Forest EcoValue

Interreg Alpine Space Programme

Carbon neutral and resource sensitive Alpine region
SO 2.2: Promoting the transition to a circular and resource efficient economy

Forest EcoValue:
Supporting multiple forest ecosystem services through new circular/green/bio markets and value chains

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Forest EcoValue

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REPORT ON BIOPHYSICAL FOUNDATIONS AND METHODOLOGIES FOR THE ASSESSMENT OF SELECTED FES.

D.1.2.1

RESPONSIBILE PARTNER: INRAE/ PP4

List of the Forest EcoValue project partners

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PP10. The French National Forest Office – Office National des Forêts [ONF]
PP11. Hozcluster Steiermark – Woodcluster Styria [HCS]

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Summary

1. Introduction

This deliverable represents the first version, developed at month 20, of the report on biophysical foundations and methodologies for the assessment of a selection of Forest Ecosystem Services (FES). This selection was made by the project's consortium partners with the support of stakeholders from the various pilot sites of the project. Before presenting the developed methodology, available data, and usable models for qualifying, quantifying, and mapping ecosystem services (ES), it is necessary to provide the ES definition as well as a brief history of the evolution of this concept since its appearance in the literature.

The concept of ecosystem services has evolved over several decades, reflecting growing recognition of the benefits that natural systems provide to human societies. This definition reflects the fact that ES are essential for human well-being and the health of the planet, supporting life and economic activities by maintaining the balance and functionality of the natural environment. These services are broadly categorized by CICES (https://cices.eu/cices-structure/). CICES stands for the Common International Classification of Ecosystem Services, a standardized framework developed by the European Environment Agency (EEA) and the European Topic Centre on Biological Diversity (ETC/BD) for classifying and categorizing ecosystem services. CICES provides a common language and structure for understanding, assessing, and communicating the diverse benefits that ecosystems provide to humans and the environment. In the context of Forest ES (FES), and using the CICES framework, 3 categories have been identified by the consortium of the project:

- Provisioning Services: These are the products obtained directly from ecosystems, including food, fresh water, wood, fiber, genetic resources, and medicines.
- Regulating and Maintenance Services: These services include the benefits obtained from the regulation of ecosystem processes such as climate regulation, water purification, disease control, pollination, and flood regulation.
- Cultural Services: These are the non-material benefits people obtain from ecosystems through recreation, tourism, aesthetic enjoyment, spiritual fulfillment, and educational experiences.

Here's a historical overview of the development of this concept (De Groot et al., 2002; De Groot et al., 2017; Millennium Ecosystem Assessment, 2005; https://www.ipbes.net/; https://sdgs.un.org/goals):

- **Early 20th Century: Foundations in Ecology**
  - **1935**: Arthur Tansley introduces the term "ecosystem," laying the groundwork for understanding how different components of nature interact and support each other.
- **1960s-1970s : Initial Recognition**
  - **1960s**: Environmental awareness grows, highlighted by works such as Rachel Carson's "Silent Spring" (1962), which underscore the interdependence of humans and nature.

    - **1970**: Paul Ehrlich and Harold Mooney begin discussing the importance of ecosystem services in their ecological research, emphasizing how ecosystems provide critical functions for human survival.
- **1980s : Conceptual Development**
    - **1981**: The term "ecosystem services" starts gaining traction. Ehrlich and Ehrlich use it in their book "Extinction: The Causes and Consequences of the Disappearance of Species" to describe the benefits derived from nature.
    - **1983**: The World Resources Institute publishes "Global Biodiversity Strategy," which discusses the value of biodiversity and the services ecosystems provide.
- **1990s : Economic Valuation**
    - **1997**: A landmark study by Robert Costanza and colleagues, published in "Nature," attempts to quantify the global value of ecosystem services, estimating it at trillions of dollars per year. This study significantly raises awareness about the economic importance of ecosystem services.
- **2000s : Institutionalization and Policy Integration**
    - **2000**: The Millennium Ecosystem Assessment (MEA) is launched by the United Nations. This comprehensive project involves over 1,300 scientists and aims to assess the consequences of ecosystem change for human well-being.
    - **2005**: The MEA publishes its findings, categorizing ecosystem services into provisioning, regulating, cultural, and supporting services. This framework becomes widely adopted in both scientific and policy contexts.
- **2010s : Implementation and Global Recognition**
    - **2010**: The Economics of Ecosystems and Biodiversity (TEEB) initiative begins, promoting the economic valuation of biodiversity and ecosystem services to inform policy and decision-making.
    - **2012**: The Convention on Biological Diversity (CBD) incorporates ecosystem services into its strategic plans, encouraging countries to integrate these concepts into national policies and planning.
- **2020s : Consolidation and Future Directions**
    - Ecosystem services are now a fundamental concept in environmental science, conservation, and sustainable development. They are integral to frameworks such as the United Nations Sustainable Development Goals (SDGs) and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES).

The concept of ecosystem services continues to evolve, with ongoing research focusing on refining their valuation, understanding their dynamics, and developing strategies to sustainably manage and protect these vital services for future generations. In this general framework of ecosystem services, the services provided by forest ecosystems are identified by the term Forest Ecosystem Services (FES).

1. Project overview

Alpine forests (AF) play a key role for climate change mitigation and resilience; they offer multiple FES (e.g., CO_2 absorption, air pollution reduction, increase of biodiversity, resilience to natural risks). However, they are threatened by abandonment, climate change and territorial degradation that progressively lead to a pauperization of natural resources and decrease in ES provision. AF maintenance costs are high, and public funds and traditional wood value chains cannot cover them: economic valuation and payment schemes for ES are challenges widely debated, but only occasionally successfully applied. The project aims to turn this challenge into an opportunity, by developing innovative sustainable win-win business models for forest management and maintenance, new bio-based value chains and ES markets, involving different sectors, public and private actors and citizens. The project is based on the acknowledgment that restoring and maintaining healthy forests can generate value for the benefit of the whole alpine region, as well as business and green job opportunities for the alpine communities.

In particular, the 36-months project Forest Eco Value a subset of FES from all three categories: provisioning (e.g., biomass, raw materials, chemicals), regulation (e.g., biodiversity, natural risk reduction, CO_2 absorption), cultural (e.g., recreation, habitat experience, health), and will:

- Map and analyze AF delivery capacity of FES
- Identify and estimate the economic potential, define business models and FES markets frameworks
- Test the models/tools in pilot living labs involving local players; compare results at transnational level, identify obstacles and facilitating factors
- Analyze the need for innovative policies to foster and facilitate AF maintenance, FES markets and new value chains
- Elaborate refined transferable tools/models and policy proposals, as to enable new markets and value chains and ensure the expected FES

2. A structured outline for assessing Forest Ecosystem Services in the Alpine Space

Assessing FES and conducting qualification, quantification, and mapping in the Alpine Space involves a comprehensive and multidisciplinary approach that integrates ecological, economic, and social dimensions. Here's a proposal for a step-by-step guide on how this could be accomplished:

1. **Identification of Forest Ecosystem Services:** Begin by identifying and categorizing the ecosystem services provided by forests. This includes provisioning services (e.g., timber, food), regulating and maintenance services (e.g., climate regulation, water purification), and cultural services (e.g., recreation, spiritual values). This identification should be conducted using existing and recognized ES classification such as the CICES one (https://cices.eu/cices-structure).
2. **Stakeholder Engagement:** Engage stakeholders such as local communities, forest managers, policymakers, scientists the assessment process. Their input is essential for

understanding the diverse perspectives and priorities related to FES with a specific attention to be paid to the economic aspects (market opportunities…).

3. **Data Collection and Analysis:** Collect relevant data on forest ecosystem structure, function, and human interactions. This may include identification of relevant input data sources and models yet available including existing and usable FES assessment, field surveys, remote sensing data, socio-economic data, and expert knowledge. Analyze the data to assess the status, trends, and drivers of change for each ecosystem service.
4. **Qualification:** Qualify each identified FES by assessing its importance, relevance, and contribution to human well-being and stakeholders' expectations. This involves understanding the ecological processes that underpin each service and evaluating their socio-economic significance.
5. **Quantification:** Quantify the supply and demand of FES. This may involve using various methods such as:
    a. Ecological assessments: Measure parameters like biomass, carbon sequestration rates, water quality, and biodiversity indices.
    b. Economic valuation: Estimate the economic value of ecosystem services using methods like market pricing, replacement cost, or willingness-to-pay surveys.
    c. Social assessments: Assess the social preferences and cultural values associated with forest ecosystem services through stakeholder consultations, surveys, or participatory mapping exercises.
6. **Mapping of Ecosystem Services:** Utilize spatial data and Geographic Information Systems (GIS) and spatial analysis techniques to map the distribution of FES in the studied area/pilot areas/the Alpine Space. Spatial mapping helps visualize the spatial patterns of FES, and identify areas of high service provision. This mapping involves:
    a. Integrating ecological data (e.g., vegetation types, land cover) with socio-economic data (e.g., population density, land use) to identify areas of high service provision and demand.
    b. Developing spatial models that predict the spatial distribution of FES based on environmental variables, land management practices, and socio-economic drivers.
    c. Creating maps that visualize the spatial patterns of FES, highlighting hotspots, trade-offs, and synergies.
7. **Validation and Uncertainty Analysis:** Validate the results of the qualification, quantification, and mapping exercises through field validation and peer review. Conduct sensitivity analysis to assess the uncertainty associated with the data, models, and assumptions used in the assessment.
8. **Integration and Synthesis:** Integrate the results of the qualification, quantification, and mapping actions to provide a comprehensive understanding of FES in the studied area (local or large scale). Synthesize the findings to identify key trends, drivers of change, and implications for sustainable forest management and conservation, including the prioritization of the efforts to be conducted.
9. **Valuation:** Assess the economic and non-economic value of forest ecosystem services. Economic valuation methods may include market-based approaches (e.g., cost-benefit analysis, contingent valuation) and non-market valuation methods (e.g., stated preference

surveys, hedonic pricing). Non-economic valuation methods consider the cultural, social, and ecological importance of ecosystem services.

10. **Communication:** Communicate the results of the assessment to stakeholders, policymakers, and the general public through reports, workshops, and outreach activities. Engage stakeholders in the interpretation of results and the development of management strategies that promote the sustainable provision of FES.
11. **Monitoring and Adaptive Management**: Establish monitoring programs to track changes in FES over time. Use this information to improve and update adaptive management strategies that respond to emerging challenges, such as climate change, land-use change, market change.
12. **Iterative Process:** Recognize that FES assessment is an iterative process that may require periodic updates and revisions. Incorporate feedback from stakeholders and new scientific knowledge to improve the accuracy and relevance of the assessment over time.

By following these steps, researchers and practitioners can conduct comprehensive assessments of FES, leading to more informed decision-making, policy-making and sustainable management of forest resources.

In this step-by-step analysis the quantification action requests the setting up of indicators which are metrics characterizing a part or the entirety of a FES. Here are the most common categories of indicators used:

1. Provisioning Indicators:
    a. Timber volume: Measures the quantity and quality of timber harvested from forests.
    b. Non-timber forest products (NTFPs) yield: Quantifies the production of goods such as mushrooms, berries, medicinal plants, and resin.
    c. Water yield: Indicates the amount of water supplied by forest ecosystems, which is crucial for various uses such as drinking water, irrigation, and hydropower generation.
2. Regulating and Maintenance Indicators:
    a. Carbon sequestration: Measures the amount of carbon dioxide removed from the atmosphere and stored in epigeal and hypogeal biomass, dead Mass, soil and litter.
    b. Air and water quality: Indicates the capacity of forests to remove pollutants and improve air /water quality through processes such as filtration and deposition.
    c. Climate regulation: Includes indicators such as temperature moderation, precipitation regulation, and mitigation of extreme weather events provided by forests.
3. Supporting Indicators:
    a. Soil quality: Measures indicators such as soil organic matter content, nutrient levels, and soil erosion rates, which are essential for maintaining soil fertility and productivity.
    b. Biodiversity indices: Assess the diversity and abundance of plant and animal species in forest ecosystems, including indicators such as species richness, evenness, and rarity.

    c. Habitat provision: Indicates the availability of suitable habitats for wildlife, including indicators such as habitat connectivity, patch size, and habitat heterogeneity.
4. Cultural Indicators:
    a. Recreation opportunities: Measures the availability and accessibility of recreational activities such as hiking, camping, birdwatching, and nature tourism.
    b. Aesthetic value: Assesses the visual and scenic qualities of forest landscapes, including indicators such as landscape diversity, naturalness, and aesthetic preferences.
    c. Spiritual and cultural values: Indicates the cultural significance of forests for indigenous communities, including indicators such as sacred sites, traditional knowledge, and cultural practices.
5. Economic Indicators:
    a. Forest economic value: Measures the economic contribution of forests to local, regional, and national economies, including indicators such as forest-based employment, revenue from timber sales, and contributions to GDP.
    b. Cost-benefit analysis: Assesses the economic efficiency of forest management practices and conservation interventions by comparing the costs and benefits associated with different options.
6. Resilience and Sustainability Indicators:
    a. Forest health: Indicates the overall condition and vitality of forest ecosystems, including indicators such as tree mortality rates, forest regeneration, and invasive species presence.
    b. Adaptive capacity: Measures the ability of forests to adapt to environmental changes and disturbances, including indicators such as genetic diversity, ecosystem connectivity, and ecosystem resilience.

One of the sources for producing data and indicators related to FES is modeling. FES involves using various techniques and approaches to simulate, quantify, and predict the provision of ES by forest ecosystems. Here's an overview of the main steps involved in modeling FES:

1. Define Objectives and Scope: Clearly define the objectives of the modeling exercise and the specific ES to be assessed. Consider the spatial and temporal scales of analysis and the stakeholders involved.
2. Identify Drivers and Indicators: Identify the key drivers that influence the provision of FES, such as climate, land use, biodiversity, and management practices. Select appropriate indicators to represent these drivers and the ES of interest.
3. Select Modeling Approaches: Choose modeling techniques and approaches that are suitable for the objectives and scope of the study. Common modeling approaches for forest ecosystem services include:
    a. Process-based Models: These models simulate the ecological processes that underpin ecosystem service provision, such as carbon sequestration, water regulation, and nutrient cycling. Examples include forest growth models, hydrological models, and biogeochemical models.

b. Spatially Explicit Models: These models integrate spatial data and GIS techniques to assess the spatial distribution and patterns of ecosystem services across landscapes. Examples include habitat suitability models, land use change models, and ecosystem service mapping approaches.
c. Economic Valuation Models: These models estimate the economic value of ecosystem services using various valuation techniques, such as contingent valuation, hedonic pricing, and cost-benefit analysis. Economic valuation models help quantify the benefits of ecosystem services in monetary terms (cf. Forest EcoValue working group ECO report: Deliverable D.1.3.1).
d. Integrated Assessment Models: These models integrate biophysical, ecological, economic, and social components to assess the interactions between human activities and ecosystem services. Integrated assessment models support decision-making by considering trade-offs and synergies among multiple ecosystem services and stakeholders.

4. Data Collection and Preparation: Collect relevant data on forest characteristics, environmental variables, land use, socio-economic factors, and ES indicators. Ensure that the data are accurate, reliable, and spatially explicit, as needed for the chosen modeling approach.
5. Model Calibration and Validation: Calibrate the model parameters and validate the model outputs using observed data, field measurements, and independent datasets. Assess the accuracy, reliability, and uncertainty of the model results to ensure their robustness for decision-making.
6. Scenario Analysis and Sensitivity Testing: Use the calibrated model to explore different scenarios and assess the potential impacts of changes in drivers or management interventions on ecosystem service provision. Conduct sensitivity analyses to understand the sensitivity of model outputs to variations in input parameters.
7. Interpretation and Communication: Interpret the model results in the context of the study objectives, stakeholders' needs, and policy implications. Communicate the findings effectively to decision-makers, stakeholders, and the broader public using visualizations, reports, and stakeholder engagement activities.
8. Iterative Improvement: Continuously refine and improve the modeling framework based on feedback, new data, and advances in modeling techniques. Incorporate lessons learned from previous modeling exercises to enhance the accuracy, relevance, and usability of the models for supporting sustainable forest management and decision-making.

By following these steps, researchers and practitioners can develop and apply models to assess, quantify, and predict the 3 components (supply, flow and demand) of FES, ultimately supporting informed decision-making and sustainable management of forest resources.

As part of the Forest EcoValue project, the previously outlined methodology for assessing FES (including the modeling one) is implemented in its broad lines and associated objectives. This report pertains to points 1, 3, 5, and 6 of this methodology. We will now present the selected FESs, as well as the available data sources and models that will be used to map and characterize these FES in the project's pilot sites/living labs.

3. The Forest Ecosystem Services selected by the Forest EcoValue project consortium

There is a wide variety of FES. Within the framework of a three-year project, it is not feasible to conduct an exhaustive study of each of these services. Therefore, the first step of the procedure involved selecting the most important/representative services in the project's Living Labs (LL). This selection process was conducted in two stages with the aim of identifying services within the three main categories presented in the previous chapter.

The first stage was carried out exclusively within the consortium based on the partners' knowledge of their LL. An inventory matrix was created to characterize the category and description of the FES and their associated indicators. Following this initial inventory for each LL, the matrix of each project partner (PP) was compared with those of the other PPs. In the end, 11 FES were identified, varying among the LLs: 6 in the Provision category, 4 in the Regulation & Maintenance category, and 2 in the Cultural category. The distribution per LL ranges from 4 to 11 FES.

The second stage involved validation by the LLs' stakeholders of the services preselected by the consortium. The final result of this selection/validation process is summarized in the table below.

Forest Ecosystem Service	AUSTRIA	FRANCE	GERMANY	ITALY	SLOVENIA
Provision of timber wood biomass	X	X	X	X	X
Provision of fuel wood biomass	X	X	X	X	X
Provision of chestnuts /mushrooms/blueberries/…				X	
Provision of habitats for wild plants and animals	X		X	X	
Seeds and fruits for reproductive materials				X	
Provision of other forest products of interest for biochemistry				X	
CO_2 storage and sequestration in forests / Climate Change Mitigation	X	X	X	X	
Natural Hazards (rockfalls, landslides, snow avalanches, erosion) prevention/mitigation/control		X	X	X	X
Maintenance of high-quality fresh waters provided by plants and animal species		X		X	
Recreation and tourism		X	X	X	X

Beauty of nature, aesthetic value		X		X	

The Forest Ecosystem Services selected for the project Forest EcoValue

As part of the action of the BIO working group of the project, data and model mining was conducted to characterize the biophysical component of these 11 FES. This mining has been conducted in association with the ECO working group in order to identify the FES indicators suitable for the economical assessment of these FES.

4. Relevant data and models available for the mapping and quantification of the selected Forest Ecosystem Service

Given that the Forest EcoValue project is not a research project but a Science-Decision-Action initiative, its objective is to mobilize existing data, knowledge, and models to inform stakeholders and assist them in their decision-making processes and efforts to improve policies for the payment of FES via different economical market (green chemistry, biodiversity conservation market, natural risk prevention, tourism...).

Results of the data mining

The scale used to map and quantify Forest Ecosystem Services (FES) depends on the framework for using this data. Broadly speaking, two scales can be distinguished:

- Local Scale (also called small scale): This corresponds to the action framework of practitioners and decision makers, often at the level of a watershed or municipality. It is the "tactical" scale, with a short to medium-term component to achieve set objectives.
- Multi-territorial Scale (also called large scale): This corresponds to the action framework of policy makers, usually at a regional or even national level. It is the "strategic" scale, with a long-term action plan.

Transitioning from one scale to another requires upscaling or downscaling actions. Upscaling by aggregating information on a given geographical grid (e.g., aggregation at the municipal level) is generally easier than downscaling because the interpolation of data and the quality of the produced data are limiting factors for this action (e.g., interpolating meteorological data to a finer spatial resolution than that of the sensors used). In the latter case, while the global data may be reliable and robust, the interpolated data is often prone to errors and may even be incorrect.

Large scale data sources

The European Union (EU) provides various datasets and resources related to forest ecosystem services through its institutions and initiatives. Here are some key sources of data and information on FES in the EU, that can be used depending on the selected FES by a stakeholder:

- The Copernicus program, initiated by the European Union, provides comprehensive Earth observation data and services to support environmental monitoring and management. Within the Copernicus program, there are several components that are relevant to FES:
    - Copernicus Land Monitoring Service (CLMS): This component provides land cover and land use information derived from satellite imagery, including data on forests. CLMS

offers data products that can be used to monitor changes in forest extent, fragmentation, and distribution over time. These datasets are valuable for assessing the provision of various ecosystem services by forests, such as habitat provision, carbon sequestration, and soil protection. Here are the 7 main data sources:

  - Copernicus High Resolution Layer (HRL) Forest Cover: This dataset provides detailed information on forest cover and non-forest areas at high spatial resolution (20 meters). It includes data on tree cover density, forest types, and forest fragmentation, derived from satellite imagery.
  - Corine Land Cover (CLC): The Corine Land Cover dataset provides information on land cover and land use across Europe. It includes categories such as broad-leaved forest, coniferous forest, mixed forest, and transitional woodland-shrub, among others.
  - Forest Fire Danger Forecast: Copernicus offers forest fire danger forecasts that provide information on the likelihood and severity of forest fires. These forecasts are based on meteorological data, vegetation conditions, and fire risk indicators.
  - Forest Monitoring: Copernicus provides monitoring services for forests, including data on forest disturbance, deforestation, and forest degradation. These services help assess changes in forest cover and condition over time.
  - Global Forest Watch (GFW) Sentinel-2 Forest Change: This dataset, developed in collaboration with Global Forest Watch, utilizes Copernicus Sentinel-2 satellite imagery to monitor forest cover change globally. It provides information on forest loss, gain, and fragmentation.
  - Sentinel Satellite Data: Copernicus Sentinel satellites (Sentinel-1, Sentinel-2, Sentinel-3) provide free and open-access satellite data that can be used to monitor forests. Sentinel data is used for tasks such as land cover classification, forest mapping, and monitoring vegetation health.
  - Copernicus Global Land Service (CGLS): The CGLS provides global land cover and vegetation products derived from satellite data. These products include information on land cover, vegetation indices, and biophysical parameters that are relevant to forests.
- Copernicus Atmosphere Monitoring Service (CAMS): CAMS provides data on atmospheric composition, air quality, and greenhouse gas concentrations. Monitoring air quality is crucial for understanding how forests contribute to regulating air pollutants and improving air quality, which is an important ecosystem service provided by forests.
- Copernicus Climate Change Service (C3S): C3S provides climate data and information to support climate change adaptation and mitigation efforts. This service offers data products related to temperature, precipitation, and other climate variables, which are essential for assessing how forests contribute to climate regulation, carbon sequestration, and climate resilience.
- Copernicus Emergency Management Service (EMS): EMS provides rapid mapping and monitoring services for disaster response and risk management. Forests play a critical role in reducing the risk of natural hazards such as landslides, floods, and wildfires. EMS

data can be used to assess the effectiveness of forest ecosystems in mitigating these risks and supporting disaster resilience.

By leveraging the data and services provided by the Copernicus program, stakeholders can better understand the role of forests in providing ecosystem services and inform decision-making processes related to forest management, conservation, and sustainable development. The availability of timely and reliable Earth observation data from Copernicus enhances our ability to monitor and assess changes in forest ecosystems and their contributions to human well-being and environmental sustainability.

- European Environment Agency (EEA):
  The EEA provides reports, assessments, and data on various environmental topics, including forests and biodiversity. Their website offers access to datasets related to forest cover, land use, biodiversity indicators, and ecosystem services assessments.
- Forest Europe:
  Forest Europe is a voluntary intergovernmental process for developing policies, recommendations, and guidelines for sustainable forest management in Europe. They provide reports, assessments, and data on forest resources, including information on forest ecosystem services.
- European Forest Data Centre (EFDAC):
  EFDAC serves as a central hub for collecting, managing, and disseminating forest-related data in Europe. They offer access to datasets on forest cover, forest resources, forest fires, and more, which can be relevant for assessing ecosystem services.
- European Forest Institute (EFI):
  EFI conducts research and provides information on various aspects of forest management and policy in Europe. They offer reports, publications, and datasets related to forest ecosystem services, biodiversity, climate change, and socio-economic aspects of forestry.
- Joint Research Centre (JRC):
  The JRC is the European Commission's science and knowledge service. They conduct research and provide data on a wide range of topics, including land use, biodiversity, and ecosystem services. Their website offers access to datasets, maps, and reports relevant to forest ecosystem services.
- Eurostat:
  Eurostat is the statistical office of the European Union. They provide data and statistics on various aspects of the EU's economy and environment, including forestry and land use. Their website offers access to datasets on forest cover, timber production, and other forestry-related indicators.
- European Environment Information and Observation Network (EIONET):
  EIONET is a network of environmental information experts and organizations across Europe. They collaborate to collect, exchange, and disseminate environmental data and information. EIONET provides access to datasets and reports on forests, biodiversity, and ecosystem services.

In the framework of the Interreg Alpine Space program, several projects have carried out mapping and characterization of FES for the entire Alpine region. The results of 4 of these projects have been identified as directly usable input data or models sources for the Forest EcoValue project. These projects are:

- https://www.alpine-space.eu/project/alpes/
  Alpine Ecosystem Services – mapping, maintenance and management. Using as model the EU initiative on Mapping and Assessment of Ecosystems and their Services (MAES), which produces and distributes annual reports with ES definition and guidelines for their assessment, mapping and calculation via selected indicators, the consortium of the AlpES project has provided reliable and rigorous scientific and spatial information about some FES that can be used to bolster sustainable and place -based decision making (Roilo et al. no date)

- https://www.alpine-space.eu/project/rockthealps/
  This project has produced and disseminated the first Alpine Space harmonized rockfall risk and protection forest webmaps. These maps are showing the results of an innovative rockfall assessment methodology called ROCK-EU using harmonized criteria, objective data, past rockfall events recorded in Alpine Space and the model ROCK-EU 2D developed by the project. The download section, of the webgis accessible via the Interreg Alpine Space Program website, gives access to the different GIS layers displayed in the webmap.

- https://www.alpine-space.eu/project/alptrees/
  The ALPTREES project investigated the opportunities and risks that non-native tree species provide for the future of our urban and forest areas. Furthermore, it developed guidelines for their use and management within the Alpine Space, it updated and proposed a downscaling of the FES maps produced by the AlpES and ROCKtheAlps projects.

- https://www.alpine-space.eu/project/greenrisk4alps/
  The GreenRisk4Alp project developed methods and decision support tools to foster an ecosystem-based integrated risk management of natural hazards and climate change impacts by focusing on protective forests as effective, cost-efficient, and long-term risk mitigation measure. One of the outputs of this project is the open-source simulation tool Flow-Py. It has been developed and applied in GreenRisk4Alps to identify forests with a direct object protective function for snow avalanches, rockfall and shallow landslides. This model can be used on both large or small scale.
  Flow-Py employs a data-based runout angle modeling approach to identify process areas and corresponding intensities of gravitational mass flows by combining models for routing and stopping, which depend on local terrain and prior movement. The only required input data are a digital elevation model, the positions of starting zones and a minimum of four model parameters. The model equations are implemented via the Python computer language allowing users to address specific questions by keeping the parameterization flexible and the ability to include custom model extensions. Information on model equations, performance, and modularity of Flow-Py can be found in: D'Amboise, C. J. L., Neuhauser, M., Teich, M., Huber, A., Kofler, A., Perzl, F., Fromm, R., Kleemayr, K., and Fischer, J.-T. (2022). Flow-Py v1.0: A customizable, open-source simulation tool to estimate runout

and intensity of gravitational mass flows. Geosci. Model Dev., 15, 2423–2439. https://doi.org/10.5194/gmd-15-2423-2022

In this report, we only present in detail the large-scale data from the AlpES and Alptrees projects because they utilize European data set and correspond to the mappings of interest for the Forest EcoValue project. Furthermore, since this information is no longer available on the websites of these two projects, we provide all the documents that their authors have sent us.

The AlpES project flowcharts for FES assessment

Information courtesy of and copyright to EURAC. Within the project AlpES each FES has been assessed by characterizing the 3 components of each service: supply, flow and demand.

Note to the reader: in order to maintain the consistency of the initial structure of the document provided by EURAC, the figures are taken from this reference document.

Surface water for drinking with minor or no treatment

ES Indicator: Flow

General description:

The drinking water flow is visualizing the water used at a tap connected to the public water supply system. Water use is understood as water utilization at the point of delivery. The alpine wide map is based on water statistics from Eurostat, the statistical office of the European Union. These datasets are collected by National Statistical Institutes, then validated and merged by Eurostat. They come on a regional scale and are further downscaled by us to municipality level based on touristic and demographic data.

Input Data

- ✓ Annual fresh water abstraction by source and by sector in million m^3 per year
- ✓ National Census data
- ✓ Occupancy rates of tourist accommodation

Calculation processes:

Extract relevant data

In a first step, after having downloaded the necessary table on water usage from EUROSTAT homepage, it needs to filter the datasets by extracting only the necessary information.

After opening the database “Water use by NUTS 2 regions”, it needs to be filtered for country, water process and classification of economic activities. Here, these are the Alpine Space Countries, public water supply and households.

Disaggregate data to municipality level

As the smallest scale here is the NUTS-2 level, we need to disaggregate the datasets to municipal level. This is done by allocating the water abstraction according to the overnight stays in hotels and population data at municipal level.

ES Indicator: Demand

General description:

The drinking water demand is displaying the abstractions from water resources for the public water supply. Water abstraction is understood as water removed from its source. We use collected data from Eurostat at regional scale, which is disaggregated to municipality level to map the drinking water demand.

Input Data

- ✓ Water use by supply category, by sector and by industrial activities in million m^3 per year
- ✓ National Census data
- ✓ Occupancy rates of tourist accommodation

Calculation processes:

Extract relevant data

Similar to the flow indicator, we are here also working with EUROSTAT data which needs to be downloaded from the Homepage (water abstractions). In a next step, the necessary table needs to be filtered as we want to extract only the necessary information.

Thus, after opening the table “Water abstractions by NUT 2 regions”, it needs to be filtered for the country, the source and the water process. Here: Alpine Space Countries, fresh surface water and total gross abstraction.

Disaggregation to municipality level

As the smallest scale here is the NUTS-2 level, we need to disaggregate the datasets again to municipal level. This is done by allocating the water abstraction according to the overnight stays in hotels and population data at municipal level.

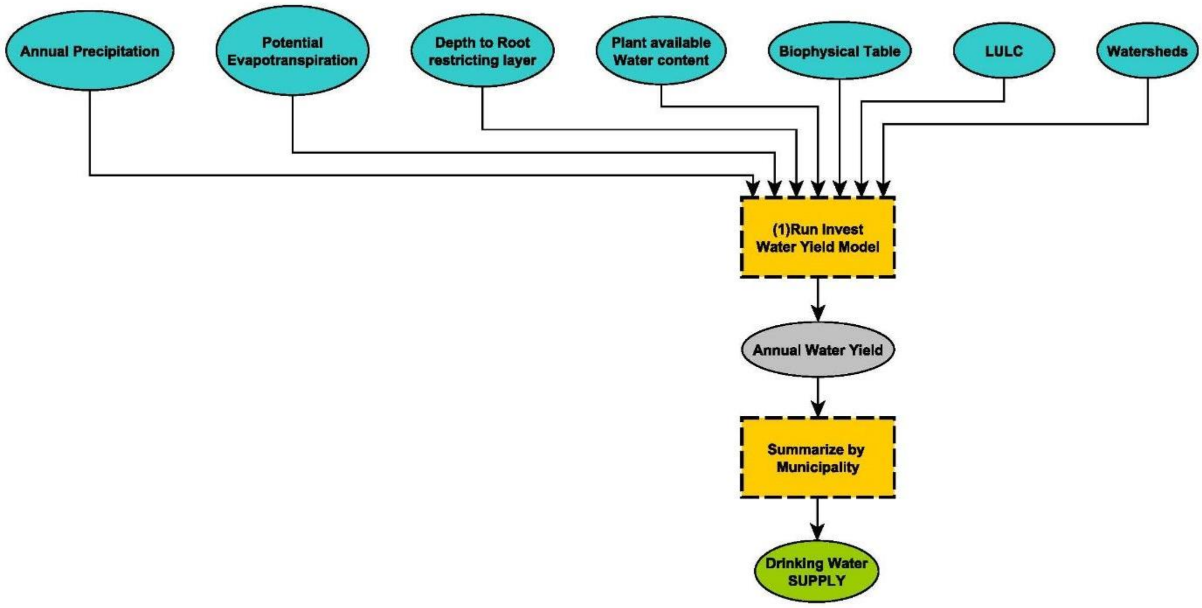


Figure 1: Flowchart depicting the procedures used to derive the supply indicator

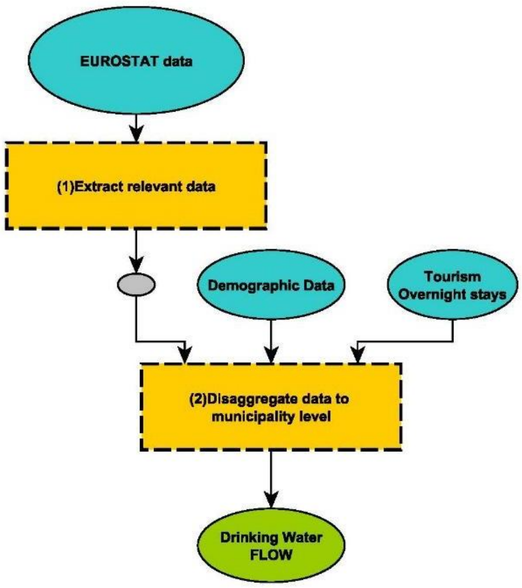


Figure 2: Flowchart depicting the procedures used to derive the flow indicator

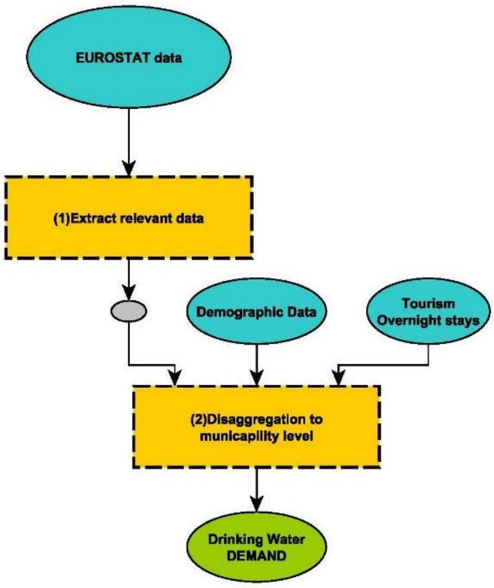
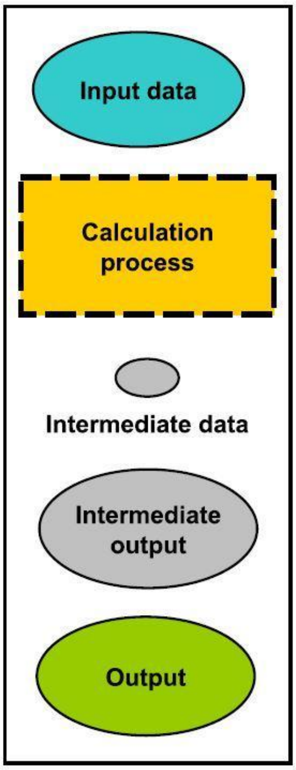


Figure 3: Flowchart depicting the procedures used to derive the demand indicator

Legend



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Fuel wood

ES Indicator: Status

General description:

Sustainable forest management is largely limited to the regrowth rate (m^3/ha/year) in order to keep forest inventory stable. Hence, this indicator reflects the net annual increment of biomass in Alpine forests based on MODIS GPP satellite data. We applied the same procedure used for deriving the CO2 sequestration indicator. Hence, for details on the calculation method of this indicator, please refer to the chapter CO2 sequestration from forests and bogs (supply/flow indicator).

