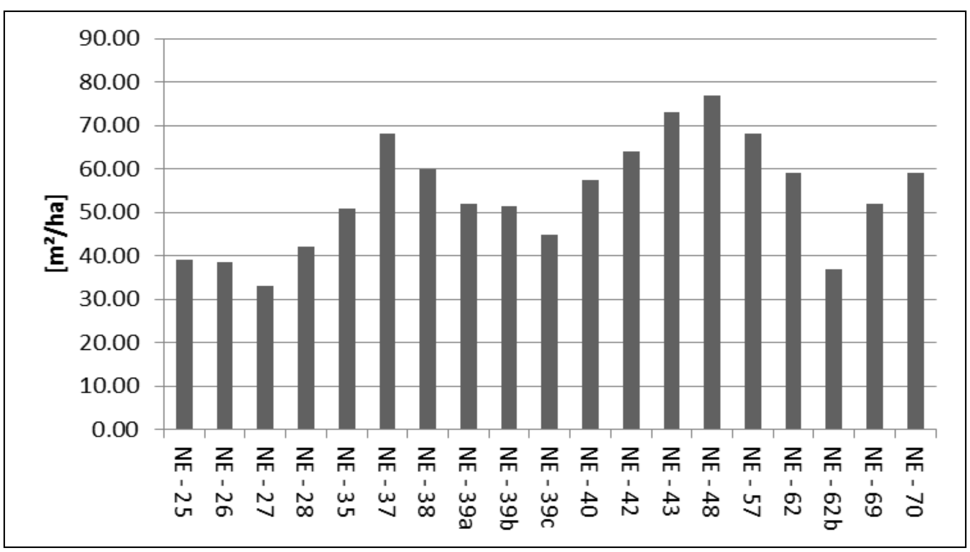


Figure 38: Basal area in examined stands at the NE-side

The stem number in the SW-side varies between 516 N/ha (SW-74) and 1315 N/ha (SW-66), at an average of 878 stems per hectare. The relative low stem number SW-114 (576 N/ha) can be explained due to thinning, whereas the stem number of SW-29 (605 N/ha) results from clearing due to biotic damage (Sirex noctilio).

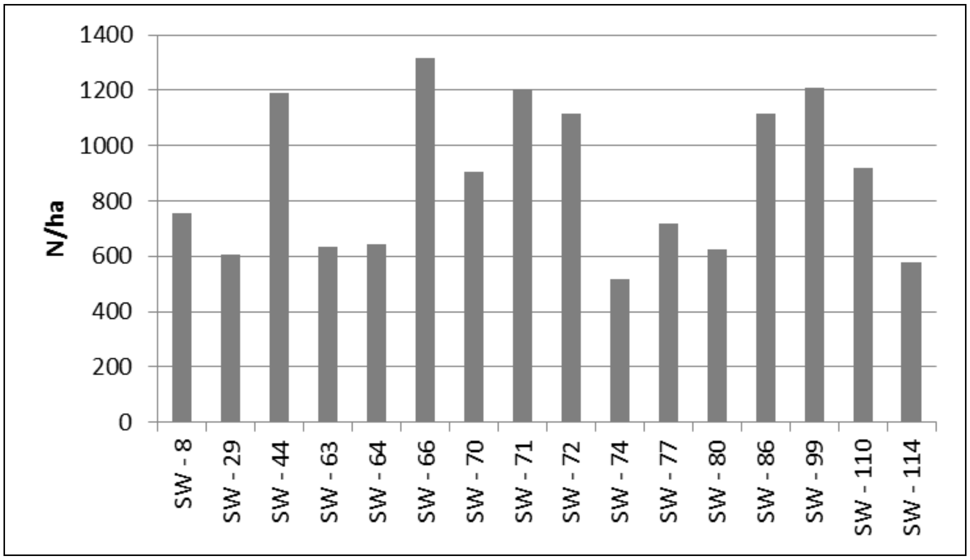


Figure 39: Stem number per hectare of examined stands in SW-side

The average stem number of the NE-side on the other hand is higher reaching 1210 N/ha. The maximum stem number was calculated for the stand NE-35 (1788 N/ha) whereas the lowest number was calculated for SW-39a (716 N/ha). Figure 40 shows the stem number n/ha in all examined stands on both sides of the estancia.

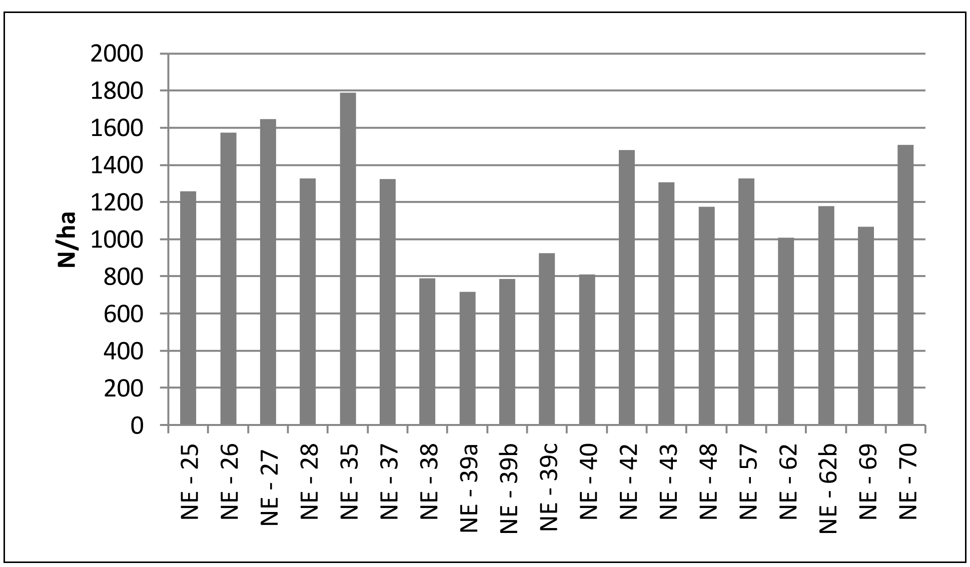


Figure 40: Stem number per hectare of examined stands in NE-side

The mean diameter in the SW-side averages 26,62 cm where the distribution reveals a maximum in stand SW-110 (35,68 cm) and a minimum in SW-99 (18,2 cm).The mean diameter distribution in the NE-side shows a minimum in stand NE-27 (15,97 cm) and a maximum in SW-38 (31,11 cm) at an average DBH of 21,9 cm (Figure 41).

