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Open Data in German Forest Governance:

Towards an EU Forest Resilience Monitor

Master Thesis

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Abbreviations

BGR	*Bundesanstalt für Geowissenschaften und Rohstoffe* (Federal Institute for Geosciences and Natural Resources)
BB	Brandenburg [state]
BE	Berlin [state]
BISE	Biodiversity Information System for Europe
BW	*Baden-Württemberg* [state]
BY	*Freistaat Bayern* (Free State of Bavaria) [state]
dbh	diameter at breast height [of tree stems]
DWD	*Deutscher Wetterdienst* (German Weather Service)
EEA	European Environment Agency
EFFIS	European Forest Fire Information System
EO	Earth Observation
ESA	European Space Agency
ESDAC	European Soil Data Centre
EU	European Union
FAO	Food and Agriculture Organization [of the United Nations]
FFI	Federal Forest Inventory
FISE	Forest Information System for Europe
FSC	Forest Stewardship Council
GGI	Greenhouse Gas Inventory
GHG	Greenhouse Gases
GIS	Geographic Information Systems
GDPR	General Data Protection Regulation [of the European Union]
HB	*Hansestadt Bremen* (Hanseatic City of Bremen) [state]
HE	*Hessen* (Hesse) [state]
HH	*Hansestadt Hamburg* (Hanseatic City of Hamburg) [state]
LULUCF	Land Use, Land Use Change and Forestry
MCBB	Monitoring of Common Breeding Birds [survey]
MRV	Monitoring, Reporting, and Verification [of carbon emissions]
MV	*Mecklenburg-Vorpommern* (Mecklenburg-Western Pomerania) [state]
NABU	*Naturschutzbund Deutschland* (Nature Conservation Union Germany)
NASA	National Aeronautics and Space Administration
NFI	National Forest Inventory
NGO	Non-Governmental Organization
NI	*Niedersachsen* (Lower Saxony) [state]
NRW	*Nordrhein-Westfalen* (North Rhine-Westphalia) [state]
ODB	Open Data Barometer
ODC	Open Data Charter
RLP	*Rheinland-Pfalz* (Rhineland-Palatinate) [state]
SFM	Sustainable Forest Management
SH	Schleswig-Holstein [state]
SL	Saarland [state]
SN	*Freistaat Sachsen* (Free State of Saxony) [state]
ST	*Sachsen-Anhalt* (SaxonyAnhalt) [state]
TH	*Freistaat Thüringen* (Free State of Thuringia) [state]
UAV	Unmanned Aerial Vehicle
UNECE	UN Economic Commission for Europe
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

The idea for this thesis was developed during a visit to the Harz mountains in Germany, a national park which today is characterized by vast areas of dead trees caused by large-scale bark beetle outbreaks and climate change-induced heat and drought periods. One reason for the forest ecosystems' damaged condition in the region stems from the monocultural plantation with Norway spruce, a tree that is very susceptible to climate-change induced effects (Kölling et al., 2009). In the European Union (EU), the Harz forest ecosystem is no exception as 81 percent of protected European habitats are in a poor or bad conservation condition (European Environment Agency, 2020, p. 5). Yet, forests provide many services, such as ensuring air and water quality, fertilizing soil and capturing and storing carbon emissions from the atmosphere, thus offsetting greenhouse gas emissions (FAO, 2020). In the EU alone, in 2017, emission removals of forest and agricultural land amounted to an estimation of about 284 million tons of CO^2, offsetting about seven percent of the EU's total greenhouse gas emissions (EEA, 2019b as cited in Savaresi, Perugini & Chiriacò, 2020, p. 212). Globally, however, large parts of forests, 178 million ha to be precise, have been removed since 1990 – mostly due to timber production (FAO, 2020, p. 2). Therefore, the potential of forests for carbon storage now lies under its natural potential (Mo et al., 2023), meaning that the forests´ ability to serve as carbon sinks decreases. Particularly old-growth forests, forests that have not been logged in a long time, have become rare although these perform best in capturing and storing carbon. In Europe, only 2.4 percent of forested areas can still be considered old-growth forests (Barredo et al., 2021).