References:

Busetto, L.; Barredo, J.; San-Miguel-Ayanz, J. (2014): Developing a spatially-explicit pan-European dataset of forest biomass increment. 22nd European Biomass Conference and Exhibition, 23-26 June 2014. Germany.

ES Indicator: Flow

General description:

Not all forests can be managed equally: accessibility (infrastructure) and technical feasibility (due to topography) play a crucial role in sustainable forest management. Hence, this indicator reflects the timber removals for fuel wood production considering both the forest accessibility (based on the OSM layer) and topographical site condition (slope angle from DEM). Data for timber removals are taken from national forestry inventories. Figure 1 describes in detail the calculation procedure to derive the amount of fuelwood (m^3/ha/year) produced per local administrative units (LAU2: formerly NUTS level 5, consists of municipalities or equivalent units in the 28 EU Member States (pre-Brexit)) of the Alpine Space.

The procedure consists of two main parts:

- Calculation of the accessible forest areas (Step 1 and 2): typically, commercial wood production occurs only on forests that are accessible and workable in terms of topographic conditions. Hence, in the following analysis only accessible and workable forest areas are included.
- Calculation of the amount of fuelwood produced in each LAU2 (Step 3 and 4): The statistical data about the amount of felling is disaggregated at LAU2 level using results from part 1.

Input data:

GIS-Data

✓ Forest roads: open street map layer (OSM)
Source: http://download.geofabrik.de/. The roads classified as “bridleway”, “service”, “track”, “track_grade1”, “track_grade2”, “track_grade3”, “track_grade4”, “track_grade5”, “unclassified” and “unknown” are used.

✓ Forest: High-resolution tree-cover-density layer
Source: http://land.copernicus.eu/. Pixels with a density between 30-100% are used; forest in agricultural and urban areas is removed.

- ✓ Digital Elevation Model: Elevation raster dataset
  Source: http://land.copernicus.eu/, v1.0
- ✓ LAU2 layer: Boundaries of the local administrative units
  Source: http://www.eurogeographics.org/products-and-services/euroboundarymap; version 10.
- ✓ Region layer: Boundaries of the areas for which the statistical data is available.
  Statistical data about the amount of felled wood is typically not available at LAU level; hence, for every country we used the finest available resource. Because these datasets have different resolutions and names, we call them "region layers" in the following description. The original names/resolutions for the different countries are the following:
  - Germany: Growing regions
    Source: https://gdi.thuenen.de/wo/wgwb/
  - Switzerland: Production regions
  - France: Nuts 2
    Source: http://www.eurogeographics.org/products-and-services/euroboundarymap
  - Italy: Nuts 2
    Source: http://www.eurogeographics.org/products-and-services/euroboundarymap
  - Liechtenstein: Nuts 2
    Source: http://www.eurogeographics.org/products-and-services/euroboundarymap
  - Austria: "Bezirke"
    Source: http://data.opendataportal.at/dataset/geojson-daten-osterreich
  - Slovenia: Forest regions (dataset provided by the Slovenia Forest Service)

Statistical data:

- ✓ Statistical data about roundwood production: The amount of wood that is extracted from the forest.
  Source: Forest inventories of single countries
- ✓ Percentage of roundwood transformed into fuelwood
  Source: http://ec.europa.eu/eurostat/statistics-explained/index.php/Wood_products_-_production_and_trade

Variables:

- Maximum access distance = 200m (after Clouet, N. and Berger, F., 2009)

Calculation processes:

(1) Calculation of the slope angle of accessible forest: Forested areas within the maximum access distance from forest roads are extracted from the original forest layer and their slope is calculated (in %) The 200m serve as a threshold, all pixels that are further away from the street are not considered in the following calculation.

(2) Calculation of access distance: Based on Clouet & Berger (2009), the maximum distance from which every pixel (extracted in Step 1) can be accessed, due to its topographic conditions, is calculated. The access distance of a pixel can be lower than the actual distance from the street and therefore, all pixels that are further away from the road than their access distance are removed.

(3) Disaggregation of statistical data to LAU2 level: The data about the production of roundwood is disaggregated to LAU2 level via the share of accessible forest in every LAU2.

$$\frac{statistical\ data\ about\ fellings}{accessible\ forest\ in\ region} = average\ fellings\ per\ unit\ of\ accessible\ forest$$

$$average\ felling\ * accessible\ forest\ in\ LAU = LAU\ felling$$

Dividing the statistical data by the accessible forest area in each region gives an average value of the produced roundwood per accessible forest for each region. For all LAUs in the region, this average value is multiplied with the total accessible forest area of the LAU2. The result is the amount of roundwood that is produced in the LAU2.

(4) Calculation of fuelwood production: With statistical data about the share of roundwood that is transformed into fuelwood, the amount of fuelwood that is produced in every LAU2 is estimated.

References:

Clouet, N. ; Berger, F. (2009) : Modélisation des surfaces débardables au tracteur forestier en zone de montagne. SIG 2009. Conférence Francophone ESRI.

ES Indicator: Demand

General description:

The usage of fuel wood as an energy source is largely varying across the Alps and high-resolution data on energy consumption is scarce. Hence, this indicator is based on the average energy requirement to heat the interior of a building (kWh/m^2*year) and the calorific value of fuelwood (kWh/m^3). Building area from the open-street-map data is used to estimate the amount of fuelwood required at municipality level. Figure 2 gives a graphical overview of the calculation steps required to derive the demand indicator at LAU2 level.

Input data:

GIS-data

✓ Buildings: Distribution and basal area of buildings.
Source: http://download.geofabrik.de/.

Statistical data

✓ Calorific value of fuelwood: The amount of energy stored in fuelwood in kWh/kg or kWh/m^3.
Source: http://www.fao.org/3/a-i4441e.pdf; Tables 15 and 16.

✓ Energy efficiency class of buildings: The amount of energy that is needed to heat $1m^2$.
Source: https://www.ewe.de/privatkunden/service/ratgeber-eigenheim/energieeffizienzklassen

Variables:

- Calorific value of wood pellets = 2800 kWh/m^3
  Source: http://www.fao.org/3/a-i4441e.pdf
- Energy efficiency class = 250 kWh/m^2

Calculation steps:

(1) Calculate building area per municipality: The total building area for every LAU is calculated.
(2) Calculate energy demand: The building area is multiplied by the energy required to heat one m^2, which gives the energy requirement per LAU. To calculate the amount of fuelwood that is needed to fulfill this energy demand, the energy requirement per LAU is divided with the calorific value of wood-pellets.

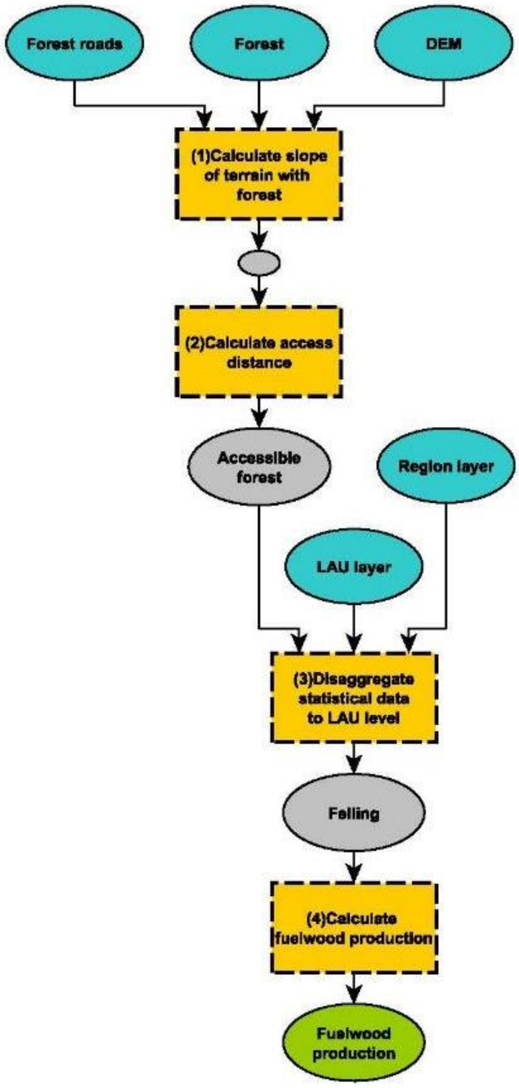


Figure 1: Flowchart depicting the procedures used to derive the flow indicator

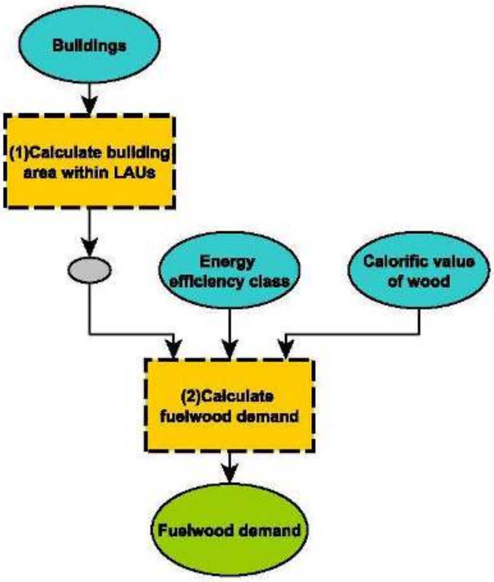
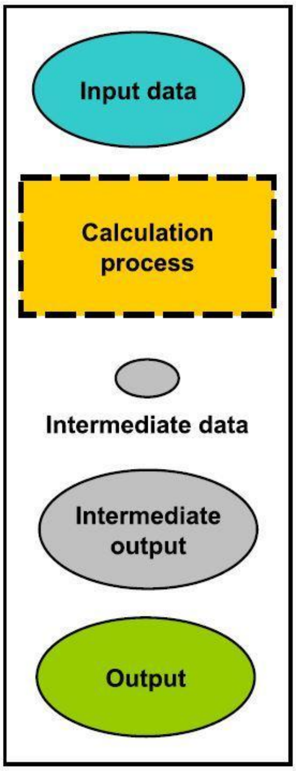


Figure 2: Flowchart depicting the procedures used to derive the demand indicator

Legend



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Filtration of surface water by ecosystem types

ES Indicator: (Flow-Supply)

General description:

The Water Filtration Flow-Supply indicator represents the amount of nitrogen (N) that is filtered by ecosystems in a given municipality. This ecosystem service is calculated using the InVEST "Nutrient Delivery Ratio (NDR)" model, specifically focusing on nitrogen.

The model uses a mass balance approach, which describes the movement of a mass of nutrients through space. Unlike more sophisticated nutrient models, the present approach does not represent the details of the nutrient cycle but rather represents the long-term, steady-state flow of nutrients through empirical relationships. A detailed description of the model can be found at: http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/ndr.html

Input Data

- ✓ Land use map
- ✓ Biophysical table with data on specific coefficients regarding Land cover/land use (LULC) type, nutrients and water (listed in Table 1 of this document).
- ✓ Nutrient runoff proxy, a raster dataset with the yearly average amount of precipitation
- ✓ LAU2 boundaries

Calculation process:

(1) Prepare Input data for InVEST NDR model

To run the model both raster and shapefile data are required. To avoid errors, it is advised to harmonize the data using the same projection, linear units, and cell size and then snapping the rasters to the DEM.

To obtain the results at the municipal level the Eurogeographics LAU2 Boundary Map was used instead of a watershed shapefile, as recommended by InVEST.

(2) Calculate the parameters required in the biophysical table

The biophysical table is a .csv table with information on LULC classes and specific nutrient and water coefficients used in the model. For some land uses these parameters have been refined using specific values (either modelled or based on a literature review) for the different regions in the Alpine Space, while for other coefficients the default values provided by InVEST have been used (See Table 1).

Table 1: default and recalculated parameters used in the Biophysical table

Parameter	Field name	Used value
Nutrient load for each land use	*load_n*	Recalculated for agricultural areas
The maximum retention efficiency for each LULC class, varying between zero and 1	*eff_n*	Default
The distance after which it is assumed that a patch of LULC retains nutrient at its maximum capacity (in meters)	*crit_len_n*	Default
The proportion of dissolved	*proportion_subsurface_n*	Default

nutrients over the total amount of nutrients, expressed as ratio between 0 and 1		

For the agricultural areas in the LULC map, the N input for the dedicated field of the biophysical table is calculated in kg/ha/year by summing up inputs from the following data sources:

- Manure-fertilization (JRC, 2012),
- Wet and dry deposition (Norwegian Meteorological Institute, 2016) □ Average
- Biological nitrogen fixation (Vries et al., 2011).

For all other LULC classes (i.e. urban fabric, forests…) the default values provided by InVEST were used.

(3) Set the other watershed parameters and Run InVEST NDR model
By running the NDR model, choosing the "Calculate Nitrogen Retention" option, the N load and N export per municipality are calculated. The model requires additional parameters that can be set before starting the calculation.

We used the following thresholds:

Table 2: Additional parameters required by the model

Parameter	Threshold
Subsurface Maximum Retention Efficiency	0.8
Subsurface Critical Length	150
Threshold Flow Accumulation	1000
Borselli k parameter	2

(4) Calculate the amount of filtered nutrients per municipality
The amount of nitrogen that is filtered in a municipality can be calculated from the outputs of the Nutrient Delivery Ratio model by subtracting the nitrogen exported per municipality from the total nitrogen load in the same area.

Map Preparation

For the visualization of the result in a choropleth map, the Flow-Supply values are normalized with the total municipal area in hectares.

Reference:

JRC (2012). Nitrogen load gridded dataset for Europe on HSMU level. http://afoludata.jrc.ec.europa.eu/dataset/nutrient-load-n-and-p-europe-basis-hsmu ; accessed: 2017-12-07.

Natural Capital Project (2017). Invest documentation. http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/ndr.html; accessed: 2017-12-07.

Norwegian Meteorological Institute (2016). Nitrogen deposition gridded dataset for years 2000-2015.
http://www.emep.int/mscw/; accessed: 2017-12-07.

Vries, W. d., Leip, A., Reinds, G., Kros, J., Lesschen, J., and Bouwman, A. (2011).
Comparison of land nitrogen budgets for european agriculture by various modeling approaches.
Environmental Pollution, 159:3254–3268.

ES Indicator: Demand

General description:

The Water Filtration demand indicator describes the amount of nitrogen that is introduced into the ecosystem per municipality in kg/year. This includes nitrogen inputs via fertilization, wet and dry nitrogen deposition, and biological nitrogen fixation. This indicator is one of the outputs of the InVEST "Nutrient Delivery Ratio" model.

Calculation processes:

(1) Run InVEST Nutrient Delivery Ratio model

By running the Nutrient Delivery Ratio model, the nitrogen load per municipality is directly calculated and displayed as a model output.

Map Preparation

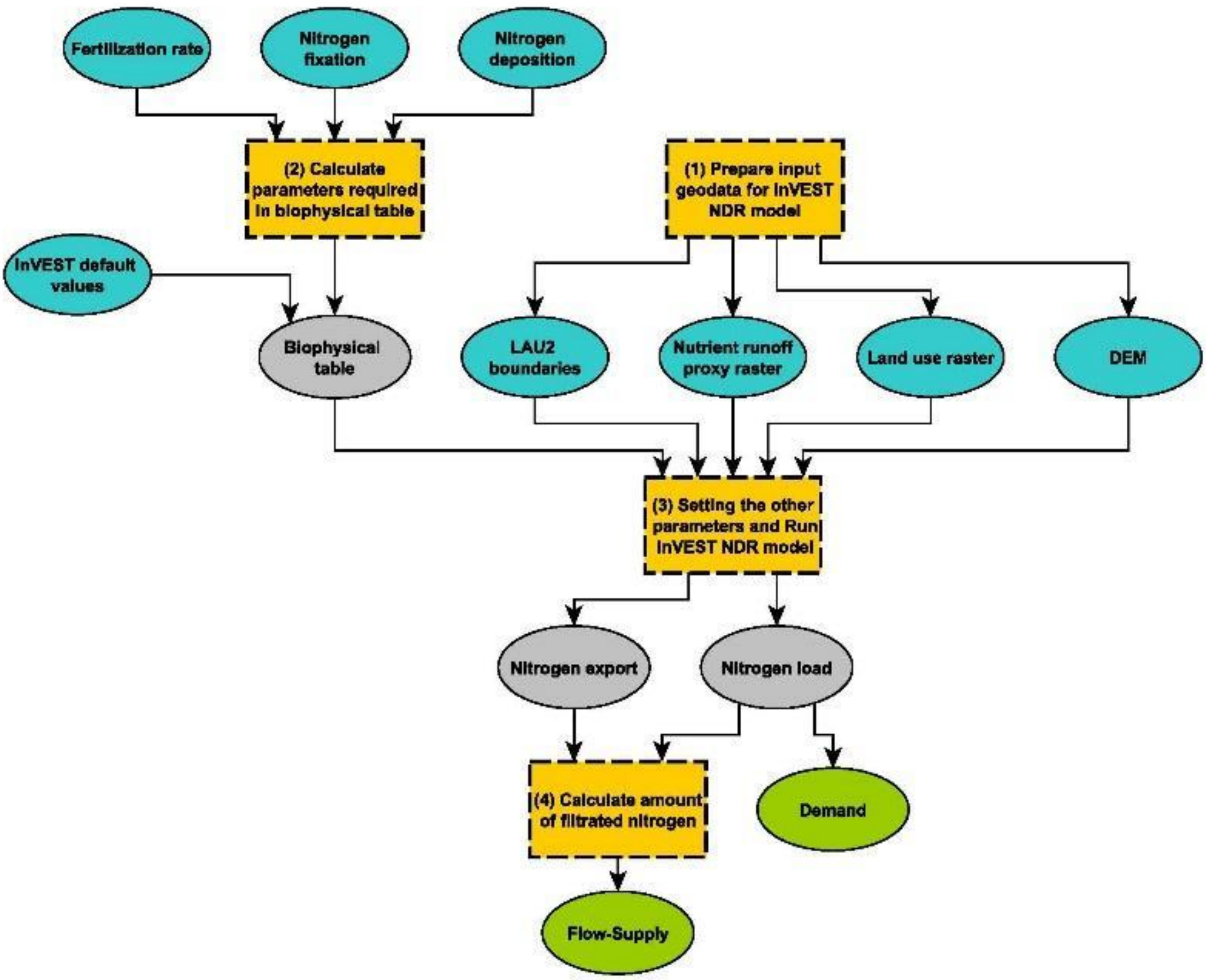
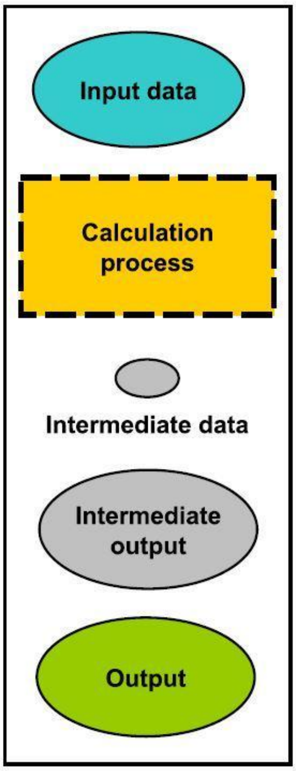


Figure 1: Flowchart depicting the procedures used to derive the Flow-Supply and Demand

For the visualization of the result in a choropleth map, the Demand values are normalized with the total municipal area in (ha).

Legend



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Protection of areas against avalanches, mudslides and rockfalls

ES Indicator: Supply, Flow, and Demand

General description:

The following model is an approach to delineate areas where the biotic ecosystems (forests) contribute to the mitigation of natural hazards and the protection of human assets from hazardous natural processes. At the alpine-wide scale, this has been done by combining separate regional models for avalanches, rock-falls and water channel relevant processes. The models use topographical information derived from the 25m EU DEM and statistically derived threshold values identified by earlier projects and assessments (performed in all alpine countries) to model potential avalanche and rock-fall release and transition zones.
Figure 1 describes in detail the calculation procedure to derive the developed indicators per local administrative units (LAU2) of the Alpine Space.

Input data:

- ✓ DEM (slope, slope-length, flow direction, watershed, plan curvature, contour lines)
- ✓ Land Cover
- ✓ River Network

Calculation processes:

Avalanche Release and Transition Zones

(1) Calculate potential avalanche release areas: Select all areas with a slope between 28° and 55°, a plan curvature between -2 and 0.2, a forest land-cover and if there is no better information on potential snow-accumulation available above an altitude threshold (Bauerhansel et al 2009).

(2) Split larger areas: To get more realistic snowfields the result of the previous calculation has to be split into smaller areas. To take flow processes of avalanches into consideration this should be done by using very small watersheds that indicate the same flow direction of an area. The areas can be split into horizontal sections using contour lines (50m) to create “snowfields” with a vertical extent no larger than 120m.

(3) Calculate avalanche cost path: The cost path represents the easiest way down a slope following the highest elevation differences from one raster pixel to the next. In Arc GIS this can be accomplished with the tool (cost path) using the Flow-Direction as Cost Backlink raster and the DEM as Cost Distance Raster.

(4) Calculate energy line angle for every release area: The energy line, or generalized gradient, represents the angle of the connecting line from the release point and the outer edge of the run-out zone of a mass movement with the horizontal plan. (Bauerhansel et al 2009)

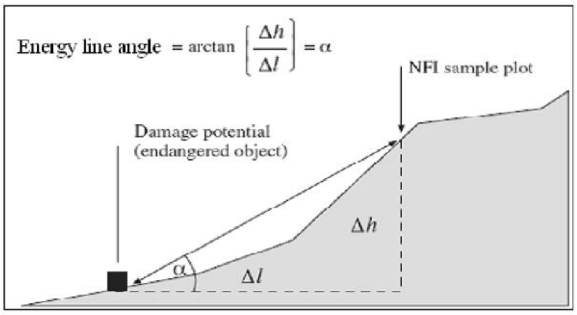


Figure 2-4: *Concept of the Energy Line Angle Method (Heim 1932): Δh = total of all flow direction heights, Δl = total of all lengths. (Figure: Mani & Balmer (1996) cited from Brassel & Lischke (2001)).*

*Figure SEQ Figure * ARABIC 1 Bauerhansl, C., Berger, F., Dorren, others, 2010. Development of harmonized indicators and estimation procedures for forests with protective functions against natural*

In Arc GIS the calculation of the Energy Line Angle can be done with the following steps:

(a) Creating an integer raster with the elevation of the release areas
(b) Running the tool Euclidean Allocation and Distance with the integer raster as Input (to speed up the calculation, a maximum distance of 2000m should be set)
(c) Using the Raster Calculator, subtract the result from the DEM. The value you get is the elevation difference from every pixel to the release zones Δh
(d) The Euclidean Distance calculated in step (b) represents Δl

(e) The energy line angle can than simply be calculated with ELA = atan(Δh/Δl) (⊠ Arc GIS calculates angles in radians to get a result in degrees you have to multiply it with 57.2958).

(5) Limit avalanche Paths with energy line angle: Knowing the avalanche path, the energy line angle allows a rough estimation of maximal runout distance. The previously measured events occurred at an ELA of 17° - 47° with the mean 28°. Events with ELA 17° are very improbable. We used this threshold for our approach to consider all possible events. (Bauerhansel et al. 2009, PARAmount Project 2012)

Rock-fall Release and Transition Zones

(6) Calculate potential rock-fall start zones: Similar to the avalanche release areas, this can roughly be done by selecting all areas with bare-rock land-cover and a slope steeper than 43°. In the Alpine-wide approach we had to use CORINE Land Cover as the input dataset where most rock surfaces are not delineated (because of resolution and minimum mapping width). For that reason, we also included all the areas without vegetation. Depending on the DEM resolution, different slope thresholds should be applied (Berger et al 2010).

$\alpha = 55 \times RES^{-0.075}$, where RES is the DTM resolution

DTM resolution/cell size [m]	Threshold slope gradient [°]
1	55
5	49
10	46
25	43

Table 2. Threshold values for determining rockfalls release area for DTM main resolutions

*Figure SEQ Figure * ARABIC 2 Berger, F., Larcher, V., Simoni, S., Pasquazzo, R., Strada, C., Zampedri, G., 2012. WP6 guidelines - Rockfall and Forecast systems.*

(7) Create Cost Raster: A cost raster represents the theoretical costs a falling rock would have to overcome from one area to the next (pixel to pixel). These costs depend on the slope length and the land-cover/surface roughness. The highest costs are found in flat, forested areas and low costs exist in steep areas without forest-cover. A single raster can be created by combining two reclassified slope rasters (one for forest areas and one for all other surfaces). The reclassification should occur with the following values:

Slope	Costs no forest	Costs in forest
<5 °	10	30
>5 – 10°	9	27
>10 – 15°	8	24
>15 – 20°	7	21
>20 – 25°	6	18
>25 – 30°	5	15
>30 – 35°	4	12
>35 – 40°	3	9
>40 – 45°	2	6

>45°	1	3

(8) Calculate energy line angle for every start zone: Energy line angle is calculated using the same methodology as in step 4.

(9) Perform Path Distance analysis to calculate maximum runout lengths of falling-rocks: The threshold of 2250 was used which is approximatly a runout of 250 meters in forested terrain (assuming the same dbh and tree density in all forests). With better information on the tree stands in forests different thresholds could be applied using the RockforNET tool, found here: http://www.ecorisq.org/rockfor-net-en .

Areas relevant for water channels

(10) Delineate Forest areas with a protective effect for water-channels: All areas with an on-surface distance to water channels of between 10m (trees too near to the channel can have negative influence) and 200m and a slope steeper than >20° are potential erosion and mudslide risk zones that could clog up the river. Forests within this zone are thus particularly important in preventing erosion and events.

Supply Indicator creation

(11) Combine areas where forests have a protective function: By merging all natural hazard zones that already have a forest land-cover, the sites of protection forests are identified. By definition, the protective function of forests exists in all avalanche release and transition zones, rock-fall transition zones and water channel relevant terrain.

Demand indicator creation

(12) Calculate natural hazard potential: Merge the spatial extent of the avalanche and rock-fall transition zones calculated above.

(13) Calculate Damage Potential: Create a raster with all human infrastructure, such as settlements areas, built up areas, buildings, roads and railways.

(14) Calculate protection forest demand index: Overlay the natural hazard potential and the damage potential areas. This allows one to identify all of the infrastructure in potential hazard zones that is in need of protection.

Flow indicator creation

(15) Backlink intersections of hazard potential and damage potential to release areas: In the case of avalanches all the transition zones that intersect with infrastructure have to be traced back to the corresponding release area. Using Raster in ArcGIS, this can be done by inverting the DEM and performing a new cost path analysis starting from the intersected damage potential areas. Finally, by combining the avalanche release and transition zones as well as rockfall transition zones that possibly harm infrastructure we are able to identify object-protecting forest.

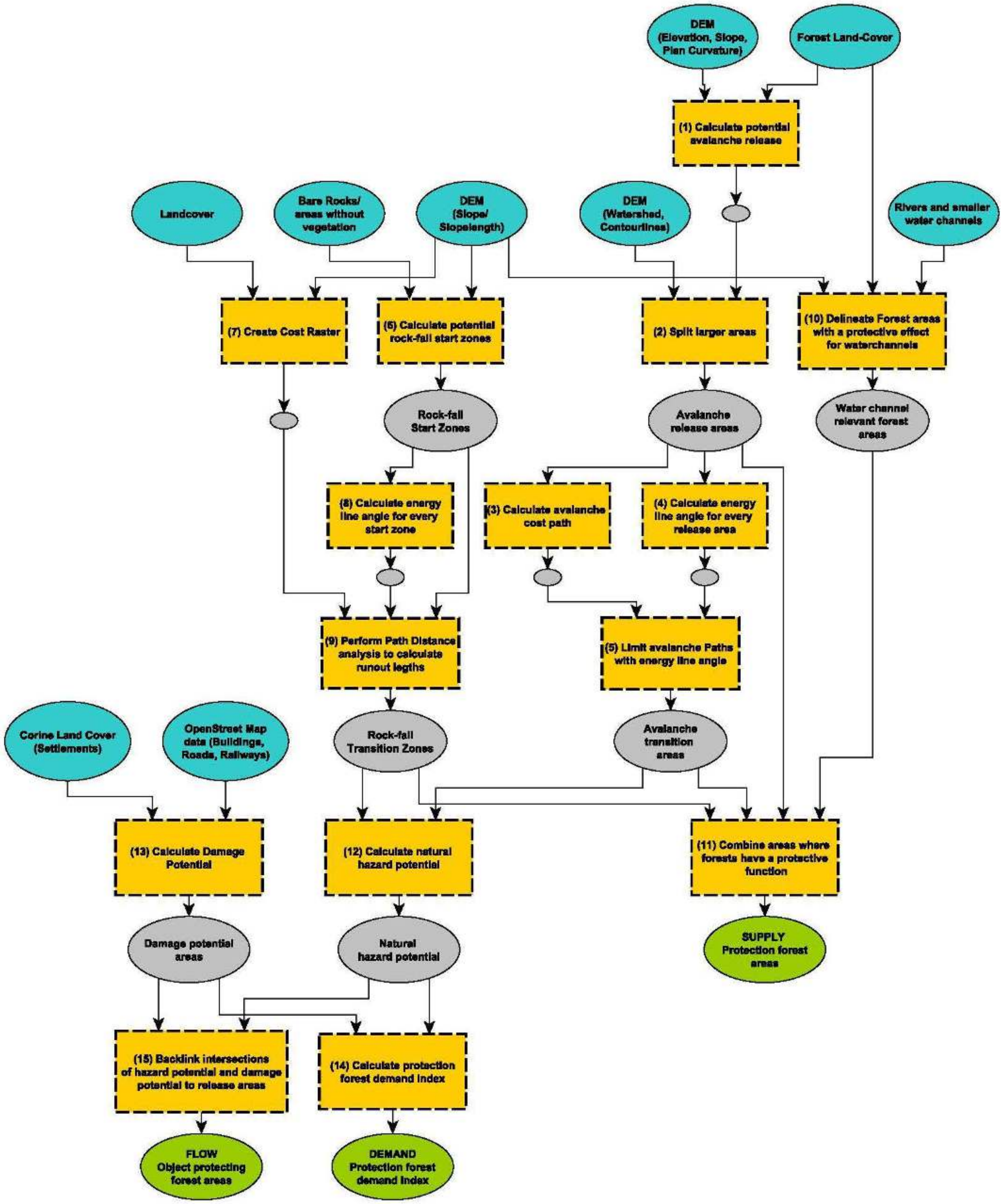
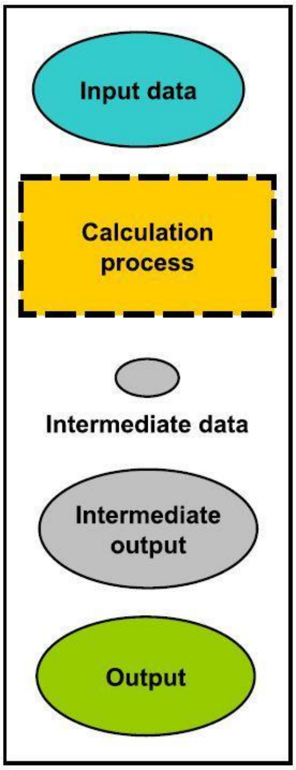


Figure 1: Flowchart depicting the procedures used to derive the supply, flow and demand indicators

Legend



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CO2 Sequestration by Forests and Bogs

ES Indicator: Flow-Supply

General description:

This indicator represents the annual rate of CO2 sequestration by forests at the municipal level (t CO2/ha-1y-1). This value is calculated on the basis of the IPCC equations used to estimate the annual increase in biomass carbon stock due to biomass increment. This method allows above and below ground estimation of biomass increase in tonnes of carbon per year. The application of a standard constant converts the result into the amount of CO2 being sequestered. Figure 1 describes in detail the calculation procedure to derive the amount of CO2 sequestration (t CO2/ha-1y-1) per local administrative units (LAU2) of the Alpine Space.

Input data:

- ✓ DEM
- ✓ Forest Type Landcover
- ✓ Forest Biomass increment factors (above and below ground)
- ✓ Climate zones

Calculation processes:

(1) Create Forest Classification

The classification is based on three criteria:

- Forest typology: coniferous or broadleaved
- Altitude, three classes have been taken into consideration: 0 - 600m; 600m-1200m; >1200m.
- Climatic regions: the alpine space has been divided in different macro-climatic areas basing on different climatic classifications: the central alps, northern alps and southern alps.

(2) IPCC Equations Calculation: application of the IPCC equations (2.9 and 2.10 of the IPCC guidelines, vol. 4, ch. 2, modified to obtain the results as quantity of CO2) with proper factors derived from different sources:

- Above ground biomass: Values for above ground biomass were derived from the dataset created by Busetto et al. (2014). As this dataset did not cover the entire alpine space, two additional methods were used to calculate these factors for the remaining area:
  - Interpolation of the values: interpolation of the factor value from (Busetto et Al. 2014).
  - Calculation based on factors from National Forest Inventories: application of the factors derived from the Swiss National Forest Inventory, scaled on the base of forest typology, altitude and climatic macro-area using the results from (1).
- Below ground biomass: The factors to be used in the equation are derived from the Swiss National Forest Inventory and scaled based on forest typology, altitude and climatic macro-area using the results from (1).

(3) Calculate Forest Sequestration per Municipality: calculate statistics of the tonnes of CO2 sequestered by hectare of forest in the single municipalities using the forest area and the sum of sequestration per municipality.

References:

IPCC, (2006) IPCC guidelines for national greenhouse gas inventories, prepared by the national greenhouse gas inventories program, Vol. 4, Ch. 2-4, Forest Land)

Busetto, L., J. I. Barredo, and J. San-Miguel-Ayanz. "Developing a spatially-explicit pan-European dataset of forest biomass increment." (2014): 41-46

Brändli, U.-B. (Red.) 2010: Schweizerisches Landesforstinventar. Ergebnisse der dritten Erhebung 2004–2006. Birmensdorf, Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft WSL. Bern, Bundesamt für Umwelt, BAFU. Pag. 111 Tab. 094-095

ES Indicator: Demand

General description:

This indicator represents the CO2 emissions per municipality (t CO_2/ha-1) for the year 2010. The CO_2 emissions dataset at the European scale (Trombetti et al. 2017), has been rescaled and integrated with the data from the EDGAR database to include the area of Switzerland. This new dataset has been aggregated at the municipal level to assess the tonnes of CO_2 emitted per hectare in the Alpine

Space. Figure 2 describes in detail the calculation procedure to derive the amount of CO_2 emissions (t CO_2/ha-1) per local administrative units (LAU2) of the Alpine Space.

Input data:

- ✓ CO2 emissions (Trombetti et Al. 2017)
- ✓ EDGAR CO2 emissions (EDGAR, http://edgar.jrc.ec.europa.eu/overview.php?v=42FT2010)

Calculation processes (for both datasets):

(1) Resampling and downscaling data: resampling of the data in order to be able to calculate the value of emissions per single municipality.

(2) Calculate CO2 emissions per municipality: calculate the statistics and the tonnes of CO2 emitted by municipality (tonnes CO2/hectare) taking into consideration its size.