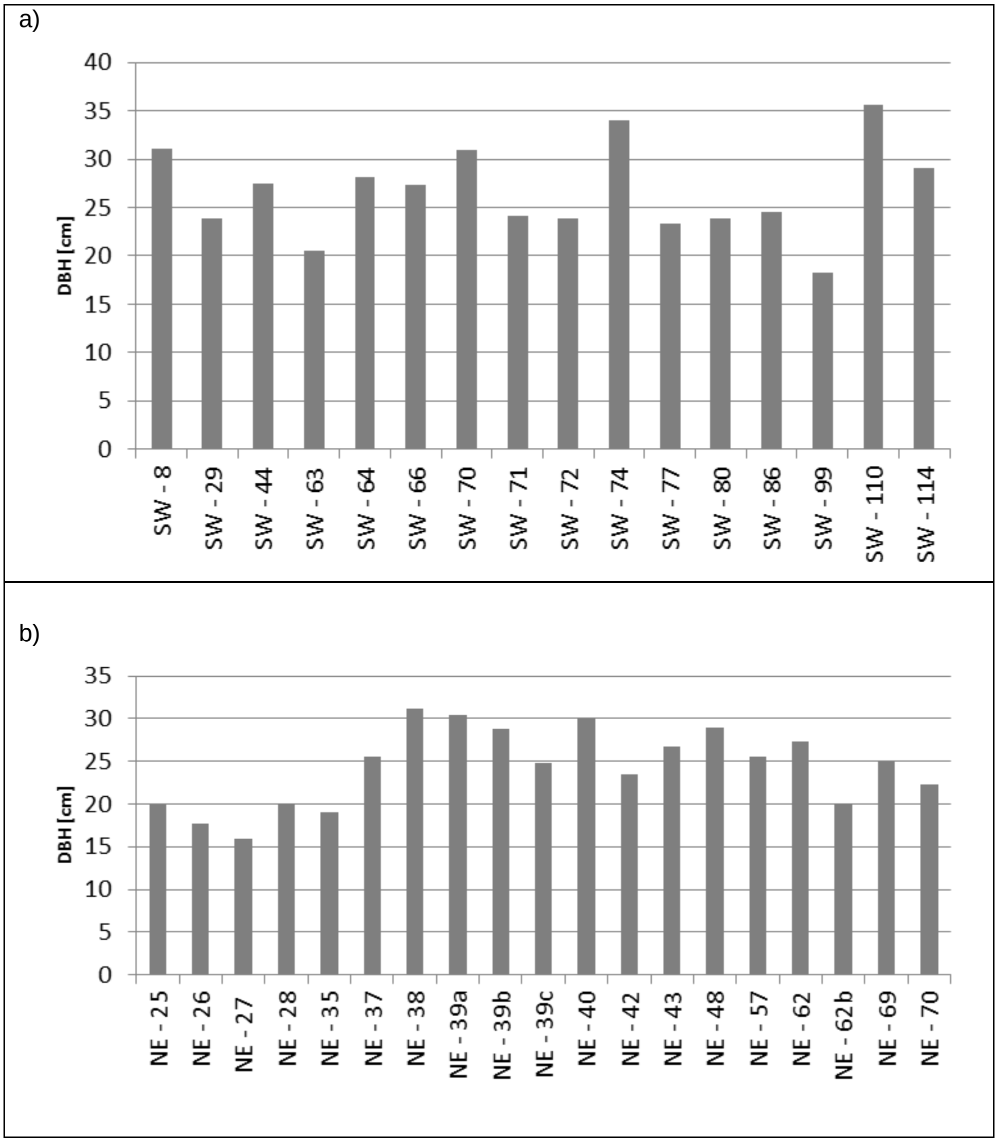


Figure 41: Mean diameter in (a) SW-side and (b) NE-side

The mean timber stock in the examined stands of the SW-side amounts to 266m^3/ha (Gonda) resp. 311m^3/ha (Pollanschütz) whereby the differences between the stands vary from 81 m^3/ha (Gonda) resp. 95 m^3/ha (Pollanschütz) in stand SW-63 and 487 m^3/ha (Gonda) resp. 555 m^3/ha (Pollanschütz) in stand SW-44. The average volume per hectare in the NE-is slightly higher with 275m^3/ha (Gonda) resp. 320m^3/ha (Pollanschütz). The results of the calculations are displayed in Figure 42.

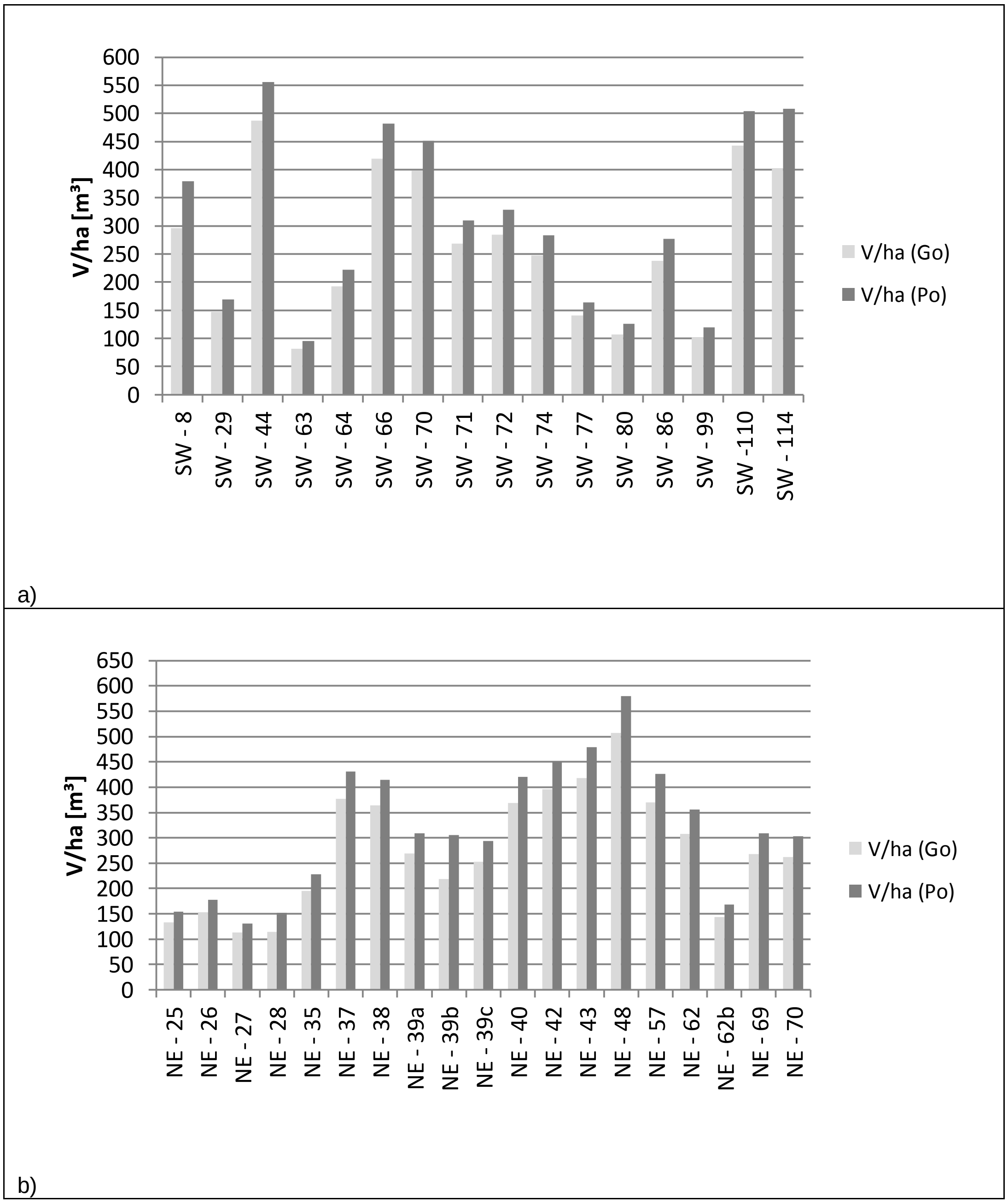


Figure 42: Timber stock in examined stands at (a) SW-side and (b) NE-side

The timber grading is displayed in Figure 43. Three stands (SW-44, SW-110 and SW-114) reach values of 20 % for pulp wood. The pulp wood in the stands SW-8, SW-29 and SW-72 vary from 12 % to 17 % whereas the remaining stands do not exceed 10 %. The usable timber stock in the stands SW-63, SW-64, SW-80 and SW-86 are fully usable as saw timber. The amount of pulp wood in the NE-side is lower than in the SW-side. Only two stands exceed 20 % (NE-38 and NE-40) and 10 % (NE-37 and NE-43 with 13 %). The remaining stands reveal values below 10 %, where six stands reach 100 % of saw timber grading (NE-25, NE-26, NE-27, NE-28, NE-39a and NE-57).

