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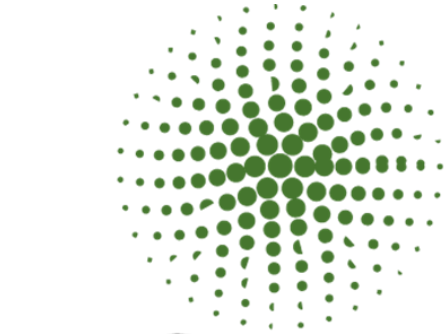

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SCIENCE-BASED INTEGRATED
FOREST MANAGEMENT
FOR CLIMATE MITIGATION

Milestone 2 - Forest management approaches in case studies

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1. Introduction

INFORMA is engaged with five case studies that are real practical examples in the form of forest management units in order to quantify differences in major ecosystem functions between managed and unmanaged forests, to simulate forest growth and dynamics, and to test identified carbon monitoring systems. They are located in 5 different biogeographical regions in Europe. Those five selected biogeographical regions represent about 96% of EU territory and 94% of EU forests. The case study areas have been selected according to several criteria among which good data coverage and high willingness from forest owners to collaborate can be highlighted. The areas are of sufficient size (thousands of hectares) in order to incorporate unmanaged forest areas and to provide a variety of forest management objectives and management practices. Additionally, the selected case study areas have been frequently included in other EU funded projects (e.g. H2020 and LIFE projects), thus allowing for synergies and access to previous data and results. Moreover, the case study areas have other relevant characteristics such as closeness to urban areas, established stakeholder networks or good collaboration with other relevant actors that make these case study areas suitable for this purpose.

Figure 1. Distribution map of INFORMA's case studies.

2. Atlantic forest (Belgium) – Case Study Brabantse Wouden

Figure 2. Sonian Forest, with the city of Brussels in the background (photo by Yves Adams – Vildaphoto).

2.1 Short statement characterizing the case study area

Brabantse Wouden are a set of ancient woodland complexes with high natural value in a densely populated and fragmented landscape. The main focus is on conservation and recreation, but production of high quality timber remains an integral part of the management. Pressures (both environmental and recreational) are high, as are the challenges for local managers having to merge all these functions and demands.

2.2 Key data / information on the case study

Forest Community	Lowland beech, oak-beech and oak-hornbeam forests, both on base-rich and acidocline sediment soils.
Main tree species and their share of the total forest area (in %)	Beech (*Fagus sylvatica*) 50%; pedunculate oak & sessile oak *(Quercus robur / Quercus petraea*) 30%; Scots pine (*Pinus sylvestris*) 10%; other: Sycamore (*Acer pseudoplatanus*), larch (*Larix* spp.), Hornbeam (*Carpinus betulus*) 10%.
Total forest area (ha)	10000
Main management objectives	Multifunctional forest management 85%; strict protection 15%
Main management types	Single and group selection; non-intervention
Management challenges (Disturbances and other challenges)	Windstorm damages; drought; pests and diseases; management of invasive tree species; high recreation pressure; high atmospheric deposition (NOx and NH3); fragmentation and isolation through infrastructure and intensive agriculture.
Total volume (m^3; m^3/ha)	300-500 m^3/ha in managed stands; 400-900 m^3/ha in set-aside areas
Total biomass (Tm CO_2 eq.; Tm CO_2 eq./ha)	Assuming roughly 1 m^3 of average density wood = 1 T CO_2 eq, the 10.000 ha of forest in Brabantse Wouden represent 4.500.000 T CO_2 eq (450 tonnes per ha), aboveground; assuming a similar amount belowground, the total C-stock represents 9 mT of CO_2 eq.
Annual growth (m^3/year; m^3/ha*year)	6 to 12 m^3/ha*year
Annual growth (Tm CO_2 eq./year; Tm CO_2 eq./ha*year)	60.000 to 120.000 T CO_2 eq; 6 to 12 T CO_2 eq /ha*year
Annual harvest (m^3/year; m^3/ha*year)	About 50-70% of the increment, so about 50.000 m^3/year; strong decrease over the last years due to public pressure.
Wood assortments, wood sales and end products	Most of the wood is sold standing, the assorting is done by the buyer. Thinning products in conifer and broadleaves are mostly sold for particle board and paper production; larger logs of broadleaves mainly aim for sawn wood; conifer mainly for industrial wood, packaging materials and particle boards. Low quality log parts and branches are often re-sold to a subcontractor for firewood. Wood is sold in local auctions, and bought by regional companies, but broadleaved logs are now often re-sold and shipped to be processed in East-Asia. Top quality logs are selected and separated from the standard sales by the managers. They are felled by contractors and presented at specialised auctions for local processing in high quality end-products (furniture, stairs, flooring). There used to be a local market specialised in the production of beech veneer, but that has disappeared gradually over the last decades.

	An estimated 70% of the wood is regionally processed, 30% is international.
Ownership	Public
Altitude (max, min and average), m.a.s.l.	50-150 m.a.s.l. (average 100m)
Climate	Average precipitation: 900mm; average temperature: 10°C
Geology and soil	Mainly dry loamy Luvisols (Tertiary calcium-rich sandstone substrate, covered with a 0.5–4 m thick layer of Quaternary niveo-aeolic loess deposits of the Weichselian glaciation); in the higher elevations, the quarternary layer is missing.
Protected forest area (total ha)	Approx. 10% of the forest area (~1000 ha) + 5% in smaller set-aside-patches.
Forest with protective functions (ha)	These forests have a function for groundwater and soil protection but no specific statute for this.
Other figures / interesting facts	Sonian forest is known for its high number of monumental beech trees (over 10.000 trees); in Meerdaal forest, old mixed oak stands occur containing more than 250 year old oak trees. The Hallerbos has a world-wide reputation for its fields of bluebells in spring, attracting visitors from all over the world.
Socioeconomic data	Number of inhabitants depends on border definition. If adjacent cities of Leuven and Brussels are excluded, it is around 250.000 inhabitants; when including the cities, it adds to about 1.5 million. Inhabitants/km²: Density around the case study area is >500 inhabitants per km². Activity sectors: Those are mainly industry and services; some agriculture; forestry is a sector of very marginal relevance both to the region and the GDP. Distance to closest main city (in km): Sonian forest is (literally) adjacent to Brussels (1 Mio inhabitants); Meerdaal-Heverlee is about 2 km from Leuven (100.000 inhabitants); Hallerbos is about 10 km from the Brussels agglomeration.

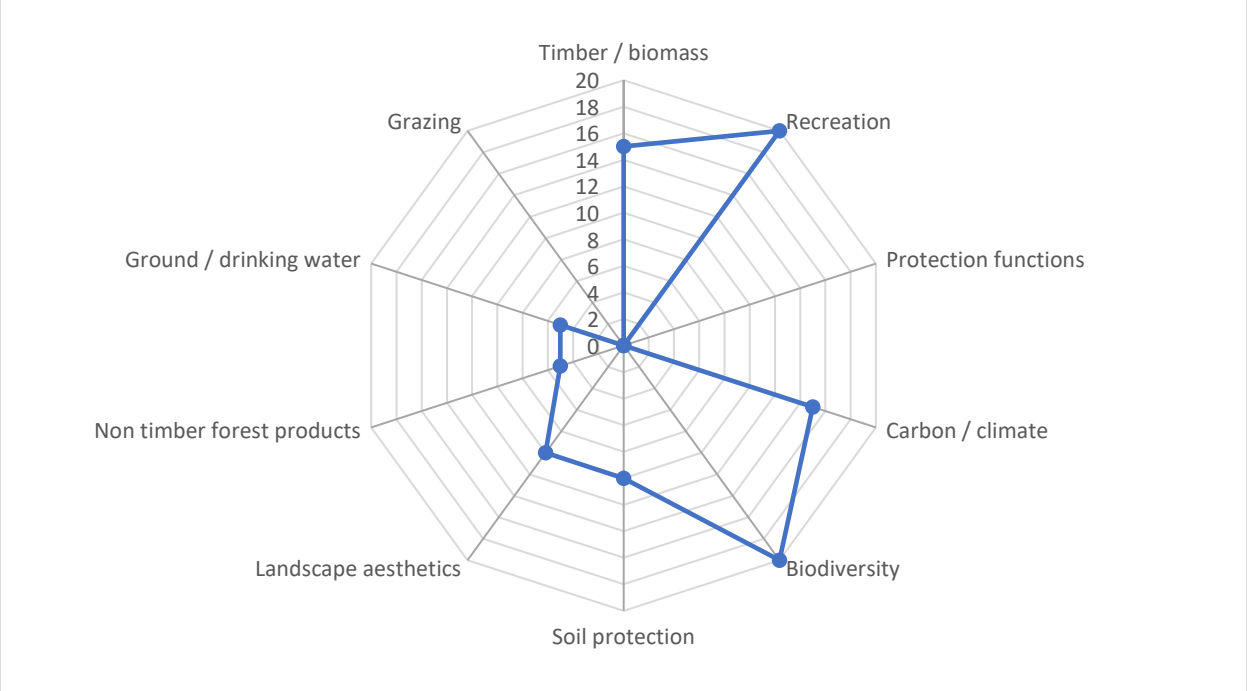

Figure 3. Case study Brabantse Wouden: Expert estimation of relative investment in resources in manpower / finances of the enterprise / forest management unit in different goods and services (in %; total 100).

2.3 General description - Brabantse Wouden case study

Among the most beautiful and oldest forests in Belgium, the 'Brabantse Wouden' (Woods of Brabant) are characterised by more than 10.000 hectares of Atlantic (and Subatlantic) forest, abundant in oak and beech trees, with admixture of maples and pines. The larger forest areas of Meerdaal, Halle, and Sonian forests alternate with smaller forest patches and open fields and larger and smaller cities, creating a mosaic in the landscape.