References:

Trombetti M., Pisoni E., Lavalle C., Downscaling methodology to produce a high-resolution gridded emission inventory to support local/city level air quality policies, Office for Official Publications of the European Communities, Luxembourg, EUR 28428 EN, doi:10.2760/51058

EDGARv4.2, European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. Emission Database for Global Atmospheric Research (EDGAR), release version 4.2. http://edgar.jrc.ec.europa.eu/overview.php?v=42FT2010, 2011

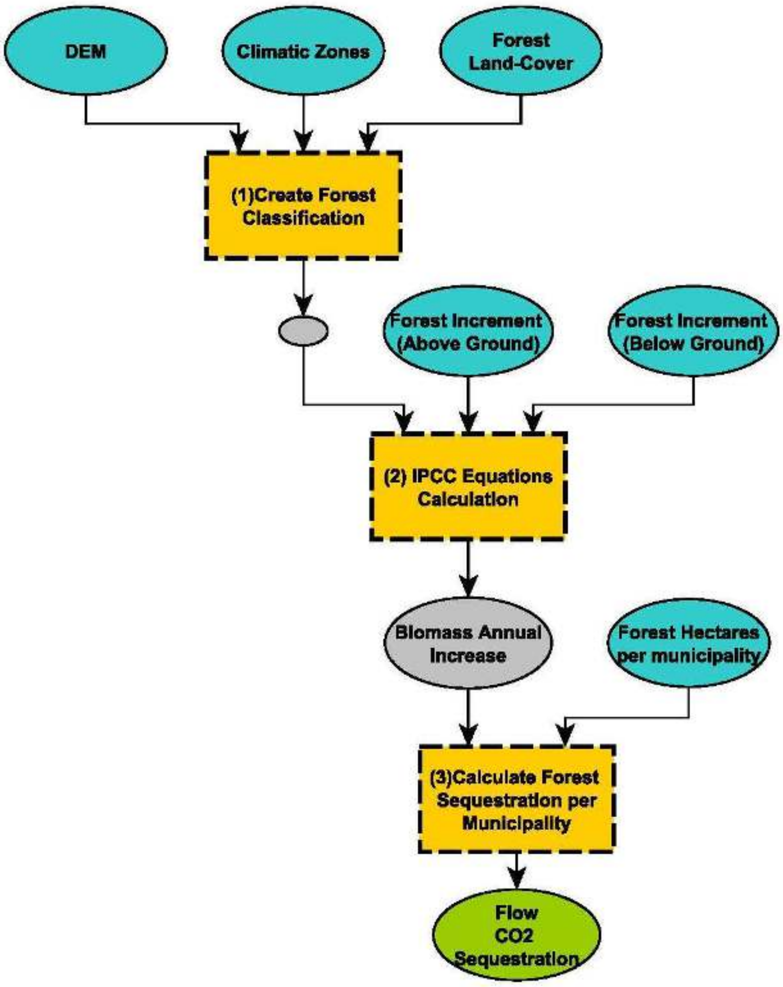


Figure 1: Flowchart depicting the procedures used to derive the flow-supply indicator

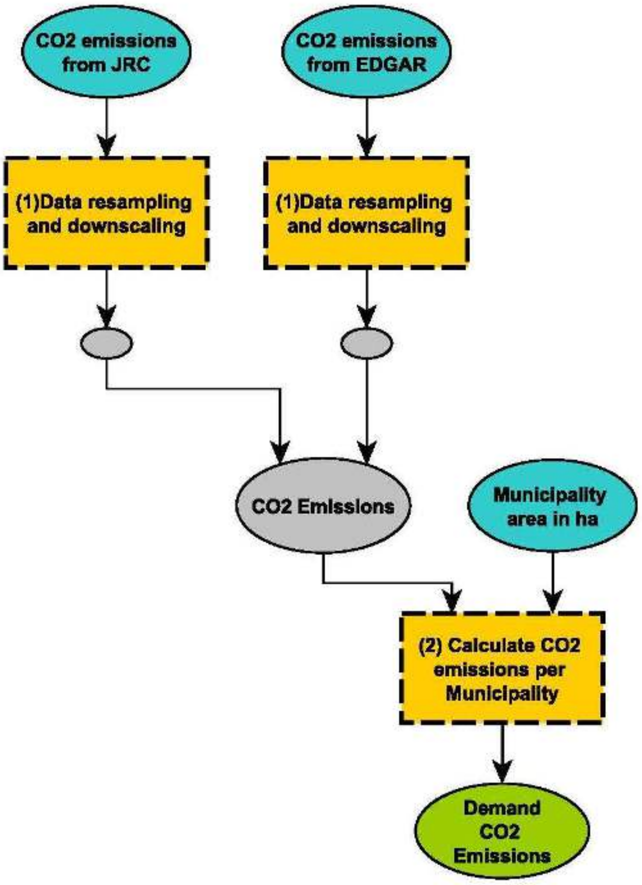
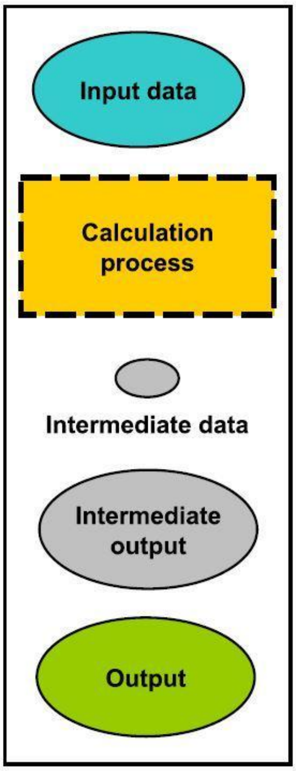


Figure 2: Flowchart depicting the procedures used to derive the demand indicator

Legend



Input data → elements that hold a value or a reference to data stored on disk. It is usually a spatial explicit information coming from official sources.

Calculation process → the actual operation performed on the data. The number preceding the item refers to the number in the model description.

Intermediate data → for each calculation process intermediate data is generated. This data, however, is usually not significant itself, but is used as an input for the next calculation step.

Intermediate output → is intermediate data that has a significance for the ES evaluation.

Output → is the result of the calculation process. It is typically one of the ES indicators, either Supply, Demand or Flow.

Outdoor recreation activities

ES Indicator: Supply

General description:

The supply of outdoor recreation is collected in three steps: First, we map the recreation potential provided by ecosystems, then the accessibility is calculated, and finally both aspects are integrated into one map.

Different landscape variables serve as indicators for the recreation potential. These are all based on recent literature (see table 1). Every dataset was converted to raster data with a spatial resolution of 100 m in order to easily overlay them. Furthermore, all indicators were considered to equally contribute to the recreation potential and were rescaled to 0–100. In a last step, they were then overlaid to obtain a recreation potential index (Paracchini et al., 2014). The recreation potential index ranges from 0 (low) to 100 (high) and was further analysed considering accessibility. All calculations were performed using standard routines provided with ArcGIS 10.4. The following explanations are quoted directly from the supplementary material of Schirpke et al. (2017).

Input Data

- ✓ Protected areas
- ✓ DEM
- ✓ Open street map
- ✓ Landcover

Calculation processes:

(1) Calculate recreational value of protected areas

Natural environment and high biodiversity contribute considerably to recreational value (Sonter et al., 2016) and, thus, protected areas are considered public recreation areas (Paracchini et al., 2014). The recreational value of protected areas was mapped considering the Natura 2000 network and the Common Database on Designated Areas (CDDA) (EEA, 2015a, b). The Natura 2000 network consists of sites designated under the Birds Directive (Special Protection Areas, SPAs) and the Habitats Directive (Sites of Community Importance, SCIs, and Special Areas of Conservation, SACs). The CDDA is an inventory of nationally designated areas. The database follows the IUCN (International Union for Conservation of Nature and Natural Resources) categories, classifying protected areas according to their management objectives. Protected areas from the Natura 2000 network and the CDDA were overlaid and reclassified in relation to their importance for recreational uses according to Zulian et al. (2013) (Table 1). The score ranges from 0 to 100. The highest score was assigned to the category of protected areas with the highest natural value, whereas 0 was used for sites that are inaccessible for recreation purposes (category Ia).

Table 1: CDDA categories and score for recreation potential according to Zulian et al. (2013)

Class	Description	Score
Ia	Strict Nature Reserve: protected area managed mainly for science	0

Ib	Wilderness Area: protected area managed mainly for wilderness protection	100
II	National Park: protected area managed mainly for ecosystem protection and recreation	80
III	Natural Monument: protected area managed mainly for conservation of specific natural features	100
IV	Habitat/Species Management Area: protected area managed mainly for conservation through management intervention	80
V	Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation and recreation	80
VI	Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural ecosystems	80
NA	Not classified	80

(2) Reclassify to hemeroby classes
The degree of environmental naturalness (hemeroby) is one of the most important factors when selecting locations for outdoor recreation (Peña et al., 2015; Willemen et al., 2008). The hemeroby index measures the extent of human impacts on the natural environment on a scale from 1 (natural) to 7 (artificial) and can be attributed to land cover types (Steinhardt et al., 1999; Wrbka et al., 2004). The hemeroby was calculated based on CORINE land cover data (EEA, 2016a). All land cover types were attributed to the hemeroby classes as proposed by Paracchini and Capitani (2011). The index was inverted to assign highest recreational values to more natural environments and rescaled from 0 to 100.

(3) Calculate distance to water
Water offers a variety of recreational opportunities (Keeler et al., 2015) and has a high visual attraction compared with or in conjunction with surrounding areas (Arriaza et al., 2004; Ode et al., 2009). To calculate the influence of water bodies on the recreation potential, inland and marine water bodies were extracted from the CORINE land cover database (EEA, 2016a). The Euclidean distance was calculated up to 2,000 m from the coastline of seas and lakes, and the recreational potential was assessed by applying an impedance function (Paracchini et al., 2014) and subsequently rescaled from 0 to 100, resulting in high values for areas close to the coastline.

(4) Calculate number of land cover types
Diverse landscapes provide high recreational and visual attractiveness (Kienast et al., 2012; Ode et al., 2009; Schirpke et al., 2016). The landscape diversity was assessed by calculating the number of different land cover types per km2 (Kienast et al., 2012) based on the CORINE land cover database (EEA, 2016a). The result was rescaled from 0 to 100. Great landscape diversity indicates high recreation potential.)

(5) Calculate Terrain roughness
Rough landscapes provide many recreational opportunities and are visually more appealing than flat landscapes (Weyland & Laterra, 2014). The Terrain Ruggedness Index (TRI) reveals the degree of topographic heterogeneity by measuring elevation differences between adjacent cells (Riley et al.,

1999). We calculated the TRI based on the DEM (EEA, 2016b), which was aggregated to 100 x 100 m and classified into seven classes as proposed by Riley et al. (1999). All scores were rescaled from 0 to 100. High ruggedness suggests high recreation potential.

(6) Calculate density of mountain peaks
Mountain peaks are very attractive for recreation, providing opportunities, for example, for mountaineering and climbing (Pomfret, 2011). Furthermore, they can be considered as a proxy for long vistas and remoteness (Kienast et al., 2012), and influence people's choices for recreational purposes due to their high visual attractiveness (D'Antonio & Monz, 2016). We used the density of mountain summits as an indicator for recreation potential, as also applied by other studies (Kienast et al., 2012; Peña et al., 2015).

To select important mountain summits on a local to regional level, several steps were applied following Podobnikar (2012):

- Calculation of local peaks by applying a moving window with the kernel of size 5 × 5 cells (focal statistics; maximum) based on the DEM (EEA, 2016b) using a spatial resolution of 100 m
- Selection of local peaks above 600 m
- Elimination of local peaks on flat areas (curvature > 0.2: significant concave areas; ruggedness >= moderately rugged)

The density of the identified mountain peaks was then calculated by counting the peaks per 10 km2 by applying a moving window. The resulting values were reclassified from 0 to 100, with high density of mountain peaks representing high recreation potential.

(7) Calculate recreation potential
All indicators were considered to equally contribute to the recreation potential. All indicators, which were first rescaled to 0–100, were overlaid to obtain a recreation potential index (Paracchini et al., 2014) by summing all layers and dividing them by 6 (number of all layers). The recreation potential index ranges from 0 (low) to 100 (high).

(8) Calculate accessibility
Accessibility through infrastructure determines whether suitable recreation areas can be used, and proximity to residential areas is a crucial factor for the use of recreational sites (Ala-Hulkko et al., 2016; Kienast et al., 2012; Paracchini et al., 2014; Peña et al., 2015; Weyland & Laterra, 2014). We therefore identified the accessible areas as well as the level of accessibility defined by the proximity to residential areas. First, we identified recreational areas that are accessible through infrastructure such as paved and unpaved roads, hiking trails, and cycling paths. Information on the road network was obtained from OpenStreetMap (OSM, 2016), which was used to calculate the Euclidean distance from roads and paths. Assuming that people would rather stick to existing paths and trails for most recreational activities rather than moving off-road, accessible areas were mapped by selecting all areas up to 1,500 m distance from the road network, as this distance contributes most to visual landscape enjoyment (Schirpke et al., 2013). To assess the level of the supply, we calculated the proximity of recreational areas from residential areas in terms of travel time by private car (on paved roads) and foot (on roads and paths closed for cars). The road network contained information on the maximum speed of most roads. Missing data were integrated by assigning each type of road a mean travelling velocity. Further, we assumed an average off-road velocity of 1 km/h, to include the

whole surface of the study area into the calculation. Residential areas were extracted from the CORINE land cover database (EEA, 2016a) (classes ‘continuous urban fabric’ and ‘discontinuous urban fabric’). The travel time from urban areas was then estimated using the cost distance algorithm as implemented in ArcGIS 10.4 (ESRI, Redlands, CA, USA). The resulting travel time was rescaled from 0 to 1.

(9) Calculate recreation supply (status)
The recreation potential was overlaid with the level of accessibility by multiplying the two layers in order to exclude inaccessible areas and map the recreation supply.

Table 2: Landscape variables used as indicators of outdoor recreation potential.

Landscape variable	Description	Relationship to recreation potential	Data sources	Mapping approach
Naturalness	Index of naturalness (hemeroby)	Preference for more natural environments for outdoor recreation (Peña et al., 2015; Willemen et al., 2008)	CORINE land cover (EEA, 2016a)	Attribution of hemeroby classes to land cover types (Paracchini & Capitani, 2011)
Protected areas	Presence of protected area	Natural environment and high biodiversity (Sonter et al., 2016) and public recreation areas (Paracchini et al., 2014)	Natura 2000 database (EEA, 2015b); Common Database on Designated Areas (CDDA) (EEA, 2015a)	Attribution of scores to IUCN categories (Zulian et al., 2013)
Presence of water	Distance to water bodies	Recreational opportunities (Keeler et al., 2015) and high visual attraction (Arriaza et al., 2004; Ode et al., 2009)	CORINE land cover (EEA, 2016a)	Impedance function of attractiveness (distance < 2000 m) from coastlines of sea and lakes (Paracchini et al., 2014)
Landscape composition	Landscape diversity	High recreational and visual attractiveness of diverse landscapes (Kienast et al., 2012; Ode et al., 2009; Schirpke et al., 2016)	CORINE land cover (EEA, 2016a)	Number of land cover types per km2 (Kienast et al., 2012)
Type of relief	Terrain Ruggedness Index (TRI)	Recreational opportunities and visual attraction of rough landscapes (Weyland & Laterra, 2014)	DEM (EEA, 2016b)	TRI classes (Riley et al., 1999)
Mountain peaks	Density of mountain summits	Recreational opportunities (Pomfret, 2011), overview and remoteness (Kienast et al., 2012), and visual attraction (D'Antonio & Monz, 2016)	DEM (EEA, 2016b)	Identification of mountain peaks (Podobnikar, 2012), number of summits per 10 km2

Reference:

Zulian G., Paracchini M. L., Maes J., Liquete M. : ESTIMAP: Ecosystem services mapping at European. Publications Office of the European Union 2013 – 54 pp. – 21.0 x 29.7 cm EUR – Scientific and Technical Research series – ISSN 1018-5593 (print), ISSN 1831-9424 (online) ISBN 978-92-79-35275-1 (print) ISBN 978-92-79-35274-4 (pdf) doi: 10.2788/64369

ES Indicator: Flow

General description:

To map recreation flow, we used metadata linked to photographs appearing on social media. These datasets are crowd-sourced and have been shown to be reliable proxies for visiting frequencies and correlate with official visitation rates. Date and time, Username and location of the picture are stored in the metadata. With this information, we can map the density of pictures taken at a specific location, which approximates visitation rates. This procedure was developed by Schirpke et al. (2017).

Input Data

- ✓ Picture metadata

Calculation processes:

(1) Define user days
In a first step, the dataset needs to be downloaded over an API – an application programming interface, where the metadata is freely accessible and can be downloaded. To estimate visitation rates, we first defined so-called 'user-days' i.e., the number of users who took at least one picture per day in each location. We defined a location by a radius of 1.5 km that refers to the near zone of a specific location and deleted multiple pictures by the same user and taken the same day, resulting in 1,089,663 pictures.

(2) Calculate mean visitation rates
Then, we calculated mean visitation rates per year and season by calculating the point density of all photographs using a moving window with a search radius of 1.5 km for the respective period. Finally, the recreation flow maps were rescaled from 0 (low) to 100 (high) to overlay them with the recreation supply and demand.

ES Indicator: Demand

General description:

The local recreation demand was mapped using the location of beneficiaries of recreational opportunities as an indicator, including both residents and tourists. Thus, we quantified the local recreation demand based on the number of residents and tourists, using national census data and occupancy rates of tourist accommodation establishments at the municipality level. The following explanations are partly cited from Schirpke et al. (2017).

Input Data

- ✓ National Census data
- ✓ Occupancy rates of tourist accommodation

Calculation processes:

(1) Calculate permanent resident equivalent

Tourism occupancy rates were converted into a 'permanent resident equivalent' by dividing the number of nights by 365 and added to the number of residents, representing the number of people that might daily benefit from recreational opportunities.

(2) Disaggregate data to municipality level

Next, the density per municipality is calculated and the demand rescaled from 0 (low) to 100 (high) to compare it with recreation supply and flow.

References:

Ala-Hulkko, T., Kotavaara, O., Alahuhta, J., Helle, P., Hjort, J., 2016. Introducing accessibility analysis in mapping cultural ecosystem services, Ecol. Ind. 66, 416-427.

Arriaza, M., Cañas-Ortega, J.F., Cañas-Madueño, J.A., Ruiz-Aviles, P., 2004. Assessing the visual quality of rural landscapes, Landscape Urban Plann. 69, 115-125. doi: DOI: 10.1016/j.landurbplan.2003.10.029.

D'Antonio, A., Monz, C., 2016. The influence of visitor use levels on visitor spatial behavior in off-trail areas of dispersed recreation use, J. Environ. Manage. 170, 79-87.

European Environment Agency (EEA), 2015a. European inventory of nationally designated areas. http://www.eea.europa.eu/data-and-maps/data/nationally-designated-areas-national-cdda-1 (accessed 21.10.16).

European Environment Agency (EEA), 2015b. Natura 2000 data - the European network of protected sites. http://www.eea.europa.eu/data-and-maps/data/natura-7 (accessed 21.10.16).

European Environment Agency (EEA), 2016a. CORINE Land Cover (CLC) 2012, Version 18.5.1. http://land.copernicus.eu/pan-european/corine-land-cover/clc-2012 (accessed 21.10.16).

European Environmental Agency (EEA), 2016b. European Digital Elevation Model (EU-DEM), Version 1.0. http://land.copernicus.eu/pan-european/satellite-derived-products/eu-dem/eu-dem-v1-0-and-derived-products/eu-dem-v1.0/view (accessed 24.10.16)

Keeler, B.L., Wood, S.A., Polasky, S., Kling, C., Filstrup, C.T., Downing, J.A., 2015. Recreational demand for clean water: evidence from geotagged photographs by visitors to lakes, Frontiers in Ecology and the Environment 13, 76-81.

Kienast, F., Degenhardt, B., Weilenmann, B., Wäger, Y., Buchecker, M., 2012. GIS-assisted mapping of landscape suitability for nearby recreation, Landscape Urban Plann. 105, 385-399.

Ode, Å, Fry, G., Tveit, M.S., Messager, P., Miller, D., 2009. Indicators of perceived naturalness as drivers of landscape preference, J. Environ. Manage. 90, 375-383. doi: DOI: 10.1016/j.jenvman.2007.10.013.

OpenStreetMap (OSM), 2016. OpenStreetMap. Available from: http://download.geofabrik.de/europe.html (accessed 09.11.16)

Paracchini, M.L., Capitani, C., 2011. Implementation of a EU-wide indicator for the rural-agrarian landscape. EUR 25114 EN. Publications office of the European Union, 89 p.

Paracchini, M.L., Zulian, G., Kopperoinen, L., Maes, J., Schägner, J.P., Termansen, M., Zandersen, M., Perez-Soba, M., Scholefield, P.A., Bidoglio, G., 2014. Mapping cultural ecosystem services: A framework to assess the potential for outdoor recreation across the EU, Ecol. Ind. 45, 371-385. doi: http://dx.doi.org/10.1016/j.ecolind.2014.04.018.

Peña, L., Casado-Arzuaga, I., Onaindia, M., 2015. Mapping recreation supply and demand using an ecological and a social evaluation approach, Ecosystem Services 13, 108-118. doi: http://dx.doi.org/10.1016/j.ecoser.2014.12.008.

Schirpke, U., Meisch, C., Marsoner, T., Tappeiner, U., 2017. Revealing spatial and temporal patterns of outdoor recreation in the European Alps and their surroundings. Ecosystem Services, doi: 10.1016/j.ecoser.2017.11.017.

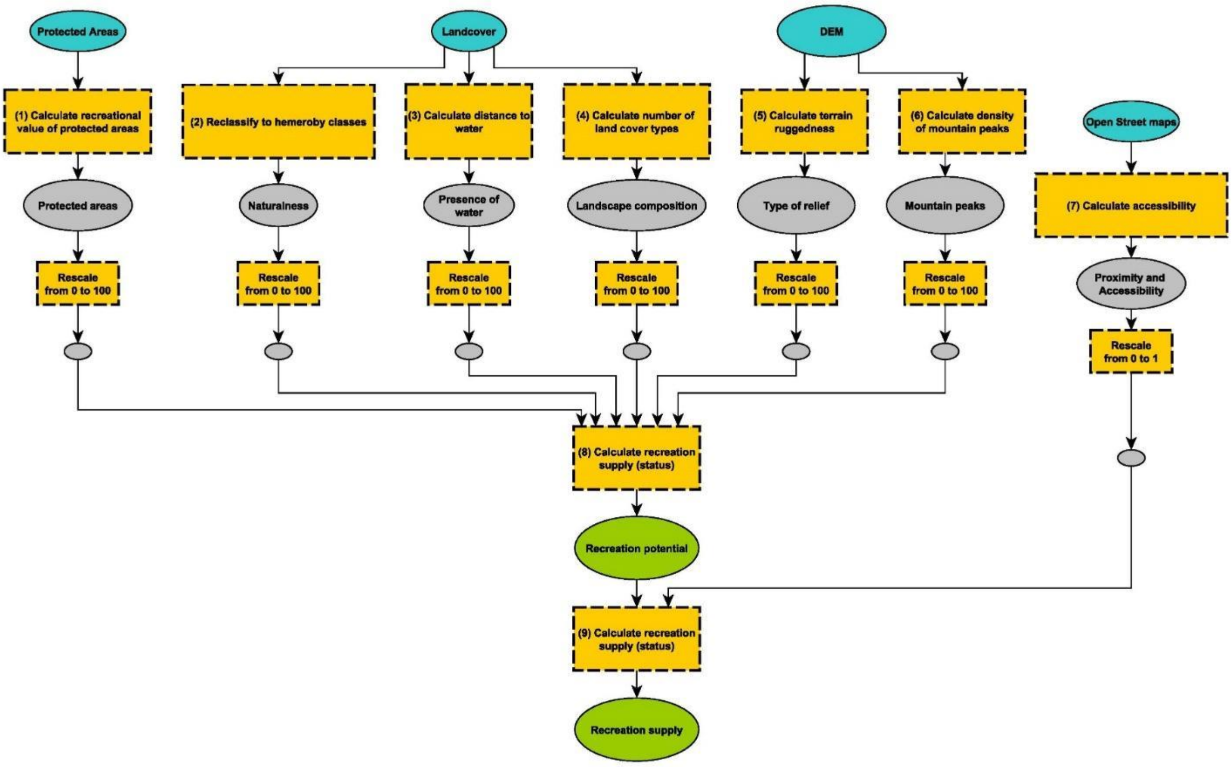


Figure 1: Flowchart depicting the procedures used to derive the supply indicator

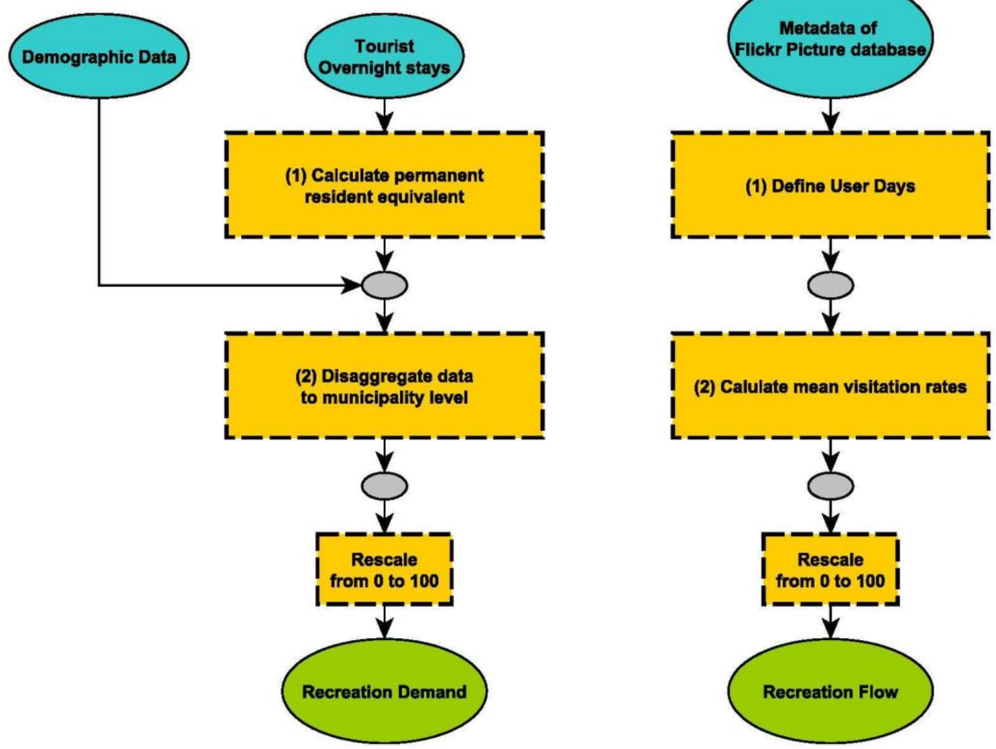
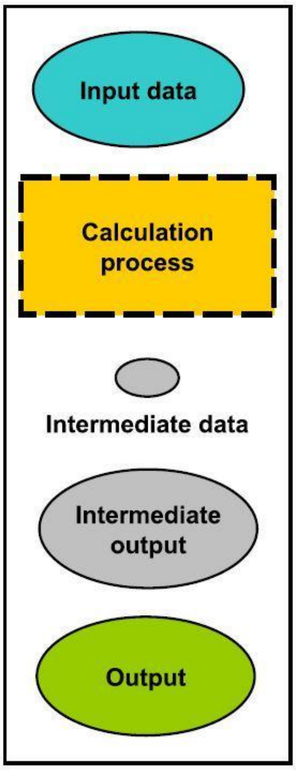


Figure 2: Flowchart depicting the procedures used to derive the demand and flow indicators

Legend



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Intermediate output → is intermediate data that has a significance for the ES evaluation.

Output → is the result of the calculation process. It is typically one of the ES indicators, either Supply, Demand or Flow.

Symbolic Alpine plants and animals, landscapes

ES Indicator: Supply

General description:

The distribution of selected plant and animal species (Table 1) in the study area was derived from actual distribution maps of the individual species or by modelling their potential habitat if the former were not available.

Table 1: Selected symbolic species that were identified for the European Alps (Schirpke et al., submitted).

Symbolic species	
Fauna	Alpine ibex (Capra ibex)
	Brown bear (Ursus arctos)
	Chamois (Rupicapra rupicapra)
	Golden eagle (Aquila chrysaetos)
	Marmot (Marmota marmota)
Flora	Alpenrose (Rhododendron hirsutum, Rhododendron ferrugineum)
	Edelweiss (Leontopodium alpinum)
	Gentian (Gentiana acaulis, Gentiana clusii)
	European larch (Larix decidua)

Symbolic species

Pine (pinus cembra, Pinus halepensis and P. brutia, Pinus mugo, Pinus nigra, Pinus pinaster, Pinus pinea, Pinus sylvestris)

Input Data

- ✓ DEM
- ✓ Land cover
- ✓ Temperature

Calculation processes:

(10) Calculate distribution of Alpine ibex

The distribution map of Alpine ibex (Capra ibex) (Aulagnier et al., 2008a) was downloaded from http://www.iucnredlist.org/details/42397/0 and converted to a raster map. The values of the raster map indicate the presence (1) or absence (0) of the species.

(11) Calculate distribution of brown bear

The distribution map of brown bear (Ursus arctos) was redrawn from the DINALP BEAR Population Status Report 2016[1], distinguishing between permanent and sporadic distribution. The polygon shapefile was converted to a raster file. The values of the raster map indicate the presence (1), sporadic presence (0.5), or absence (0) of the species.

(12) Calculate distribution of chamois

The distribution map of chamois (Rupicapra rupicapra) (Aulagnier et al., 2008b) was downloaded from http://www.iucnredlist.org/details/39255/0 and converted to a raster map. The values of the raster map indicate the presence (1) or absence (0) of the species.

(13) Calculate distribution of golden eagle

Occurrences of golden eagle (Aquila chrysaetos) since the year 2000 were downloaded from GBIF.org[2]. For all points, a buffer of 9 km, which corresponds to the core home range (Soutullo et al. 2006), was calculated using ArcGIS standard routines and converted to a raster map with a spatial resolution of 100 m. The values of the raster map indicate the presence (1) or absence (0) of the species.

(14) Calculate distribution of marmot

The spatial distribution of marmot (Marmota marmota) was modelled based on Galluzzi et al. (2017), applying the following steps:

- Selection of raster cells with elevation between 2,000 and 2,500 m a.s.l. from DEM
- Calculation of slope from DEM and selection of raster cells with slope between 0° and 20°
- Calculation of aspect from DEM and selection of raster cells with south-facing aspect (112.5–247.5°)
- Selection of raster cells with subalpine–alpine open grasslands, shrubs and heath (CORINE 231-Pastures, 321-Natural grasslands, 322- Moors and heathland, 323-Sclerophyllous vegetation, 333-Sparsely vegetated areas)

[1] http://dinalpbear.eu/wp-content/uploads/Annex-C5-2-PopulationStatusReport2016.v1.pdf

[2] http://www.GBIF.org, GBIF Occurrence Download http://doi.org/10.15468/dl.j82qce (downloaded on 29 May 2017)

All raster cells were classified to 1 if they met the selected criteria; all other raster cells were reclassified to 0. All raster cells fulfilling all different criteria were then mapped by multiplying all single layers.

(15) Calculate distribution of edelweiss

The spatial distribution of edelweiss (Leontopodium alpinum) was modelled based on Ischer et al. (2014), applying the following steps:

- Calculation of slope from DEM and selection of raster cells with slope > 30°
- Selection of raster cells with a mean summer temperature (June–August) < 10°
- Calculation of aspect from DEM and selection of raster cells with south-facing aspect (112.5–247.5°)
- Selection of raster cells with subalpine–alpine open grasslands with a low grass cover (CORINE 321-Natural grasslands, 333-Sparsely vegetated areas)

All raster cells were classified to 1 if they met the selected criteria; all other raster cells were reclassified to 0. All raster cells fulfilling all different criteria were then mapped by multiplying all single layers.

(16) Calculate distribution of gentian

The spatial distribution of gentian (Gentiana acaulis, Gentiana clusii) was modelled based on Bilz (2013) and Oberdorfer et al. (2001), applying the following steps:

- Selection of raster cells with elevation between 800 and 3,000 m a.s.l.
- Selection of raster cells with subalpine–alpine grasslands with a low grass cover (CORINE 231-Pastures, 321-Natural grasslands, 333-Sparsely vegetated areas)

All raster cells were classified to 1 if they met the selected criteria; all other raster cells were reclassified to 0. All raster cells fulfilling all different criteria were then mapped by multiplying all single layers.

(17) Calculate distribution of alpenrose

The spatial distribution of alpenrose (Rhododendron hirsutum, Rhododendron ferrugineum) was modelled based on Francon et al. (2017), applying the following steps:

- Selection of raster cells with elevation between 1,600 and 2,200 m a.s.l.
- Calculation of slope from DEM and selection of raster cells with north, west, and northwest-facing slopes (0–67.5°, 292.5–365°)
- Selection of raster cells with mainly shrubs (CORINE 323-Sclerophyllous vegetation, 324-Transitional woodland-shrub, 333-Sparsely vegetated areas)

All raster cells were classified to 1 if they met the selected criteria; all other raster cells were reclassified to 0. All raster cells fulfilling all different criteria were then mapped by multiplying all single layers.

(18) Calculate distribution of larch

The distribution maps for the European larch (Larix decidua) provided by Da Ronch et al. (2016) were reclassified to presence (1) using a threshold of 0.3 or absence (0).

(19) Calculate distribution of pine
The distribution maps for the Pine (pinus cembra, Pinus halepensis and P. brutia, Pinus mugo, Pinus nigra, Pinus pinaster, Pinus pinea, Pinus sylvestris) provided by Caudullo and de Rigo (2016) were reclassified to presence (1) using a threshold of 0.3 or absence (0).

(20) Calculate symbolic species index
After calculating for all selected symbolic species, the zonal statistics for all municipalities, an area-weighted index was obtained by summing the mean values of the different species within each municipality and rescaling them to values from 0 to 1.

ES Indicator: Flow

General description:

Symbolic species can be used in many symbolic ways, ranging from depiction on flags, coins, emblems, and logos to naming of hotels, restaurants, brands, and political parties. Due to availability of data of the same category at the municipality level, the use of symbolic species was mapped through the number of hotels that refer to symbolic species in their names.

Input Data

- ✓ Georeferenced data on hotels
- ✓ Municipality borders

Calculation processes:

(1) Select hotels
All hotels that refer to symbolic species in their names were selected from a database (DELTA CHECK[3]) with information on hotel names and geographic locations. Thereby, individual species were distinguished and the number of hotels within each municipality of each species was counted. To obtain the total number of hotels referring to the selected species, all ten species were summed up.

(2) Map number of hotels
To map the spatial distribution of this indicator at the municipality level, the indicator was joined to the municipality borders.

ES Indicator: Demand

General description:

As the demand of such a subjective value is evaluated through a questionnaire, this indicator cannot be mapped.

References:

Aulagnier S, Giannatos G, Herrero J (2008b) Rupicapra rupicapra. The IUCN Red List of Threatened Species 2008: e.T39255A10179647. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T39255A10179647.en. Downloaded on 01 June 2017

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[3] http://www.delta-check.com/en/

Aulagnier S, Kranz A, Lovari S, Jdeidi T, Masseti M, Nader I, de Smet K, Cuzin F (2008) Capra ibex. The IUCN Red List of Threatened Species 2008: e.T42397A10695445. http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T42397A10695445.en. Downloaded on 26 May 2017

Bilz M (2013) Gentiana acaulis. The IUCN Red List of Threatened Species 2013: e.T203217A2762385. http://dx.doi.org/10.2305/IUCN.UK.2013-1.RLTS.T203217A2762385.en.