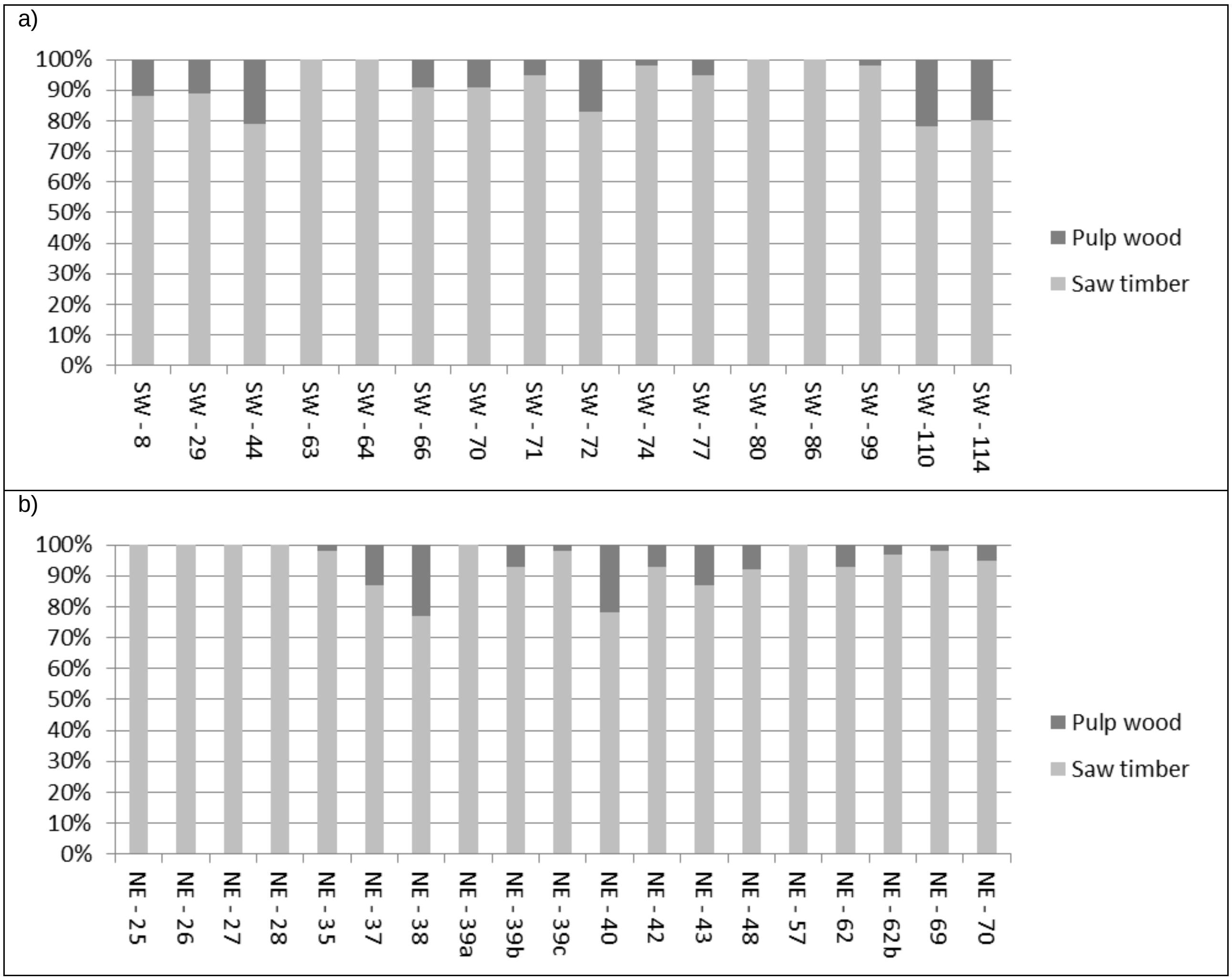


Figure 43: Timber grading in (a) SW-side and (b) NE-side

Considering the top diameter of 16 cm being the limiting factor in the saw mill, the actual volume per hectare is displayed in Figure 44. The strong taper is the main reason for the significant lower volume values than the overall timber stock.

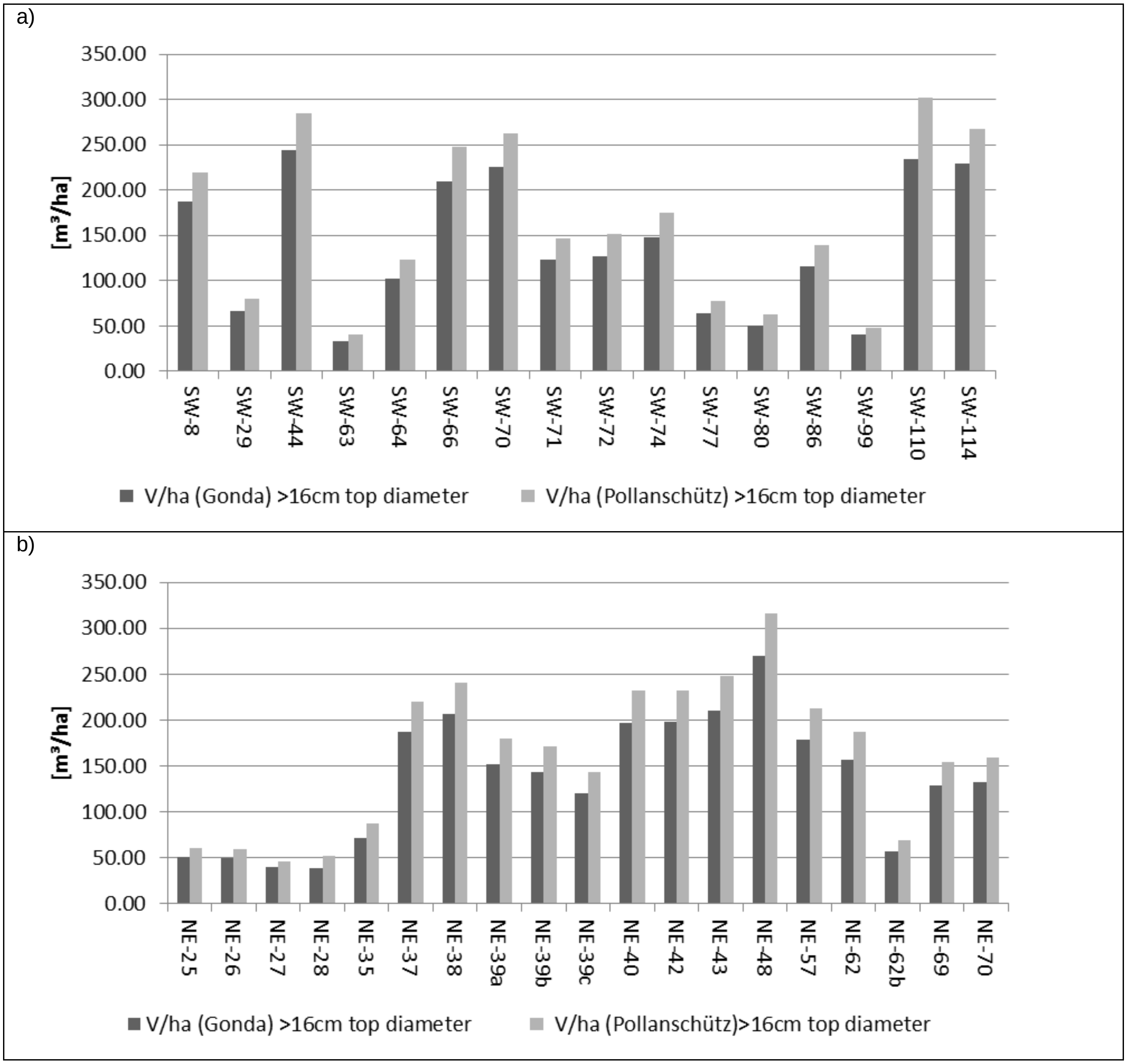
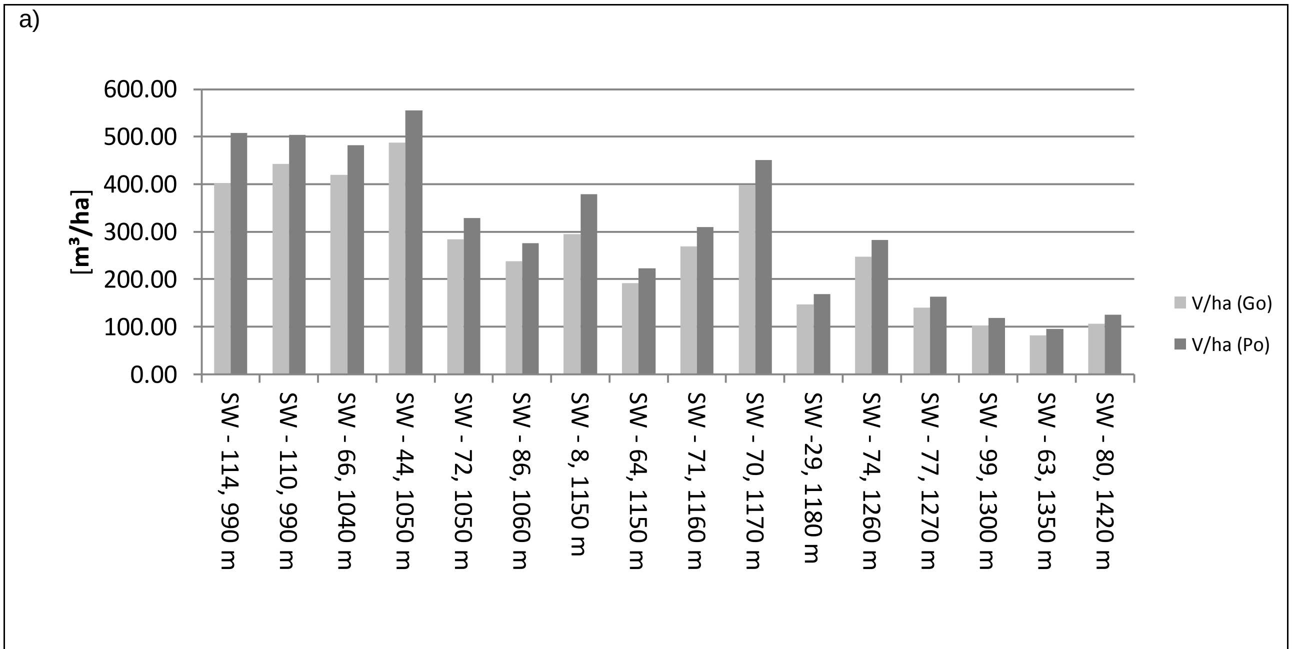


Figure 44: Volume per hectare with top diameter >16 cm in (a) the SW-side and (b) at the NE-side

A comparison of the obtained timber stock per hectare in the individual stands showed that the age was not the limiting factor concerning the productivity. A regression analysis revealed a relation between the sea level and volume per hectare; the following figure demonstrates a decreasing trend of volume with increasing sea level (Figure 45).