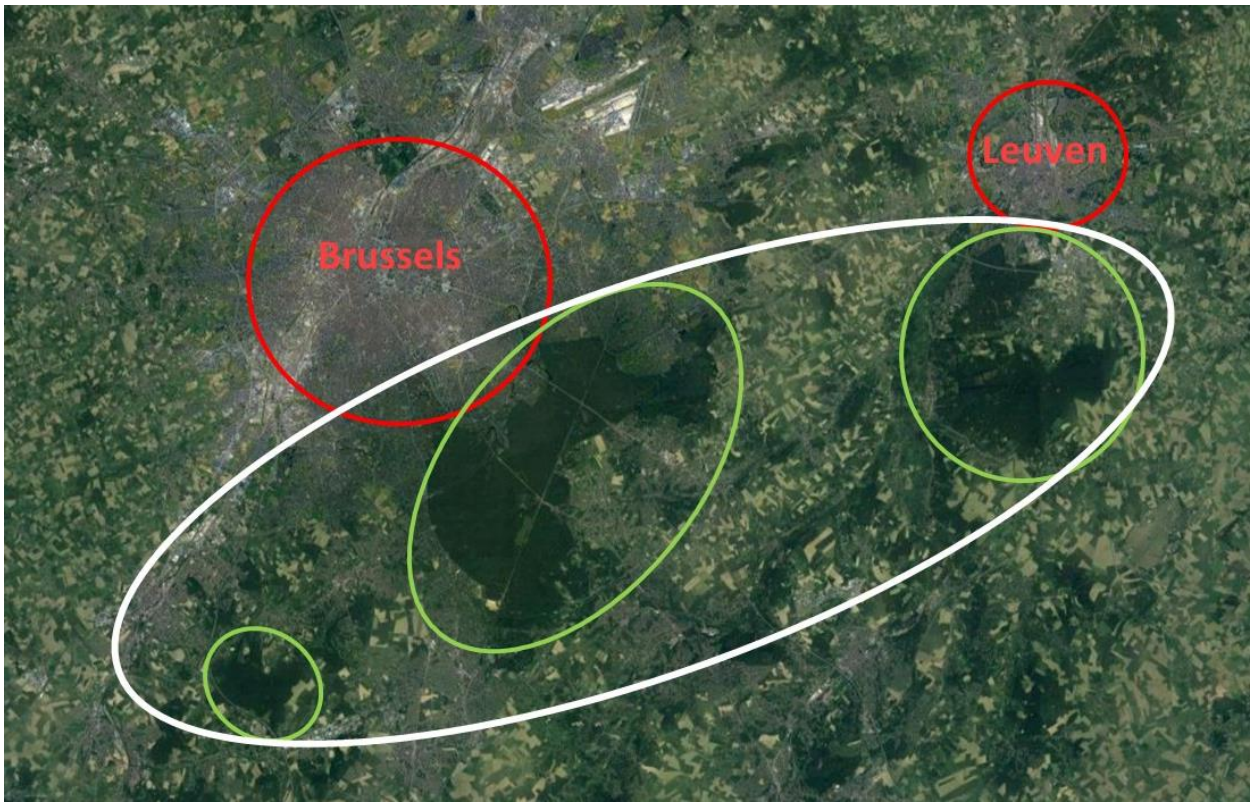

Figure 4. Brabantse Wouden case study forest area map. White = Brabantse Wouden with from left to right: Hallerbos, Sonian, and Meerdaal-Heverlee forest. Remark the proximity of major cities, the dense infrastructure and intensive agriculture in the immediate surroundings. (Background: Google Maps).

The forests are partly under strict protection (about 600 ha of strict reserves + smaller set-aside patches), while other sections are managed for multiple purposes. In the managed areas, small-scale close-to-nature management is the rule, but also patches with more intensive management (mostly conversion of conifer to broadleaved forest) are present. The management aims to ensure that the woods retain their beauty, ecological functionality, and wood production capacity in times of climate change. In order to do so, management practices are adapting to account for more frequent windstorms, drought, pests, and diseases.

All of the forests in Brabantse Wouden have a high natural value: They are all ancient woodland sites, with a rich fauna and flora and are all included in the Natura 2000 network. As Brabantse Wouden is located within a highly urbanised landscape, recreation plays an important role in these forests, receiving over 2 million visitors per year. Management planning and infrastructure therefore need to cater for this high recreational pressure.

Figure 5. A view of a young beech stand in Hallerbos. When bluebells are flowering, large numbers of visitors from far and wide come to see this natural spectacle.

Forest management history and practice

The forests of Hallerbos, Meerdaal, and Sonian Forest are all public forests, managed by the regional forest management service. All of them are 'ancient woodlands', which means that they were never cleared for other land uses. They are shaped by many centuries of intensive but sustainable forest management, but also periods of instability and plundering.

Hallerbos and Meerdaal forest were traditionally managed as mixed coppice-with-standards forests, dominated by oak. Meerdaal forest was gradually transformed into a high forest, mainly of oak and beech, with many of the old oaks still preserved and reaching the age of 200-250 years. Hallerbos was heavily impacted by fellings during the First World War, and was completely replanted with stands of beech and oak in the 1920's. On sandy outcrops, stands of pine and larch were planted in both forests.

Sonian forest has a long tradition of high forest, mainly of beech. The forest has been renowned for its high quality of beech trees. Over the last 150 years, managers have been reluctant to perform final harvesting due to visitor protests and political pressure. This explains the high density of old and impressive trees. While the uneven age structure was long considered a problem from a silvicultural point of view, the old trees are now considered a recreational and ecological asset of the forest and are conserved.

Over the last decades, these forests were mainly managed through selective high thinnings; final harvest was mainly done in small group cuttings (Femelschlag) covering 20 acres to 1 ha.

In the conifer stands, some larger final fellings were performed. Also, some larger fellings were done in beech stands both in Meerdaal and Sonian forest, in both cases because of conversion of the stands to other dominant tree species (e.g. oak and lime) in order to enhance the diversification of the forest.

Challenges for conservation and recreation

As stated before, all three forests have a very high conservation value. They are considered amongst the richest and most valuable oak and beech forests in Flanders, harboring a rich and (relatively) complete typical fauna and flora of Atlantic beech and oak forests. All sites are part of the Natura 2000 network and were designated for the habitat types 9120, 9130 and 9160 (and some smaller patches of 3130 and 6230). They are also important habitats for species of Annex II and IV (including e.g. honey buzzard, middle spotted and black woodpecker, and bats). Stag beetle has some of its last populations in Flanders at the borders of these forests.

Apart from this legal protection, there is also a strong commitment for nature conservation in the management planning. Strict reserves and smaller set-asides have been designated to protect a representative network of the oldest stands in the forest, and within the managed stands, efforts are made to conserve habitat trees, old trees, and increase the amount of deadwood. This already resulted in the return of species like middle-spotted woodpecker.

Important challenges to the conservation efforts are the strong fragmentation of the forests, surrounded by intensive agriculture and infrastructure (e.g. roads, railways, and built-up areas), and related atmospheric deposition. These depositions have diminished over the last decades, resulting in a slow but gradual recovery of the natural vegetation.

Another challenge for forest managers is pressure from the public. These forests have very high visitor numbers, coming from the close by cities. They need to be catered for, and streamlined, by providing parking areas, hiking, and biking trails etc. This public also became more empowered, and informed, so sometimes also criticize the management of the forest, even up to challenging certain harvests in court. To prevent conflicts with the public, forest management also avoids interventions with strong 'visual' impact, such as large final fellings, and organizes public hearings and excursions to explain the management.

Management types

The current management in the three forests can be categorized as follows:

- In young to middle-aged stands: regular selective high thinning (every 6-8 years)
- In older oak stands: mainly group selection final harvest (Femelschlag); some experiments with a light-rich irregular shelterwood (Futaie claire irrégulière)
- In older beech stands: such stands used to be harvested with group selection (Femelschlag), but also here a gradual switch towards irregular shelterwood and continuous cover forestry to place (Plenterwald)
- Conversion: conifer stands (pine, larch) are gradually converted to mixed stands through selective thinnings; the few stands of non-native species like Douglas fir and Norway spruce are gradually phased out using small clearcuts and converted to natural vegetation types (e.g. oak, birch). In the north of the complex Meerdaal-Heverlee forest, there is a local dominance of American red oak (*Quercus rubra*). These stands are gradually transformed to indigenous stands.

Forest management is under continuous evolution as new challenges and demands arise, both new requirements from the public, but also challenges regarding climate change. For instance, it was observed that stands with larger canopy openings suffer much more from prolonged droughts than closed-canopy stands.

More information

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3. Alpine Forest (Austria) - Case Study Northern Limestone Alps

Figure 6. Northern Limestone Alps case study, Austria.

3.1 Short statement characterizing the case study

Extending East-West in Austria, the Northern Limestone Alps are covered by forests extending from subalpine to submontane elevation zones. These forests are of great ecological, economic, and recreational value. Due to climate change, large shifts in growth conditions are expected in mountain forests, requiring the adaptation of forest management practices. Natural disturbances are increasingly frequent, particularly windstorms, and bark beetles. Current management in the Austrian case study focuses on timber production in certain areas and on nature conservation in others (i.e. nature reserves), where there is no human intervention or very low-intensity management. The naturally predominant tree species are Norway spruce, silver fir, larch, beech, and mountain maple, but the current composition is dominated by Norway spruce, which has been favored historically for its superior growth performance and ease of management.