Caudullo G, de Rigo D (2016) Pinus cembra in Europe: distribution, habitat, usage and threats. In: San-Miguel-Ayanz J, de Rigo D, Caudullo G, Houston Durrant T, Mauri A (Eds.), European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e01bd9b+

Da Ronch F, Caudullo G, Tinner W, de Rigo D (2016) Larix decidua and other larches in Europe: distribution, habitat, usage and threats. In: San-Miguel-Ayanz J, de Rigo D, Caudullo G, Houston Durrant T, Mauri A (Eds.), European Atlas of Forest Tree Species. Publ. Off. EU, Luxembourg, pp. e01e492+

Galluzzi M, Armanini M, Ferrari G, Zibordi F, Scaravelli D, Chirici G, Nocentini S, Mustoni A (2017) Habitat Suitability Models, for ecological study of the alpine marmot in the central Italian Alps. Ecological Informatics 37:10-17

Ischer M, Dubuis A, Keller R, Vittoz P (2014) A better understanding of the ecological conditions for Leontopodium alpinum Cassini in the Swiss Alps. Folia Geobotanica 49:541-558

Oberdorfer E, Schwabe A, Müller T (2001) Pflanzensoziologische Exkursionsflora für Deutschland und angrenzende Gebiete. 8. Auflage, Eugen Ulmer, Stuttgart (Hohenheim), ISBN 3-8001-3131-5, pp. 756

Schirpke U., Meisch C., Tappeiner U., (submitted) Symbolic species as a cultural ecosystem service in the European Alps: insights and open issues. Landscape Ecology

Soutullo A, Urios V, Ferrer M (2006) How far away in an hour? Daily movements of juvenile Golden Eagles (Aquila chrysaetos) tracked with satellite telemetry. Journal of Ornithology 147:69-72

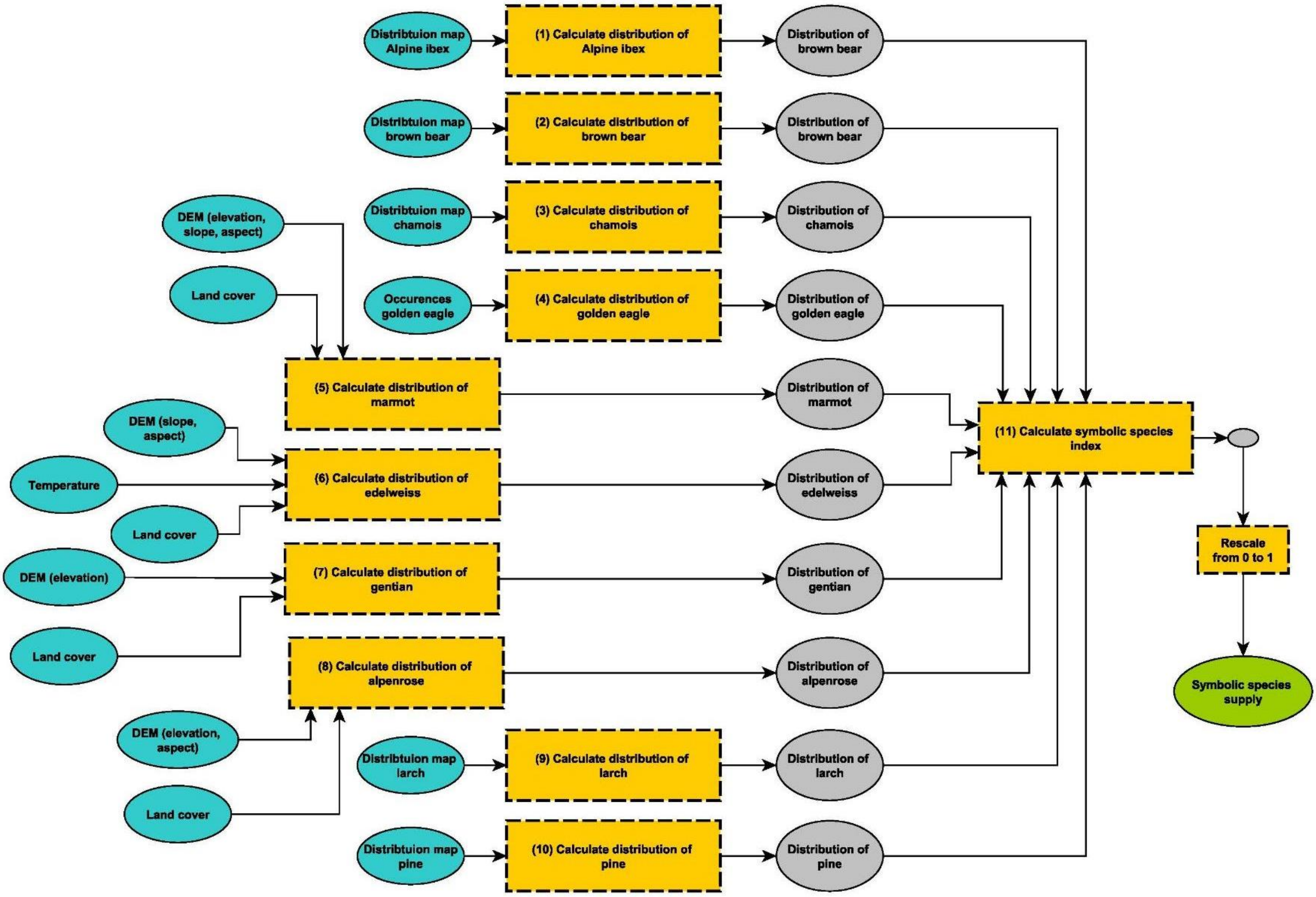


Figure 1: Flowchart depicting the procedures used to derive the supply indicator

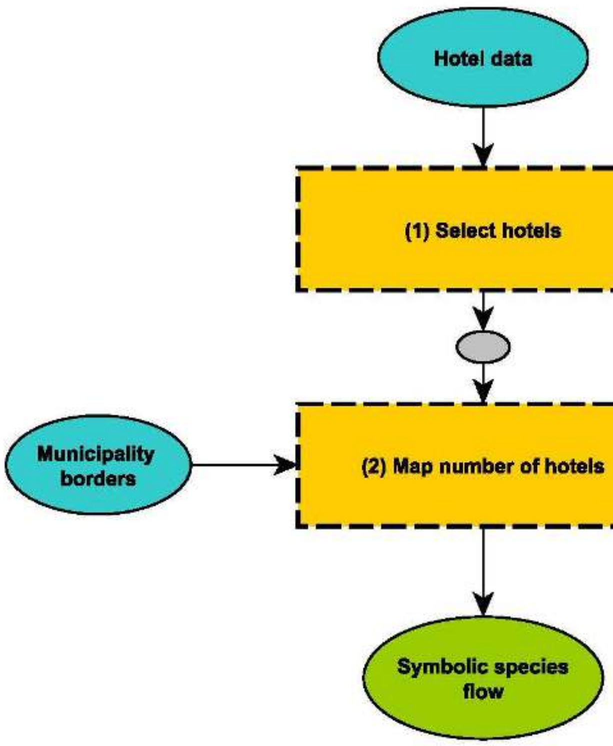
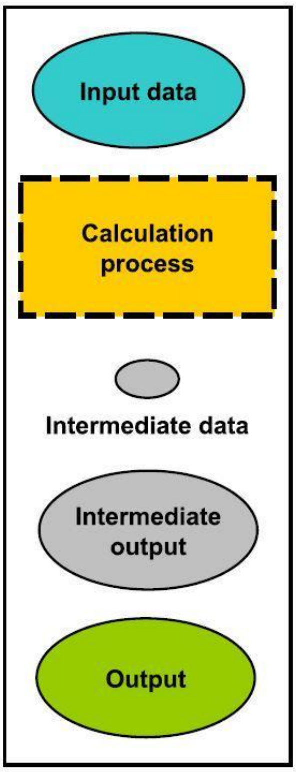


Figure 2: Flowchart depicting the procedures used to derive the flow indicator

Legend



Input data →elements that hold a value or a reference to data stored on disk. It is usually a spatial explicit information coming from official sources.

Calculation process → the actual operation performed on the data. The number preceding the item refers to the number in the model description.

Intermediate data → for each calculation process intermediate data is generated. This data, however, is usually not significant itself, but is used as an input for the next calculation step.

Intermediate output → is intermediate data that has a significance for the ES evaluation.

Output → is the result of the calculation process. It is typically one of the ES indicators, either Supply, Demand or Flow.

Metadata of the input data used by the AlpES project

Information courtesy of and copyright to EURAC.

Surface water for drinking with minor or no treatments – Supply

Section	Description
Resource Title	Surface water for drinking with minor or no treatments – Supply
Resource Abstract	Integrated water management is one of the main issues for the sustainable development of the Alpine region. Surrounding areas are highly dependent on alpine water and thus, on the ecosystems having an impact on water resources. Therefore, we assess and map the provisioning ecosystem service “Surface water for drinking with minor to no treatment” and provide information on the availability, the use and the abstractions of water resources. Hence, information on water availability as well as on water demands and usages can quickly be analysed, evaluated and visualized in a spatially explicit, cartographic way. Three maps were produced for management authorities, differentiating between surface water availability, water use and water abstraction.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10022&catalogNodes=101000000,101000003&layers_opacity=1,0.7
Unique Resource Identifier	UE9Y-ZSYG-Y738-TE5Y
Resource Language	eng
Topic Category	Environment Inland Waters Geoscientific Information Climatology/Meteorology/Atmosphere
Keyword value	Hydrography (INSPIRE Spatial Data Theme) Drinking water supply (GEMET concepts) Freshwater (GEMET concepts) Natural Environment, Anthropic Environment (GEMET concepts) Hydrosphere (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic	West = 1.986194

bounding box	East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	1801-2014
Date of publication	2018-07-20
Lineage	The surface water supply is displayed as the average annually available runoff of drinkable water. Using the InVEST water yield model, the annual average quantity of water runoff from each sub-catchment of the alpine space is calculated. The model estimates the water runoff based on gridded information on climatic, soil, topographic and land-cover characteristics.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-02-30
Metadata language	eng

Surface water for drinking with minor or no treatments – Flow

Section	Description
Resource Title	Surface water for drinking with minor or no treatments – Flow
Resource Abstract	Integrated water management is one of the main issues for the sustainable development of the Alpine region. Surrounding areas are highly dependent on alpine water and thus, on ecosystems having an impact on water resources. Hence, the consequences on all domains of water resources management must be considered in sustainable development. Therefore, within the AlpES project, we

	assess and map the ecosystem service “Water for drinking with minor to no treatment” and provide information on the availability of water meeting the quality standards for human consumption to decision makers. Hence, information on water availability and quality as well as on water demands and usages can quickly be analysed, evaluated and visualized in a spatially explicit, cartographic kind.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10023&catalogNodes=101000000,101000003&layers_opacity=1,0.7
Unique Resource Identifier	5L3W-E7AY-ALJ8-UTHK
Resource Language	eng
Topic Category	Environment Inland Waters Geoscientific Information
Keyword value	Hydrography (INSPIRE Spatial Data Theme) Water Management (GEMET concepts) Freshwater degradation (GEMET concepts) Environmental Policy (GEMET concepts) Hydrosphere (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2008-2013
Date of publication	2018-07-20
Lineage	The water use is assessed and mapped in annual average water usage at the point of use [m^3/ha]. The alpine wide map is based on water statistics from Eurostat, the statistical office of the European Union (European Commission 2016). These datasets are collected by National Statistical Institutes, then validated and merged

	by Eurostat (Eurostat, the Statistical Office of the European Union 2016). They come on a regional scale see NUTS level 2 and need further downscaling to municipality level based on touristic and demographic data, This by allocating the water use to the relative overnight stays in hotels and population data onto municipal level. The data is downloaded using the EUROSTAT R Package and filtered by extracting the needed information within R statistical software. As such, in a first step we filter the data for the countries and NUTS-2 regions of the Alpine Space Cooperation Area as well as households and tertiary sector. If several yearly values were available, the most actual were selected. We follow the definitions of the FAO and Eurostat and speak of “source” where the water is extracted and of “point of use” where the water is needed. Resources online following EUROSTAT (http://ec.europa.eu/eurostat/data/database) ⊠ Environment and energy ⊠ Environment ⊠ Water ⊠ Water statistics on subnational level ⊠ Water Statistics by NUTS 2 region ⊠ Water use by NUTS 2 regions (env_watuse_r2)
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-02-30
Metadata language	eng

Surface water for drinking with minor or no treatments – Demand

Section	Description
Resource Title	Surface water for drinking with minor or no treatments – Demand
Resource Abstract	Integrated water management is one of the main issues for the sustainable development of the Alpine region. Surrounding areas are highly dependent on alpine water and thus, on the ecosystems having an impact on water resources.

	Therefore, we assess and map the provisioning ecosystem service “Surface water for drinking with minor to no treatment” and provide information on the availability, the use and the abstractions of water resources. Hence, information on water availability as well as on water demands and usages can quickly be analysed, evaluated and visualized in a spatially explicit, cartographic way. Three maps were produced for management authorities, differentiating between surface water availability, water use and water abstraction.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10021&catalogNodes=101000000,101000003&layers_opacity=1,0.7
Unique Resource Identifier	CLKA-A5ML-N3SX-SCZP
Resource Language	eng
Topic Category	Environment Inland Waters Geoscientific Information
Keyword value	Hydrography (INSPIRE Spatial Data Theme) Water Demand (GEMET concepts) Consumption Pattern (GEMET concepts) Water Management (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2010-2013
Date of publication	2018-07-20
Lineage	This indicator represents the total annual water abstraction (from fresh water source) per municipality. The indicator map is based on water abstraction statistics from Eurostat. They come on a regional scale and are further downscaled to

	municipality level based on touristic and demographic data.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-02-30
Metadata language	eng

Biomass production from grassland – Supply

Section	Description
Resource Title	Biomass production from grassland – Supply
Resource Abstract	In the Alps, grassland is the basis for forage farming owing to local conditions like climate and slope steepness. Due to structural change of agriculture in the Alps, the supply of biomass production from grassland is influenced among others by the use of fertilizers and selection of forage plants. Grassland formations range from intensively managed pastures in the valley bottoms to extensive meadows and Alpine swards upwards the altitudinal belt. Location factors like temperature, soil and radiation have a significant impact on the productivity. Grassland ecosystems can provide multiple ecosystem services: Depending on the use of the biomass, the service can be described in dry matter per hectare or energy content per amount of dry matter.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10002&catalogNodes=101000000,101000001&layers_opacity=1,0.7
Unique Resource Identifier	MZR4-X77D-NHRV-U3NW
Resource	eng

Language	
Topic Category	Farming Environment
Keyword value	Land cover (INSPIRE Spatial Data Theme) Land use (INSPIRE Spatial Data Theme) Agriculture and cattle industry (GEMET Concepts) Cattle (GEMET Concepts) Biomass (GEMET Concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012
Date of publication	2018-07-20
Lineage	Fodder production of Alpine grassland, from colline to Alpine level (DM t/ha municipal area) In the Alps, there are different types of grassland (extensive meadows, frequently cut pastures, natural grassland in high altitude zones, …) Hence, the growth depends on the grassland type and location parameters like number of vegetation days (days with a minimum temperature of 5 degrees), precipitation and energy budget of the grassland plot. The Supply of biomass production is calculated according to the "Almbewertungsmodell" as proposed by Egger et al. (2004). Here, each grassland type is connected to a growth function, which represents the yield in DM per Ha and year. Egger, G., et al. (2004). GIS-gestützte Ertragsmodellierung zur Optimierung des Weidemanagements auf Almweiden. Irdning, Irdning: BAL.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards

	interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-03-14
Metadata language	eng

Fuelwood - Flow

Section	Description
Resource Title	Fuelwood - Flow
Resource Abstract	Timber is an important resource provided by forest ecosystems that is typically processed into three different products: round wood, industrial wood or fuel wood. In a sustainable forest management cycle, timber production is limited to the net biomass increase in order to keep the forest inventories stable. Sustainably produced fuel wood, such as firewood, charcoal, chips, pellets, and sawdust management, can hence be a promising alternative for renewable energy production. The selected indicators aim to reflect potential fuel wood production, its actual usage and the current need for it at the scale of Alpine Space municipalities.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10043&catalogNodes=101000000,101000005&layers_opacity=1,0.7
Unique Resource Identifier	99BB-38J7-B93C-WK6D
Resource Language	eng
Topic Category	Environment Economy
Keyword value	Energy resources(INSPIRE Spatial Data Theme) Fuel wood (GEMET Concepts) Forest (GEMET Concepts)

	Biomass (GEMET Concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012
Date of publication	2018-07-20
Lineage	Not all forests can be managed equally: accessibility (infrastructure) and technical feasibility (due to topography) play a crucial role in sustainable forest management. Hence, this indicator reflects the timber removals for fuel wood production (data is taken from national inventories) considering both topographical site condition (slope angle from DEM) and the forest accessibility (based on the OSM layer).
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2017-09-18

Metadata language	eng

Fuelwood - Demand

Section	Description
Resource Title	Fuelwood - Demand
Resource Abstract	Timber is an important resource provided by forest ecosystems that is typically processed into three different products: round wood, industrial wood or fuel wood. In a sustainable forest management cycle, timber production is limited to the net biomass increase in order to keep the forest inventories stable. Sustainably produced fuel wood, such as firewood, charcoal, chips, pellets, and sawdust management, can hence be a promising alternative for renewable energy production. The selected indicators aim to reflect potential fuel wood production, its actual usage and the current need for it at the scale of Alpine Space municipalities.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10041&catalogNodes=101000000,101000005&layers_opacity=1,0.7
Unique Resource Identifier	BQMC-5P47-T94Z-HBAA
Resource Language	eng
Topic Category	Environment Economy
Keyword value	Energy resources(INSPIRE Spatial Data Theme) Fuel wood (GEMET Concepts) Forest (GEMET Concepts) Biomass (GEMET Concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate	EPSG: 3035 (ETRS89, LAEA)

reference System	
Temporal extent	2012
Date of publication	2018-07-20
Lineage	The usage of fuel wood as an energy source is largely varying across the Alps and high-resolution data on energy consumption is scarce. Hence, this indicator is based on the fuelwood consumption at the NUTS2 level. Building area from the open-street-map data, together with the heating degree days are used to disaggregate the amount of fuelwood required at municipality level.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2018-04-20
Metadata language	eng

Filtration of surface water by ecosystem types – Flow/Supply

Section	Description
Resource Title	Filtration of surface water by ecosystem types – Flow/Supply
Resource Abstract	Filtration of surface water by terrestrial ecosystems is an important service that directly contributes to mitigate water pollution. This multi-faceted ES includes a variety of ecosystem types and pollutants. Among the different types of pollutants are nutrients, such as nitrogen or phosphorous, pesticides, heavy metals or organic matter. Within AlpES the outcomes of the InVEST NDR model (Nutrient Delivery Ratio) have been used to assess the nitrogen loads and the filtration capacities by different ecosystems. This model follows a mass balance approach, describing the movement of the mass of nutrient through space. Unlike more sophisticated nutrient models, NDR does not represent the details of the nutrient cycle but rather represents the long-term, steady-state flow of nutrients through empirical relationships.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10072&catalogNodes=101000000,101000008&layers_opacity=1,0.7
Unique Resource Identifier	Z6WH-RYRJ-LQ56-CC3S
Resource Language	eng
Topic Category	Environment
Keyword value	Land use (INSPIRE Spatial Data Theme) Land cover (INSPIRE Spatial Data Theme) Filtration (GEMET Concepts Nitrogen (GEMET Concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012

Date of publication	2018-07-20
Lineage	The flow/supply indicator represents the actual amount of nitrogen that is reduced within a single municipality. This is the capacity of nitrogen filtration, determined by the difference between the loaded nitrogen (N loads per land-use type, N atmospheric deposition and N biological fixation) and the nitrogen exported from the area of a municipality. Both these values are calculated using the InVEST NDR model.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2018-04-20
Metadata language	eng

Filtration of surface water by ecosystem types - Demand

Section	Description
Resource Title	Filtration of surface water by ecosystem types - Demand
Resource Abstract	Filtration of surface water by terrestrial ecosystems is an important service that directly contributes to mitigate water pollution. This multi-faceted ES includes a variety of ecosystem types and pollutants. Among the different types of pollutants are nutrients, such as nitrogen or phosphorous, pesticides, heavy metals or organic matter. Within AlpES the outcomes of the InVEST NDR model (Nutrient Delivery Ratio) have been used to assess the nitrogen loads and the filtration capacities by different ecosystems. This model follows a mass balance approach, describing the movement of the mass of nutrient through space. Unlike more sophisticated nutrient models, NDR does not represent the details of the nutrient cycle but rather represents the long-term, steady-state flow of nutrients through empirical relationships.

Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10071&catalogNodes=101000000,101000008&layers_opacity=1,0.7
Unique Resource Identifier	8RLT-ZU4P-3QQH-V9JV
Resource Language	eng
Topic Category	Environment
Keyword value	Land use (INSPIRE Spatial Data Theme) Land cover (INSPIRE Spatial Data Theme) Atmospheric nitrogen load (GEMET Concepts Nitrogen Load (GEMET Concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012
Date of publication	2018-07-20
Lineage	This indicator represents the actual loads of nitrogen per year in kg, calculated without the filtering from the landscape. This includes the nitrogen emitted in the atmosphere and then deposed in the landscape and the nitrogen from the fertilization in agriculture.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions	CC BY-NC 4.0

applying to access and use	
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2018-04-20
Metadata language	eng

Protection of areas against avalanches, mudslides and rockfalls – Supply

Section	Description
Resource Title	Protection of areas against avalanches, mudslides and rockfalls – Supply
Resource Abstract	The protection function of ecosystems against slope movements and avalanches is part of the regulating service group ‘natural hazard mitigation’ and commonly known as 'Protection Forests’. They include both site-protecting and object-protecting forests and respectively refer to the prevention of erosional processes and the safeguard of human settlements or economic assets. Thus, the selected indicators aim at representing the protective functions of Alpine forests, considering gravitational processes and mass movements as main perils.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10012&catalogNodes=101000000,101000002&layers_opacity=1,0.7
Unique Resource Identifier	FWBN-YU4U-V9YJ-RLTK
Resource Language	eng
Topic Category	Environment GeoscientificInformation
Keyword value	Land cover (INSPIRE Spatial Data Theme) Land use (INSPIRE Spatial Data Theme) Natural risk zones (INSPIRE Spatial Data Theme) Landslide(GEMET concepts) Avalanche(GEMET concepts) Avalanche protection (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012
Date of publication	2018-07-20

Lineage	To delineate the protection forest areas, all the possible avalanche and rock-fall release areas as well as possible transition zones are identified based on topographic factors (slope, plan curvature, and land cover). All the forest areas in these potential 'hazard zones' are considered protection forest areas. The protective function of these forests is being assessed based on the crown cover density for avalanches and transition distance in forested slopes for rock fall events.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2017-09-18
Metadata language	eng

Protection of areas against avalanches, mudslides and rockfalls – Flow

Section	Description
Resource Title	Protection of areas against avalanches, mudslides and rockfalls – Flow
Resource Abstract	The protection function of ecosystems against slope movements and avalanches is part of the regulating service group 'natural hazard mitigation' and commonly known as 'Protection Forests'. They include both site-protecting and object-protecting forests and respectively refer to the prevention of erosional processes and the safeguard of human settlements or economic assets. Thus, the selected indicators aim at representing the protective functions of Alpine forests, considering gravitational processes and mass movements as main perils.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10013&catalogNodes=101000000,101000002&layers_opacity=1,0.7
Unique Resource	VR9U-7ZSG-MB2X-CZM7

Identifier	
Resource Language	en
Topic Category	Environment GeoscientificInformation
Keyword value	Land cover (INSPIRE Spatial Data Theme) Land use (INSPIRE Spatial Data Theme) Natural risk zones (INSPIRE Spatial Data Theme) Landslide(GEMET concepts) Avalanche(GEMET concepts) Avalanche protection (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012
Date of publication	2018-07-20
Lineage	To map the object-protecting forests, only potential hazard events that impact human infrastructures directly are being taken into account. The forest areas that protect these zones are considered object-protecting forest.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation

Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2017-09-18
Metadata language	eng

Protection of areas against avalanches, mudslides and rockfalls – Demand

Section	Description
Resource Title	Protection of areas against avalanches, mudslides and rockfalls – Demand
Resource Abstract	The protection function of ecosystems against slope movements and avalanches is part of the regulating service group 'natural hazard mitigation' and commonly known as 'Protection Forests'. They include both site-protecting and object-protecting forests and respectively refer to the prevention of erosional processes and the safeguard of human settlements or economic assets. Thus, the selected indicators aim at representing the protective functions of Alpine forests, considering gravitational processes and mass movements as main perils.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10011&catalogNodes=101000000,101000002&layers_opacity=1,0.7
Unique Resource Identifier	5ZPR-GCYA-HXD4-WDMX
Resource Language	eng
Topic Category	Environment GeoscientificInformation
Keyword value	Land cover (INSPIRE Spatial Data Theme) Land use (INSPIRE Spatial Data Theme) Natural risk zones (INSPIRE Spatial Data Theme) Landslide(GEMET concepts) Avalanche(GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication

	-date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012
Date of publication	2018-07-20
Lineage	This Indicator shows the need of protection from natural hazards and quantifies this in a simplified manner. It is calculated by summing up areas of human infrastructure in potential hazard zones, all the areas are threatened equally and are therefore not weighted by importance or value. Thus, the result is a qualitative approximation of the area or infrastructure that is theoretically in danger within a given municipality.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2017-09-18
Metadata language	eng

CO2 sequestration from forest and bogs – Flow/Supply

Section	Description
Resource Title	CO2 sequestration from forest and bogs – Flow/Supply
Resource Abstract	Atmospheric CO2 is one of the most well-known greenhouse gases and one of the most powerful drivers of climate change. The sequestration of CO_2 from the atmosphere is therefore an important regulating ecosystem service that is recognized by international environmental obligations and reporting programmes. The benefits of CO_2 sequestration are not limited to the Alpine population, but represent the contribution of the Alpine area to global climate protection. Within AlpES, the ecosystem service CO_2 sequestration is considered in relation to the ecosystems mountain forest and Alpine bogs. However, due to data availability and reliability, the indicator maps produced within AlpES only include the contribution to CO2 sequestration given by forests.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10063&catalogNodes=101000000,101000006&layers_opacity=1,0.7
Unique Resource Identifier	4UZ9-AFM9-9LVA-TZ8C
Resource Language	eng
Topic Category	Environment Climatology/Meteorology/Atmosphere
Keyword value	Atmospheric conditions (INSPIRE Spatial Data Theme) Carbon sequestration (GEMET Concepts) Forest (GEMET Concepts) Biomass (GEMET Concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)

Temporal extent	2012
Date of publication	2018-07-20
Lineage	The indicator represents the annual rate of CO2 sequestration by forests at the municipal level. This value is calculated on the base of the IPCC equations (2.9 and 2.10 of the IPCC guidelines, vol. 4, ch. 2) used to estimate the annual increase in biomass carbon stock due to biomass accumulation. This method allows for the assessment of above- and below-ground estimation of biomass increase in tonnes of carbon per year. The application of a standard constant converts the result into the amount of CO2 being sequestrated. IPCC, (2006) IPCC guidelines for national greenhouse gas inventories, prepared by the national greenhouse gas inventories program, Vol. 4, Ch. 2-4, Forest Land
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2017-09-18
Metadata language	eng

CO2 sequestration from forest and bogs – Demand

Section	Description
Resource Title	CO2 sequestration from forest and bogs – Demand
Resource Abstract	Atmospheric CO2 is one of the most well-known greenhouse gases and one of the most powerful drivers of climate change. The sequestration of CO2 from the atmosphere is therefore an important regulating ecosystem service that is recognized by international environmental obligations and reporting programmes. The benefits of CO2 sequestration are not limited to the Alpine

	population, but represent the contribution of the Alpine area to global climate protection. Within AlpES, the ecosystem service CO2 sequestration is considered in relation to the ecosystems mountain forest and Alpine bogs. However, due to data availability and reliability, the indicator maps produced within AlpES only include the contribution to CO2 sequestration given by forests.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10061&catalogNodes=101000000,101000006&layers_opacity=1,0.7
Unique Resource Identifier	CYVE-UK6K-NAJK-YMX2
Resource Language	eng
Topic Category	Environment Transportation Climatology/Meteorology/Atmosphere
Keyword value	Atmospheric conditions (INSPIRE Spatial Data Theme) Emission to air (GEMET concepts) Atmospheric emission (GEMET concepts) Carbon emission (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2010
Date of publication	2018-07-20
Lineage	The indicator represents the CO2 emissions per municipality for the year 2010. The original data (Trombetti et al. 2017), has been integrated with the dataset

	from the EDGAR database to include the area of Switzerland. The datasets were disaggregated at the municipal level to assess the tons of CO_2 emitted per hectare. Trombetti M., Pisoni E., Lavalle C. (2017). Downscaling methodology to produce a high-resolution gridded emission inventory to support local/city level air quality policies, Office for Official Publications of the European Communities, Luxembourg, EUR 28428 EN, doi:10.2760/51058 EDGARv4.2, European Commission, Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency. Emission Database for Global Atmospheric Research (EDGAR), release version 4.2.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Metadata date	2017-09-18
Metadata language	eng

Outdoor recreation activities – Supply

Section	Description
Resource Title	Outdoor recreation activities – Supply
Resource Abstract	Outdoor recreation in natural and semi-natural environments plays a crucial role for physical and mental health, contributing substantially to human well-being. Mountain regions are attractive destinations for nature-based recreation and tourism due to their appealing landscapes, access to wilderness and wildlife, and opportunities for outdoor recreation activities like hiking, mountain biking, climbing, or skiing.

	The outdoor recreation supply includes two aspects: the recreation potential provided by ecosystems and the possibility to benefit from it. Whereas the recreation potential corresponds to the capacity of ecosystems to provide recreation opportunities due to the natural preconditions without human input and regardless of these being actually used, the service is only provided if people can reach the supply area to carry out recreational activities. Therefore, the indicator includes six landscape indicators to map the recreation potential (naturalness, protected areas, presence of water, landscape diversity, terrain ruggedness, and density of mountain peaks) and is subsequently weighted by the accessibility.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10032&catalogNodes=101000000,101000004&layers_opacity=1,0.7
Unique Resource Identifier	C5R6-3WBB-EQPS-UL99
Resource Language	eng
Topic Category	Environment
Keyword value	Land use (INSPIRE Spatial Data Theme) Cultural ecosystem services (GEMET concepts) Recreational area (GEMET concepts) Leisure activity (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012
Date of publication	2018-07-20

Lineage	Recreation supply index, ranging from 0 (low) to 100 (high). The recreation potential is mapped considering six landscape variables as indicators (naturalness, protected areas, presence of water, landscape diversity, terrain ruggedness, and density of mountain peaks) based on recent literature. All indicators are considered to equally contribute to the recreation potential and, thus, all indicators are rescaled to 0–100 and overlaid to obtain a recreation potential index, ranging from 0 (low) to 100 (high). Accessibility through infrastructure determines whether suitable recreation areas can be used, and proximity to residential areas is a crucial factor for the use of recreational sites. Using travel time as a proxy for accessibility, recreation supply is mapped by overlaying the recreation potential with the level of accessibility, excluding inaccessible areas. See Schirpke et al. (2017) for further details. Schirpke, U., Meisch, C., Marsoner, T., & Tappeiner, U. (2017). Revealing spatial and temporal patterns of outdoor recreation in the European Alps and their surroundings. Ecosystem Services. https://doi.org/10.1016/j.ecoser.2017.11.017
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-03-19
Metadata language	eng

Outdoor recreation activities – Flow

Section	Description
Resource Title	Outdoor recreation activities – Flow
Resource Abstract	Outdoor recreation in natural and semi-natural environments plays a crucial role for physical and mental health, contributing substantially to human well-being. Mountain regions are attractive destinations for nature-based recreation and tourism due to their appealing landscapes, access to wilderness and wildlife, and opportunities for outdoor recreation activities like hiking, mountain biking, climbing, or skiing. The outdoor recreation flow refers to the actual level of use and can be measured by the number of people practicing outdoor activities in a defined area and time.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10033&catalogNodes=101000000,101000004&layers_opacity=1,0.7
Unique Resource Identifier	4B4K-ZE6K-QABU-CDFK
Resource Language	eng
Topic Category	Environment
Keyword value	Land use (INSPIRE Spatial Data Theme) Cultural ecosystem services (GEMET concepts) Recreational area (GEMET concepts) Leisure activity (GEMET concepts) Tourism (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal	2005-2016

extent	
Date of publication	2018-07-20
Lineage	Visitation rates from 0 (low) to 100 (high). To map outdoor recreation flow in terms of visitation rates, metadata linked to photographs appearing on social media such as Flickr can be used, as this crowd-sourced information can be considered a reliable proxy for visiting frequencies. Visitation rates can be estimated by calculating 'user-days', i.e., the number of users who took at least one picture per day in each location. See Schirpke et al. (2017) for further details. Schirpke, U., Meisch, C., Marsoner, T., & Tappeiner, U. (2017). Revealing spatial and temporal patterns of outdoor recreation in the European Alps and their surroundings. Ecosystem Services. https://doi.org/10.1016/j.ecoser.2017.11.017
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-03-19 The date of the day you are compiling the metadata.
Metadata language	eng

Outdoor recreation activities – Demand

Section	Description
Resource Title	Outdoor recreation activities – Demand
Resource Abstract	Outdoor recreation in natural and semi-natural environments plays a crucial role for physical and mental health, contributing substantially to human well-

	being. Mountain regions are attractive destinations for nature-based recreation and tourism due to their appealing landscapes, access to wilderness and wildlife, and opportunities for outdoor recreation activities like hiking, mountain biking, climbing, or skiing. The outdoor recreation demand refers to the demand areas within the study area quantifying local beneficiaries such as residents and tourists.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10031&catalogNodes=101000000,101000004&layers_opacity=1,0.7
Unique Resource Identifier	RXF4-JRZC-D2HT-H8Y6
Resource Language	eng
Topic Category	Environment Society
Keyword value	Population distribution — demography (INSPIRE Spatial Data Theme) Cultural ecosystem services (GEMET concepts) Leisure activity (GEMET concepts) Tourism (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2014-2017
Date of publication	2018-07-20
Lineage	Density of potential beneficiaries was calculated per municipality from 0 (low) to 100 (high).

	The local recreation demand can be quantified based on the number of potential beneficiaries such as residents and tourists. See Schirpke et al. (2017) for further details. Schirpke, U., Meisch, C., Marsoner, T., & Tappeiner, U. (2017). Revealing spatial and temporal patterns of outdoor recreation in the European Alps and their surroundings. Ecosystem Services. https://doi.org/10.1016/j.ecoser.2017.11.017
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-03-19
Metadata language	eng

Symbolic alpine plants and animals, landscapes – Supply

Section	Description
Resource Title	Symbolic alpine plants and animals, landscapes – Supply
Resource Abstract	Symbolic species and landscapes form part of the heritage of the Alpine area and represent Alpine nature to people, inside and outside the Alps. They are valuable for the ecologic, cultural and economic development of the Alpine space. The supply of this cultural ecosystem service can be mapped by determining the spatial distribution of selected symbolic plants and animals, including edelweiss, gentian, alpenrose, larch, pine, Alpine ibex, chamois, marmot, brown bear, and golden eagle.
Resource Type	Dataset
Resource	http://www.alpes-

locator	webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10052&catalogNodes=101000000,101000007&layers_opacity=1,0.7
Unique Resource Identifier	WAEE-6ATJ-KAYN-HACK
Resource Language	eng
Topic Category	Environment Society
Keyword value	Cultural ecosystem services Plant species Animal species Spatial distribution
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2000-2018
Date of publication	2018-07-20
Lineage	Area-weighted index ranging from 0-1. The distribution of the selected plant and animal species can be derived from actual distribution maps of the individual species or by modelling their potential habitat if the former is not available. The presence (1) or absence (0) of each species is mapped in a raster map and the area-weighted index can be obtained by summing the area-weighted mean values of the different species within each municipality. See Schirpke et al. (2018) for further details. Schirpke, U., Meisch, C., & Tappeiner, U. (2018). Symbolic species as a cultural

	ecosystem service in the European Alps: insights and open issues. Landscape Ecology. https://doi.org/10.1007/s10980-018-0628-x
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible party	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-03-19
Metadata language	eng

Symbolic alpine plants and animals, landscapes – Flow

Section	Description
Resource Title	Symbolic alpine plants and animals, landscapes – Flow
Resource Abstract	Symbolic plants and animals form part of the heritage of the Alpine area and represent Alpine nature to people, inside and outside the Alps. They are valuable for the ecologic, cultural and economic development of the Alpine space. Symbolic species can be used in many different ways, ranging from depiction on flags, coins, emblems, and logos to naming of hotels, restaurants, brands, and political parties. This indicator represents the number of hotels per municipality named after symbolic species, including edelweiss, gentian, alpenrose, larch, pine, Alpine ibex, chamois, marmot, brown bear, and golden eagle.
Resource Type	Dataset
Resource locator	http://www.alpes-webgis.eu/?X=850359.92&Y=5947762.56&zoom=6&lang=en&focus=focus_alpes&bgLayer=alpes.osm.stamentoner.60002&layers=alpes.alpinespace.40001.wms,alpes.essi.10053&catalogNodes=101000000,101000007&layers_opacity=1,0.7
Unique	28G5-LTKU-BNC6-LY55

Resource Identifier	
Resource Language	eng
Topic Category	Environment
Keyword value	Geographical names (INSPIRE Spatial Data Theme) Cultural ecosystem services (GEMET concepts) Plant species (GEMET concepts) Animal species (GEMET concepts) Tourism (GEMET concepts)
Originating controlled vocabulary	- title: GEMET - INSPIRE themes, version 1.0 - date: -dateType: publication -date: 2008-06-01 - title: GEMET - Concepts, version 4.0.1 - date: -dateType: publication -date: 2017-06-28
Geographic bounding box	West = 1.986194 East = 18.622061 North = 50.068114 South = 42.700501
Coordinate reference System	EPSG: 3035 (ETRS89, LAEA)
Temporal extent	2012
Date of publication	2018-07-20
Lineage	Number of hotels referring to the selected number of species per municipality.
Spatial resolution	100000
Specification	Commission Regulation (EU) No 1089/2010 of 23 November 2010 implementing Directive 2007/2/EC of the European Parliament and of the Council as regards interoperability of spatial data sets and services, date of publication: 2010-12-08.
Degree	Null
Conditions applying to access and use	CC BY-NC 4.0
Limitations on public access	No Limitation
Responsible	Eurac Research, Viale Druso 1, 39100 Bolzano, Italy

party	Institute for Alpine Environment - alpine.environment@eurac.edu
Responsible party role	Author
Metadata point of contact	University of Innsbruck, Sternwartestraße 15, 6020 Innsbruck, Austria Department of Ecology - ecology@uibk.ac.at
Metadata date	2018-03-19
Metadata language	eng

The Alptrees project FES assessment and mapping methodology and results

Information courtesy of and copyright to Cerema (D.1.3.1 of the Alptrees project). The Cerema has been one of the French PPs in both the AlpES and Alptrees Interreg Alpine Space projects. The AlpES project has provided FES indicators mapping based on the aggregation of the results at the municipalities level. If this scale is adapted to regional scale decision making, at the level of a municipality Local decision-makers need non-aggregated data and thus spatialized indicators. According to this fact and based on some of the outputs of the project AlpES, the Cerema has so provided within the Alptrees project non municipally aggregated FES indicators maps. Here is in extenso the Alptrees D.1.3.1.