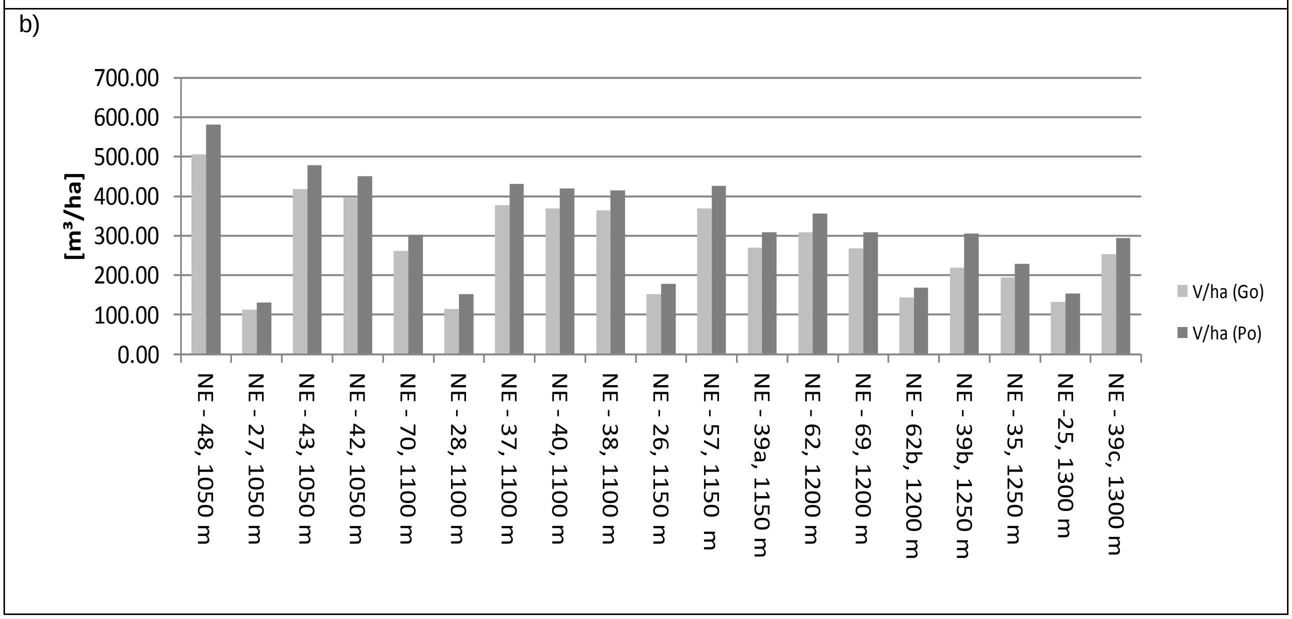


Figure 45: Volume per hectare of the examined stands in (a) SW – side, and (b) NE-side, arranged in ascending altitude.

The estimation of the site index for Pinus ponderosa showed the following results. On average, the NE-side scored higher SI values than the SW-side, reaching the maximum value of 140 in stand NE-48. Five stands, SW–64, SW–80, NE–26, NE–27 and NE–35 obtained the lowest values, with a SI of 80, whereas the majority of the stands (12) reached an SI of 120. Nine stands achieved a SI of 100 and two stands where showed a site index of 110 (cf. Table 33). According to the local manager, the main reason for the distinction is the different provenience of the plant material used in afforestations.

Table 32: Site index for Pinus ponderosa

SI – Pinus ponderosa	Stands
80	SW – 64, SW – 80, NE – 26, NE – 27, NE - 35
100	SW – 77, SW – 86, SW – 99, NE – 25, NE – 28, NE - 39a, NE - 39b, NE – 69, NE - 70
110	SW – 70, SW - 71
120	SW – 8, SW – 44, SW – 66, SW – 74, SW -110, SW – 114, NE – 37, NE – 38, NE - 39c, NE – 40, NE – 42, NE – 43, NE – 57, NE - 62
140	NE - 48

The site indices for Pinus contorta vary from poor to good, most of the stands (7) being in the medium class. Only two stands (SW-63 and SW-29) were classified as poor whereas five stands reached good site indices (cf. Table 33).

Table 33: Site index for Pinus contorta

SI – Pinus contorta		Stands
low	≤12,2	-
poor	≤18,9	SW – 63, SW – 71
medium	≤24,4	SW – 70, SW – 80, NE – 35, NE - 62b, NE – 27, NE - 39c, NE - 25
good	>24,4	SW – 99, SW – 72, NE - 39b, SW – 29, NE - 69

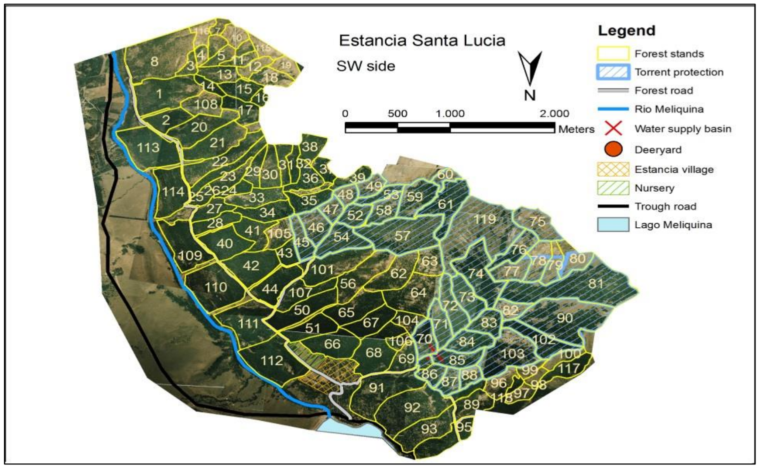
Concerning the site index of Pseudotsuga menziesii only one stand was classified as poor where the remaining three stands obtained good site conditions (cf. Table 34).

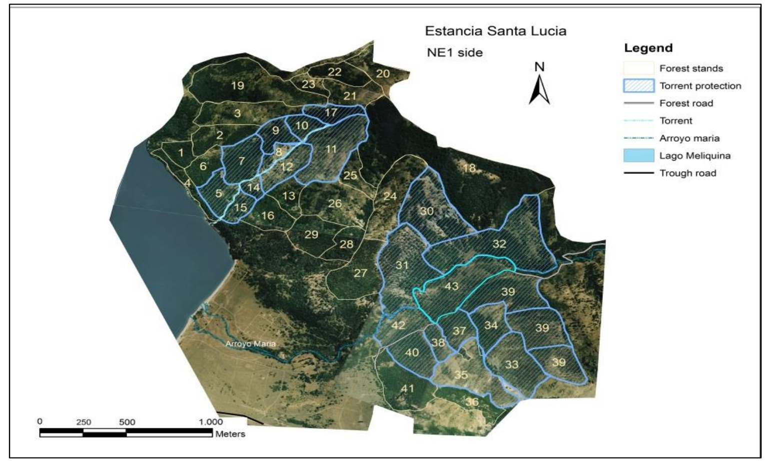
Table 34: Site index for Pseudotsuga menziesii

SI – Pseudotsuga menziesii		Stands
low	≤12,2	-
poor	≤21,3	NE – 35
medium	≤27,4	-
good	>27,4	SW – 44, NE -39a, NE – 69

4.4 Torrential processes and erosion

The maps displayed in Figure 46 show the stands assigned to torrential processes and flood protection.