3.2 Key data/ information on the case study

Forest Community	Submontane: beech; montane: spruce-fir-beech. subalpine: spruce-larch
Main tree species and their share of the total forest area (in %)	Norway spruce (Picea abies); Common beech (Fagus sylvatica); Silver fir (Abies alba); sycamore (Acer pseudoplatanus); different pine species (Pinus spp.); European larch (Larix decidua)
Total forest area (ha)	10000
Main management objectives	Timber production; nature conservation; protection against gravitational hazards
Main management types	Strip cutting or strip wise shelterwood approach with aim of timber production; low or no intensity management in the case of nature conservation objectives
Management challenges (Disturbances and other challenges)	Windstorm damages; bark beetle infestations; browsing by ungulates
Total volume (m^3; m^3/ha)	Mean volume is appr. 342 m^3/ha
Total biomass (Tm CO_2 eq.;Tm CO_2 eq./ha)	NA (not available)
Annual growth (m^3/year; m^3/ha*year)	Appr. 9-10 m^3 ha^{-1} yr^{-1}
Annual growth (Tm CO_2 eq./year; Tm CO_2 eq./ha*year)	NA (not available)
Annual harvest (m^3/year; m^3/ha*year)	Appr. 70.000 m^3 yr^{-1}
Wood assortments, wood sales and end products	Wood assortments: sawn wood; industrial wood (pulp & paper); fuel wood Wood sales: 10% local; >70% regional; (<20% national)
Ownership	Federal land
Altitude (max, min and average), m.a.s.l.	600-1700 m.a.s.l.
Climate	Dependent on the elevation zone; in general, characterised as humid (MAP >1500 mm yr^{-1})
Geology and soil	Limestone; glacial deposits; cambisol; rendzic cambisol
Protected forest area (total ha)	Wilderness area “Dürrenstein”
Forest with protective functions (ha)	Appr. 30%
Socioeconomic data	District Scheibbs (appr. 40.000 inhabitants, appr. 1000km^2)

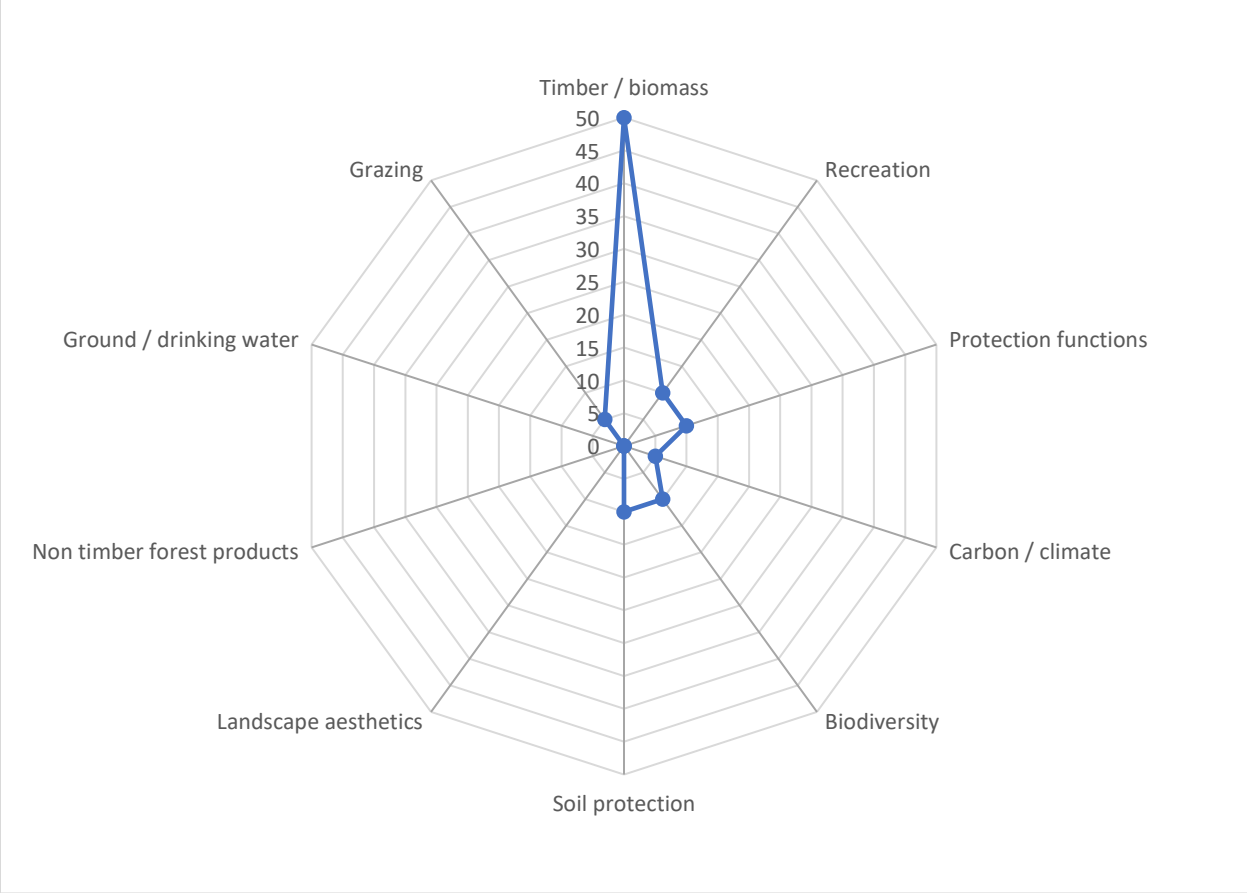


Figure 7. Case study Northern Limestone Alps: Expert estimation of relative investment in resources in manpower / finances of an enterprise / forest management unit in different goods and services (in %; total 100).

3.3 General description - Northern Limestone Alps case study

The Management District Göstling is the INFORMA case study area Northern Limestone Alps. Göstling is part of the Unit Voralpen of the Austrian Federal Forests (AFF) and comprises of appr. 10.000 ha of primarily forests but include alpine unproductive land as well. The land base extends from appr. 600 m at the valley bottom to appr. 1800 m in altitude. The area is rather remote and is located next to the National Parks "Dürrenstein" and "Kalkalpen". Traditional forest management objectives include timber production, wildlife management, and hunting as well as protection from gravitational hazards (avalanches, rockfall, erosion, and landslides).

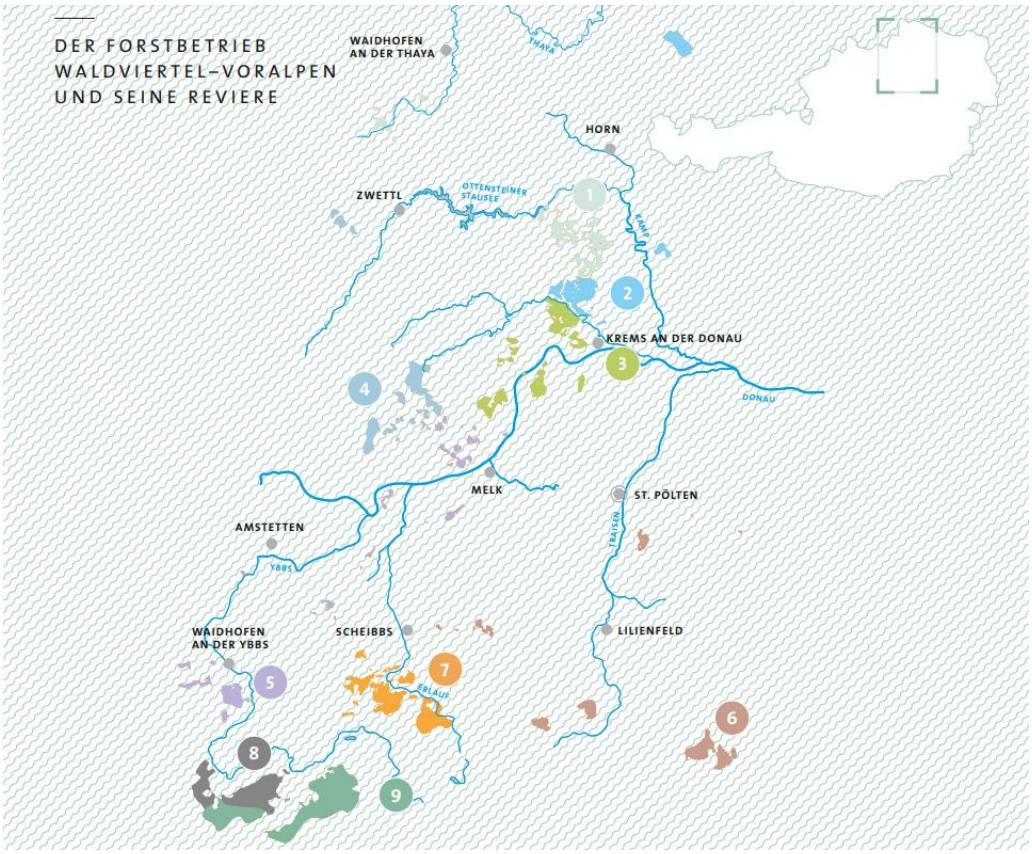


Figure 8. Austrian Federal Forest Management Unit Voralpen. Göstling (#7) is the INFORMA case study area (top). Unmanaged forests located in the nearby National Park Dürrenstein (bottom).

Extending from Austria to South-Eastern Germany, the Northern Limestone Alps are covered by alpine forests of great ecological, economic, and recreational importance. Due to climate change, large shifts in growth conditions are to be expected in mountain forests in this region. Such impacts will require well adapted forest management practices. Natural disturbances in the case study region are increasingly frequent, in particular windstorms and bark beetle infestations. Even though not as obvious as other disturbances the impact of ungulate browsing constitutes a severe problem for stand regeneration (natural, planting) and may require costly protection measures.