To fight these rapid developments of forest loss, the EU has set a target in the policy field of Land Use, Land Use Change and Forestry (LULUCF) to reach net removals of 310 million tons of CO_2 equivalent by the year 2030. However, even the European Commission itself expects to miss these targets by 70 million tons (European Commission, 2023, pp. 31-33). In general, FOREST EUROPE (2020) summarizes that the "condition of European forests is deteriorating" (p. 17) and names "extreme droughts, heat waves, extensive bark beetle outbreaks, and more extensive forest fires" (p. 17) as significant threats. To effectively address these challenges and halt the rapid loss of nature, the restoration of over-used, degraded forests and the protection of the remaining natural forests is necessary. To do so, however, a common understanding of forest degradation and a quantification of deforestation is required (Liang & Gamarra, 2020) This is the mission of forest information systems, in both public and private management. Thanks to recent innovations in earth monitoring (EO) technology, be it through satellites or unmanned aerial vehicles (UAVs), new opportunities arise in the monitoring of short- and long-term forested land cover.

Restoring ecosystems and establishing resilient natural equilibria with a diverse species composition has become a core feature of modern ecological policies (Cortina-Segarra et al, 2021; UN General Assembly, 2019). Local, regional, national as well as supranational and international actors are involved in forest governance, yet detailed information on the actual conditions of forest ecosystems is often inaccessible to the common public. Following the logic of an Open data society, citizens could, however, serve as a significant watchdog to hold policy makers and forest owners accountable to ensure a sustainable management which is in line with nature restoration targets, e.g. in the LULUCF sector. To do so, citizens must be equipped with the tools and up-to-date information to easily understand and monitor local forest conditions. Therefore, this work explores public institutions in Germany at different policy levels and their degrees of compliance with Open data regimes in the field of forest data.

1.1 Research Questions and Structure

While academic research has so far mostly focused on the more technical side of forest monitoring systems, less attention has been paid to the actual administrative implementation of Open data policies. However, the degree of openness of forest information systems has implications on the effective user group, the coherence of monitoring efforts across borders, and custom-fit restoration policies. Improved access to information on ecosystem conditions might even be "a necessity to help maintain public support and legitimacy when dealing with complex, multidimensional environmental issues" (Arts et al., 2016). Therefore, my research aims at understanding how public forest authorities in EU member states collect and store data on their forested lands. This includes the study of laws and reporting obligations as well as the implementation of forest information policies, investigating which data is collected by whom in which cycles and formats and in which form it is then published. More specifically, my first objective is to understand the extent to which data on forest resilience is publicly accessible in the 16 German *Länder* and at the federal and EU level. Building on this Open data compliance analysis, my secondary research objective is to determine prevalent data gaps and access limitations that affect the potential development of an EU Open Data Forest Resilience Monitor. The resulting research question hence reads: "**To what extent is data on forest resilience publicly accessible in forest information systems in Germany and how can shortcomings of information accessibility be overcome for the development of an EU Forest Resilience Monitor based on Open Data?**"

The thesis starts with a broad theoretical background, introducing the latest research and conceptual definitions for forest governance in Europe, forest information systems, Open data policies and ecological resilience conceptualizations. This part serves as the foundation for understanding the complexities that an EU Forest Resilience Monitor will need to navigate. This section will explain forest governance in a multi-level governance system and key legislation impacting the forestry sector in Europe, such as through the European Green Deal. Additionally, the reader is made familiar with the capabilities of forest information systems and innovative advancements in the field of forest monitoring. One component of this section is also the discussion on Open data policies, examining their potential benefits and risks in forest monitoring. The theoretical background ends by elaborating on the different conceptualizations of resilience, particularly in relation to forests, setting the stage for the methodological approach adopted in this study. The methodology chapter starts by justifying the selection of Germany as the focus of the study and explains the selection of forest resilience indicator groups and the principles of Open data compliance. The section provides a thorough explanation of the research design, including the methods used to investigate compliance with Open data principles at various governance levels. The methodology then presents the quantification of Open data utilized in the subsequent analysis chapter: Analysing compliance with Open Data principles at multiple governance levels of public forest authorities, offering a detailed evaluation of the current state of Open data in the forestry sector in Germany. The analysis systematically compares forest information systems across sectors and policy levels and highlight areas where information gaps and exemplary practices exist. This then feeds into the discussion chapter: Here, the critical question of what data is necessary for establishing an EU Forest Resilience Monitor is discussed, in light of the results for Germany. The thesis ends by identifying practical implications and future directions for forest resilience monitoring in the conclusion.