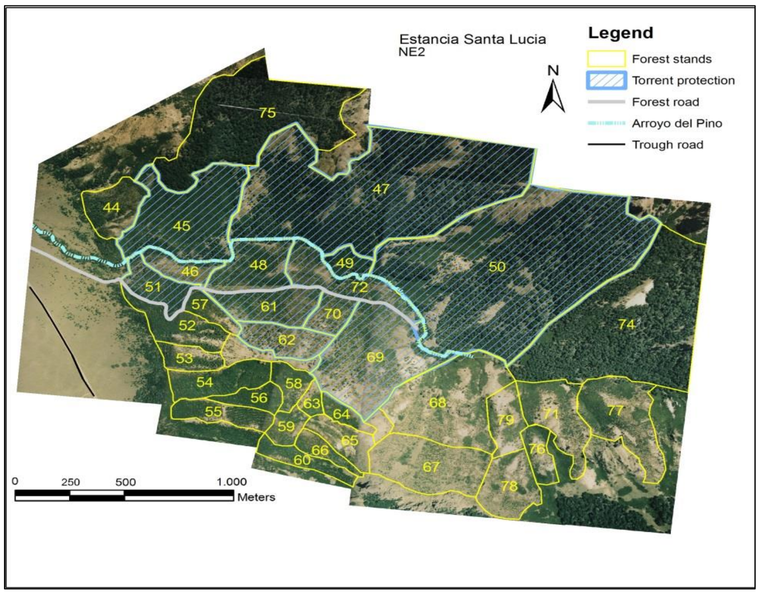


Figure 46: Overview of stands with Flood protection service

Since all soil types are sands or silty sands, the curve CN A has been chosen. The condition of the stands concerning the soil vegetation (combination wood-grass) is displayed in Table 35.

Table 35: Ground vegetation in selected stands

Stand	Ground vegetation cover %	Maximum height [cm]	Mean height [cm]	Species
NE - 35	20	100	50	Lomatia hirsuta
NE - 37	30	200	50	Schinus montanus
NE - 38	10	60	30	Berberis darwinii
NE - 39a	-	-	-	-
NE - 39b	30	180	60	Schinus montanus, Lomatria hirsuta
NE - 39c	10	180	40	Berberis darwinii, Schinus montanus
NE - 40	10	40	20	Schinus montanus
NE - 43	20	200	70	Schinus montanus
NE - 48	-	-	-	-
NE - 62	10	200	50	Schinus montanus, gras
NE - 61	20	100	30	Berberis darwinii, gras
NE - 69	70	200	80	Laurus nobilis
NE - 70	30	180	50	Lomatia hirsuta
NE - 72	30	200	90	Schinus montanus, gras
SW - 70	10	50	20	Schinus montanus
SW - 71	10	150	20	Schinus montanus
SW - 72	-	-	-	-
SW - 74	30	250	100	Nothofagus antartica
SW - 77	60	60	30	gras
SW - 80	-	-	-	-

Table 35 shows that except for the stands NE-39a, NE-48, SW-72 and SW-80 all stands fall into the category “good woods” whereas the rest can be seen as “fair forest”. Nevertheless the curbing effects barely differ. To obtain reference values a rainfall intensity of 89,4 mm/d was entered into the equations (20) and (21). The results can be seen in Table 36, where the effects of the afforestations are visible; comparing both runoff values, from stocked and not stocked areas. While the runoff values of pastures reach up to 31 mm resp. 21 mm, the forest can reduce the values to 5 mm resp. 2 mm

Table 36: Effective rainfall at 20 % resp. 5 % initial subtraction

Class ↓	Cover type ↓	N_{eff} [mm] (20 %)	N_{eff} [mm] (5 %)
Poor	Pasture, grassland, -	31	21
Fair		15	3
Good		9	0
Poor	Woods - grass combination (2)	21	9
Fair		11	1
Good		6	1
Poor	Woods (3).	13	2
Fair		8	0
Good		5	2

The field reconnaissance did not reveal actual erosion surfaces within the forest stands, but in the non-afforested areas in the estancia. Figure 47 shows the erosion areas and the surrounding forest stands that were assigned to the service of erosion protection. The characteristics of the erosion areas are listed in Table 37. Two erosion areas were identified in the SW-side both can be considered as sheet wash erosion areas. In the NE side on the other hand the erosion areas are smaller and classified as ravine erosions (NE-E1, NE-E2, NE-E3 and NE-E4).

Table 37: Characteristics of erosion areas

Erosion surface n°	Length [m]	Width [m]	Type	Form	[°]
SW-E1	350	200	Sheet wash	Elliptic	270/310
SW-E2	600	90	Sheet wash	Elliptic	35
NE-E1	110	80	Ravine	Elliptic	120
NE-E2	220	65	Ravine	Elliptic	260
NE-E3	45	130	Ravine	Elliptic	120
NE-E4	140	65	Ravine	Elliptic	250

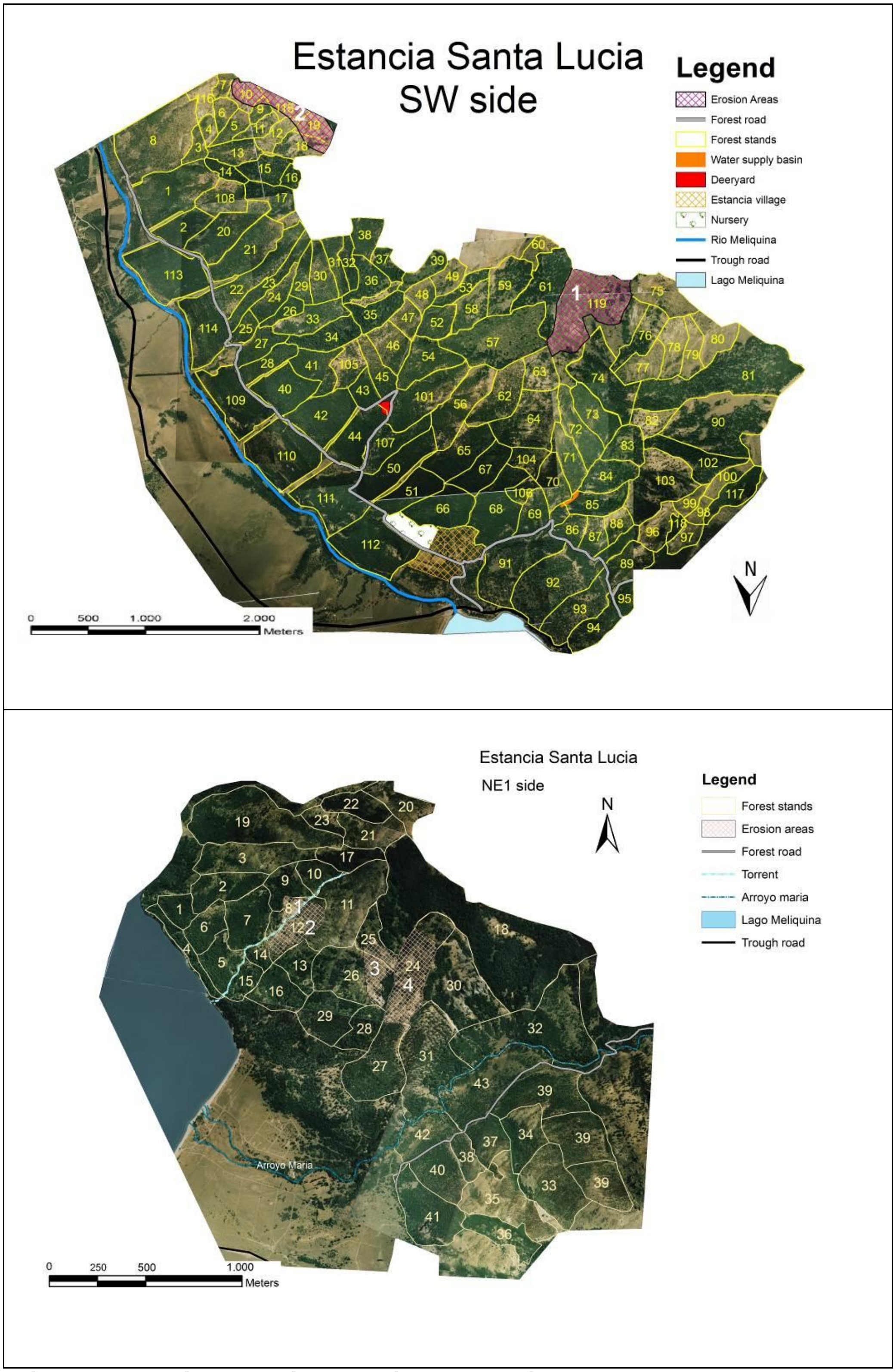
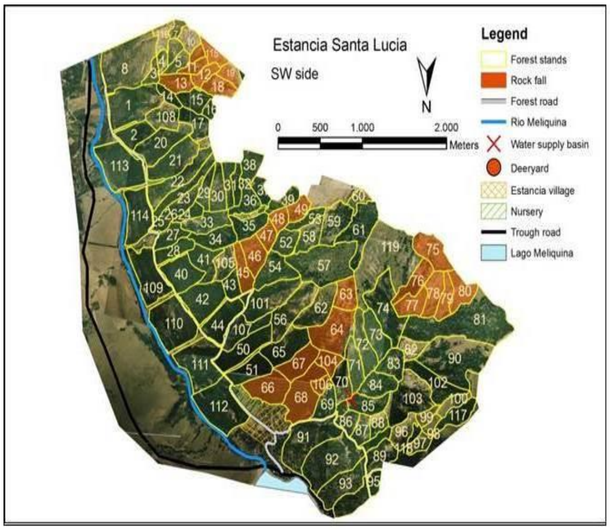
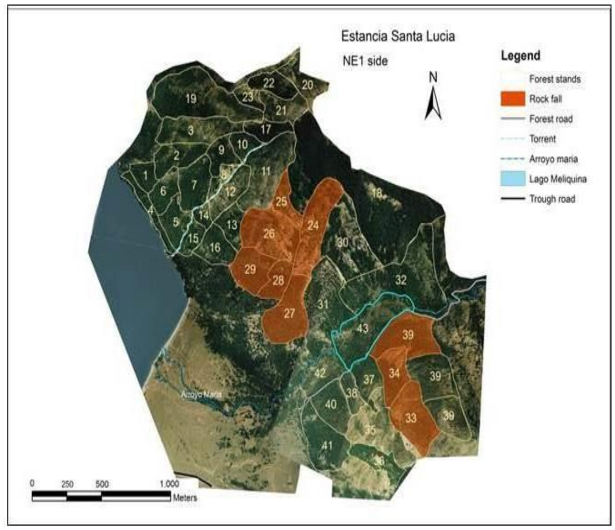