Current management in the Austrian case study focuses on timber production in certain areas and on nature conservation in others (i.e. nature reserves), where there is no human intervention or very low-intensity management. Main management approach is the strip wise shelterwood method in which mature trees are removed in a series of cuttings, enabling the stand to regenerate below the partial shelter of the remaining old trees. Regeneration may also be actively supported by planting. The naturally predominant tree species are Norway spruce, fir, larch, beech, and mountain maple. The current composition is dominated by Norway spruce, which has been favoured historically for its superior growth performance and ease of management.

As Norway spruce is a particularly vulnerable species in a changing climate, the overall strategic aim is to reduce its share in species composition and establish mixed-species stands. In order to achieve this shift in tree species composition measures to minimise browsing of target species (in particular silver fir and beech) need to be implemented.

4. Continental forest (Romania) – Case Study Râșca Forest District

Figure 9. Râșca Forest District case study landscape image.

4.1 Short statement characterizing the case study

The case study is characterised as a multifunctional forest with an emphasis on timber production, embedded in a complex socio-cultural context. It has a high diversity of forest species, ranging from mixed forest stands with beech, Norway spruce, and silver fir to pure stands of beech or Norway spruce. There is a traditional community in the proximity of the forest, with monasteries built within the forested areas. Forest management planning considers multiple ecosystem services through a functional zoning system and a strict timber production continuity approach.

4.2 Key data/ information on the case study

Forest Community	Mixed silver fir-beech forests and Norway spruce-silver fir-beech forests
Main tree species and their share of the total forest area (in %)	Silver fir (Abies alba), Norway spruce (Picea abies), and beech (Fagus sylvatica).
Total forest area (ha)	13.000 ha
Main management objectives	Wood production
Main management types	Shelterwood cutting and group selection management; rotation periods >120 years); natural regeneration.
Management challenges (Disturbances and other challenges)	Windstorms, snow, and pest disturbance; limited management infrastructure
Total volume (m^3; m^3/ha)	311 m^3/ha
Total biomass	80 Tm CO_2 eq./ha
Annual growth (m^3/ha*year)	6.9 m^3/ha*year
Annual growth (Tm CO_2 eq./year; Tm CO_2 eq./ha*year)	1.7 Tm CO_2 eq./ha*year
Annual harvest (m^3/year; m^3/ha*year)	65.000 m^3/year; 5 m^3/ha*year
Wood assortments, wood sales and end products	Wood assortments produced in the case study are e.g., sawn wood, industrial wood and wood chips. Wood sales take place at local and regional level. End products include planks, construction beams, pellets/briquettes, and plywood.
Ownership	State owned
Altitude (max, min and average), m.a.s.l.	200 to 1200 m.a.s.l.
Climate	Precipitation (annual sum): 730 mm; Temperature (annual average): 6.5˚ C
Geology and soil	Geology: mainly sandstone and marl Soils: eutric cambisol (pH=5.8–6.9; 8-10% humus; silty loam clay texture) dystric cambisol (pH = 4.5–5.1; 10-13 % humus; sandy clay texture)
Protected forest area (total ha)	0 ha
Forest with protective functions (ha)	1.000 ha
Other figures / interesting facts	Game management unit with wild boar, red and roe deer; bear, wolf, lynx, and wild cat are excluded from hunting Local use of berries and mushrooms with low level of organization for picking and trading.
Socioeconomic data	Nº inhabitants in case study area 8.900 inhabitants/230 km^2.

	Percentage by activity sectors in the case study area: 40% agriculture; 30% forest related activities; 10% tourism; 10% administrative sector; 10% commerce. Distance to closest main city (in km), 30 km to Falticeni Area of touristic and religious importance: one UNESCO World Heritage Site – Rasca Monastery; Slatioara Monastery; two religious hermitage sites in the forest. Small manufactures for wood furniture and religious sculptures.

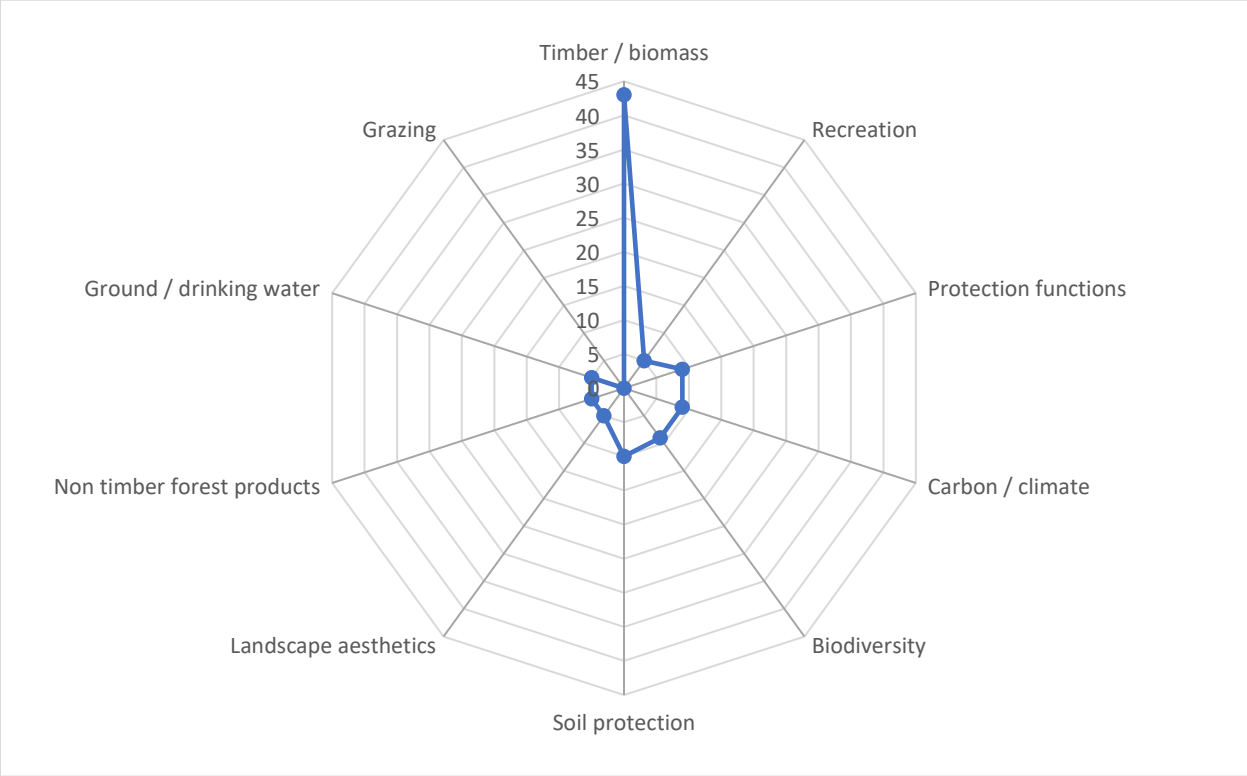


Figure 10. Case Study Râșca Forest District: Expert estimation of relative investment in resources in manpower / finances of an enterprise / forest management unit in different goods and services (in %; total 100).

4.3 General description - Râșca Forest District case study

The total area covered by forests in Romania amounts to 7.04 million ha (27% of Romania's territory) of which 4.16 million ha are in mountain areas. Also, it includes a large portion of Europe's continental primary beech forests. Of the total forest area, 3.14 million ha are owned and managed by the state. The Romanian forests are classified into three main management types: strictly protected forests (no harvest), protection forests, which are forests for which the primary objective is not wood production, and

production forests. For the protection forests, the main management objective is to protect ecosystem services, which are further split into multiple possible categories, depending on the scope: water protection, soil protection, protection against climate change impacts, society protection, scientific interest, and biodiversity conservation. More than 26.7% of state-owned forests belong to the soil protection category. In the protection forests, management is strongly conditioned by the protective function, resulting in limitations of harvesting methods and their intensity, and even complete exclusion of forests from wood production.

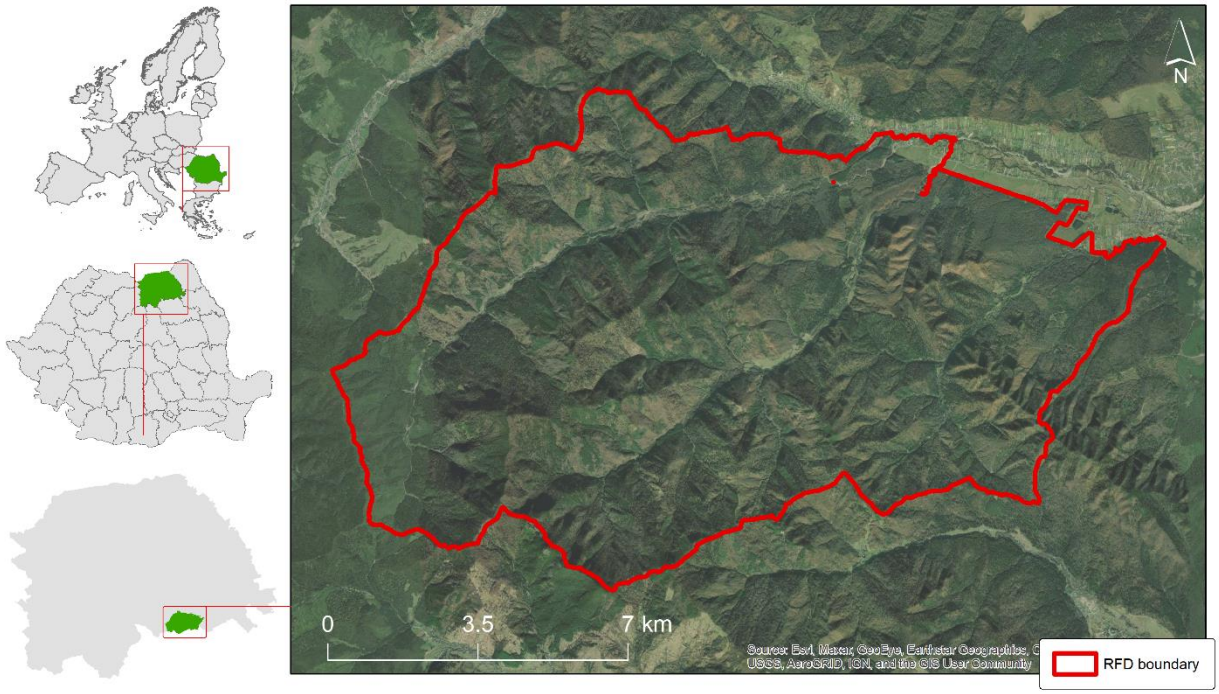


Figure 11. Râșca Forest District case study forest area map.