Alpine Space area

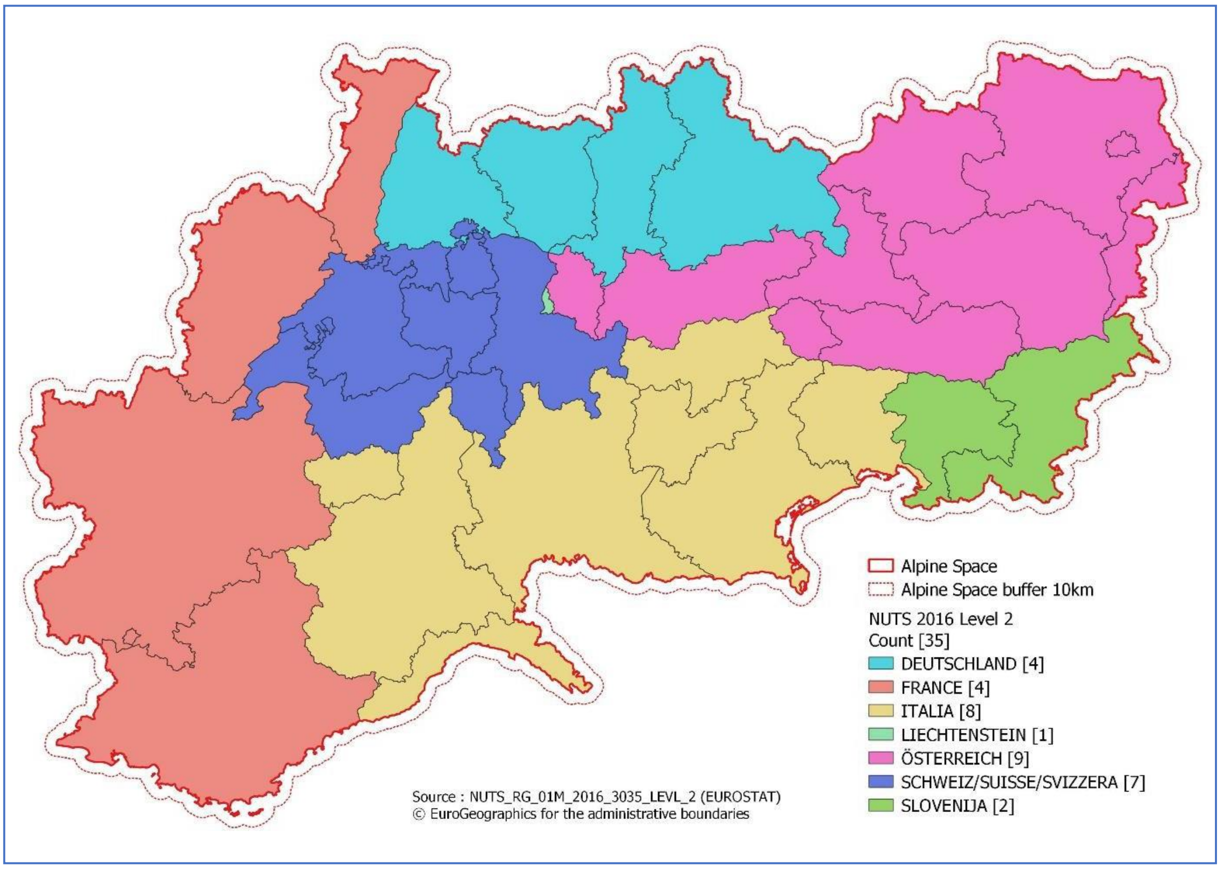
Data Source: EUROSTAT

Nomenclature of Territorial Units for Statistics (NUTS) 2016: This dataset represents the regions for levels 1, 2 and 3 of the Nomenclature of Territorial Units for Statistics (NUTS) for 2016. The NUTS nomenclature is a hierarchical classification of statistical regions and subdivides the EU economic territory into regions of four different levels (NUTS 1, 2 and 3, moving respectively from larger to smaller territorial units. This dataset has been created mainly from the EuroBoundary Map v 12 (Eurogeographics).

The public dataset is available under the Download link: NUTS - Eurostat (europa.eu)

Study area

The Alpine Space study area is obtained by selection and aggregation of the NUTS_2016 composing the territory of the Alpine Space. Alpine Space covers 35 NUTS level 2 from seven European countries. In order to avoid edge effects a larger area called Alpine_Space_buffer_10km is obtained by applying a 10km buffer to Alpine Space.



Forest area: Forest 2018

Source: High Resolution Layer (HRL): Forest Type (FTY) 2018

Please be aware that while the overall term for this group of products is "HRL Forest", there are multiple different definitions of what a "forest" is in technical terms. Strictly speaking: the primary products of this HRL are tree cover products (TCD and DLT), that map trees wherever they occur, also outside of what is (technically) a forest. As part of the HRL "Forest" group of products, there is only one product that applies a FAO forest definition and can therefore be called a (*sensu stricto*) forest product: the forest type (FTY) product (in 10m and 100m resolution). The fact that TCD and DLT do not have forest definition and filtering applied makes it possible for users to adapt the existing tree cover density / dominant leaf type products to their forest definition (if different from the FAO definition).

The Forest Type 2018 at 100m spatial resolution is an aggregated version of the secondary status layer, fully aligned to the EEA reference grid. It has the following main specifications:

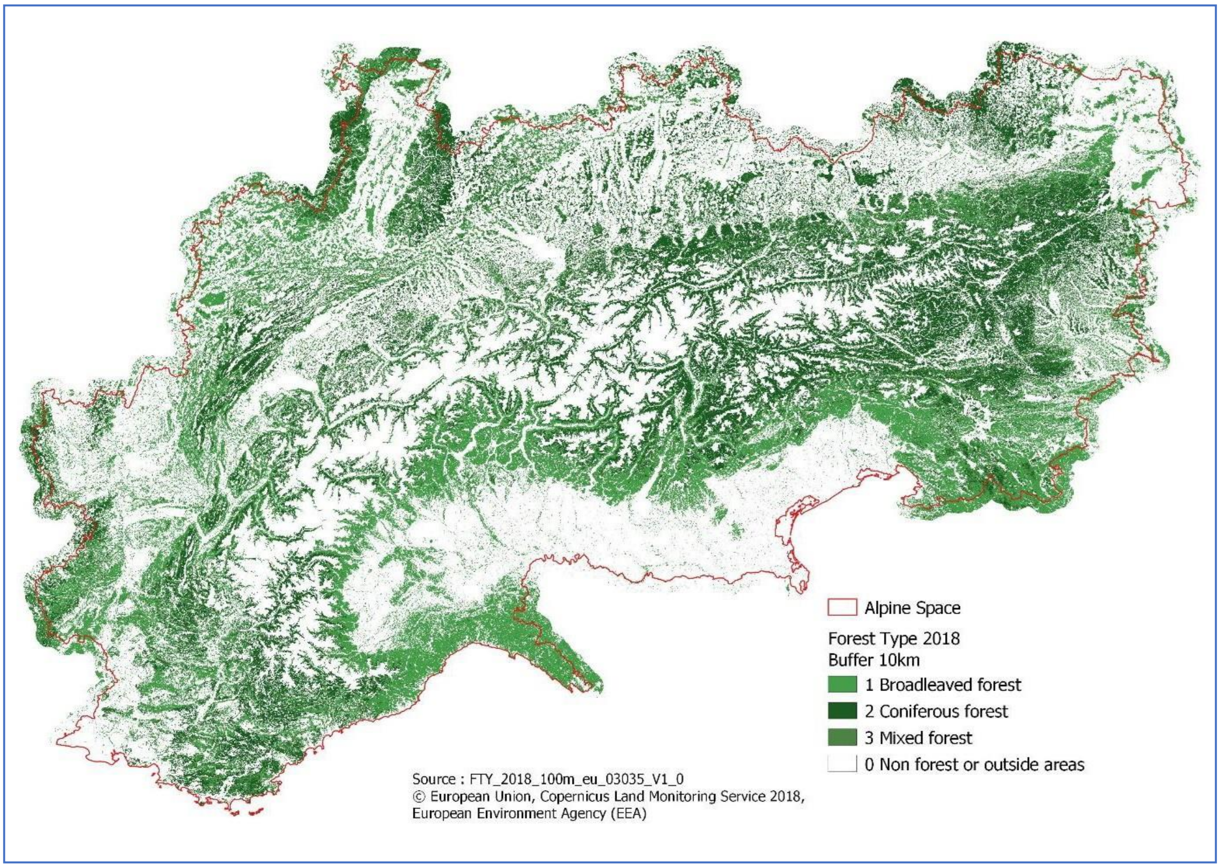
- 100m spatial resolution
- TCD range of ≥10-100%
- No Minimum Mapping Unit (MMU); pixel-based
- Providing information on the leaf type following the CLC forest definition with 3 thematic classes: 1: broadleaved forest; 2: coniferous forest; 3: mixed zones.

Data: Forest Type 2018 — Forest Type 2018 — Copernicus Land Monitoring Service

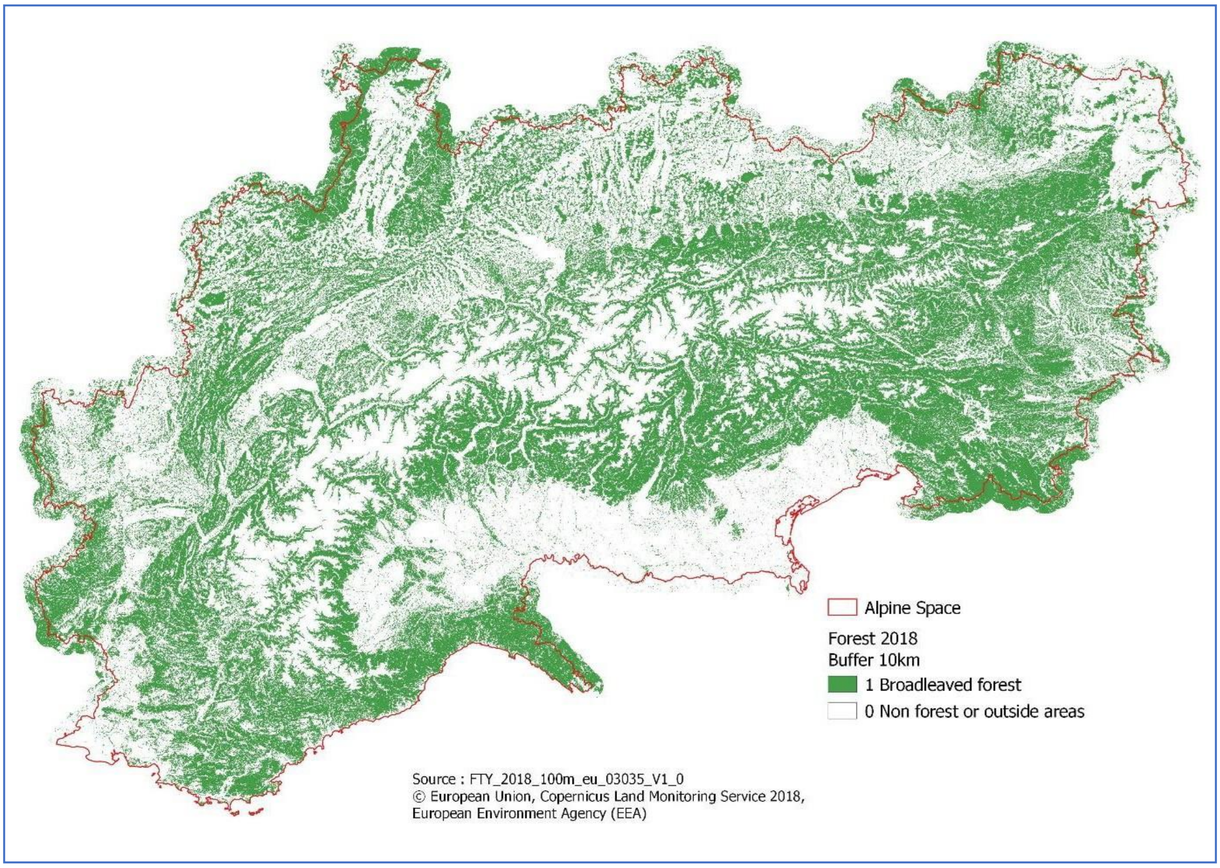
Service User manual: Forest 2018 user manual (copernicus.eu)

Extraction of the forest study area: Forest 2018

The forest study areas known as Forest_Type_2018 and Forest_Type_2018_buffer_10km are obtained by cutting the FTY_2018 raster according to the Alpine Space and Alpine_Space_buffer_10km mask layers.



Forest_2018 et *Forest_2018_buffer_10km* rasters are obtained by reclassifying *Forest_type_2018* and *Forest_Type_2018_buffer_10km* in 2 classes: 0: Non forest or outside areas; 1 :Forest.



Statistics about Alpine Space Forest area

Areas	Pixels or hectares	Forest %	Study area %
Broadleaved forest	7.183.869	43,3	-
Coniferous forest	6.272.170	37,8	-
Mixed forest	3.145.622	18,9	-
Forest	16.601.661	100	42,5
Non forest	22.421.623	-	57,5
Alpine Space	39.023.284	-	100

Carbon storage ecosystem service

Indicator definition

Through photosynthesis, Alpine forests capture carbon dioxide (CO2) from the atmosphere and store the carbon in above and below-ground plant tissue and then in the soil via dead organic matter. Atmospheric CO2, whose concentration is increasing, is an important greenhouse gas. Alpine forests, because of their lifespan and the relatively large amount of biomass, are real carbon reserves. Forests provide an important and long-term carbon storage, both in the soil and in the biomass, and thus contribute to limiting global warming. CO2 is considered as one of the most important greenhouse gases contributing to global climate change. This service is assessed by estimating the CO_2 stock by above and below-ground forest biomass, but also by forest soils, in tons of CO2 equivalent per ha ($tCO_2eq.ha$-1).

This value is calculated from the carbon stock in forest biomass (obtained by estimating the stock of above-ground forest biomass, the ratio of below-ground to above-ground biomass, and the carbon fraction in dry matter) and the stock of organic carbon in the forest soil.
The application of a standard coefficient allows this value to be converted into captured CO_2 equivalent.

Above-ground forest biomass

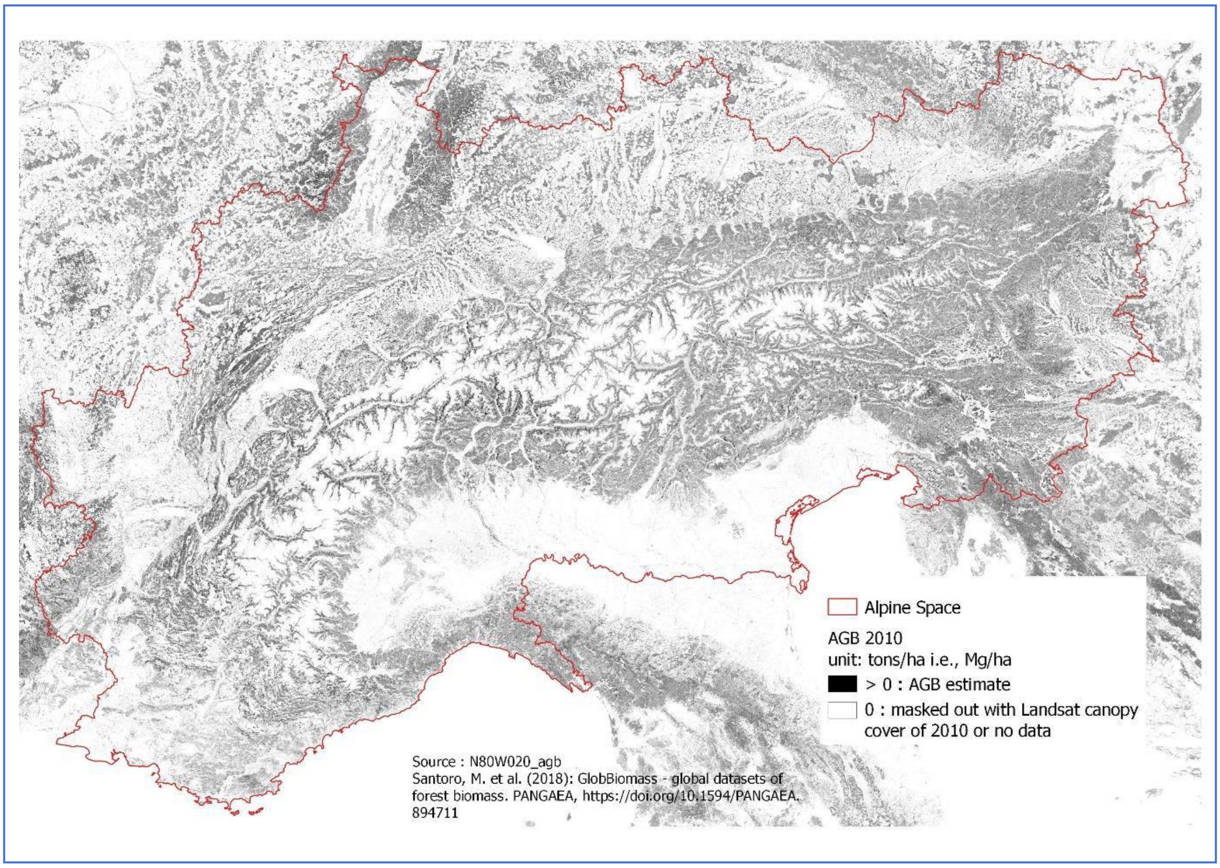
Source: GLOBBIOMASS, N80W020_agb
The data products consist of global datasets including estimates of :

- growing stock volume (GSV, unit: m^3 /ha) for the year 2010: volume of all living trees more than 10 cm in diameter at breast height measured over bark from ground or stump height to a top stem diameter of 0 cm. Excludes: smaller branches, twigs, foliage, flowers, seeds, stump and roots (definition of FAO). A separate data layer is provided with per-pixel uncertainty expressed as standard error in m3/ha.
- above ground biomass (AGB, unit: tons/ha i.e., Mg/ha) for the year 2010: the mass, expressed as oven-dry weight of the woody parts (stem, bark, branches and twigs) of all living trees excluding stump and roots. A separate data layer is provided with per-pixel uncertainty expressed as standard error in Mg/ha.

Data: Santoro, M., Cartus, O., Mermoz, S., Bouvet, A., Le Toan, T., Carvalhais, N., Rozendaal, D., Herold, M., Avitabile, V., Quegan, S., Carreiras, J., Rauste, Y., Balzter, H., Schmullius, C., Seifert, F.M., 2018, GlobBiomass global above-ground biomass and growing stock volume datasets, available on-line at http://globbiomass.org/products/global-mapping

Alignment of the source raster with the forest study area: AGB_2010

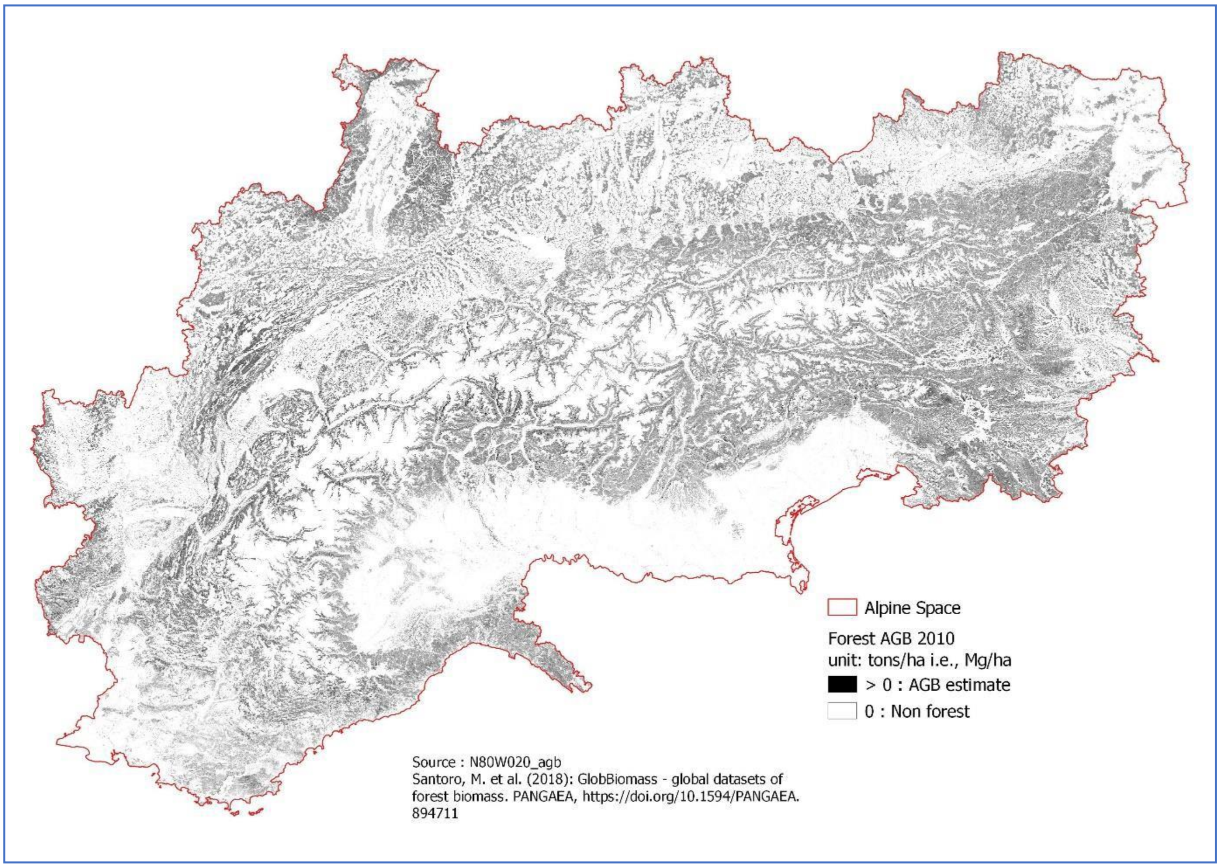
The aerial biomass raster called ***AGB_2010*** is obtained by aligning the N80W020_agb raster with the ***Forest_2018_buffer_10km*** raster. The layer is resampled by bilinear interpolation, this method uses the value of the centre of the four nearest input cells to determine the value on the output raster. The new value for the output cell is the weighted average of these four values, adjusted for the distance from the center of the output cell. The values at zero are then reclassified as non-data.



Extraction of above-ground biomass from forests: forest_AGB_2010

The above-ground forest biomass raster called Forest_ AGB_2010 is phased:

1. Reclassify the raster AGB_2010 values to zero by « no data »: in a first step a temporary raster OUTPUT is created by reclassifying AGB_2010 raster: 1 for all values strictly above zero and no data for zero. This temporary raster is then multiplied by AGB_2010 using « raster calculator ». This step result is called AGB_2010_nodata.
2. Fill in the values « no data » de AGB_2010_nodata by interpolation: For regions without data, the values for the contour pixel values are calculated using inverse distance weighting. After interpolation, a smoothing of the results takes place. This algorithm is generally suitable for interpolating missing regions of rasters that vary quite continuously (such as elevation models for example). This step result is called AGB_2010_interpole30pixels.
3. Trim AGB_2020_interpole30pixels with the mask layer Alpine_Space_buffer_10km. This step result is called AGB_2010_buffer_10km_30pixels.
4. Biomass values are selected only for forests: the raster AGB_2010_buffer_10km_30pixels is multiplied by the raster Forest_2018 with « raster calculator ». This final step result is called Forest_AGB_2010. This is a raster giving an estimate of the above-ground forest biomass 2010 for the forest pixels 2018 within the boundaries of Alpine Space.



Statistics on above-ground forest biomass in the study area

Above-ground forest biomass	Area (pixels or hectares)	Sum (tons)	Min (tons/ha)	Max (tons/ha)	Mean (tons/ha)
Broadleaved forest	7.183.869	907.440.846	1	470	126,3
Coniferous forest	6.272.170	1.119.351.048	1	449	178,5
Mixed forest	3.145.622	477.889.299	1	446	151,9
Forest	16.601.661	2.504.456.455	1	470	150,9

Total forest biomass

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 4: Agriculture, Forestry and Other Land Use – Chapter 4: Forest Land. [2006 IPCC Guidelines Volume 4 Chapter 4]

Domain	Ecological zone	Forest type	Above-ground biomass (tons ha^{-1})	R [ton root d.m. (ton shoot d.m.)$^{-1}$]
Temperate	Continental forest, Mountain systems	Conifers	< 50	0,40 (0,21 – 1,06)
			50-150	0,29 (0,24 – 0,50)
			> 150	0,20 (0,12 – 0,49)
		Other broadleaf	< 75	0,46 (0,12 – 0,93)
			75-150	0,23 (0,13 – 0,37)
			> 150	0,24 (0,17 – 0,44)
Subtropical	Dry forest	All	< 20	0,56 (0,28 – 0,68)
		All	> 20	0,28 (0,27 – 0,28)

Source Table 4.4: Ratio of Below-Ground Biomass to Above-Ground Biomass (R) ; applies to above-ground biomass, above-ground biomass growth, biomass removals and may differ for these components. References: Mokany et al., 2006.

Creation of a raster of ratio values Below-Ground Biomass to Above-Ground Biomass (R)

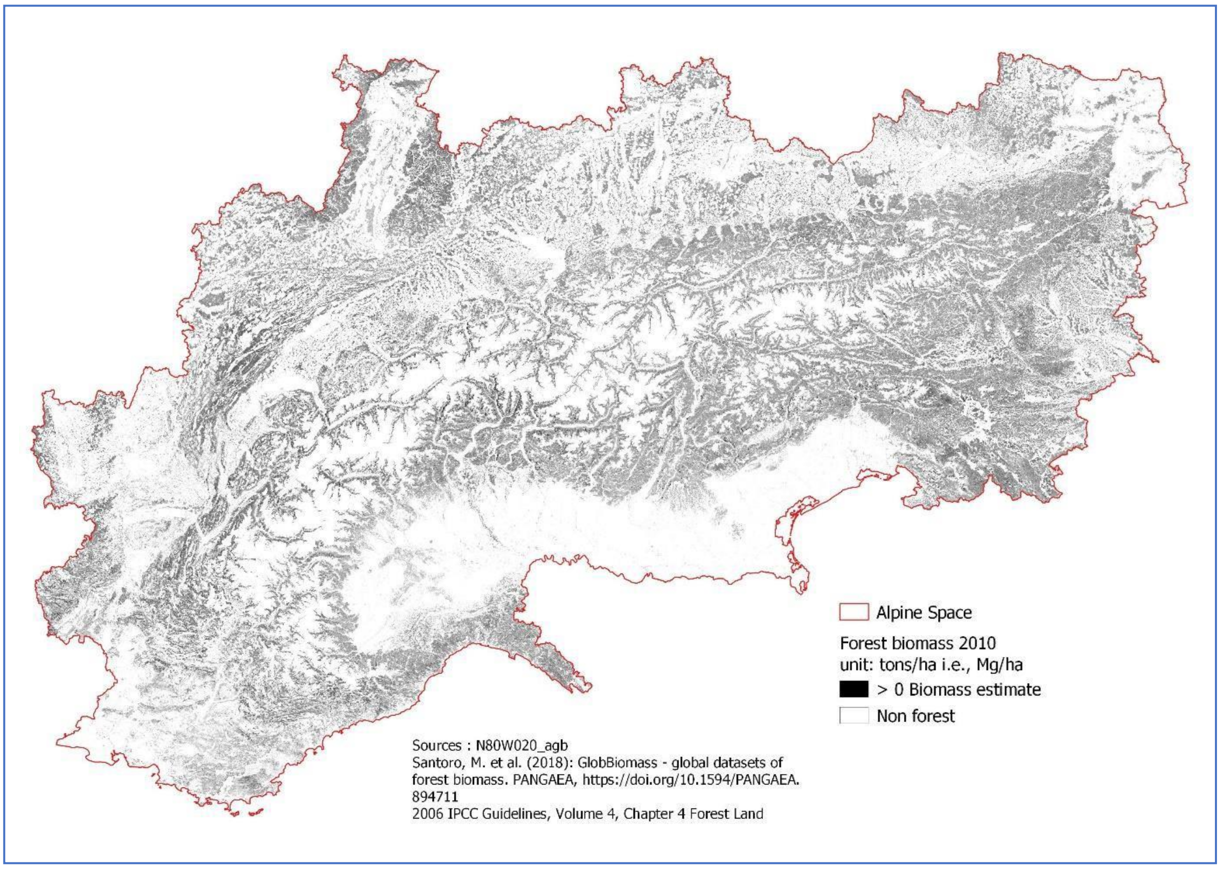
The creation of the R values Tx_biomass_racin_foret raster is done in two steps:

1. Creation of a typology of intersecting territories: Domain / Ecological zone, Forest type and Above ground Biomass of forests.
2. Assignment of R values (2006 IPCC table 4.4) according to the typology created.

(The method is detailed in the section devoted to the CO_2 sequestration service.)

Estimated total forest biomass

Forest_biomass_2010 raster is obtained with raster calculator by multiplying Forest_AGB_2010 by 1 plus Tx_biomass_racin_foret.



Statistics on total forest biomass in the study area

Biomasse aérienne des forêts	Area (pixels ou hectares)	Sum (tons)	Min (tons/ha)	Max (tons/ha)	Mean (tons/ha)
Broadleaved forest	7.183.869	1.140.186.413	1,46	582,8	158,7

Coniferous forest	6.272.170	1.366.492.548	1,40	538,8	217,9
Mixed forest	3.145.622	592.858.048	1,43	563,2	188,5
Forest	16.601.661	3.099.537.010	1,40	582,8	186,7

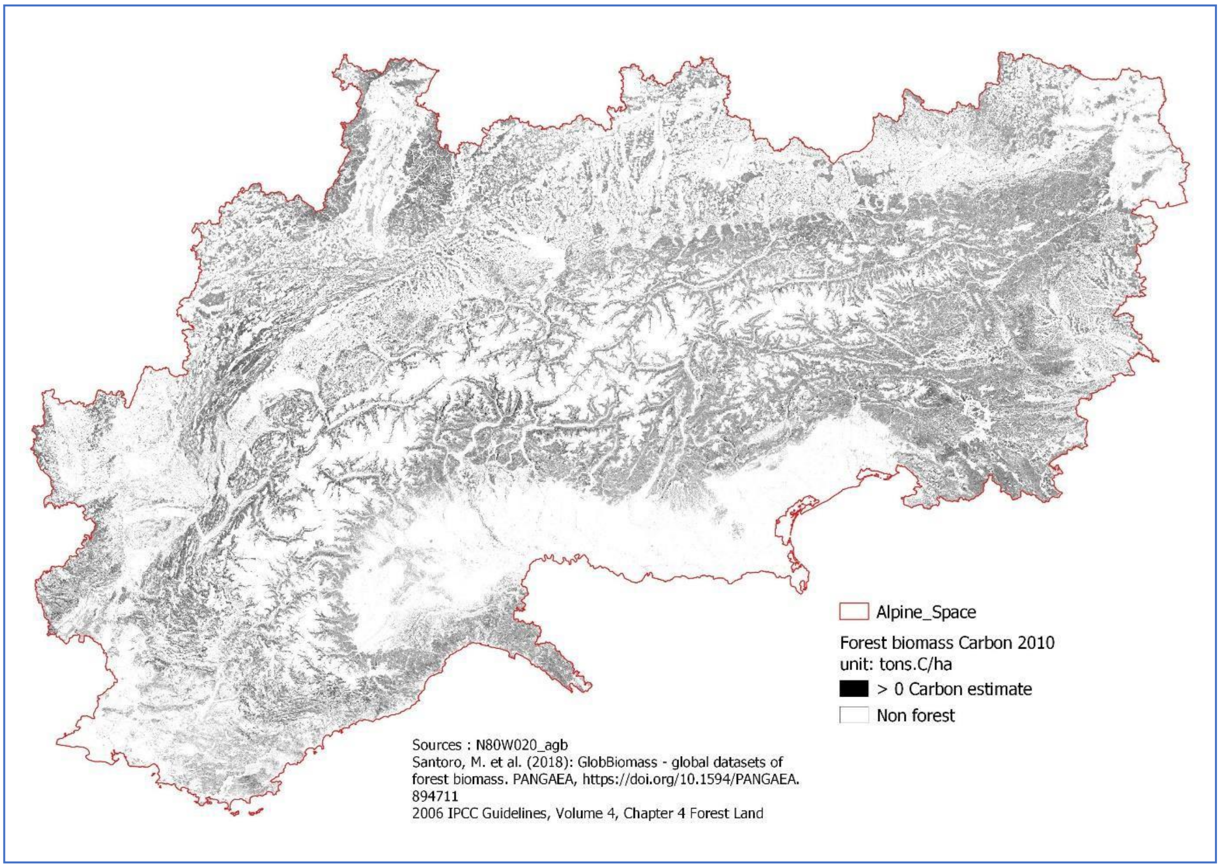
Carbon stock in the forest biomass

Source: 2006 IPCC Guidelines for National Greenhouse Gas Inventories - Volume 4: Agriculture, Forestry and Other Land Use – Chapter 4: Forest Land. [2006 IPCC Guidelines Volume 4 Chapter 4]

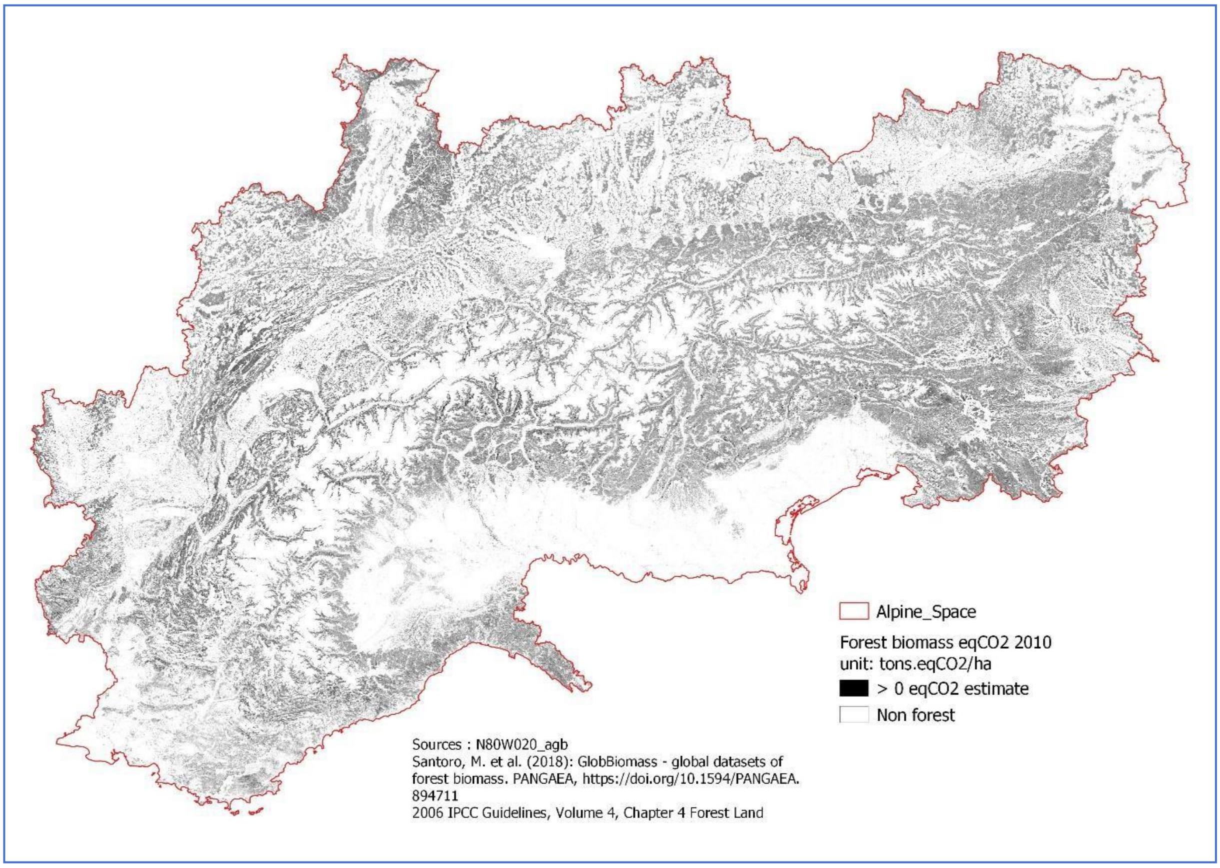
Domain	Part of tree	Carbon fraction, (CF) [ton C (ton d.m.)$^{-1}$]	References
Temperate Subtropical	All	0.47 (0.47 - 0.49)	Andreae and Merlet, 2001; Gayoso et al., 2002; Matthews, 1993; McGroddy et al., 2004
Carbon Fraction of Above-Ground Biomass			

Estimation of Carbon stock in forest biomass

Forest_biomass_C_2010 raster is obtained with raster calculator by multiplying Forest_biomass_2010 raster by 0,47. Values are expressed in tons of C per hectare.