2 Theoretical Background

2.1 Forest Governance in Europe

According to Tucker (2010), forest governance refers to the exercise of authority in a forest, which encompasses all processes, acts, and decisions made by a group or entity on design, implementation, and enforcement of institutions (p. 690). Effective forest governance hence balances and rules over the different competing values associated with forests: ecological sustainability, social equity, and economic considerations. While forests provide economic values mainly through the (semi-) industrial extraction of timber, forests also provide ecological values as they, for instance, provide clean air and water, and natural habitats for different species of fauna and flora. Finally, forests produce social values, be it through mountain bike or walking trails that are open to anyone. These competing values are embedded in a complex network in which many actor groups are involved, “ranging from forest custodians such as private forest owners, local communities and state forestry agencies to forest-based industries, governments, NGOs and private citizens” (Rantala et al., 2020, p. 2).

In Europe, every square meter of forests is, at least *de jure*, delineated and owned by either private or public bodies, and distinctive property rules have been institutionalized “on the continuum from open access to private property” (Schlueter, 2008, p. 256). In practice, this means that there is traditionally open access for everyone, for instance for walking or picking mushrooms, even in a privately owned forest. Also, the right to hunt is often organized under cooperative groups outside of the private ownership system and forest owners are generally restricted in simply converting their land to another form of usage. While globally most forests are owned by government, the European Forest Institute determines private forest ownership In Europe at about 60 percent (Weiss, Wolfslehner & Zivojinovic, 2024). Concerning the management of forests, companies with large-scale industrial silviculture operations on the one side and small-scale private owners on the other operate in fragmented, and often very inaccessible, strips of forested lands. Tasks are different according to the management plan of the land: While some forests are governed by specific sustainability principles, specific management decisions are based on the land use class, either focused on timber production, agroforestry or other forms of economic usage, including the transformation into industrial, residential or touristic areas. Sustainable Forest Management (SFM) involves certification through adhering to standards set by certification bodies like the Forest Stewardship Council (FSC) or the Programme for the Endorsement of Forest Certification (PEFC). However, these certification schemes are not known for their transparent processes: Some certification schemes that label timber products as coming from sustainable management still "permit the unsustainable clearance of large patches of natural habitat, which retain much biodiversity" (Edwards & Laurance, 2012). While these problems are most associated with the tropical regions, also in Europe, increased demand for biomass makes timber stocks a valuable resource. Cases of illegal logging are increasingly uncovered even in Europe, often by small, organized crime groups, ranging to cases reported from Estonia to the Carpathian Mountains (Colantoni, Sarno & Bianchi, 2022). Still, Europe's forests are in some parts recovering from excessive logging that took place in the last century. However now, the effects of climate change are increasingly putting pressure on forests.

2.1.1 Muli-Level Nature of Forest Governance

In terms of forest governance, specific attention must be paid to the multi-level nature: Policies and political actors at local, regional, national, supranational and international levels are involved in forest governance and "[a]t each level, recognized entities can have authority to make certain decisions and shape the processes and activities affecting a given forest" (Tucker, 2010, p. 690). This multi-level nature of forest governance provides for ample political capacity to centralize or decentralize forest governance: Agrawal and Ostrom (2001) have studied attempts of decentralization in forest governance; they argue that it is necessary to transform local users into proprietors of forests and not only delegate operational rights to them (p. 508). This can then result in stronger ties among the community of forest users and a better forest management in general. But despite decentralization efforts, many forests remain in a governance limbo. Referring to the case of Germany, Schlueter (2008) argues that some forests in Europe are faced with economic underutilisation as the "tragedy of the anticommons emerges from an excessively fragmented bundle of property rights" (p. 258). A management decision can only be taken if all owners of a wider area agree to the same usage. However, reaching an agreement on the local or regional level for a common use policy is often not possible as owners are not interested in their land, have long moved away, or cannot be reached or identified. While this limited utilization of forest resources in Europe can be explained by the more competitive timber imports from tropic regions, it also has to do with the fragmented ownership. 'Absentee forest owners' often live far away and do not depend on the income from their lands which they have in many cases acquired due to inheritance laws (Schlueter, 2008). Scattered ownership makes forest management a difficult task and public intervention varies a lot according to the geographical context.