Within INFORMA, the case study is Râșca Forest District in the County of Suceava (North-Eastern Romania). The area of 13.000 ha is dominated by Norway spruce and beech. These forests are typically mixed broadleaved and coniferous forests. Admixture is frequent, with both conifers (Abies alba, Pinus sylvestris) and broadleaved (Fraxinus sp., Acer sp., Prunus sp.). Admixture, locally adapted species, natural regeneration, and long rotation periods are the main targets of the forest management.

In productive forests, the regular management is based on long rotation periods of over 120 years. Natural regeneration is obtained using both shelterwood cutting and group selection. Thinning intensity is likewise rather low. Consequently, the growing stock (above ground biomass) are quite high. When stands exceed the age of 80 years, harvest is possible only in the form of salvage cuttings. Within the district, an area of 1.000 ha is protected for soil erosion control and thus managed with an even lower intensity of harvesting.

Damages caused by windstorms and limited management infrastructure (lack of forest roads) are the most relevant management challenges faced in the Râșca Forest District. Currently, the enterprise sees no eminent need for adapting their forest management approaches.

Socioeconomic description

Râșca Forest District is a compact forest area of 13.000 ha, owned by the state and managed through Râșca Forest District Administration, a part of the Romanian National Forest Administration. The forest is located on the Eastern part of the Carpathian Mountains with altitudes ranging from 200 to 1200 m. The two municipalities in the Râșca river basin (which originates from the forest area) are Râșca and Bogdanesti, with a total number of inhabitants of about 9000. Most of the inhabitants are involved in agricultural activities, even though it is not their main livelihood (most of them being employed locally or in the nearby city). The small-scale farms are oriented on crops and dairy farming. The local timber industry is represented by few small to medium-size sawmills.

Some of the locals are involved in small manufactures of handcrafted furniture and sculpture of religious items. Most of the tourism revolves around the several religious entities in the area: two monasteries (one of which is a UNESCO World Heritage site) and two hermitage settlements in the forest. The area was also, to some extent, affected by the exodus to the city and working abroad (a general tendency in the entire region).

Figure 12. Râșca Forest District case study representative stand image.

References:

RNP, 2019. Forest management plan, Râșca Forest district. Ministerul Cercetării și Inovării, Institutul Național de Cercetare-Dezvoltare în Silvicultură “Marin Drăcea” - Stațiunea BRAȘOV, Amenajamentul Ocolului Silvic Râșca Direcţia Silvică Suceava, Studiu General. Unpublished.

5. Mediterranean forest (Spain) – Case study Segre-Rialb Basin

Figure 13. Segre-Rialb Basin case study landscape images.

5.1 Short statement characterizing the case study

Mediterranean forests are a unique natural world heritage in terms of biological diversity. In North-eastern Spain, the Rialb reservoir, fed by the river Segre, is encircled by scenic Mediterranean forests that climb the surrounding hills and mountains. The oak and pine forests in the area serve a multitude of purposes such as water provision, carbon sequestration, and wood production. The Mediterranean has been identified as a major hotspot in relation to climate change. The primary projected impacts on Mediterranean forests are increased risk of large and more frequent fires and a decrease in water availability. These challenges are present in the case study area Segre-Rialb Basin.

5.2 Key data/ information on the case study

Forest Community	Pre-Pyrenean forests dominated by black pine in north-facing slopes and holm oak in south facing slopes. Regeneration of Portuguese oak covers the area affected by a wildfire in the 70s. Scots pine dominates the highest altitudes and Aleppo pine, the lowest.
Main tree species and their share of the total forest area (in %)	59% Black pine (Pinus nigra), 20% holm oak (Quercus ilex) and 14% Portuguese oak (Quercus faginea)
Total forest area (ha)	26.900 ha (forest + bushes + pasture) 21.385 ha (forests > 20% canopy cover); pines (15.000), holm oak (3000), and other tree species (3385)
Main management objectives	Wood production; fire prevention; water provision; carbon storage
Main management types	Uneven-aged management for pines, with negative selection of trees, leading to an even-aged structure with no regeneration
Management challenges (Disturbances and other challenges)	Forest fires; drought and low water availability; orographic constraints and accessibility; intensive harvesting in the past and negative selection (thinning based on diameter)
Total volume (m^3; m^3/ha)	75,52 m^3/ha; 2.640.540,6 m^3 (35.000 ha)
Total biomass (Tm CO_2 eq.;Tm CO_2 eq./ha)	Total Aerial Biomass: 56,86 t/ha; 1.988.229,3 t (35.000 ha) Carbon: 28,37 t/ha; 991.963,8 t (35.000 ha)
Annual growth (m^3/year; m^3/ha*year)	55.800 m^3/year (18.000 x 3.1); 3.1 m^3/ha/year (Only oak and pine species)
Annual growth (Tm CO_2 eq./year; Tm CO_2 eq./ha*year)	n.a.
Annual harvest (m^3/year; m^3/ha*year)	10.441 m^3/year; approx. 30 m^3/ha every 15 years
Wood assortments, wood sales and end products	Wood assortments produced in the case study: sawn wood from pines and firewood from oaks. Wood sales; local/regional: 100% End products: pallets, pellets, firewood, and a small percentage of structural wood

Ownership	Mainly private
Altitude (max, min and average), m.a.s.l.	362 to 1600 m.a.s.l.; average 700 m.a.s.l.
Climate	Annual average temperature 13.5 C (average max: 20.4 C; average min: 7.2 C; monthly max: 31.0 C; monthly min: 0.0 C); Annual average precipitation: 750 mm
Geology and soil	We provide data for 2 different plots in the area: <u>Plot 1</u> Topography — Elevation (m): 1235 Slope (º): 14 Aspect (º): 40 (NE) Soil — Texture (% and/silt/clay): 0-30: 85/7/8; 30-50: 83/7/10 Bulk density (kg/m^3): 1.26 / 1.43 Rock fragment content (% vol.): 2.8% / 8.1% Soil depth (cm): 50 Soil extractable water (mm): 5 <u>Plot 2</u> Topography — Elevation (m): 705 Slope (º): 16 Aspect (º): 320 (NW) Soil — Texture (% sand/silt/clay): 0-30: 55/30/12; 30-50: 46/31/25 Bulk density (kg/m^3): 1.11/1.26 Rock fragment content (%vol): 8.4% / 39% Soil depth (cm): 90 Soil extractable water (mm): 216
Protected forest area (total ha)	7.800 ha (30% of the case study area)
Forest with protective functions (ha)	n.a.
Other figures / interesting facts	• Num. forest owners: 1.061 • Mean forest area: 25 ha (6 ha in Ponts area to 67 ha in La Baronia) • Increment of forest area in last 25 years = 5.2% • Areas under Natura 2000: 23% of forested area (6,390 ha) • 44.7% reduction in precipitation and 27.6% in water flow in the last 55 years
Socioeconomic data	• Inhabitants (6 municipalities): 5.382 • Main activity sectors: agriculture, husbandry, and related industry (50%); tourism (50%) • Distance to closest main city (Lleida: 70 km)