According to the molar mass ratio, it takes 1 ton of carbon to obtain 3.67 tons of CO_2. Forest_biomass_eqCO2_2010 raster is obtained with raster calculator by multiplying Forest_biomass_C_2010 raster by 3,67. Values are expressed in tons eqCO_2 per hectare.



Statistics on the Carbon stock in the total biomass of the forests in the study area

BioGeoRegion	Forest Type	Area (pixels ou hectares)	Sum (tons.C)	Min (tons.C/ha)	Max (tons.C/ha)	Mean (tons.C/ha)
Alpine	Broadleaved	2.643.108	216.975.955	0,69	269,3	82,1
	Conifers	3.972.099	401.023.510	0,66	253,2	101,0
	Mixed	1.639.799	148.049.379	0,67	255,7	90,3
	Forest	**8.255.006**	**766.048.844**	**0,66**	**269,3**	**92,8**
Continental	Broadleaved	3.398.857	243.489.407	0,69	273,9	71,6
	Conifers	1.749.769	196.418.905	0,66	243,1	112,3
	Mixed	1.136.127	105.494.211	0,67	240,8	92,9
	Forest	**6.284.753**	**545.402.523**	**0,66**	**273,9**	**86,8**
Mediterranean	Broadleaved	1.141.904	75.422.253	0,69	271,9	66,0
	Conifers	550.302	44.809.083	0,73	241,2	81,4
	Mixed	369.696	25.099.693	0,73	264,7	67,9
	Forest	**2.061.902**	**145.331.028**	**0,69**	**271,9**	**70,5**
All	Broadleaved	7.183.869	535.887.615	0,69	273,9	74,6
	Conifers	6.272.170	642.251.498	0,66	253,2	102,4
	Mixed	3.145.622	278.643.283	0,67	264,7	88,6
	Forest	**1.456.782.395**	**1 456 782 396**	**0,66**	**273,9**	**87,7**

Soil organic carbon stock

Global organic carbon density (t.ha-1) for the topsoil (0 – 30cm) from the amended Harmonised World Soil Database. Data is available at 30 arc second resolution

Hiederer, R. and Köchy, M. (2011). Global Soil Organic Carbon Estimates and the Harmonized World Soil Database. EUR 25225 EN. Publications Office of the European Union. 79pp. https://esdac.jrc.ec.europa.eu/content/global-soil-organic-carbon-estimates

Extraction, alignment and calculation of the data on the study area

The global raster data is cut around the study area.

The no-data areas of the raster are filled by an interpolation method from the edges. The FillNoData tool in QGIS is used to create a raster, interpolating up to 10 pixels.

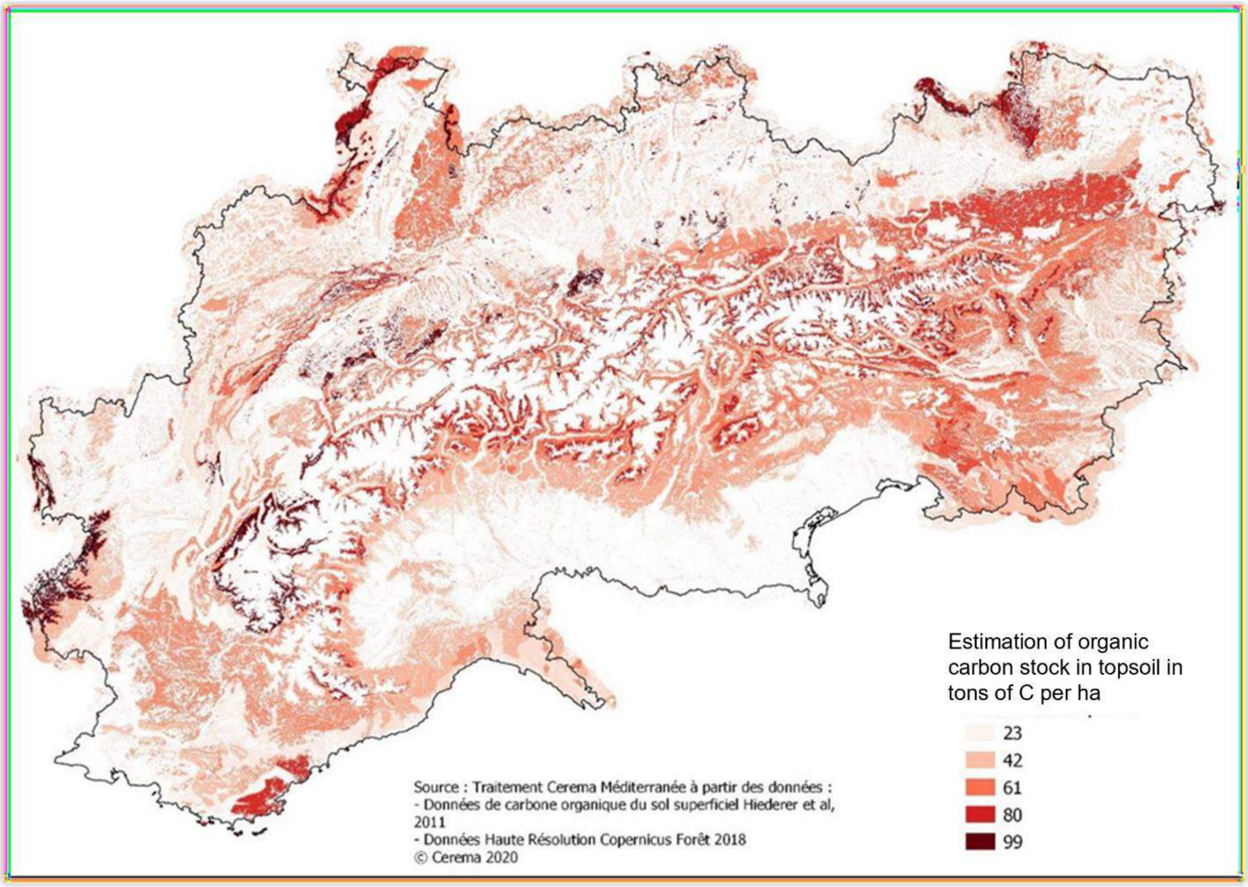
The resulting raster data is then aligned to the Forest_2018_buffer_10km forest study area, resulting in a 100m resolution raster, after resampling by bilinear interpolation.

Finally, only the soil data concerning the forest areas are kept, using the raster calculator with Forest_2018_buffer_10km.

We thus obtain the data stock_C_topsol_hiederer_sous_foret.tif, corresponding to the estimation of the organic carbon stock of the surface layer of the soil in the forests of the Alpine arc, expressed in tons per ha.

The analysis of the data obtained in the Alpine region shows an organic carbon stock in the surface soil of the forests of about 870 million tons of carbon, with an average in the forest of

52.3 tons/ha organic carbon stock in Forest surface soil



Estimating the total carbon stock in forests

Addition of forest carbon stocks

Carbon stock data in forest biomass Forest_biomass_C_2010 is summed with the carbon stock data in the forest topsoil stock_C_topsol_hiederer_sous_foret.tif using the raster calculator.
The final carbon stock figure for the forest, including the living biomass and the soil, is thus obtained Stock_carbon_biomass_sol_alptrees.tif

The analysis of the data obtained in the Alpine region shows a carbon stock in the living biomass and in the surface soil of the forests of about 2.33 billion tons of carbon, with an average in the forest of

140 tons/ha living biomass + organic carbon stock in Forest surface soil

Data source : Yigini et al, 2016.
Current soil organic carbon stocks (2016) in Europe, expressed in tons per ha. This estimate, derived from a model based on LUCAS soil data, is available at a resolution of 1km at the European Union scale.
Yigini, Y., Panagos, P. 2016. Assessment of soil organic carbon stocks under future climate and land cover changes in Europe. Science of The Total Environment, Vol. 557–558, 1 July 2016, Pages 838–850"(http://dx.doi.org/10.1016/j.scitotenv.2016.03.085)

https://esdac.jrc.ec.europa.eu/content/soil-organic-carbon-soc-projections-europe

Carbon sequestration ecosystem service

Indicator definition

Through photosynthesis, Alpine forests capture carbon dioxide (CO_2) from the atmosphere and store the carbon in above- and below-ground plant tissue. Atmospheric CO_2, whose concentration is increasing, is an important greenhouse gas. Alpine forests, through their growth, thus contribute to limiting global warming.

Carbon sequestration is "the process of increasing the carbon content of a reservoir other than the atmosphere" (Reid 2005) 1. Others define it as "the process of removing carbon from the atmosphere and depositing it in a reservoir" (UN 2014). Thus, the sequestration of CO_2 is an important climate regulating service.

A common indicator for carbon sequestration is the amount of carbon sequestrated from the atmosphere per year (tC/ha/y). This amount can be quantified by a range of possible methods, spanning from the estimation of Net Ecosystem Productivity to the calculation of the change in biomass stock. Within the project the provision dynamics of the ES Carbon sequestration by forests in the Alps were assessed by means of the following supply - flow indicators: (t CO_2 ha-1 y-1)

We evaluate this service by estimating the annual Carbon capture by above-ground and underground forest biomass in tons of CO_2 equivalent per ha and per year (tCO2eq.ha−1.an−1).

This value is calculated based on the IPCC equations (2.9 and 2.10 Tier 1, from the IPCC Guidelines, Volume 4, Chapter 2). These equations estimate an annual increase in biomass carbon stock based on above-ground biomass growth data, the ratio of below-ground to above-ground biomass and the carbon fraction in dry matter. The application of a standard coefficient allows this value to be converted into captured CO_2 equivalent.

Annual growth in above-ground forest biomass

Source Data Busetto and al, 2014 : AGB_All_FF_Full_ISE_v2

This is a pan-European map of forest biomass increment. The map was implemented using MODIS GPP data (NASA Product MOD17A3) adjusted with GPP data derived from upscaling FLUXNET observations using the Model Tree Ensemble (MTE) technique (Jung et al., 2011) to derive a 1 km resolution woody biomass increment map. The map was validated using regional information from the most recent publicly available National Forest Inventories data of several European countries.

Busetto, Lorenzo; Barredo Cano, José Ignacio; San Miguel-Ayanz, Jesús (2014): Pan-European Map of Forest Biomass Increment. European Commission, Joint Research Centre (JRC) [Dataset] PID: http://data.europa.eu/89h/38a3b611-eae1-423f-a4aa-c5cfdea03bd9

Data Format : GEOTIFF in LAEA

Projection Units : ton d.m. ha-1 y-1

Interpolation of the AGB_All_FF_Full_ISE_v2 data to fill in the uncovered forest areas: Busetto_interpol

Data-free areas of the AGB_All_FF_Full_ISE_v2 are filled by an interpolation method from the edges. The QGIS FillNoData tool is used to create the Busetto_interpol raster. In order to cover the whole study area, the interpolation is carried out up to 30 pixels, i.e., 30km.

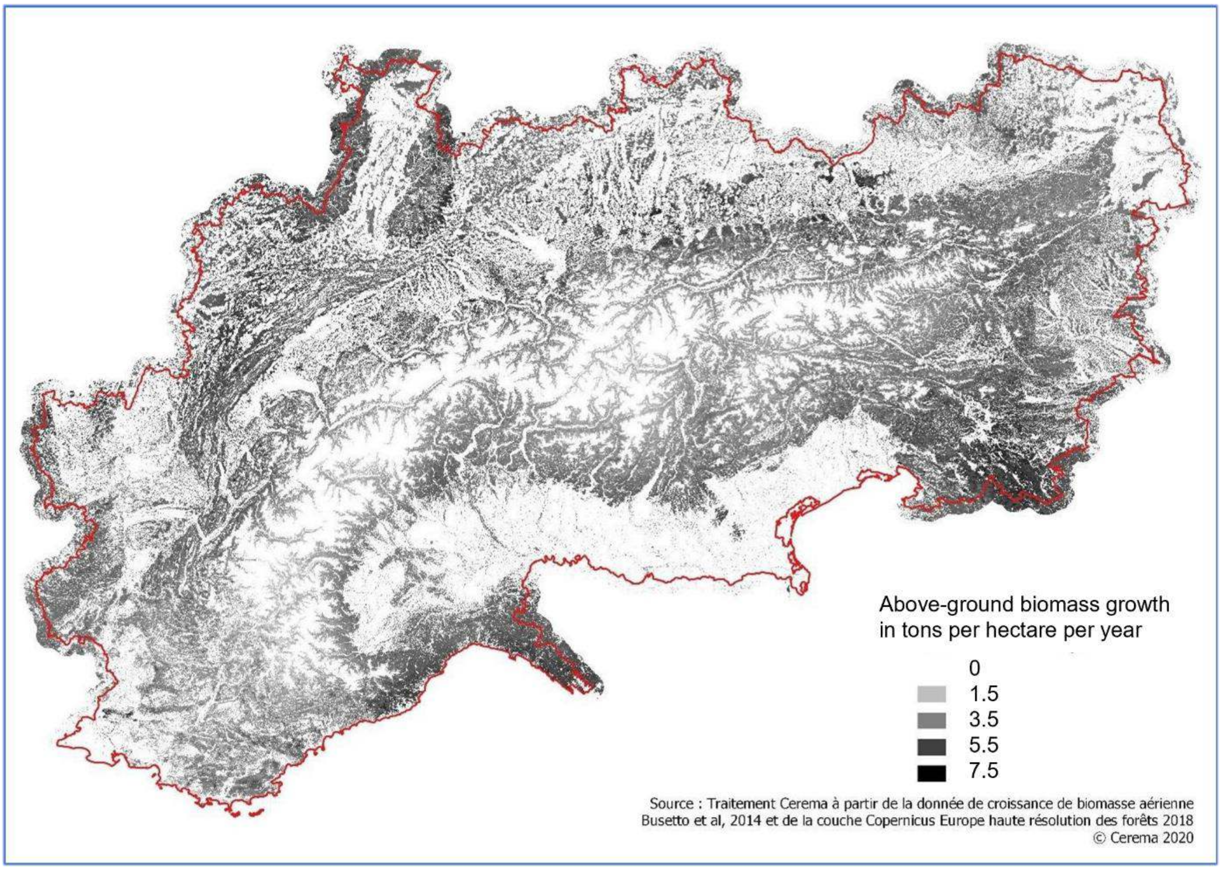
Fill raster regions with no data values by interpolation from edges. The values for the no-data regions are calculated by the surrounding pixel values using inverse distance weighting.

Alignment of the Busetto_interpol raster to the forest study area: Busetto_interpol_align

The so-called Busetto_interpol_align raster is obtained by aligning the Busetto_interpol raster with Forest_2018_buffer_10km raster. This changes from a 1x1km raster to a 100x100m raster. The layer is resampled by bilinear interpolation, this method uses the value of the centre of the four nearest input cells to determine the value on the output raster. The new value for the output cell is the weighted average of these four values, adjusted for the distance from the center of the output cell.

Obtaining the growth raster of above-ground forest biomass in the Alpine space: Busetto_foret_alptrees

The above ground biomass growth raster of the Alpine space known as Busetto_foret_alptrees is obtained by calculation from the raster calculator: Busetto_interpol_align x Forest_2018_buffer_10km.



Statistics on the annual growth of above-ground forest biomass in the study area

Annual growth of above-ground forest biomass	Area (pixels or hectares)	Sum (tons m.s $.an^{-1}$)	Min (tons m.s. $.ha^{-1}.an^{-1}$)	Max (tons m.s. $.ha^{-1}.an^{-1}$)	Mean (tons m.s. $.ha^{-1}.an^{-1}$)
Broadleaved forest	7.183.869	29.453.338	0,41	9,80	4,10
Coniferous forest	6.272.170	23.141.740	0,25	9,48	3,69
Mixed forest	3.145.622	12.315.884	0,43	9,13	3,92
Forest	16.601.661	64.910.962	0,25	9,80	3,91

Annual growth of the underground (root) biomass of forests

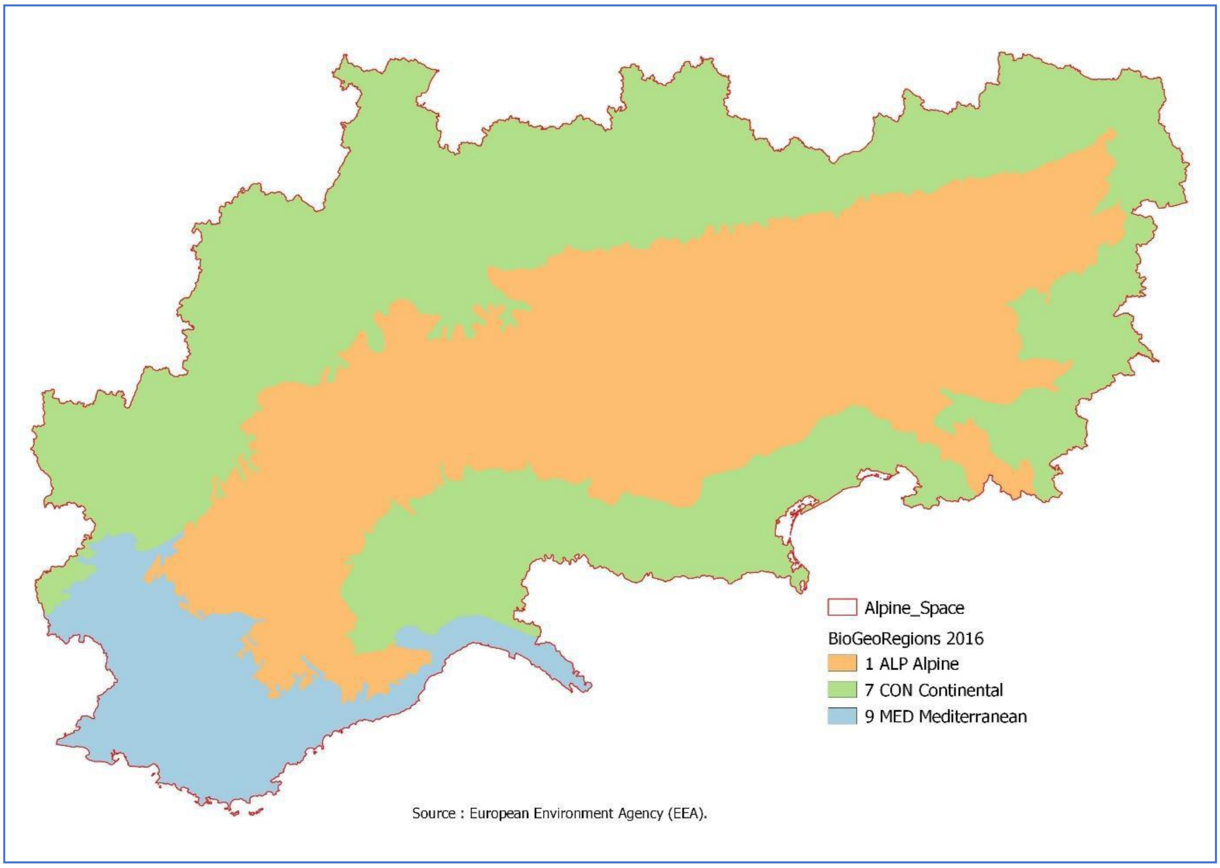
Source: IPCC Guidelines for National Greenhouse Gas Inventories

2006 IPCC Guidelines, Volume 4, Chapter 4: Forest Land [2006 IPCC Guidelines for National Greenhouse Gas Inventories]

<table>
<tr><th>Domain</th><th>Ecological zone</th><th>Forest type</th><th>Above-ground biomass (tons ha⁻¹)</th><th>R [tonne root d.m. (tonne shoot d.m.)⁻¹]</th></tr>
<tr><td rowspan="6">Temperate</td><td rowspan="6">Oceanic forest, Continental Forest, Mountain systems</td><td rowspan="3">Conifers</td><td>< 50</td><td>0,40 (0,21 – 1,06)</td></tr>
<tr><td>50-150</td><td>0,29 (0,24 – 0,50)</td></tr>
<tr><td>> 150</td><td>0,20 (0,12 – 0,49)</td></tr>
<tr><td rowspan="3">Other broadleaf</td><td>< 75</td><td>0,46 (0,12 – 0,93)</td></tr>
<tr><td>75-150</td><td>0,23 (0,13 – 0,37)</td></tr>
<tr><td>> 150</td><td>0,24 (0,17 – 0,44)</td></tr>
<tr><td rowspan="2">Subtropical</td><td rowspan="2">Dry forest</td><td>All</td><td>< 20</td><td>0,56 (0,28 – 0,68)</td></tr>
<tr><td>All</td><td>> 20</td><td>0,28 (0,27 – 0,28)</td></tr>
<tr><td colspan="5">Ratio of Below-Ground Biomass to Above-Ground Biomass (R) ; applies to above-ground biomass, above- ground biomass growth, biomass removals and may differ for these components.
References: Mokany et al., 2006.</td></tr>
</table>

Bio-geographical areas

Biogeographical classification system used by Habitats Directive (92/43/EEC). European Environment Agency (EEA). https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3



Creation of a forest classification consistent with the IPCC source data on the ratio of underground biomass

To calculate the annual growth of total biomass, we use IPCC data that estimate the ratio of underground biomass to above-ground biomass. These ratios can also be used for biomass growth.

These reference data are available by ecological zone, forest type and above-ground biomass density. In this way, an adapted classification of the forests of the Alpine arc is carried out.

1. Bioecological zone classification

   The ratios are distinct according to the bioecological zone. The Alpine Space is thus classified into two zones: "dry subtropical forest zone" and "oceanic, continental and mountainous temperate forest zone". To determine their location, we use the EEA biogeographic zones. The Mediterranean region is considered as "subtropical dry forest area", and the other regions (Alpine, Atlantic, Continental, Pannonian) are classified as "temperate oceanic, continental and mountainous forests".

   Thus, BiogeoRegions2016 raster, resulting from the rasterisation of the official delimitations of biogeographical zones and aligned with the Forest_Type_2018_buffer_10km Data, has been reclassified into 1 "dry subtropical forest" and 2 "oceanic, continental and mountainous temperate forests»: Zone_biogeo_reclass.

   In addition, the coastal zones have been interpolated over 1km to avoid edge effects.

2. Forest type classification

   Forest_Type_2018_buffer_10km raster has been the subject of a simple reclassification into 3 classes allowing the creation of Forest_Type_2018_buffer_10km_reclass raster. The classes are Broadleaved Forest: 10, Coniferous Forest: 20, Mixed Forest: 30.

3. Above-ground biomass density Classification

   AGB_2010 raster crossed with the Forest_2018_buffer_10km raster creates a raster with the density of above-ground forest biomass over the wider area of the Alpine Space: Forest_AGB_2010_buffer_10km.

   This raster has been reclassified into 5 classes to correspond to the different cases encountered in the IPCC tables.

   The result is Forest_AGB_2010_buffer_10km_reclass raster. Classes are:

   - 100: 0 to 20 tons.ha^{-1} of above-ground biomass
   - 200: 20 to 50 tons.ha^{-1} of above-ground biomass
   - 300: 50 to 75 tons.ha^{-1} of above-ground biomass
   - 400: 75 à 150 tons.ha^{-1} of above-ground biomass
   - 500: more than 150 tons.ha^{-1} of above-ground biomass

4. Final forest classification

   The addition of these three reclassified rasters results in a raster of 30 classes, covering the different cases presented in the IPCC tables. The resulting raster is named Classif_foret_biomass_racin.

	Above-ground biomass density classes				
Bioecological zone classes	100	200	300	400	500

1: Mediterranean system 2: Temperate system		0-20 tons.ha^{-1}	20-50 tons.ha^{-1}	50-75 tons.ha^{-1}	75-150 tons.ha^{-1}	More than 150 tons.ha^{-1}
Forest type classes	10: broadleaved forest	111 112	211 212	311 312	411 412	511 512
	20: coniferous forest	121 122	221 222	321 322	421 422	521 522
	30: mixed forest	131 132	231 232	331 332	431 432	531 532

Application of IPCC subsurface biomass ratios

This is a simple Classif_foret_biomass_racin raster assignment of the IPCC ratios of subsurface biomass to above-ground biomass. The final raster is Tx_biomass_racin_foret.

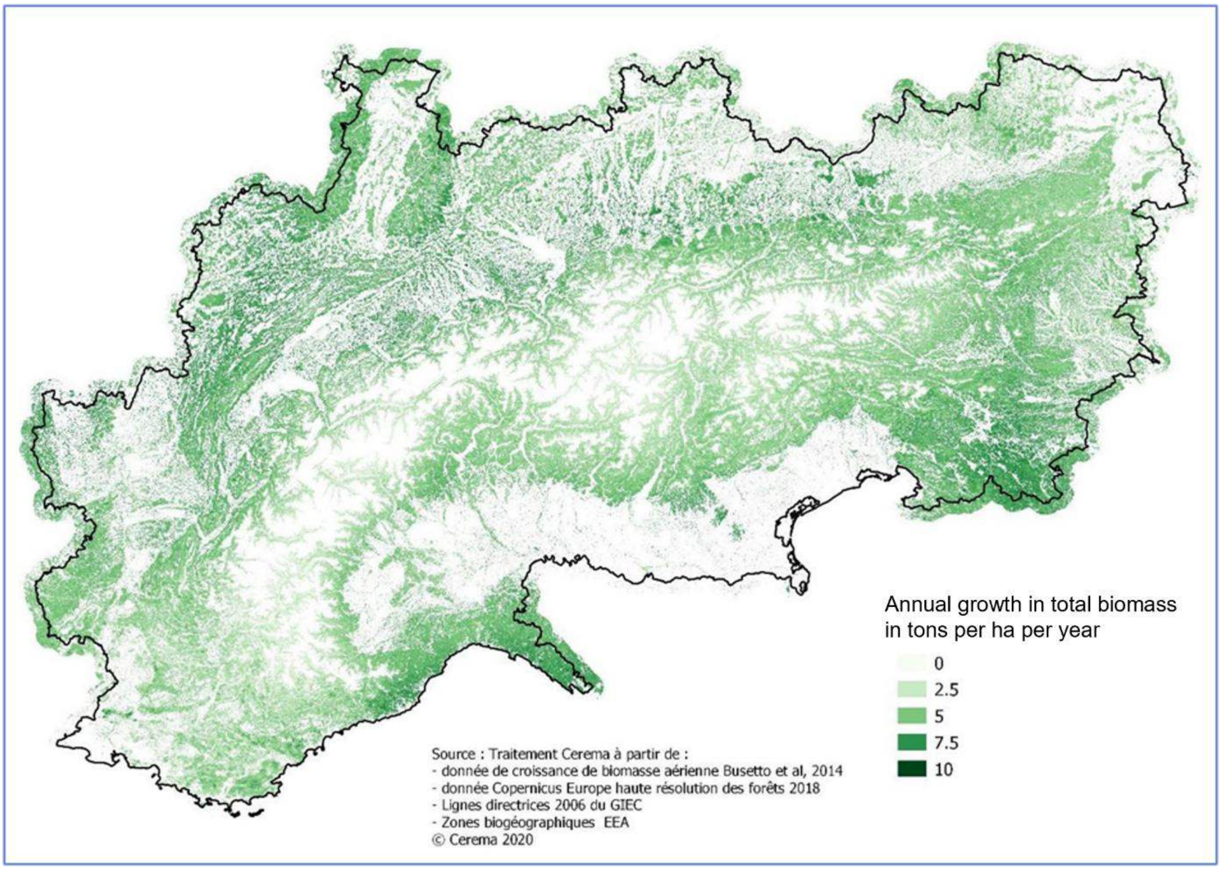
Class	Ratio of root biomass to above-ground biomass
111	0.56
112	0.46
121	0.56
122	0.40
131	0.56
132	0.43
211	0.28
212	0.46
221	0.28
222	0.40
231	0.28
232	0.43
311	0.28
312	0.46
321	0.28
322	0.29
331	0.28
332	0.38
411	0.28
412	0.23
421	0.28
422	0.29
431	0.28
432	0.26

511	0.28
512	0.24
521	0.28
522	0.20
531	0.28
532	0.22

Calculation of total forest biomass annual growth

Using raster calculator, forest biomass growth Croiss_biomass_tot_buffer10km is calculated from the above ground forest biomass growth rate Busetto_foret_alptrees, and underground biomass rate Tx_biomass_racin_foret.

Croiss_biomass_tot_buffer10km = Busetto_foret_alptrees + (Tx_biomass_racin_foret x Busetto_foret_alptrees)



Statistics on the annual growth of total forest biomass in the study area

Annual growth of above-ground forest biomass	Area (pixels or hectares)	Sum (tons m.s .an^{-1})	Min (tons m.s. .ha^{-1} .an^{-1})	Max (tons m.s. .ha^{-1} .an^{-1})	Mean (tons m.s. .ha^{-1} .an^{-1})

Broadleaved forest	7.183.869	37.790.918	0,59	14,32	5,26
Coniferous forest	6.272.170	28.463.346	0,32	12,23	4,54
Mixed forest	3.145.622	15.452.199	0,63	13,05	4,91
Forest	16.601.661	81.706.463	0,32	14,32	4,92

Annual CO2 sequestration by forests

Carbon fraction in dry matter

2006 IPCC Guidelines for National Greenhouse Gas Inventories.
https://www.ipcc-nggip.iges.or.jp/public/2006gl/french/index.html Volume 4: Agriculture, forestry and other land uses. Chapter 4: Forest land.
The values suggested are:

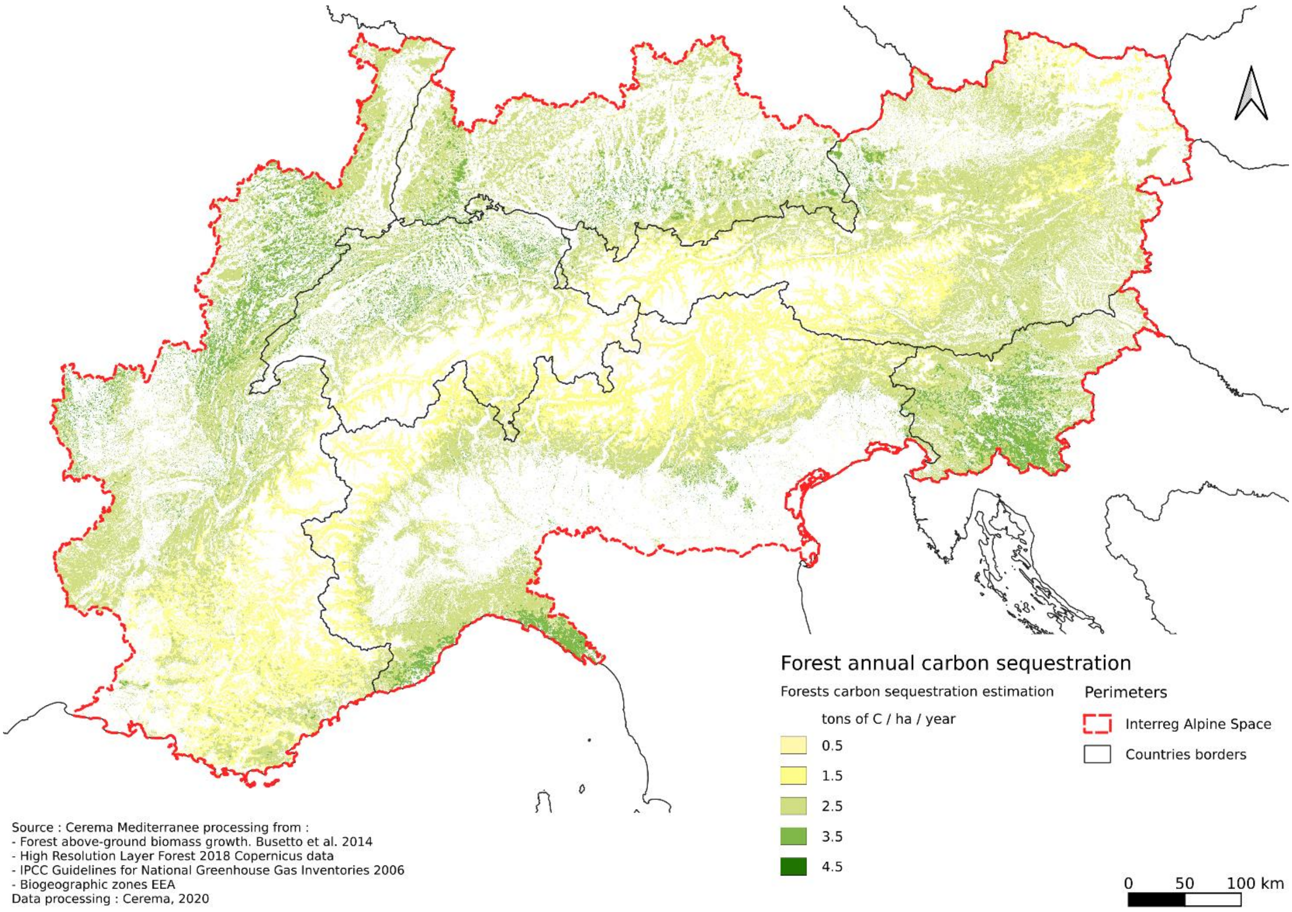
Domain	Tree part	Carbon fraction, (CF) [tonne C (ton m.s.)$^{-1}$]	References
Temperate and Subtropical	Entire tree	0,47	McGroddy et al., 2004

McGroddy, M.E., Daufresne, T. and Hedin, L.O. (2004). Scaling of C:N:P stoichiometry in forests worldwide: Implications of terrestrial Redfield-type ratios. Ecology 85: 2390-2401.