Figure 47: Erosion areas in Estancia Santa Lucia

4.5 Rock fall

47 stands were assigned with the service of rock fall protection, where 27 are located in the SW-side and 20 are located in the NE-side. 11 Stands were particularly examined, 5 situated in the SW-side and 6 in the NE-side. The maps displayed in Figure 48 show the forest stands assigned to rock fall protection.





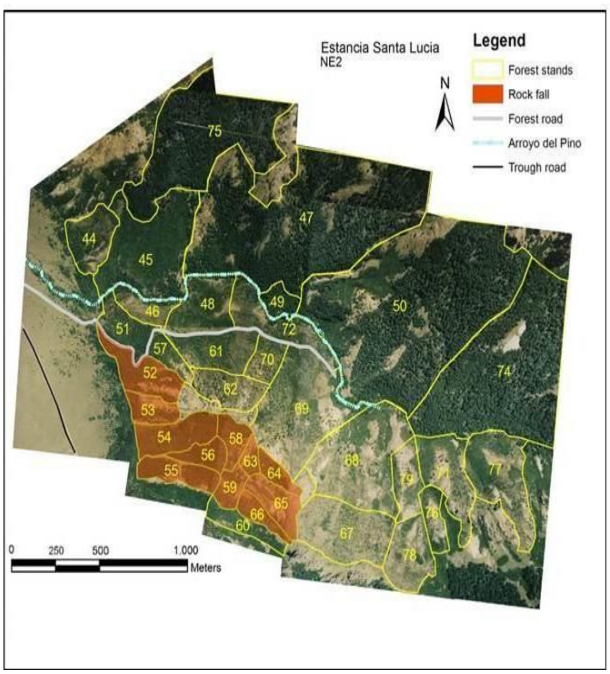


Figure 48: Overview of stands with rock fall protection service

The comprehensive inventory revealed the following results concerning the stand parameters for rock fall protection (see Table 38).

Table 38: Stand parameters for rock fall protection

Stand	NE-25	NE-26	NE-27	NE-28	NE–39a	NE-57	SW–63	SW-64	SW-66	SW-77	SW-80
N /ha	1259	1573	1646	1327	716	1325	634	643	1315	717	623
altitude [m]	1300	1150	1050	1100	1150	1150	1400	1150	1040	1270	1420
Incliniation [°]	36	36	23	35	25	20	35	34	15	33	34
Zone	1	2	3	1	3	2	1	2	3	2	2

The stands NE-25 and NE-63 are located in the trigger zone for potential rock fall. The stands NE-26, NE -28, SW-64, SW-77 and SW-80 lie in the transit zone whereas Ne-27, NE39a, NE-57 and SW-66 are situated in the deposition zone. The sea level varies from 1040m ASL (SW-66) to 1420m ASL (SW-80). Regarding the rock distribution, the comprehensive inventory revealed the results listed in Table 39. Except for the stands NE-63 and SW-77, where the rock size did not exceed 0,2 m^3, the rock size class 3 (0,20 m^3 to 5,00 m^3) was the base for rating. The requirements for the stands NE-25 and SW-63 (no instable, heavy trees in the trigger zone) are fulfilled whereas all other stands (SW-64, SW-80, NE-26 and NE-57) only fulfill the minimum requirements in the transit zone, meeting the minimum stem number with the required DBH >36 cm. and therefore were rated with the lowest grade 3. The stand SW-77 was rated with 2, since the DBH threshold lies at 24 cm and the minimum requirements were fulfilled. The diameter distribution in the assigned stands is displayed in Figure 49. The combination of the aforementioned parameters in the examined stands leads to the rating listed in Table 40.

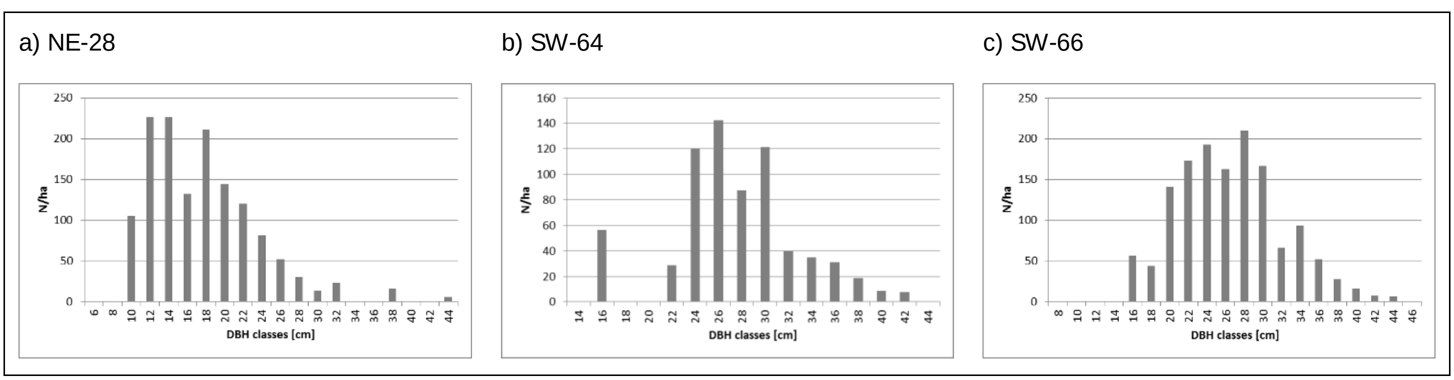


Figure 49: Example of diameter distribution in stands in (a) trigger zone, (b) transit zone and (c) deposition zone

Table 39: Rock distribution in examined stands

Stand	Microrelief class	Size	Shape	Distribution
NE-25	2	1	2	2
	2	1	1	2
	3	3	1	1
	3	3	2	3
NE-26	1	3	2	3
NE-27	3	-	-	-
NE-28	3	-	-	-
NE-39a	3	2	1	2
NE-57	3	2	2	3
	3	3	2	3
SW-63	2	2	2	3
SW-64	2	1	2	2
	2	2	3	3
	2	3	3	1
SW-66	2	2	2	2
SW-77	2	2	2	2
	2	2	1	3
SW-80	3	1	2	3
	3	1	2	3
	3	3	2	3
	3	3	2	1

Table 40: Rating of forest stands assigned to rock fall protection

Stand nr.	SW-63	SW-64	SW-66	SW-77	SW-80	NE-25	NE-26	NE-27	NE-28	NE-39a	NE-57
Rating	1	3	1	2	3	1	3	1	1	1	3

4.6 Nature Conservation

Due to the fact that the SW-side of the estancia is located in a national reserve, all stands in the SW-side were examined towards nature conservation (cf. figure 52).

Figure 50: Map of stands assigned with nature conservation in the SW side

The comprehensive inventory led to the following results concerning nature conservation in the SW- side. Table 41 shows the results concerning the coverage per species in canopy and regeneration.