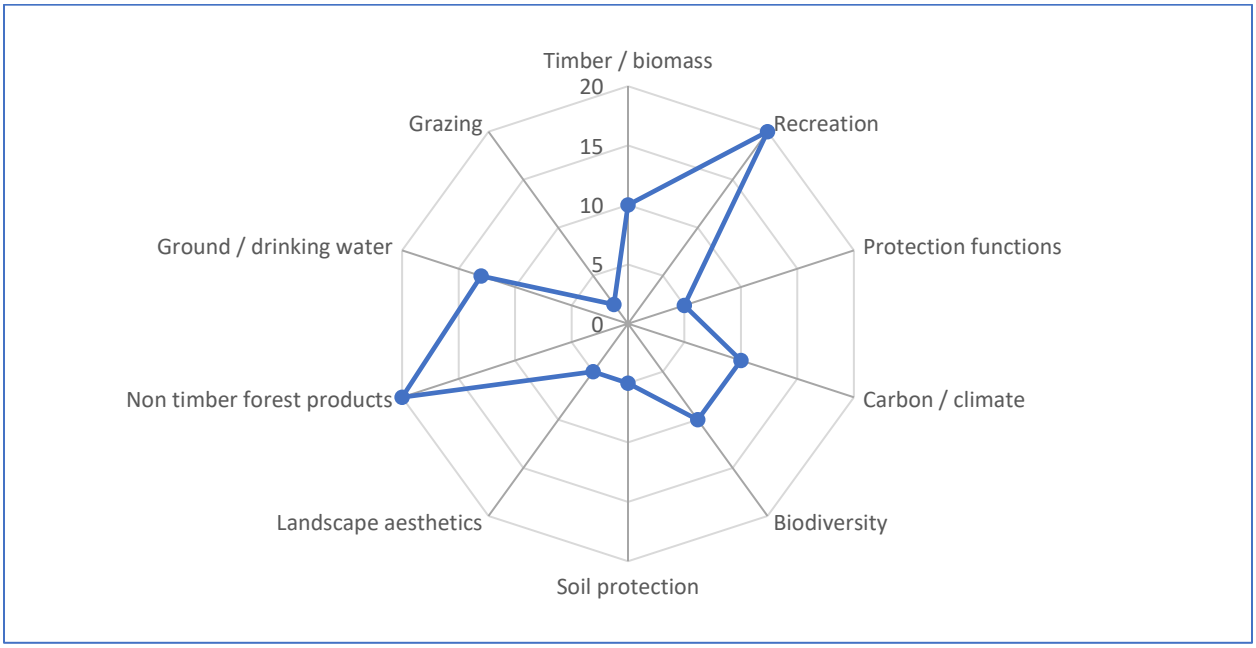


Figure 14. Case study Segre-Rialb Basin: Expert estimation of relative investment in resources in manpower / finances of an enterprise / forest management unit in different goods and services (in %; total 100).

5.3 General description - Segre-Rialb Basin case study

The Segre-Rialb basin area comprises the 35.000 hectares covering the 6 municipalities affected by the construction of the Rialb water reservoir: La Baronia del Rialb, Bassella, Oliana, Peramola, Ponts, and Tiurana. A continuous rural exodus has led to a significant decrease in local population during the past century. For instance, La Baronia de Rialb decreased from 1.244 inhabitants in 1900 to 835 in 1950 with currently (2022) no more than 229 inhabitants. Like in other Mediterranean countries, this rural abandonment has caused a forest transition in the last sixty years: depopulation, associated with decreasing agricultural activities, led to land abandonment, which induced land use change with former fields naturally evolving into new forests. The water reservoir of Rialb is the second largest and the most recent reservoir in Catalonia. It was constructed in 1992 and caused the submersion of the lowest and most fertile pieces of land of the valley. Eventually inaugurated in 2000, the Rialb reservoir has a 400 hm^3 capacity and provides water to 80 municipalities, through the Segarra-Garrigues Canal and the Urgell Canal, and two small hydroelectric power plants. In 2008, the Consortium Segre-Rialb was created to coordinate economic development and tourism promotion in the six municipalities. Thanks to the touristic appeal of the water reservoir, the forested landscape aesthetics and opportunities for hiking and mushroom picking, tourism is now an important source of income in the area. For instance, La Baronia de Rialb counts the highest number of rural tourism homes in Catalonia, with over 150 *masies* (rural homes).

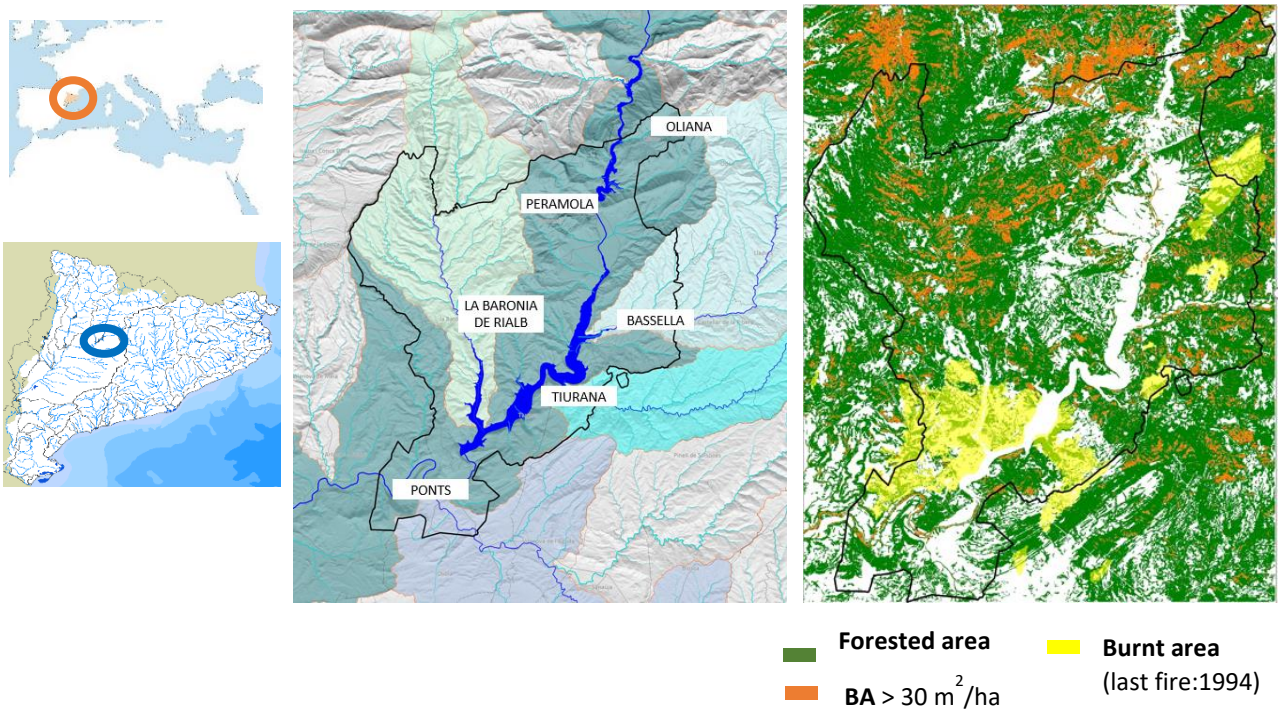


Figure 15. Segre-Rialb Basin case study forest area map (BA = basal area).

Main trees species in the case study area are black pine (Pinus nigra), holm oak (Quercus ilex), and Portuguese oak (Quercus faginea). The forest is mainly privately owned. Main management objective is wood production, but also truffles are a good source of income for forest owners. However, forestry is limited because it is considered a non-profitable activity. Besides the typical low productivity of Mediterranean forests, the complex topography of the area and inaccessibility of some of the most productive areas, make harvest operations difficult and expensive, thereby again reducing profitability. In addition, many forests require investment to become productive in the mid-term, especially after regular heavy thinnings in the past or after the occurrence of wildfires. These factors are particularly relevant in a region where around 80% of forests are privately owned. Nowadays, truffle production is the most profitable forest activity in the region.

36% of the total private forest lands are under a forest management plan (in accordance with the average for Catalonia, where forest management plans are voluntary). The percentage varies considerably between the six municipalities. The highest percentage of private forests under management plan is in La Baronia de Rialb with 47%, which is due to an increase in truffle production in the municipality over the last decade. Observations regarding non-managed forest areas indicate that they may increase the risks of large forest fires, diseases, and mortality during drought episodes, which are only expected to be exacerbated by climate variability and change. While tree cover in the basins is essential to water quality, increasing vegetation cover impacts the amount and efficiency of water use by forests, thereby potentially decreasing water availability for humans. In the area, forest management is seen as potentially being able to attain three different targets:

- Wood production: most common management objective;
- Fire prevention: work with horizontal and vertical forest continuity;
- Water provision: Increment of removed basal area

Wood production is usually the only objective for private forest owners although fire prevention measures are more and more being taken into account. The Catalan Government has recognised the threat of more extreme fires and droughts and is promoting and pushing for more sustainable forest management practices. Hence, the government is providing tools (i.e. maps with priority areas) and incentives for private forest owners to engage in forest management in strategic locations, mainly for fire prevention. In addition to fire prevention measures, research is being conducted to identify the most promising locations for water production. Direct investments in private property for fire prevention objectives are also being made.

In Catalonia, a set of silvicultural models for different tree species were devised integrating two main objectives: wood production and fire prevention. They are called the Sustainable Forest Management Guidelines of Catalonia (ORGEST). Here you can see two examples for Pinus nigra applied in the area:

Model ORGEST Pn03: Even-aged stand – Pinus nigra

High quality site with main objective wood production and fire prevention in fire prone areas; rotation: 85-105 years (diameter ~40 cm); low thinnings every 10-20 years; final tree density: 450 stems/ha; natural regeneration by successive thinnings in three phases.

Table 1: Model parameters of even-aged Pinus nigra model. Explanations of abbreviations in table: **RM** (bush cover); **AM** (bush height); **DC** (distance between fuels - crown fuel and bush fuel); **N** (Tree density); **AB** (Basal Area); **VAE** (Volume including bark); **Edat** (Age).