Calculation

The simple use of the ratio of carbon in biomass allows the calculation of the annual carbon sequestration by forests in the wider Alpine Space: Seq_carbone_buffer10km

Seq_carbone_buffer10km = 0,47 x Croiss_biomass_tot_buffer10km



Statistics on annual carbon sequestration by forests

	Area [ha]	% of the study zone	% per biogeographical zone	Total sequestration in Miot C/year	Mean sequestration in Ton C /ha.year
Forest in the Alpine area	8254896	50%		17,07	2,07
Broadleaves	2642822		32%	5,88	2,22
Coniferous	3972165		48%	7,74	1,95
Mixed	1639909		20%	3,45	2,10
Forest in the Continental area	6284701	38%		16,90	2,69
Broadleaves	3399006		54%	9,24	2,72
Coniferous	1749677		28%	4,58	2,62
Mixed	1136018		18%	3,07	2,70
Forest in the Mediterranean area	2062064	12%		4,43	2,15
Broadleaves	1142041		55%	2,64	2,31
Coniferous	550328		27%	1,05	1,91
Mixed	369695		18%	0,74	2,00
Total	16601661	100%		38,40	2,31

References:
AlpES, Alpine Ecosystem Services - mapping, maintenance, management. Project co-financed by the European Union via Interreg Alpine Space. 2015-2018. Eurac Research
IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). Published: IGES, Japan.
Busetto, Lorenzo; Barredo Cano, José Ignacio; San Miguel-Ayanz, Jesús (2014): Pan-European Map of Forest Biomass Increment. European Commission, Joint Research Centre (JRC) [Dataset] PID: *http://data.europa.eu/89h/38a3b611-eae1-423f-a4aa-c5cfdea03bd9*
McGroddy, M.E., Daufresne, T. and Hedin, L.O. (2004). Scaling of C: N:P stoichiometry in forests worldwide: Implications of terrestrial Redfield-type ratios. Ecology 85: 2390-2401.
Mokany et al., 2006. K. Mokany, R. Raison, A.S. Prokushkin. Critical analysis of root: shoot ratios in terrestrial biomes. Glob. Chang. Biol., 12 (1) (2006), pp. 84-96.
Santoro, M. et al. (2018). GlobBiomass - global datasets of forest biomass. PANGAEA, *https://doi.org/10.1594/PANGAEA.894711*
Santoro, M., Cartus, O., Mermoz, S., Bouvet, A., Le Toan, T., Carvalhais, N., Rozendaal, D., Herold, M., Avitabile, V., Quegan, S., Carreiras, J., Rauste, Y., Balzter, H., Schmullius, C., Seifert, F.M. (2018). GlobBiomass global above-ground biomass and growing stock volume datasets, available on-line at *http://globbiomass.org/products/global-mapping*
Yigini, Y., Panagos, P. 2016. Assessment of soil organic carbon stocks under future climate and land cover changes in Europe. Science of The Total Environment, Vol. 557–558, 1 July 2016, Pages 838–850" (*http://dx.doi.org/10.1016/j.scitotenv.2016.03.085*)

Timber

General description of the indicator

Timber is a forest provisioning service. This is a familiar, tangible and direct product extracted from forests to be used or sold. They are the logs, wood, fiber and fuel. Large swaths of forested land are one of the defining features of the Alps. These numerous forests provide for many social and economic benefits: one of the most significant being timber. Timber can be processed in numerous ways and serve a variety of purposes: from constructing buildings to being burned as fuel.
In order to better understand the benefits humans derive from timber it is important to identify how much timber ecosystems supply. Many factors affect these values, such as the rate at which a forest grows, how accessible wood resources are for extraction.
This indicator measures the total annual timber removals - based on national inventories - for timber production, considering also the forest accessibility and the technical feasibility of harvesting due to topographical site conditions.
Forest management is only possible if there is viable infrastructure to reach the felling sites. Moreover, topographical site conditions affect the technical feasibility of the tree felling activities and the subsequent collection and transportation of the timber. All these factors, together with data on the forests available for wood supply, were utilized to develop the flow indicator for timber.

Estimation of growing stock of forests

Source: GLOBBIOMASS, N80W020_gsv

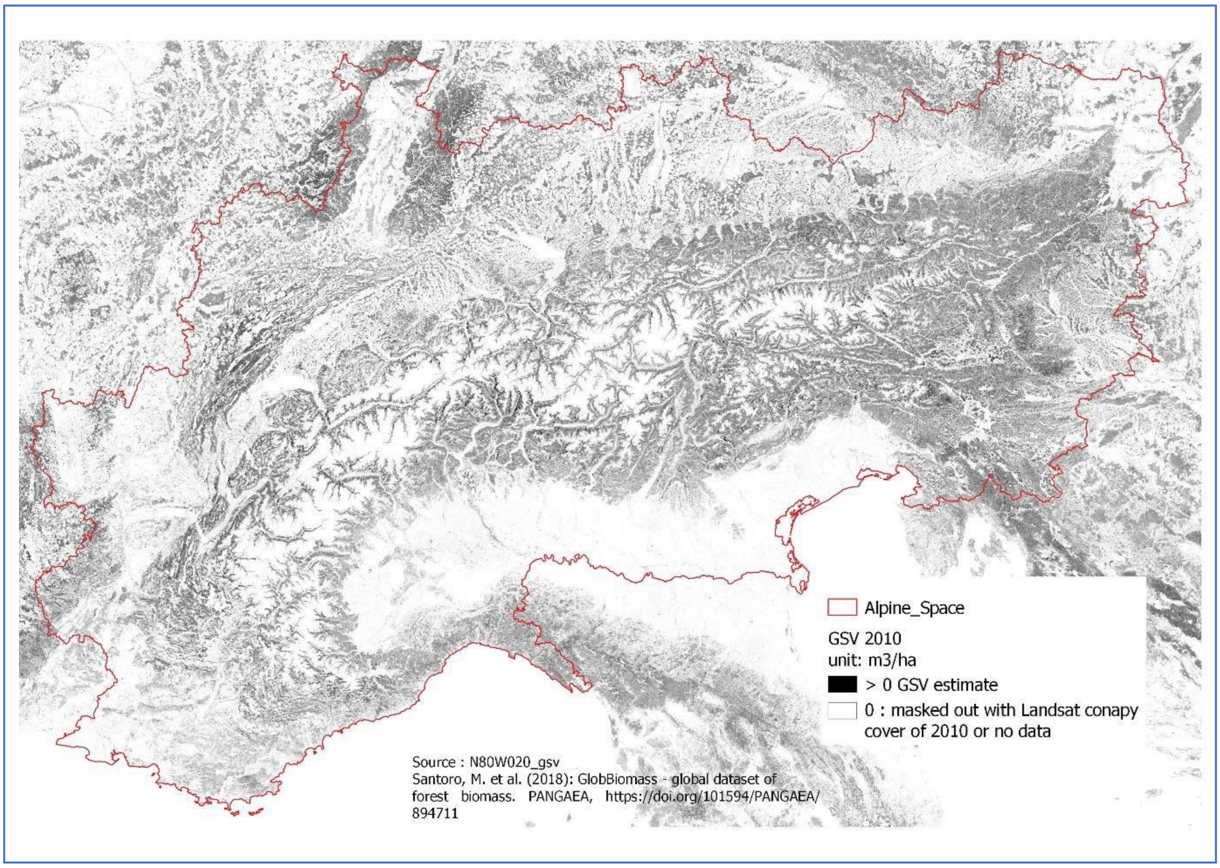
The data products consist of global datasets including estimates of

1. growing stock volume (GSV, unit: m3/ha) for the year 2010: volume of all living trees more than 10 cm in diameter at breast height measured over bark from ground or stump height to a top stem diameter of 0 cm. Excludes: smaller branches, twigs, foliage, flowers, seeds, stump and roots (definition of FAO). A separate data layer is provided with per-pixel uncertainty expressed as standard error in m3/ha.
2. above ground biomass (AGB, unit: tons/ha i.e., Mg/ha) for the year 2010: the mass, expressed as oven-dry weight of the woody parts (stem, bark, branches and twigs) of all living trees excluding stump and roots. A separate data layer is provided with per-pixel uncertainty expressed as standard error in Mg/ha.

Data: Santoro, M., Cartus, O., Mermoz, S., Bouvet, A., Le Toan, T., Carvalhais, N., Rozendaal, D., Herold, M., Avitabile, V., Quegan, S., Carreiras, J., Rauste, Y., Balzter, H., Schmullius, C., Seifert, F.M., 2018, GlobBiomass global above-ground biomass and growing stock volume datasets, available on-line at http://globbiomass.org/products/global-mapping

Alignment of the source raster to the forest study area : GSV_2010

The standing timber raster, GSV_2010, is obtained by aligning the N80W020_gsv raster with the Forest_2018_buffer_10km raster. The layer is resampled by bilinear interpolation, which uses the center value of the four nearest input cells to determine the value on the output raster. The new value for the output cell is the weighted average of these four values, adjusted for distance from the center of the output cell. The zero values are then reclassified as non-data.



Statistics on growing stock of forests in the study area

Growing stock of forests	Area (pixels or hectares)	Sum (m^3)	Min (m^3/ha)	Max (m^3/ha)	Mean (m^3/ha)
Broadleaved forest	7.183.869	1.394.054.471	1	716	194,1
Coniferous forest	6.272.170	1.848.614.879	1	713	294,7
Mixed forest	3.145.622	765.541.452	1	713	243,4
Forest	16.601.661	4.008.210.801	1	716	241,4

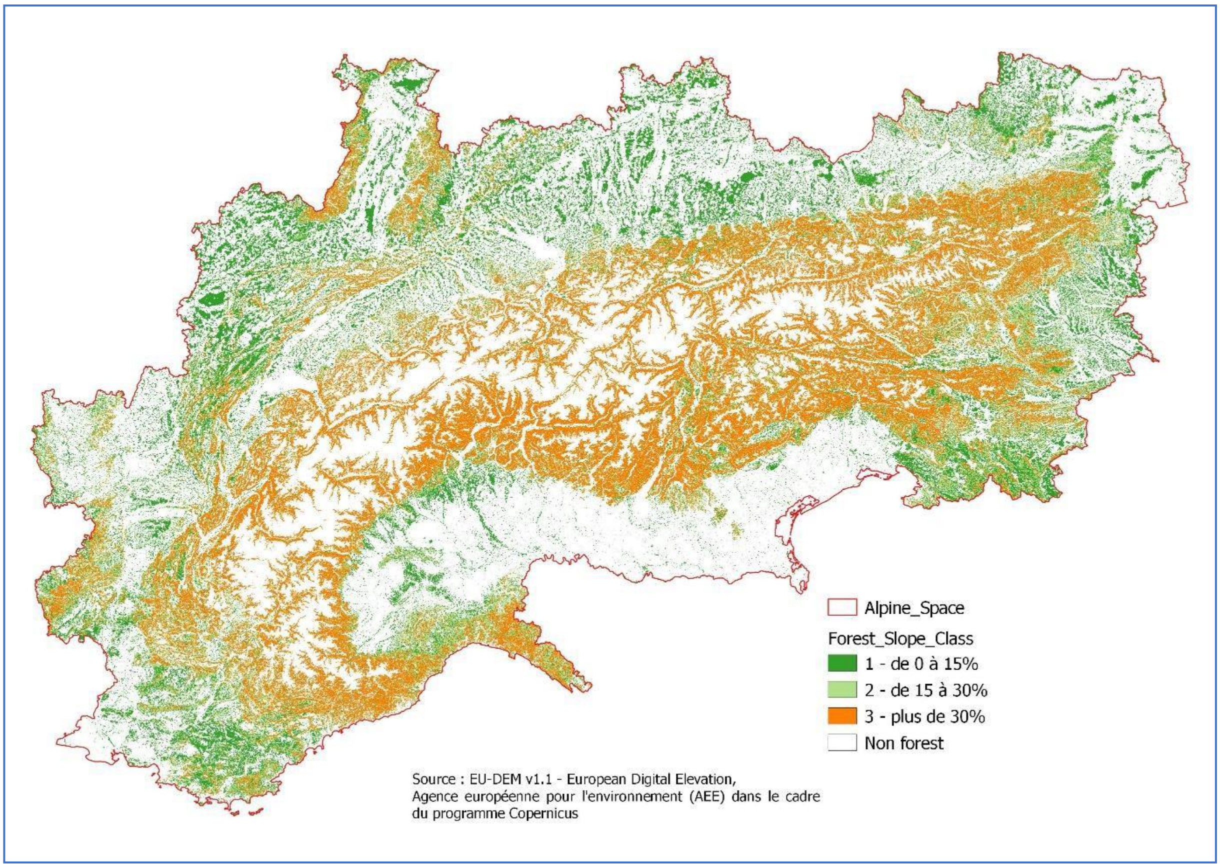
Harvestable forest

Sources

- Open Street Map (access on 4-5/07/2021) – gis_osm_roads_free_1 https://www.geofabrik.de/data/
  Geofabrik provides you with geodata that matches your needs. We mainly work with free data from the OpenStreetMap project and use the lean OpenStreetMap tools for cartography of all kind. Our download server has free and current geodata from OpenStreetMap in various formats.
  All OpenStreetMap derived data on the download server is licensed under the Open Database License :You may use the data for any purpose, but you have to acknowledge OpenStreetMap as the data source. Derived databases have to retain the same license.
- Copernicus Land (access 07/21) - European Digital Elevation Model (EU-DEM) https://land.copernicus.eu/imagery-in-situ/eu-dem
  EU-DEM v1.0 is a digital surface model (DSM) of EEA39 countries representing the first surface as illuminated by the sensors. It is a hybrid product based on SRTM and ASTER GDEM data fused by a weighted averaging approach. The statistical validation of EU-DEM v1.0 documents a relatively unbiased (-0.56 meters) overall vertical accuracy of 2.9 meters RMSE, which is fully within the contractual specification of 7m RMSE (European Commission 2009). The EU-DEM v1.1 is a resulting dataset of the EU-DEM v1.0 upgrade which enhances the correction of geo-positioning issues, reducing the number of artefacts, improving the vertical accuracy of EU-DEM using ICESat as reference and ensuring consistency with EU-Hydro public beta.
- World Database on Protected Areas https://www.protectedplanet.net/en/thematic-areas/wdpa?tab=WDPA
  The World Database on Protected Areas (WDPA) is the most comprehensive global database of marine and terrestrial protected areas. It is a joint project between UN Environment Programme and the International Union for Conservation of Nature (IUCN), and is managed by UN Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), in collaboration with governments, non-governmental organisations, academia and industry.The WDPA is updated on a monthly basis, and can be downloaded using.

The forest slope class called Forest_slope_class is obtained by steps:

1. Alignment of the elevation rasters eu_dem_v11_E30N20 N80W020 and eu_dem_v11_E40N20 with Alpine_Space_buffer_10km. The layer is resampled by averaging.
2. Calculation of the slope in percent.
3. Reclassification of the slope into three classes: (1) 0-15%; (2) 15-30%; (3) > 30%.
4. With raster calculator, the above raster is multiplied by the raster Forest_2018. The result is a coded raster: (1) forest pixel with 0 à 15% slope; (2) forest pixel with 15 à 30% slope; (3) forest pixel with more than 30% slope; (no data) non-forest pixel.

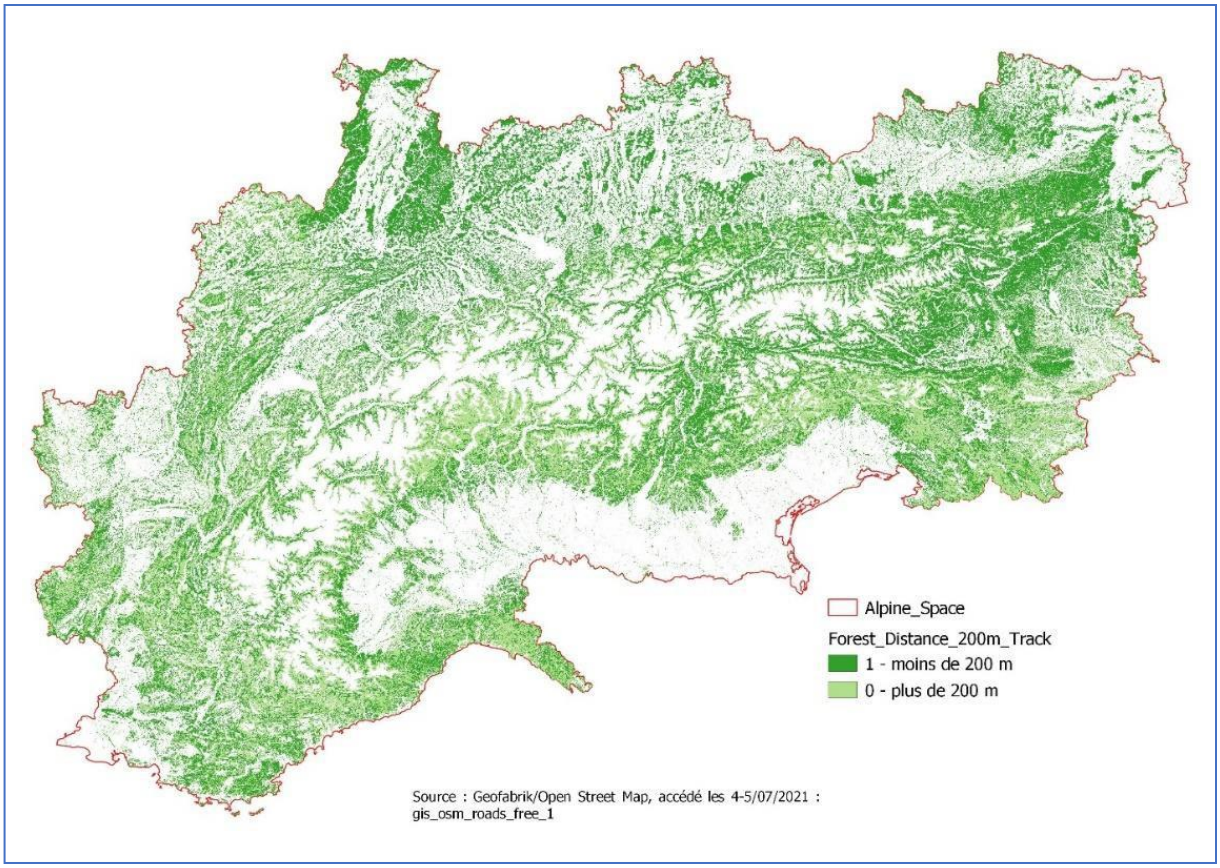


Calculation of the skidding distance between the forest and a track

The raster distance from the forest to a track Forest_Distance_200m_Track is obtained in steps:

1. Selection of tracks, bridges and tunnels in Open Street Map
2. Calculation of a 200 m buffer zone around the selected tracks

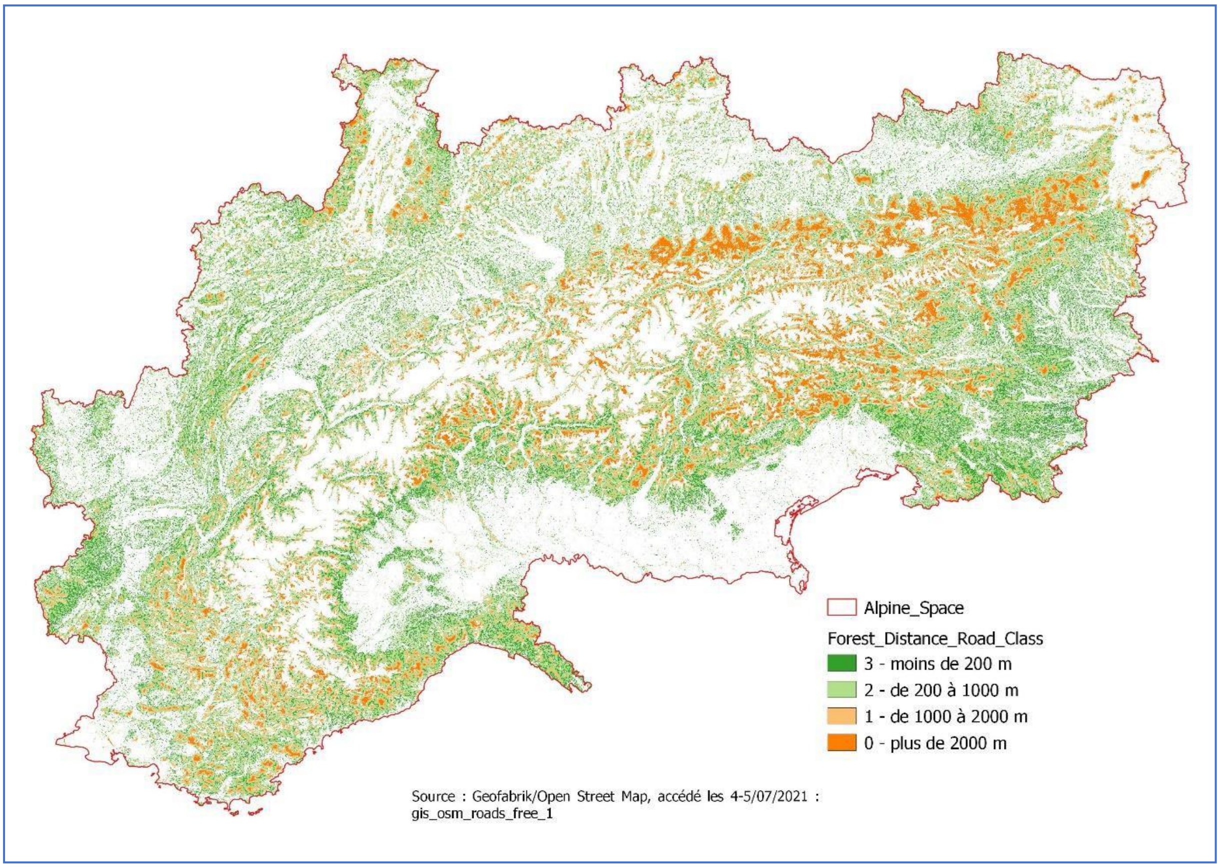
3. Rasterisation of the buffer aligned to the Alpine Space right of way with a 100 m pixel
4. With raster calculator, the above raster is multiplied by the raster Forest_2018. The result is coded raster: (1) forest located within 200 m of a track; (0) forest pixel located within 200 m of a track ; (no data) non-forest pixel



Calculation of the skidding distance between the forest and a tertiary classified road or an unclassified road

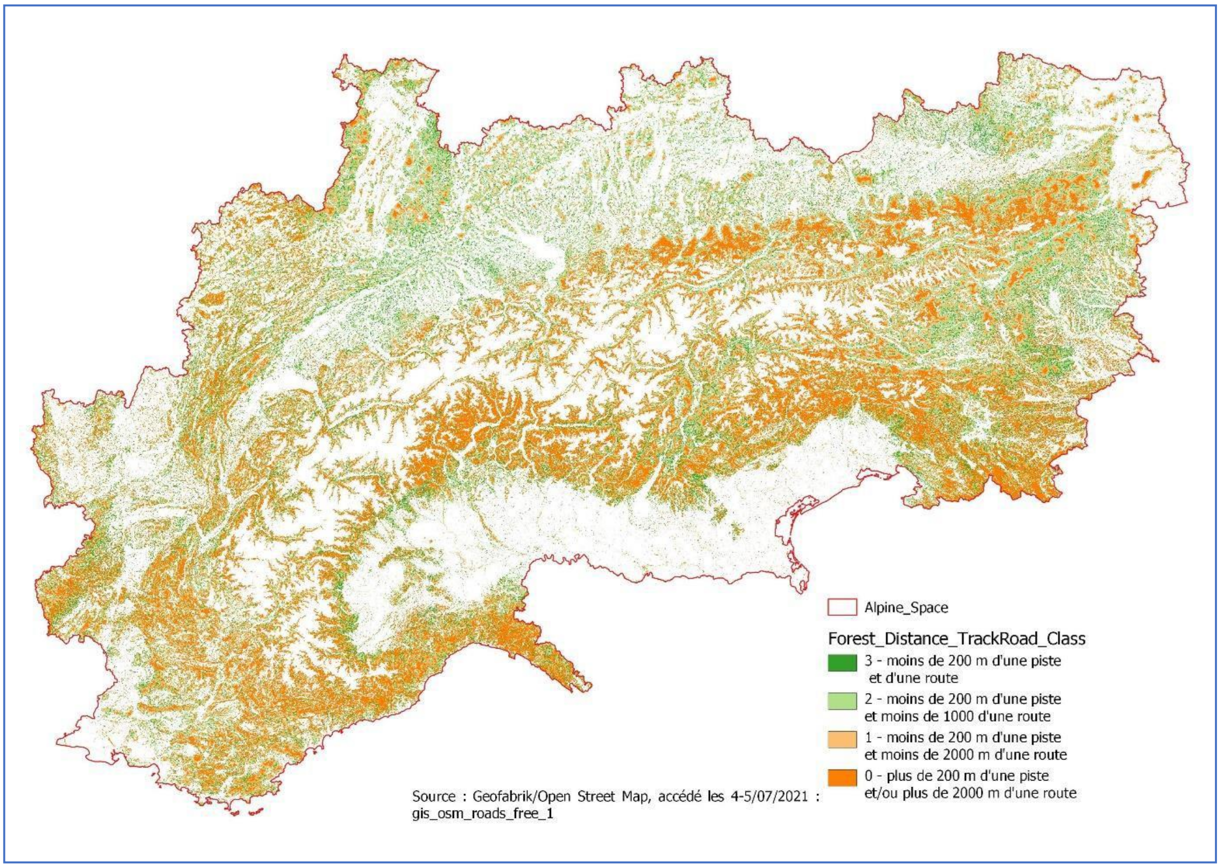
The raster of distance classes from the forest to a tertiary or unclassified road called Forest_Distance_Road_Class is obtained by steps:

1. Selection of tertiary or unclassified roads except bridges and tunnels in Open Street Map
2. Calculation of a 200 m buffer zone around the selected roads
3. Rasterisation of the buffer aligned to the Alpine Space rifgt-of-way with a 100 m. pixel
4. With raster calculator, multiply the above raster by Forest_2018. The result is a coded raster:
   (1) forest pixel within 200 m of a tertiary or unclassified road; (o) forest pixel more than 200 m from a tertiary or unclassified road; (no data) non-forest pixel
5. Repeat for distances of 1000 m and 2000 m
6. With raster calculator, the three rasters corresponding to the distances of 200 m, 1000 m and 2000 m are added together. The result is a coded raster: (3) forest pixel located within 200 m of a tertiary or unclassified road; (2) forest pixel located between 200 m and 1000 m of a tertiary or unclassified road; (1) forest pixel located between 1000 m and 2000 m of a tertiary or unclassified road; (0) forest pixel located more than 2000 m of a tertiary or unclassified road; (no data) pixel outside the forest



Calculation of the skidding distance between the forest located within 200 m of a track and a tertiary classified road or unclassified road

With raster calculator, raster Forest_Distance_200m_Track is multiplied by Forest_Distance_Road_Class. The result is a coded raster: (3) forest pixel located within 200 m of a track and a tertiary or unclassified road; (2) forest pixel located within 200 m of a track and between 200 and 1000 m of a tertiary or unclassified road; (1) forest pixel located within 200 m of a track and between 1000 and 2000 m of a tertiary or unclassified road; (0) forest pixel located more than 200 m of a track and/or more than 2000 m of a tertiary or unclassified road. The result is called Forest_Distance_TrackRoad_Class.

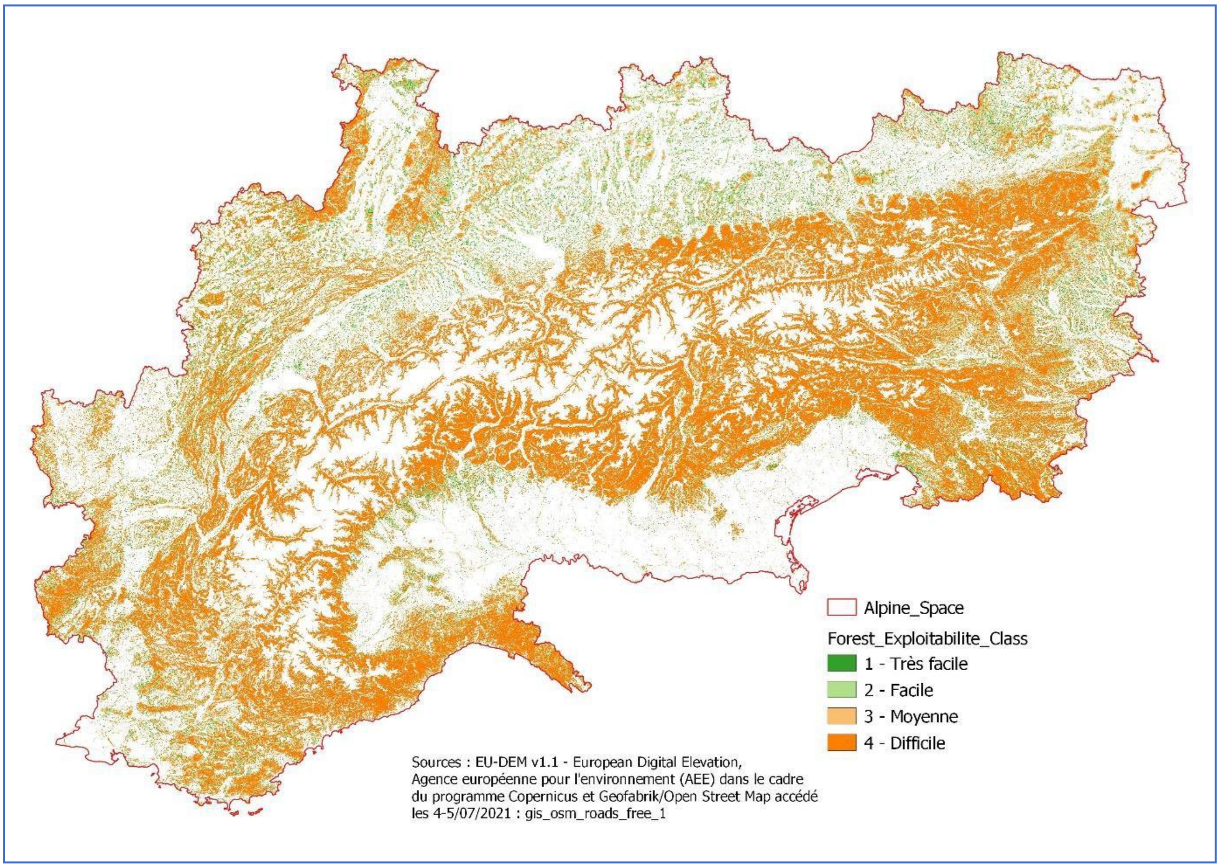


Calculation of the forest exploitability

The forest exploitability raster called Forest_Exploitabilite_Class is obtained by steps:

1. With raster calculator, the raster Forest_Distance_TrackRoad_Class is multiplied by 10 and the raster Forest_Slope_Class is added. The result is a raster coded with values ranging from 0 to 33, the first number corresponds to the logging distance class, the second to the slope. For example, the value 31 corresponds to forest pixels located within 200 m of a runway and a tertiary or unclassified road, with 0 to 15% slope.
2. Reclassification of forest operability into four classes. A coded raster is obtained: (1) very easy forest operability; (2) easy forest operability; (3) medium forest operability; (4) difficult forest operability; (no data) out of forest

Exploitability classes	Slope classes		
Distance classes	0-15%	15-30%	>30%
Less than 200 m	Very easy	Easy	Difficult
200-1000 m	Easy	Medium	Difficult
1000-2000 m	Medium	Difficult	Diffiicult
Over 2000 m	Difficult	Difficult	Difficult



Statistics on the volume of standing timber by forest exploitability classes

Forest exploitability classes	Area (pixels or hectares)	Sum (m^3)	Min (m^3/ha)	Max (m^3/ha)	Mean (m^3/ha)
Very easy	855.405	153.122.768	1	669	179,0
Easy	2.834.206	620.109.199	1	707	218,8
Medium	2.000.598	494.106.825	1	708	247,0
Difficult	10.911.452	2.740.872.009	1	716	251,2
Forest	16.601.661	4.008.210.801	1	716	241,4

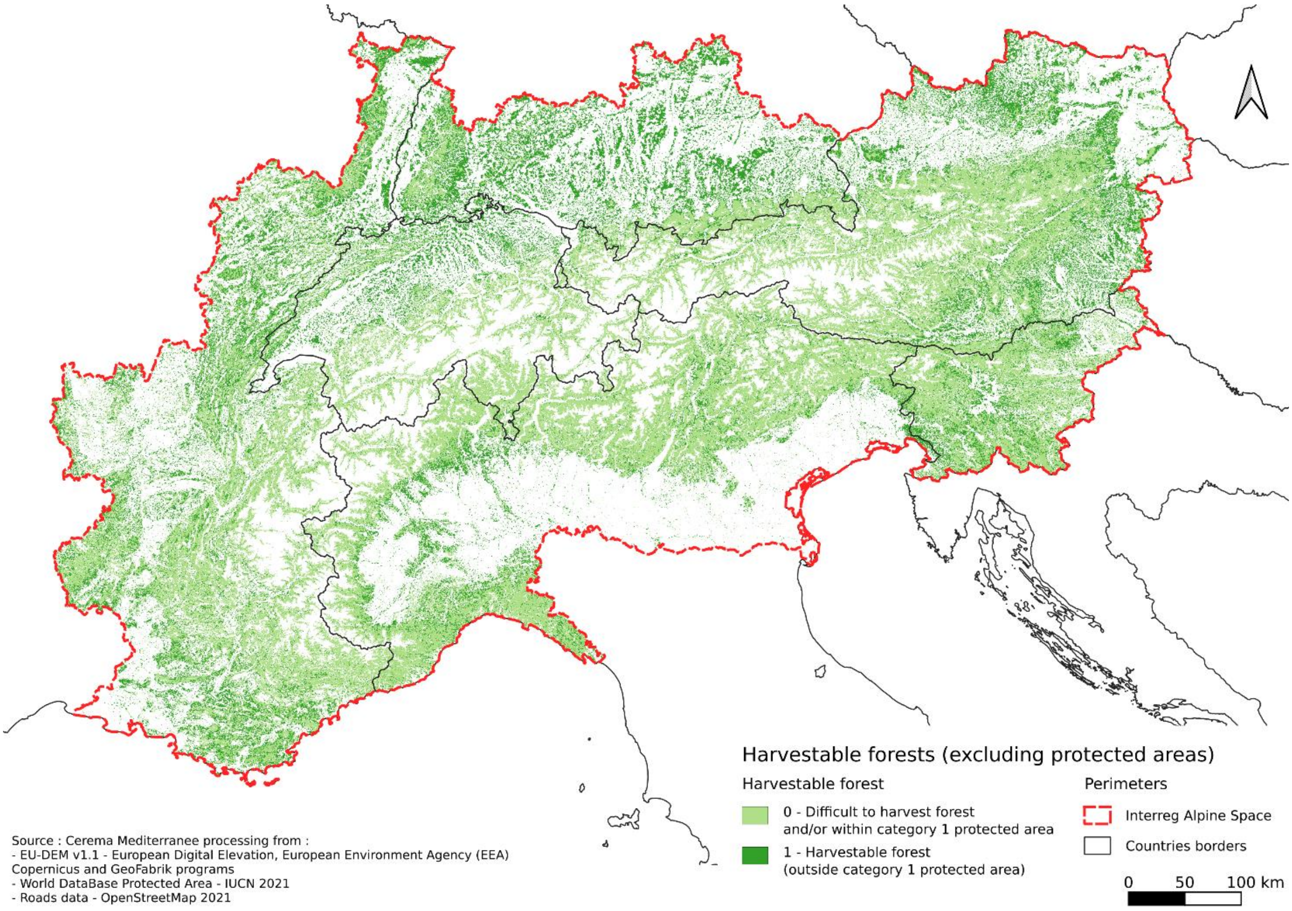
Calculation of the harvestable forest (excluding protected areas)

The raster of the harvestable forest excluding protected areas, called Forest_exploitable, is obtained in 3 steps:

1. Rasterisation of IUCN category 1 protected areas: Selection of Alpine Space category Ia and Ib protected areas from the World Database of Protected Areas (WDPA), then rasterisation of the result aligned to the Alpine Space right-of-way with a 100 m pixel. The result is a WDPA_IUCN_CATI_Alpine_Space coded: (1) outside category I protected areas; (0) category 1 protected areas.
2. Reclassification of Forest_Exploitabilite_Class raster into two classes: (1) harvestable forest; (0) forest difficult to harvest; (no data) out of forest. The harvestable forest corresponds to the

grouping of the very easy, easy and medium exploitable classes. The result is Forest_Exploitabilite_Class2.