Table 41: Coverage per species in canopy and regeneration

		Pinus ponderosa	Pinus contorta	Pinus oregon	Austrocedrus chilensis	Lomatia hirsuta	Maitenus boaris
SW - 8	**Canopy**	91 %	-	-	7 %	2 %	-
	Regeneration	-	-	-	-	-	0-5 %
SW - 29	**Canopy**	**-**	**93 %**	**-**	**7 %**	**-**	**-**
	Regeneration	**-**	**-**	**-**	**-**	**-**	**-**
SW - 44	**Canopy**	68 %		32 %	-	-	-
	Regeneration	-	-	10 %	-	-	-
SW - 63	**Canopy**	-	100 %	-	-	-	-
	Regeneration	-	-	-	-	-	-
SW - 64	**Canopy**	100 %	-	-	-	-	-
	Regeneration	5 %	-	-	-	-	-
SW - 66	**Canopy**	90 %	-	-	10 %	-	-
	Regeneration	-	-	-	-	-	-
SW - 70	**Canopy**	94 %	2 %		4 %	-	-
	Regeneration	3 %	-	-	-	-	-
SW - 71	**Canopy**	84 %	9 %		7 %	-	-
	Regeneration	-	-	-	-	-	-
SW - 72	**Canopy**	48 %	52 %	-	-	-	-
	Regeneration	-	-	-	-	-	-
SW - 74	**Canopy**	100 %	-	-	-	-	-
	Regeneration	-	2 %	-	-	-	-
SW - 77	**Canopy**	100 %	-	-	-	-	-
	Regeneration	1 %	-	-	-	-	-
SW - 80	**Canopy**	86 %	14 %	-	-	-	-
	Regeneration	-	-	-	-	-	-
SW - 86	**Canopy**	100 %	-	-	-	-	-
	Regeneration	-	-	-	-	-	-
SW - 99	**Canopy**	75 %	25 %	-	-	-	-
	Regeneration	-	-	-	-	-	-
SW -110	**Canopy**	100 %	-	-	-	-	-
	Regeneration	5 %	-	-	-	-	-
SW - 114	**Canopy**	100 %	-	-	-	-	-
	Regeneration	5 %	-	-	-	-	-

Applying the obtained basal area values resp. regeneration coverage values to the classes in the matrix shown in Table 27, the following results are revealed (see Table

42). As expected none of the autochthonous species in the examined stands exceed the status of “admixed species”. Whether in regeneration neither in canopy a percentage higher than 10 % of cover is reached.

Table 42: Rating of naturalness in forests at SW-side (1 = high, 2 = average, 3 = poor).

Stand	PNV class		Rating	Stand	PNV class		Rating
SW – 8	Canopy	3	3	SW - 72	Canopy	0	0
	Regeneration	3			Regeneration	0	
SW – 29	Canopy	3	3	SW - 74	Canopy	0	0
	Regeneration	0			Regeneration	0	
SW – 44	Canopy	0	0	SW - 77	Canopy	0	0
	Regeneration	0			Regeneration	0	
SW – 63	Canopy	0	0	SW - 80	Canopy	0	0
	Regeneration	0			Regeneration	0	
SW – 64	Canopy	0	0	SW - 86	Canopy	0	0
	Regeneration	0			Regeneration	0	
SW – 66	Canopy	3	3	SW - 99	Canopy	0	0
	Regeneration	0			Regeneration	0	
SW – 70	Canopy	3	3	SW -110	Canopy	0	0
	Regeneration	0			Regeneration	0	
SW – 71	Canopy	3	3	SW - 114	Canopy	0	0
	Regeneration	0			Regeneration	0	

4.7 Hunting

To derive the habitat conditions for deer in the estancia the stand development stages on the SW- and NE-side were determined. The majority of the planted forest stands in the SW-side are classified as young timber (66) followed by pole wood (16). The remaining 6 stands are classified as middle timber. The situation on the NE-side is similar, where 36 stands are in the young timber phase and 12 are classified as pole wood. Terminal phases prevail in natural forests with 12 stands on the SW-side resp. 4 on the NE-side. The optimal phase is represented in 8 stands on the SW side and 4 stands on the NE side. Three stands are in the Initial phase in the SW-side and one on the NE–side. The number and percentage of stands per phase as well as the aptitude towards deer habitat are listed in Table 43 and Table 44.

Table 43: Development stages and habitat aptitude on SW-side of the Estancia

SW-Side				
Development stage	**Number**	**Percentage**	**Habitat aptitude**	**Total**
PW	16	14 %	TC, HC	75 %
YT	66	56 %	TC, HC	
MT	6	5 %	TC, HC	
YG/shrubs	4	3 %	F, HC	25 %
IP	3	3 %	F	
OP	8	7 %	F	
TP	12	10 %	F	
DP	2	2 %	F	

Table 44: Development stages and habitat aptitude on NE-side of the Estancia

NE-Side				
Development stage	**Number**	**Percentage**	**Habitat aptitude**	**Total**
PW	12	18 %	TC, HC	71 %
YT	36	53 %	TC, HC	
YG/shrubs	11	16 %	F, HC	29 %
IP	1	1 %	F	
OP	4	6 %	F	
TP	4	6 %	F	

Concerning the aptitude for deer habitat both sides do not meet the required ratio of 60 % forage to 40 % cover. The afforested stands were all determined as dense since the examined stands exceeded the threshold of 25 m²/ha (cf. Figure 37 and Figure 38)

Concerning the hunting sites, five locations were determined, two in the SW-side and three in the NE-side. The hunting sites in the SW-side are displayed in figure 53.

Figure 51: hunting sites in SW-side

The hunting site 1 is located in the south east part of the SW-side and accessible in a 30 minute walk from the water supply basin of the estancia. The visibility ranges from class 3 at the bottom slope to 1 in the upper slope and therefore was classified with 2. The hunting site 2 is more difficult to access (> 30 minute walk) and therefore rated 3. Concerning the visibility the site was rated 2 due to low visibility on the lower slopes and the good visibility uphill. Applying the matrix (Table 29), the rating of the hunting sites in the SW-side is shown in Table 45

Table 45: Rating of hunting sites in SW-side

	Accessibility Distance next road	Visibility	Rating
Hunting site 1	2	2	2
Hunting site 2	3	2	3

The hunting sites determined in the NE-side are displayed in figure 54 and figure 55.