Paràmetres silvícoles del model												
										Requeriments en zona d'alt risc		
H_0 (m)	N (peus/ha)	D_g (cm)	AB (m^2/ha)	VAE (m^3/ha)	Edat (anys)	Actuacions	Ne (peus/ha)	VAEe (m^3/ha)	ABe (%)	RM* (%)	AM* (m)	DC* (m)
6	>4.000	6	-	-	12-16	Aclarida de plançoneda	>1.900	-	-	<30	<1,3	ind
10	**2.100**	10	18	68	20-24	Aclarida baixa	1.000	-	23			
16	**1.100**	20	33	204	36-44	Aclarida baixa	400	47	23	ind	<1,3	>4
20	**700**	28	42	321	53-67	Aclarida baixa	250	73	23			
22	**450**	33	39	333	69-85	Tallada preparatòria	225	135	41	-		
23	**225**	~40	28	244	79-99	Tallada disseminatòria	135	146	60			
23,5	**90**		12	110	85-107	Tallada final	90	110	100			
Opció d'allargar el torn (recomanat en zona d'alt risc)												
22	**450**	33	39	333	69-85	Aclarida baixa	130	78	23	ind	<1,3	>4
25,3	**320**	42	50	481	118-148	Tallada preparatòria	130	195	41	-		
25,7	**170**	~45	31	306	129-161	Tallada disseminatòria	115	185	61			
26	**70**		13	126	138-172	Tallada final	75	126	100			

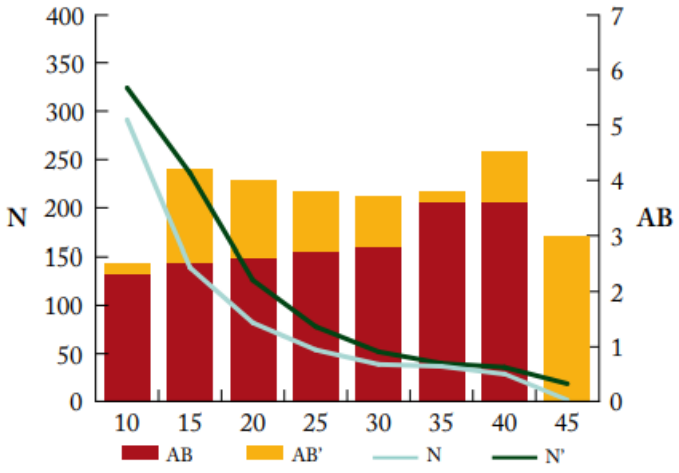
Model ORGEST Pn03: Uneven-aged stand – Pinus nigra

High quality site with main objective of wood production and fire prevention in fire prone areas; maximum harvest diameter is 40 cm; selection thinnings take place every 10-12 years; creating gaps up to 1.000 m^2; keeping trees from size groups "medium diameters" and "high diameters" and less number of trees of the lowest diameter class (diameter class 10-15: 24% of the basal area; diameter class 20-30: 40% of the basal area; diameter class ≥35: 36% of the basal area; the maximum basal area removed is 33%; treatments to reduce vulnerability to fire (pruning and bush clearing)).

Table 2: Model parameters of uneven-aged Pinus nigra model. Explanations of abbreviations in table: **CD** = diameter class; **AB** = basal area **RM** (bush cover); **AB** (Basal Area); **VAE** (Volume including bark) N (Tree density); Fcc (Canopy cover); Petita (Small); Mitjana (Medium); Gran(Big)

Grup de grandària	CD	Referència				Abans d'intervenció				A extreure		
		N (peus/ha)	AB (m^2/ha)	AB (%)	Fcc (%)	N' (peus/ha)	AB' (m^2/ha)	AB' (%)	Fcc (%)	N (peus/ha)	AB (m^2/ha)	AB (%)
Petita	10-15	430	4,8	24	21	560	6,7	23	28	130	1,9	23
Mitjana	20-30	175	8,1	40	26	256	11,5	39	38	81	3,4	39
Gran	≥35	66	7,2	36	19	95	11,3	38	31	29	4,2	38
Total		671	20,1		~66	911	29,5		~96	240	9,4	
		VAE (m^3/ha): 113,7				VAE (m^3/ha): 171,7				VAE (m^3/ha): 58,0		
Requeriments en zona d'alt risc		(*) RM: < 30%; AM: < 1,3 m.; DC: ind.										

(*) *RM: recobriment de matollar; AM: alçada de matollar; DC: distància del matoll a la base de capçades.*



Management alternatives to the current approaches foresee an increased integration of biodiversity conservation within managed forests as well as the improvement of water management. For contributing to forests as a carbon sink, enrichment plantations are also considered. Enrichment plantations seek to introduce or increase the proportion of one or more species into the pre-existent forest. The overall aim is to increase the complexity of forest composition and structure, thus improving the resilience of forests to disturbances and taking advantage of the productive potential of the most favourable micro-sites (e.g. valley floor, ditches, affixed areas). Besides this, holm oak (Quercus ilex) is planted for truffle production on former agricultural land.

Figure 16. Thinned pine-tree stand (left). Unthinned oak stand in the area affected by a fire (right).

Figure 17. Segre-Rialb Basin case study representative stand.

6. Boreal Forest (Finland) - Case Study North Karelia

Figure 18. North Karelia case study landscape image (aerial photo by Maanmittauslaitos - National land survey of Finland).

6.1 Short statement characterizing the case study

The boreal forests in eastern most region of Finland, North Karelia, have great ecological, economic, and societal (e.g., recreational) values for the society. As a result of climate change, the growth conditions of boreal forests are expected to change and many natural disturbances to increase. Thus, there is a need to adapt forest management practices to increase forest resilience. Especially wind damages are expected to increase due to the decreasing duration of frozen soil periods. Also outbreaks by bark beetles are expected to increase, and they may also have cascading effects on forests. Browsing of young trees by moose is another typical forest management challenge in the region. Current forest management in our Finnish case study area focuses, depending on the forest area, especially on timber production, recreational values, and nature conservation. Consequently, the intensity of forest management ranges from more to less intensive management and to no human intervention depending on forest area. In North Karelia, the predominant boreal tree species are Norway spruce, Scots pine, and birch. In our case study, pine forests dominate the landscape. However, there will be a need to increase mixed forests and decrease monocultures of Norway spruce under the changing climate to increase forest resilience.

6.2 Key data/ summary information case study

Forest Community	Boreal: Scots pine
Main tree species and their share of the total forest area (in %)	Scots pine (Pinus sylvestris) 93.3 % (84.0 % of total volume); Norway spruce (Picea abies) 5.2 % (9.5 % of total volume); broadleaves, including birch species (Betula spp.) 1.4 % (5.6 % of total volume)
Total forest area (ha)	7800 ha
Main management objectives	Timber production; forest recreation; nature conservation
Main management types	Multipurpose forestry consists of both even-aged (rotation) and uneven-aged forest management (2400 ha); Low to no management actions in recreational forests (3000 ha); In areas with nature conservation as the main aim there are no management actions (2400 ha)
Management challenges (Disturbances and other challenges)	Windstorm damages; bark beetle infestations; wildlife browsing particularly by moose
Total volume (m^3; m^3/ha)	1,017 Mm^3
Total biomass (Tm CO_2 eq.;Tm CO_2 eq./ha)	NA (not available)
Annual growth (m^3/year; m^3/ha*year)	NA (Northern Karelia region: 6.1 m^3/ha*year, National Forest Inventory (NFI) 12 and 13 (Natural Resources Institute Finland, LUKE))
Annual growth (Tm CO_2 eq./year; Tm CO_2 eq./ha*year)	NA (not available)
Annual harvest (m^3/year; m^3/ha*year)	NA (Northern Karelia region: 4.0 m^3/ha*year (in year 2020) (LUKE))
Wood assortments, wood sales and end products	NA (Northern Karelia: wood assortments: logs of pine 1.0 Mm^3, spruce 0.9 Mm^3, and broadleaves 0.1 Mm^3, in total 2.0 Mm^3; pulp wood of pine 1.6 Mm^3, spruce 0.8 Mm^3, and broadleaves 0.9 Mm^3, in total 3.3 Mm^3; logs and pulpwood in total 5.3 Mm^3; additionally energy wood 0.05 Mm^3 (Statistics for commercial fellings by roundwood, 2000-2020, LUKE); woods sales and end products info NA
Ownership	State owned forest
Altitude (max, min and average), m.a.s.l.	123 to 201 m.a.s.l.; average 144 m.a.s.l.
Climate	Precipitation annual average of 570 mm; Temperature annual average of 1,9°C (period of 1981-2010)
Geology and soil	Podzol soil, both mineral and peatland soils
Protected forest area (total ha)	2400 ha (31% of total case study area)
Forest with protective functions (ha)	NA (not available)
Socioeconomic data	Nº inhabitants in North Karelia region 162.540 (31.12.2022, source: Statistics Finland). City Joensuu is within 95 km distance (to south-west direction) from the case study area.