3. Using raster calculator, Forest_Exploitabilite_Class2 is multiplied by WDPA_IUCN_CATI_Alpine_Space. The result is the raster Forest_Exploitable coded: (1) exploitable forest outside protected areas; (0) forest difficult to exploit and/or in protected areas; (no data) outside forest.

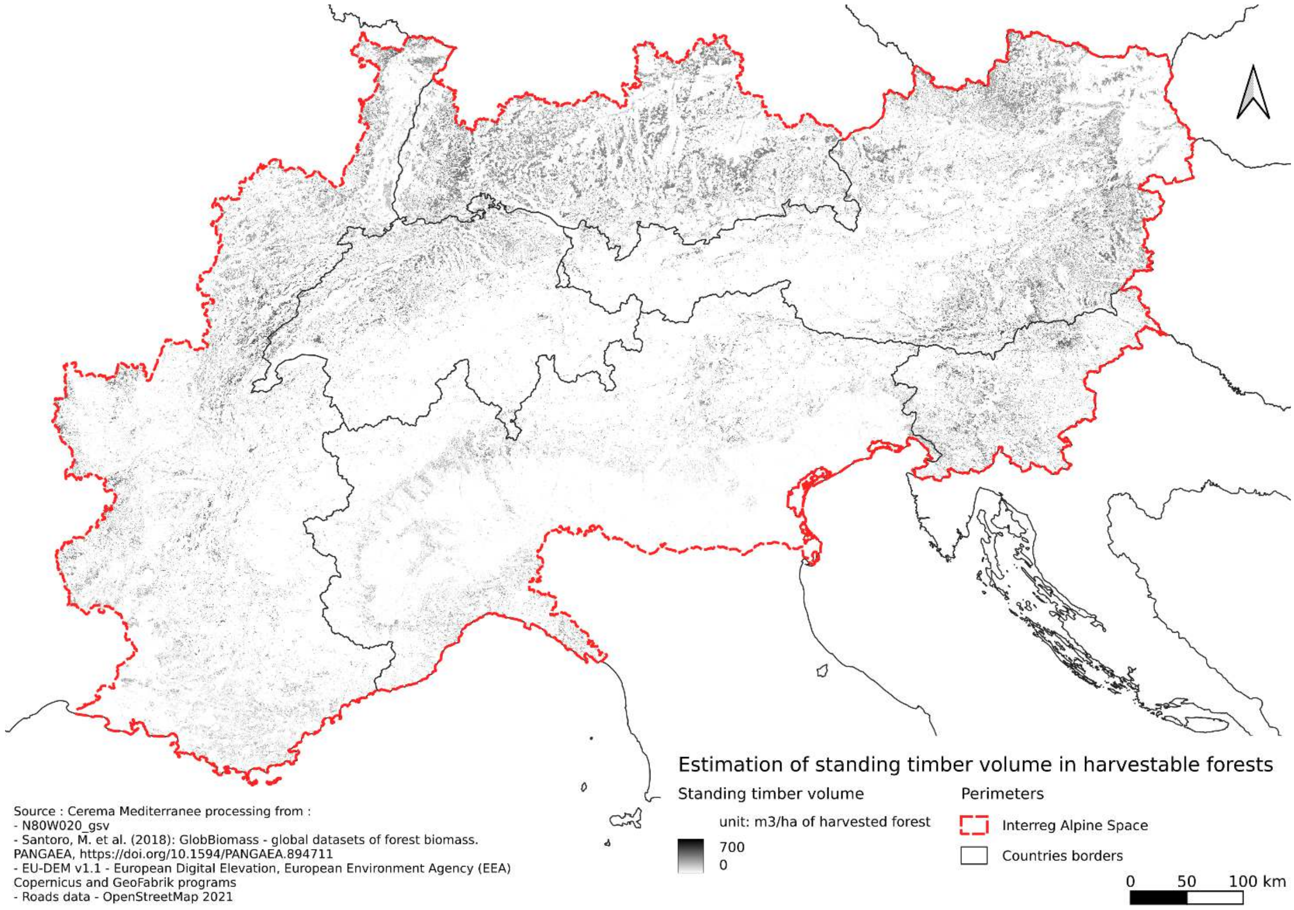


Statistics of the standing volume of harvestable forest

Harvested forest	Area (pixels or hectares)	Sum (m^3)	Min (m^3/ha)	Max (m^3/ha)	Mean (m^3/ha)
Harvestable forest outside protected areas	5.686.718	1.266.444.505	1	708	222,7
Forest difficult to harvest and/or in protected areas	10.914.943	2.741.766.296	1	716	251,2
Forest	16.601.661	4.008.210.801	1	716	241,4

Estimation of standing timber volume in harvestable forests

The raster standing timber volume in harvestable forests Forest_Exploitable_GSV_2010 is obtained with raster calculator. The raster Forest_GSV_2010 is multiplied by Forest_Exploitable. The result is a coded raster: (1) Standing timber volume in m^3/ha per pixel of harvested forest; (0) zero per pixel of difficult to harvest forest; (no data) outside the forest.



Protective forests against rockfalls risk

Use of ROCKtheALPS project Data

The overall objective of the project ROCKtheALPS (2016-2019) has been to reinforce and strengthen the implementation of rockfall risk prevention policy and mitigation strategy support in line with a sustainable forest management approach. For achieving that objective, the first harmonized rockfall natural risk and protection forest mapping for the entire Alpine Space have been provided.
https://www.alpine-space.eu/projects/rockthealps/en/home

Source:

ROCKtheALPS 2019, Interreg Alpine Space, alpine-space.eu/projects/rockthealps/ Funded by the European Regional Development Fund, Alpine Space Program, Project "ROCKtheALPS" Rockfall protection forest in Alpine Space - map as a result of a new rockfall model ROCK-EU of an Alpine Space project ROCKtheALPS.

The project ROCKtheALPS has been dedicated to develop a method to map forests with a protection function against rockfall hazard for the Alpine Space. A methodology has been developed to gather and treat harmonized cartographic information in order to create input data for a rockfall trajectory simulation model (Rock-EU-Map). The model Rock-EU-Map has been used to simulate rockfall propagation and mapping forests with a protection function against rockfall hazard. Calibration and validation of the methodology has been carried out using a database gathering information on rockfalls events initiated in the framework of the Interreg Alpine Space project ROCKTheALPS.

An output of the model is the map of forests that have a potential protective function. The layer returns the areas of forest that have a potential protective function. As for the rockfall hazard, a distinction is made in the attribute table for protection forests mapped using block released areas of 'more than 42°' or '28° to 42°'.

Reference:

Report on the project mapping tool and methodology performances evaluation. 2019. WP3 – Deliverable D.T3.5.1. Alpine Space Project 462: ROCK the ALPS. The ROCK the ALPS consortium, under the supervision of D. TOE (INRAE) and E. GERHARDT (BMLFUW).

Data Format: ESRI shapefile, polygon, in PseudoMercator Projection (EPSG 3857). Units: slope treshold from release areas

Rasterisation of Data

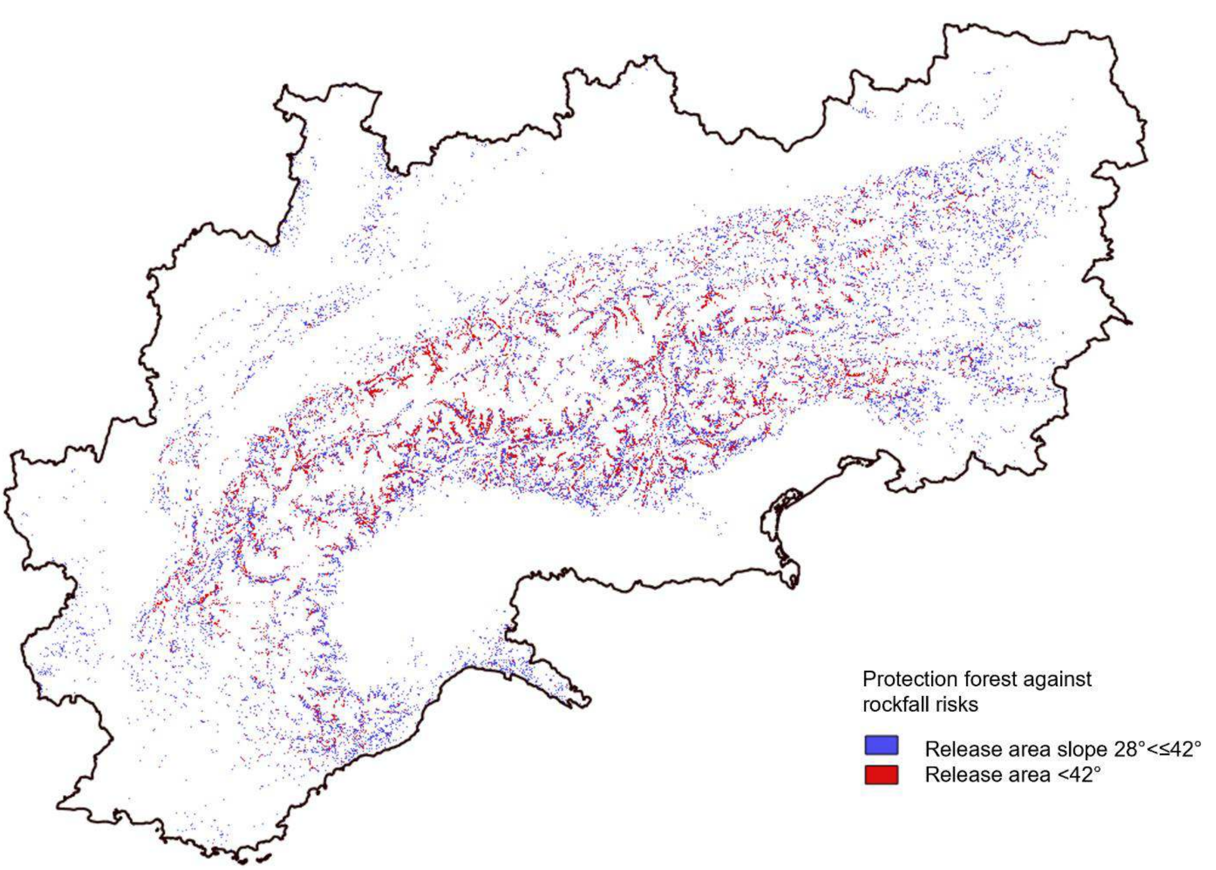
After a change of projection of the vector data to EPSG 3035 (LAEA), the protection forest data is rasterised at the resolution of 25m ((in order to keep a rather fine level of accuracy), and creating 2 classes:

- class 28, corresponding to protection forest for block fall trigger areas with a slope between 28 et 42°;
- class 42, corresponding to protection forests for block fall trigger areas with a slope greater than 42°.

Alignment and application on the forest raster of the Alpine Space Forest 2018

The protection forest raster data is aligned with the Forest 2018 Alpine Space raster data. Thus, the resolution is 100m, and the resampling method chosen is the maximum one in order not to lose the initial fine knowledge of the protection forests, prioritizing those corresponding to trigger zones with slopes higher than 42°, where the risk of boulder fall is more likely.

In order to apply the protection forest data on the same forest reference frame as the other ecosystem services analyzed, the data is then calculated by multiplying it with Forest 2018 using the raster calculator



(forest: 1, non-forest: 0).

Statistics on the study area

	Pixels or ha	%
Alpine Space forests	16 601 661	100
Protective forest with triggering slope above 28°	2 596 726	16
Deciduous forest	*1 113 389*	*43*
Conifers forest	*972 297*	*37*
Mixed forest	*511 040*	*20*
Protective forest with triggering slope above 42°	904 521	5
Deciduous forest	*393 207*	*43*
Conifers forest	*325 845*	*36*
Mixed forest	*185 469*	*21*

Rockfall protective forests cover about 16% of the forests in the Alpine Space

Outdoor recreation activities - forest cultural ecosystem service

Indicator definition

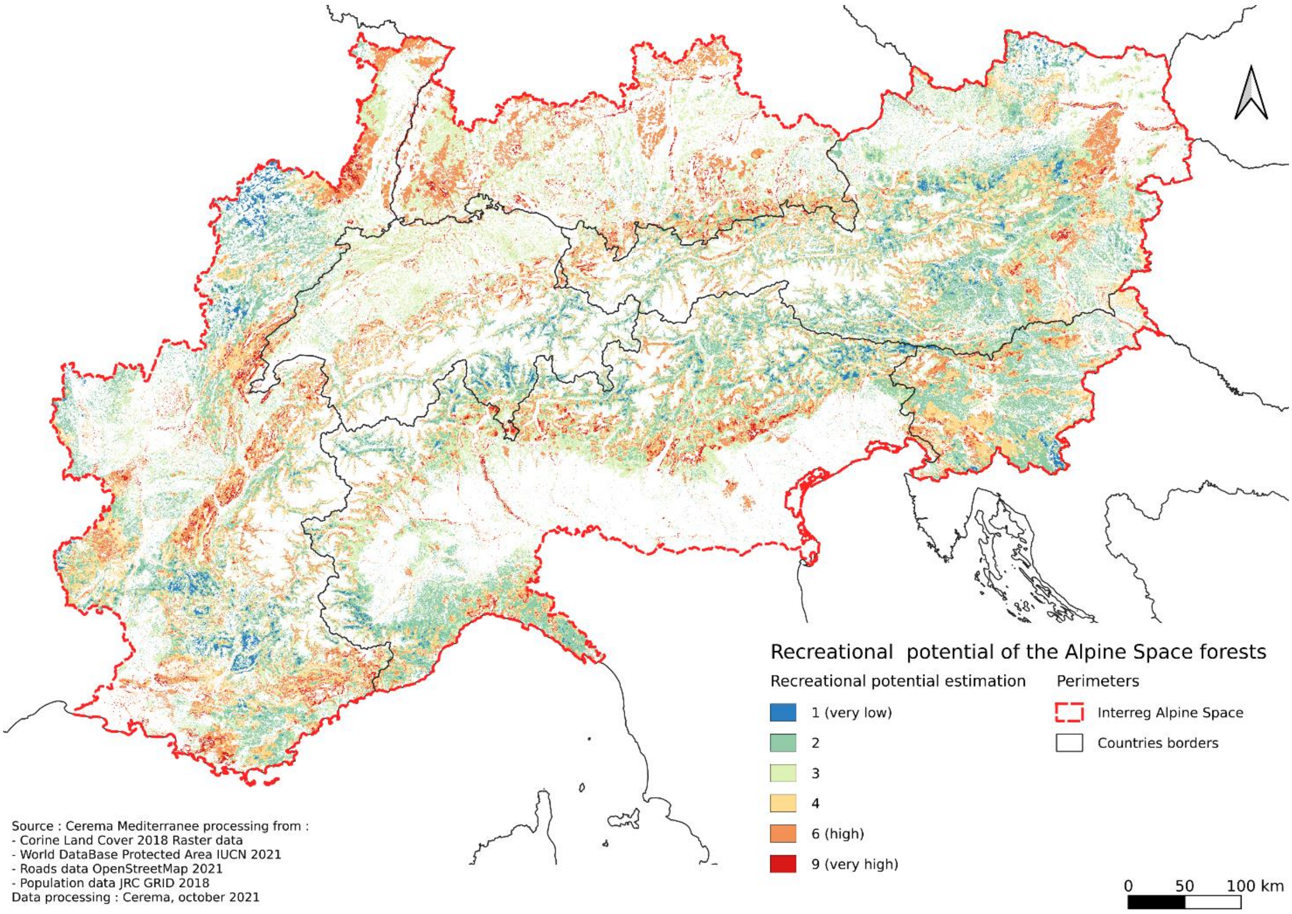
Forests provide people with an attractive natural space for recreational activities such as hiking and walking. The difficulty in evaluating this service is the lack of homogeneous and exhaustive data on the use of forests. The method used was inspired by the "Recreational Opportunity System" (Clark, 1979), which aims to combine different data such as the attractiveness of the forest (site quality) and its accessibility in order to evaluate the recreational potential. The quality of the forest site is evaluated on the basis of its level of protection and the landscape attractiveness of its edge. The level of protection of the forest is taken from the IUCN database of protected areas. The level of protection of the forest is derived from the IUCN protected area database and is divided into three classes: forest in an IUCN category II protected area (national parks, etc.) or a UNESCO protected area, other forest in a protected area, and forest outside a protected area. The landscape attractiveness of the forest edge is assessed using the Corine Land Cover 2018 land cover. Forests located less than 1km from open natural areas (natural grasslands, rocky, sandy or glacial areas) and wetlands (lake, river, marsh, sea, etc.) are considered to have a higher landscape attractiveness than the other forests

The accessibility of the forest site is assessed on the basis of its road access, its proximity to urban areas and its density of tracks and paths. The road access of the forest is estimated from OpenStreetMap data, by calculating the distance separating the forest from a motorway. The population catchment area within 50km as the crow flies of the forest is estimated from the European population data JRC 2016 (https://publications.jrc.ec.europa.eu/repository/handle/JRC102420). The number of inhabitants living within this 50km radius (distance considered as maximum for a recreational outing) is then evaluated, allowing to define 5 forest classes. The density of tracks and paths is estimated from OpenStreetMap data, within a radius of about 500m around the forest pixel. 5 classes are also defined. The intersection of these classes and their reclassification allows to define the accessibility of the forest site, in 3 classes: low, medium, high accessibility. The recreational potential is then derived from the intersection between the quality and the accessibility of the forest site.

Results

The application of the above method allows the mapping of the recreational potential of the Alpine Forest area.

Forests with a very high recreational potential (class 9) constitute 3% of the Alpine space. Forests with high recreational potential (class6) constitute 20% of the Alpine Space forests.



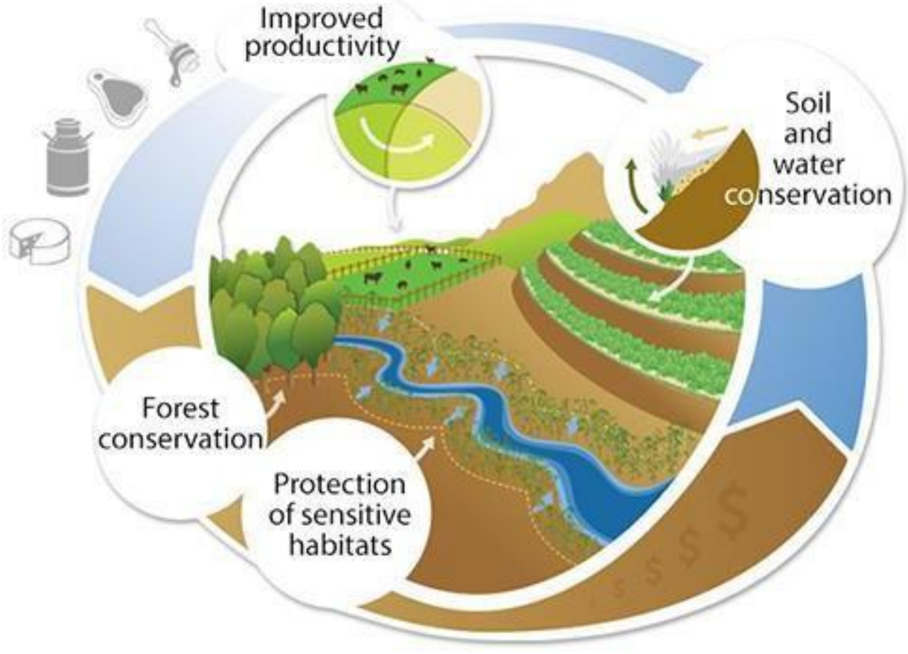
Provisioning of habitat

Use of IUCN protected areas Data

The supporting ecosystem service of provisioning of habitat would be characterized by identifying the protected areas of the Alpine region according to IUCN standards.

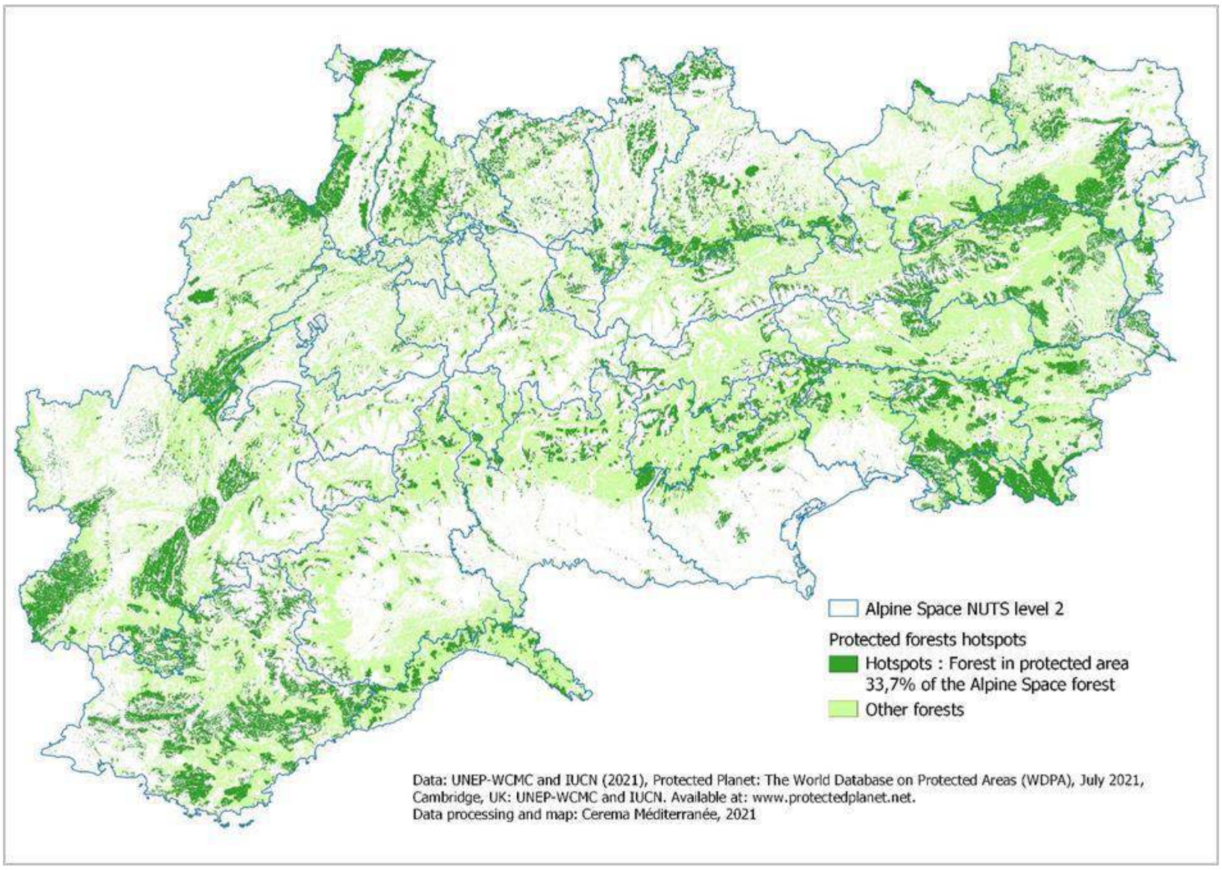
IUCN 3 defines a protected area as: “A clearly defined geographical space, recognized, dedicated and managed, through legal or other effective means, to achieve the long-term conservation of nature with associated ecosystem services and cultural values.”

These areas provided natural habitats with biodiversity maintenance and protection (genetic, species and habitat diversity).



Source: FAO.org

The map below shows the forests classified as protected areas which constitute 33.7% of the Alpine Space.



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Use and limits of these data to create the GIS for the Forest Living Labs of the Forest EcoValue project

All the data produced by these projects are free of rights. They were collected by 1) direct request to the organizations that produced them (EURAC and Cerema), and 2) online download for those available on the web. The GIS data for the spatial extent of each of the Forest Living Labs of the Forest EcoValue project were obtained by direct request to the project partners. These extents were used as a mask to extract the previously presented data. All of this work was carried out using the QGIS software. As previously mentioned, the limitation of using these large-scale data lies in the fact that some data do not allow for precise analysis and quantification of certain FES at a local scale. Examples include:

- The evaluation of forest timber volumes, which comes from national forest inventories that, while providing valid data at the regional scale, are inaccurate at a finer scale. This inaccuracy is partly due to statistical confidentiality imposed by some national forest inventories.
- The evaluation of the risk mitigation service, which requires identifying and characterizing the assets threatened in the absence of the forest and protected in its presence by comparing the results of simulations with and without considering the forest effect, as well as quantifying the effectiveness of this protection (reduction in propagation energy, impact pressures, impact heights, etc.).

Therefore, it is necessary to test and validate these data by conducting field surveys (based on inventory points) and comparing them with data available at the scale of the LL (expertise on natural risks, tourist attendance inventory, maps of accessibility to forested areas, etc.).

Local scale data source and adapted models

Note to the reader: an addendum to this chapter will be drawn up at the end of the project. This addendum will take into account feedback from each of the project's living labs and will present the models and data sources that are operational at local level.

The proposed methodology involves, for local-scale analysis, an important step which is the identification, retrieval, and production of data at the study sites' scale to overcome the limitations of exclusively using data produced for large-scale analyses. The critical analysis of comparing large-scale data with local-scale data should characterize the error rate or uncertainty level of the large-scale data. This rate helps evaluate the level of uncertainty and therefore the confidence interval of the data used for decision-making at the regional scale.

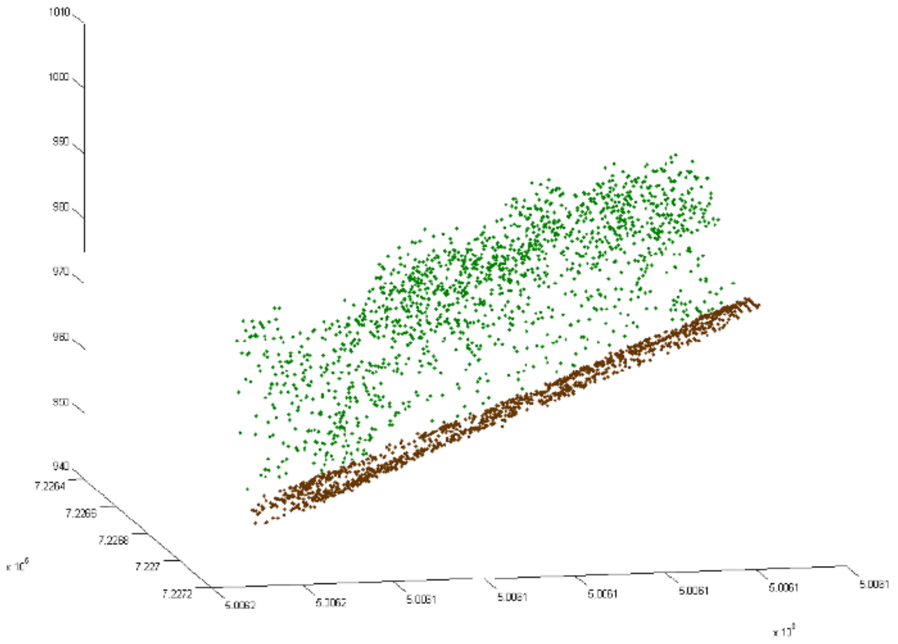
Therefore, it is important to conduct a precise inventory of available data at this local scale necessary for characterizing the studied FES.

The first and most crucial data is having a precise inventory of the forest resources present at the study site. For public forests, these data are available (sometimes with usage limitations) from the relevant authorities. However, for private forests, owners may not always have conducted an inventory (often depending on the property size, which may or may not require a forest management plan based on country-specific regulations). If such an inventory exists, its availability from the owner depends on their

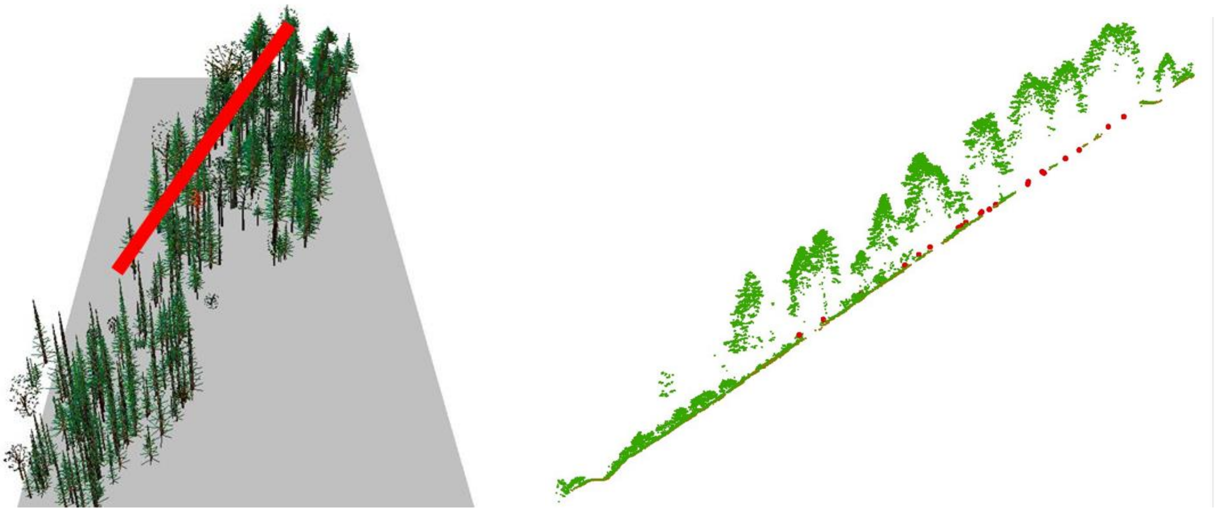
willingness. An option for obtaining comprehensive inventory data regardless of forest ownership type exists: LiDAR data and associated processing tools.
LiDAR is an airborne laser scanning technology that provides a large number of laser echoes over a small area (around 10 points per square meter depending on the sensors). Some of these points represent the ground, while others represent obstacles intercepting the laser beam.
With this data, it is possible to locate trees within a plot and assess their height. Foresters use allometric functions that relate a tree's height to its diameter measured at breast height. By using these functions, it is then possible to conduct a high-precision inventory (height, diameter, volume) of detected trees with LiDAR data.

The Interreg Alpine Space project Newfor (Operational programme 2007-2013) developed new tools and methodologies to improve mountain forest accessibility, and to ensure better wood harvesting efficiency, while sustainably managing forests. Through the use of remote sensing technology (LiDAR: aerial and terrestrial laser scanning), as well as the use of drones, the project was able to improve the mapping, harvesting, and transport of forest resources in the Alpine area (https://www.alpine-space.eu/wp-content/uploads/2022/12/Call_03_postcards_ALL_01.pdf. All countries of the Alpine Space have acquired these data, making it possible to conduct an inventory of forest resources depending on their availability and condition of uses.

Lidar data also provide a very precise and high-resolution digital terrain model (DTM). This DTM is a crucial input for using natural hazard propagation models and therefore for analyzing the protection service provided by forest stands. We have already mentioned the FLOW-PY model for simulating snow avalanches and landslides, accessible through platforms such as https://docs.avaframe.org/en/latest/. Another platform worth mentioning is PLATROCK http://platrock.org/) for rockfalls risks analysis. PlatRock is a multi-model software for the numerical simulation of rockfalls. This scientific tool assists the expert assessment of rockfall risk (retro analysis, trajectory modelling, evaluation of the protective role of forest, protective structure design, risk and protective forest mapping. PlatRock-WebUI is a closed-source GUI for PlatRock, currently hosted at Inrae (Grenoble, France).



Example of LiDAR point clouds in forest : Green points = poinst in the forest canopy, braun points = points on the soil surface.



Example of a LiDAR transect in a forest plot : Green points = points in the forest canopy, red points = base of the trees

Regarding recreational and tourism services, the use of local data related to the attendance of forest sites will again help to better understand the current offerings and the potential of forest areas. Such data is often available from tourist offices as well as from nature conservation associations, both of which conduct counts to assess the attendance of trails and sites. The potential for accommodation and the activities of socio-professionals linked to natural environments also represent interesting proxies for evaluating this FES. Data from chambers of commerce and industry should also be consulted. These data will help to define the pressure on forest areas. It has been crossed with the dynamics of the forest stands (not all the developement stages of forest allow recreational and touristic actities) and the protected areas for identifying the forest areas capable of welcoming the public without harming its dynamics. And sustainable developement.

For activities related to forest foraging, this aspect is very difficult to evaluate directly because there are no data or models to analyze the productivity of forest ecosystems concerning berries and mushrooms. Only hazelnut and chestnut orchards can provide data on their production. The data sources that can be used to evaluate this service are the tax declarations of harvesters and producers, but for some products (berries, mushrooms), this data is fragmentary and not representative of reality.

Regarding productions of interest for green chemistry, we face limitations in the current scientific knowledge about the production of tannins, resins, and other chemical components by forest ecosystems. These productions depend on tree species, age, growth conditions, and the forestry practices implemented. Pines have been the most studied species concerning resin production. For example, in France, it is estimated that the average resin production under optimal productivity conditions is 2.8 kg/tree/year (CRPF Nouvelle Aquitaine 04/2021). However, competition from synthetic products derived from petrochemicals hinders the development of this market as it is not currentlu economically competitive. Furthermore, the characterization of this ecosystem service for the benefit of green chemistry can only progress if the demand and the nature of the raw products are clearly identified and specified by the concerned stakeholders.

The final element to consider is the accessibility of forest areas to logging machinery and the transportation of timber. Indeed, this information is necessary to characterize the possibilities for mobilizing forest resources at a site. At the local level, it is therefore imperative to have a thorough knowledge of the forest road network and to take into account the terrain constraints to define exploitable areas. With the mapping and characterization of this network of forest roads, and a precise and reliable Digital Terrain Model (DTM), it is then possible to use a model such as Sylvaccess: Sylvaccess is a software allowing to automatically map forest accessibility according to different forest operations systems (currently skidder, forwarder and cable yarding). This tool has been developed at the Mountain ecosystems research unit of the Grenoble center of INRAE within the framework of the European Alpine Space project Newfor (https://sourcesup.renater.fr/projects/sylvaccess/).

Of course, in addition to all these data sources, it is essential to include data available from national geographic institutes or similar organizations. This data will provide the necessary cartographic backgrounds to create high-quality map supports (toponymy, contour lines, land use, aerial photographs).

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