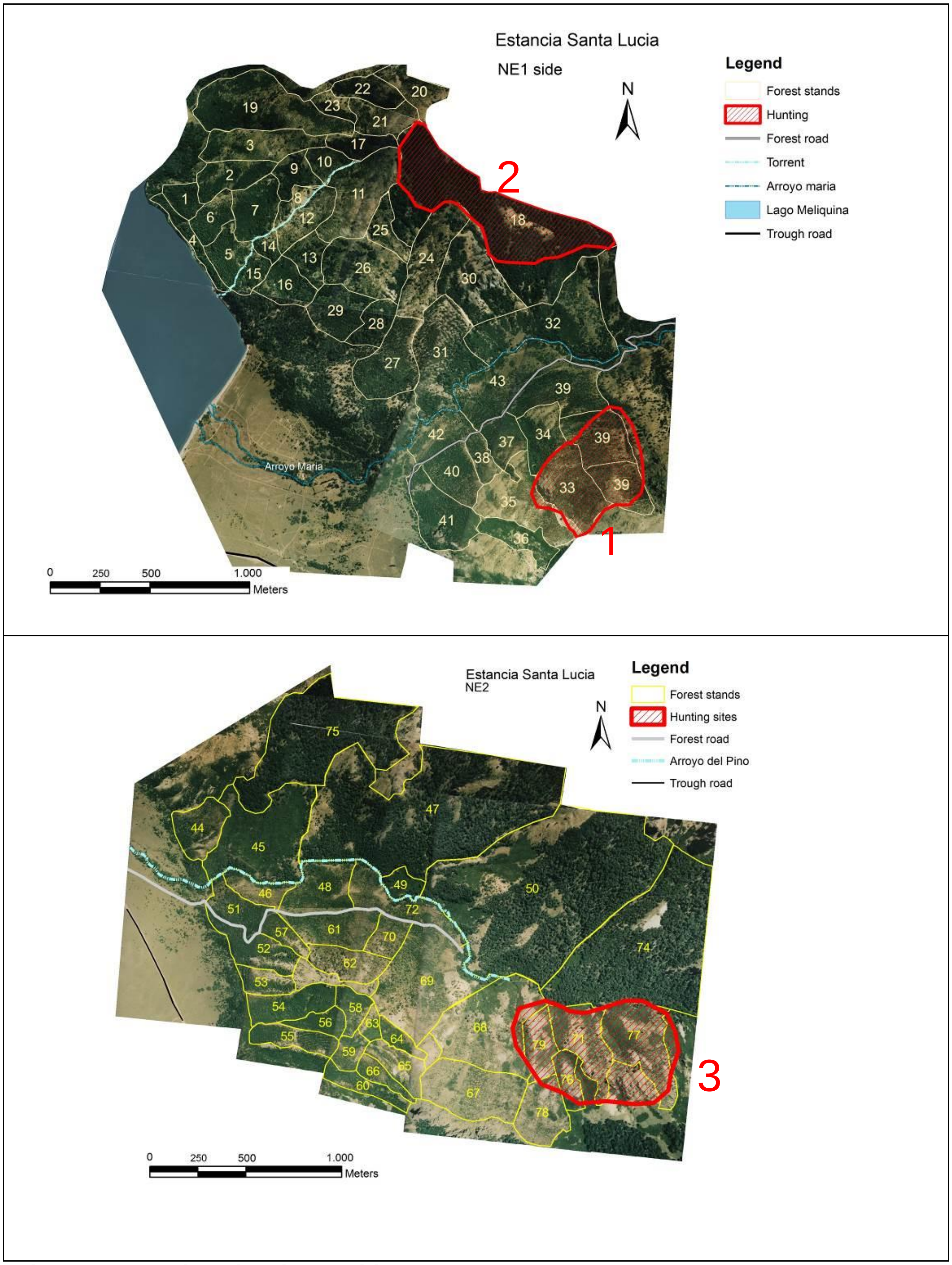


Figure 52: Hunting sites in NE-side

The hunting sites on the NE-side are more accessible than on the SW-side. The average hiking time to the hunting sites 1 and 3 is less than 30 minutes. The hunting site 2 is accessible in less than 10 minutes. The visibility in the site 1 is rated 2 since it is fully stocked at the bottom and almost unstocked at the top. The hunting site 2 is fully stocked and therefore rated 3. The hunting site 3 shows a mixture of forest, shrubs and open spaces, hence the visibility was rated 3. Applying the matrix (Table 29), the resulting rating of the hunting sites in the NE-side is shown in Table 46.

Table 46: Rating of hunting sites in NE-side

	Accessibility Distance next road	Visibility	Rating
Hunting site NE-1	2	2	2
Hunting site NE-2	1	3	2
Hunting site NE-3	2	2	2

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5 Discussion

5.1 General

The assessment of multiple service provisioning is part of modern forest management in countries with a developed and sustainable forestry (Hanewinkel, 2011) The Austrian forest development plan, for example, differentiates between productive service, protective service, welfare service and recreational service of forests (WEP 2012) whereas in the region of Neuquen only a management plan, focusing on timber production (Plan forestal Neuquen, 2006) exists.

Although the Meliquina valley still is sparsely populated, ongoing house constructions indicate a raise in settlements (Olga et al., 2011) which simultaneously raises expectations towards the surrounding forests and vulnerability towards natural hazards. Discussions with residents showed that the awareness towards natural hazards, such as rock fall or floodings, is low. Therefore, the protective services were assigned presuming the needs of the local residents.

With regard to the methodology the intention of this work was to create a data basis for the assessment of forest services. Various methods for a forest inventory are provided (e.g. Schreuder, 1993; WEP 2012) but since no digital forest map material was available, the premises were aggravated. New satellite images were ordered but did not arrive during this work. Due to the lack of georeferenced photos some area related key parameters (e.g. stand areas, areal distribution, stocking level) could not be determined, and therefore complicated the assessment. The age of the aerial photographs also complicated the field reconnaissance since they do not represent the actual forest image. The assessment of services was carried out by adapting guidelines, such as NaiS (Frehner et al., 2005), to the afforestations in the andino patagonian forest. This approach lacked since on the one hand the afforestations are only 30 years old and, on the other hand, the location types differ strongly. Another problem was that the expectations from the residents towards protection and/or recreation are not legally articulated and hence had to be .

5.2 Timber production

The assessment of timber production in terms of volume per hectare proved itself difficult since there are no suitable volume equations for Pinus species. in this region. The equations provided by Gonda (1998) were developed on young growth ponderosa pines between the age of 12 to 20 years. The equations after Pollanschütz (1974) on the other hand, tend to overestimate the volume. Since the trees show an extremely high taper, reaching h/d ratios of 0,4 new equations should be developed to adapt the stem form. This adaptation of existent volume equations could be achieved by measuring the volume of a single stem in sections and therefore determining the stem form (cf. Kramer, 1982). Gonda et al. (2009) proved that the growing rates of Patagonian Pinus ponderosa afforestations exceed those of Oregon and California, where the species grows naturally. A comparison with Californian plantations also revealed that the yield increases proportionally with the number of trees per stand until the age of 40 (Gonda et al., 2009). The basal area can reach values of 100 m²/ha in Patagonian stands whereas Californian stands reach a maximum of 64 m²/ha on best sites. Taking this into account the examined plantations still have not reached their maximum with values between 21 m²/ha (SW-63) and 77 m²/ha (NE-48). The site index curves used in this work are not transferable one to one and should just serve as benchmarks. The different SI values of Pinus ponderosa and Pinus contorta resp. Pseudotsuga menziensii result due to the fact that no site index curves for all species were available from the same region.

No wood trade standards like e.g. Holzhandelsusancen in Austria (FHP, 2006) exist; hence the grading of timber was performed in consultation with the local manager and is whether a standard neither legally binding. None of the local saw mills could give information on any preferences concerning roundwood.

Nevertheless pre commercial thinning is recommended not only to enhance plus trees but also to control possible biotic risk factors.

5.3 Nature conservation

Nature conservation was assessed exemplarily in terms of naturalness of the stands by using the ratio of autochthonous and exotic species. Obviously the biodiversity in afforested stands is rather low and therefore the approval of the afforestations by local residents is poor. Many claim that forests should be managed with autochthonous species (Diario Rio Negro 15.05.2003). But as already mentioned in chapter 2.4 , before the afforestations almost no forest existed and degradation took place. One of the possibilities to increase biodiversity could be a forest conversion from afforested to natural forests by underplanting Nothofagus species. Experiments have already been made in the estancia and the preliminary results look promising. The problem hereby could be negative financial consequences at the beginning due to high investments (van Gember, Meyer Reichelt, 1997). Natural regeneration can be a less expensive option where regeneration cuttings or increment thinning could be carried out to enhance the forest soil conditions due to light (Leibundgut, 1984).

5.4 Torrential processes and erosion protection

The positive impacts of forests on erosion have been proven in many field experiments (Broquen et al. 2003). The capacity of water retention and curbing of overland flow by forests has been discussed and confirmed by several studies (e.g. Markart, 2009). The porosity of soils caused by roots, interception and evapotranspiration by trees also leads to a diminished overland runoff (Ammer et al., 1996). Rickli et al. (1997) showed that the positive impact increases if forests are adapted to the location, which in this case would be accompanied with a conversion into natural forest. Due to lack of information on precipitation or bare material loss in the zone, the results presented in this work just give a brief insight in the effects of forests on precipitation related erosion. Nevertheless, to avoid an enlargement of the erosion areas, no excessive cutting should be performed without ensuring a sustainable regeneration. Existing erosion areas should be refforested considering the positive impact of forests on slope- and soil erosion.

5.5 Rock fall protection

The results presented in chapter 4.4 show different conditions towards the protection capacity of forests. While the stands in the trigger zone fulfill the requirements that were used in this work (Frehner et al., 2005), the stands in the transit zone do not meet the stated demands. The main reason surely is the young age and the correlating small diameters. Nevertheless a curbing of the effects is existent and field experiments have shown that forests cannot fully prevent the occurrence of rock fall events but diminish their impacts (Rickli et al. 2004). Concerning the silvicultural management, Dorren (2005) suggests well-structured stands with a broad diameter distribution.

5.6 Recreation

The recreation service was mentioned but not assessed due to the fact that trespassing is forbidden. Nevertheless, people enter the grounds of the estancia causing the conflicts as shown in Table 47 and making it a very delicate issue. Especially fire hazard, due to incautious behavior of people entering the estancia grounds, states a great hazard e.g. in the year 1998 a fire destroyed great afforested areas in a part of the estancia. This is the main reason why the owners do not want people to enter the estancia grounds. Another urging topic is the problem of poaching which on the one hand leads to a loss of income concerning the guided hunting trips and other the other hand also states an endangerment to the workers. To cope with the problem caused by trespassing, the local forest entrepreneurs have financed a police- and a fire station, one located at the main road 14 km from the estancia, the other situated in the Meliquina valley. However, the police station is barely occupied and the fire station burned down in 2012 (Diario Rio Negro 10.08.2012)

Table 47: Trespassing and possible conflict fields (based on interview with local forest manager)

Form	Possible conflicts/consequences
Tourism/trekking	• Fire hazard • Disturbance of fauna • Endangerment due to accidents/insurance • Trespassing • Illegal
Collection of fire wood	• Fire hazard • Timber robbery • Trespassing • Illegal
Poaching	• Fire hazard • Safety hazard • Trespassing • Uncoordinated “hunting” • Illegal

Yet there is no universal solution to this problem. One way could be to raise the awareness towards fire hazard and integrate all the stakeholders into seeking a dialogue.

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