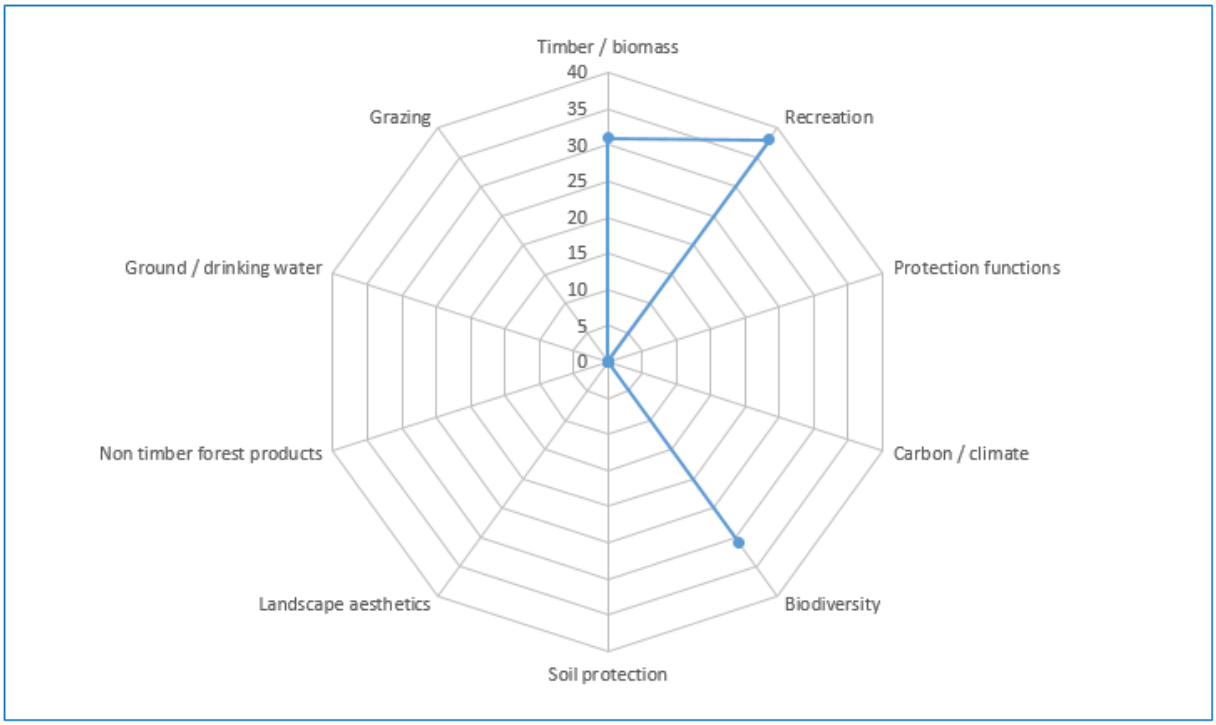


Figure 19. Case Study North Karelia: Expert estimation of relative investment in resources in manpower / finances of an enterprise or forest management unit in different goods and services in % (total 100).

6.3 General description - North Karelia case study

The Boreal forests in North Karelia, the easternmost region of Finland, hold great ecological, economic, societal, and recreational value. Growing conditions of forests in the Boreal region will be affected considerably by ongoing climate change. It is likely that natural disturbances will occur more frequently. Especially occurrence of wind damages could increase due to shorter periods of frozen soil, which nowadays still anchorages trees well to soil during winter storms. Also, more frequent bark beetle outbreaks are to be expected under warmer climate, which may have cascading effects with wind damages, and especially if wind damaged trees are left in forests and not timely harvested. Browsing of young trees by moose is another typical forest management challenge in the region. Therefore, proper adaptive forest management practices are needed to tackle these challenges and to enhance forest resilience.

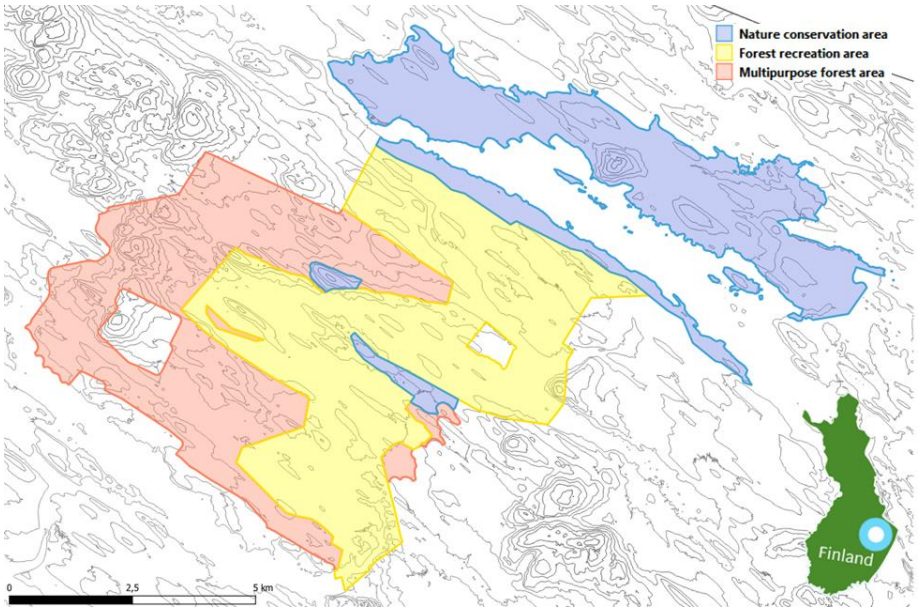


Figure 20. North Karelia case study forest area map.

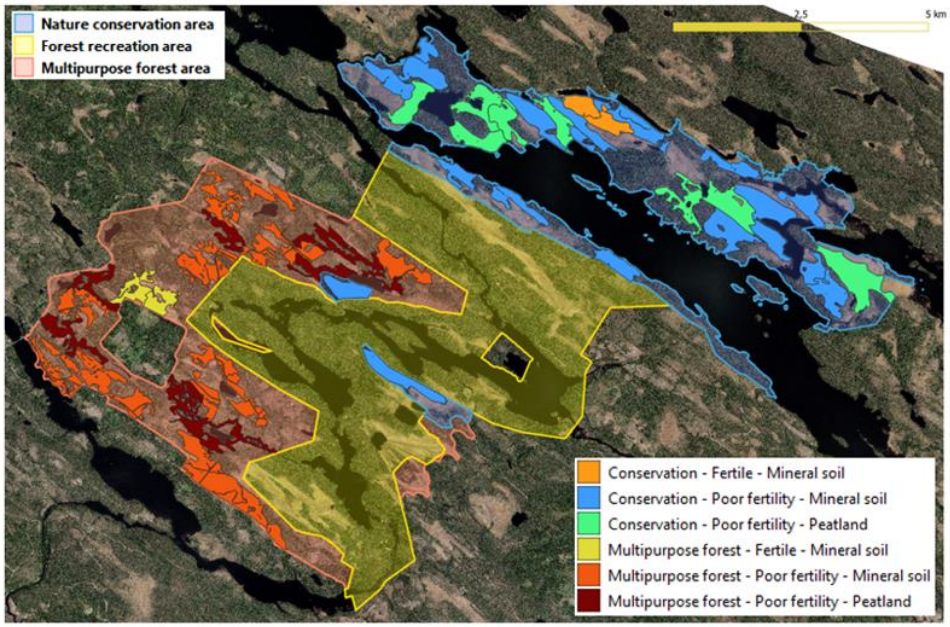


Figure 21. Patch types, area types and aerial photo of Finnish North Karelia case study area (aerial photo by Maanmittauslaitos - National land survey of Finland).

In the Finnish case study, current forest management focuses on either timber production (multipurpose forestry), recreational values, or nature conservation. This depends on the sub-area. The intensity of forest management ranges from relatively intensive to less intensive, but also includes areas, where no human intervention takes place. Even-aged (rotation) and uneven-aged forest management are applied in forests managed for multiple purposes with emphasis on timber production. Under even-aged forestry, forest regeneration may be done either using natural regeneration (typically in pine on less fertile sites)

or artificially by using seeding (pine) or planting (all tree species, typically from medium to fertile sites) with soil preparation. Forest regeneration is usually followed by precommercial (tending of seedling stand), and one to two commercial thinnings, before final cut. Where recreation plays a more pivotal role, management intensity is low (uneven-aged forestry with selective or gap cuttings) or may even be completely abandoned. If nature conservation is the main aim, then no management measures are allowed.

Figure 22. North Karelia case study representative stand image (photo by Harri Silvennoinen - UEF)

The major boreal tree species in the case study area is Scots pine (93.3 % of forest area and 84.0 % of total volume), followed by Norway spruce (5.2 and 9.5 %), and broadleaved trees with birch species (1.4 % and 5.6 %). The dominance of pine can be explained by the fact that major part of the study area represents less fertile sites. Despite this, there may be a need to still decrease the use of Norway spruce monocultures and increase use of mixed forests (e.g. pine or spruce with each other or with broadleaves) and cultivation of broadleaved species stands also (on medium fertile and fertile sites types) to boost forest resilience under a changing climate.

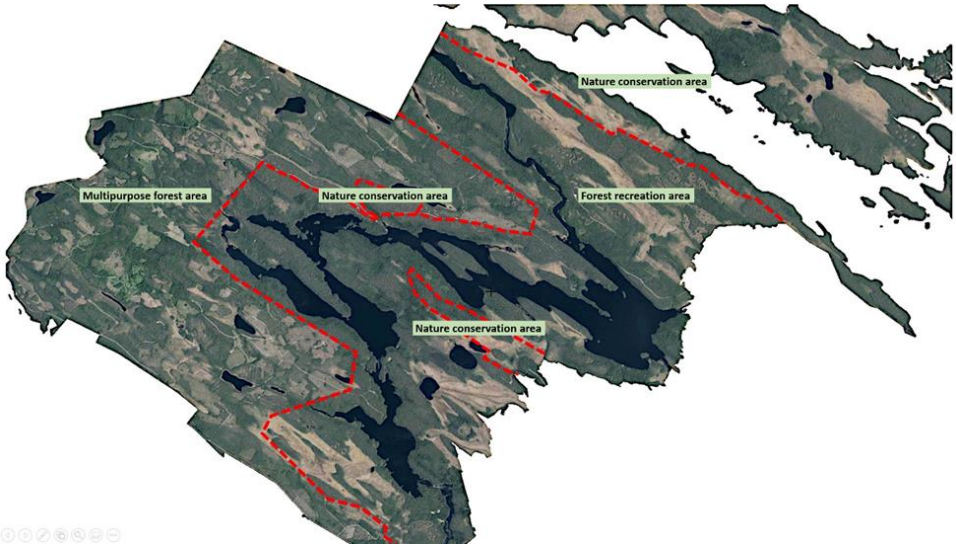


Figure 23. Aerial photo with location of nature conservation areas, forest recreational areas, and multipurpose forest area of Finnish case study area (aerial photo by Maanmittauslaitos - National land survey of Finland).