Zooming out to the international level, the 1997 Kyoto Protocol under the umbrella of the United Nations Framework Convention on Climate Change (UNFCCC) necessitates the accounting and provision of LULUCF data. It commits its parties, including the EU, to binding emission reduction targets. In terms of forestry, this framework counts emissions and emission removals from “managed forest land; land subject to deforestation, afforestation or reforestation activities in the past 20 years” (LULUCF Regulation (n 11) Art 4. as cited in Savaresi, Perugini & Chiriacò, 2020, p. 214). The focus here lies in the monitoring, reporting, and verification (MRV) of carbon emissions. Here lie the main touchpoints of national policies with forest governance. National governments are charged with providing relevant and up-to-date data on their land and forest management and the respective carbon sequestration. This work is carried out mostly by public agencies through national forest inventories (NFIs) which collect information on landscape composition, the structure and type of forest, biodiversity data, often based on sample plots (Tomppo et al., 2008). NFIs are traditionally focussed on the monitoring for timber stock exclusively, yet the international reporting obligations and the increasing effects of climate change they account for a myriad of indicators, growing timber stock to biodiversity and carbon stock calculations.

The German government has also pledged to invest in environmental restoration (ER) and aims to implement its environmental adaptation policies by means of nature-based solutions (Umweltbundesamt, 2023; BMUV, 2023). ER can be defined as “an intentional activity that initiates or accelerates the recovery of an ecosystem with respect to its health, integrity and sustainability” (Society for Ecological Restoration International, 2004, p. 1). ER efforts have been a part of the EU’s environmental policies for decades already, particularly thanks to the LIFE program. However, many barriers to ER remain, mainly, “insufficient funding, conflicting interests among different stakeholders, and low political priority” (Cortina-Segarra et al., p. 1). Focus in forest mo

2.1.2 The EU’s Role in Forest Governance

National governments of EU member states have long resisted an EU competence in the forest sector. Consequently, the EU has so far not been able to develop a “consistent regulatory […] approach on forestry and the forest-based sector” (Aggestam & Pülzl, 2018, p. 2). Nevertheless, many EU policies and initiatives directly affect forest governance, not only due to the accession of the EU to international climate conventions, but also due to legislation in the area of the common European market: Already in 2010, the EU introduced the Timber Regulation which obliges operators who place timber and timber products on the internal market for the first time to prove that these products come from legal harvesting. These due diligence obligations can be reported by the operators themselves or by independent monitoring organisations (BLE, n. d.). In December 2024, the EU Regulation on Deforestation Free Products will enter into application which broadens similar due diligence obligations to other product groups that are associated with deforestation, such as palm oil, beef, soy, or coffee. Operators have to demonstrate that their products were produced on land that has not been logged after December 31st, 2020, also for goods coming from within the EU. They must provide specific geographic information directly to the European Commission (European Commission, n. d.). EU legislation in the area of ecosystem protection through the Natura 2000 programme also affects forest governance in EU member states. Furthermore, several data-sharing initiatives, such as the European Forest Fire Information System (EFFIS) and the Forest High Resolution Layer of the Copernicus Land Monitoring Service have been set up at EU level, relying on observations provided by eight satellites of the SENTINEL family (Copernicus, n. d.). Based on such EO information and the NFI-transmitted information by member states, EU institutions are involved in compiling different forest-related reports, such as Eurostat reports, the State of European Forests Report by FOREST EUROPE, and the Natura 2000 State of Europe's Nature Report. These institutionalized procedures have helped to harmonize some rules and standards, yet there remains a "complex network made of national and regional systems, which makes the collection of harmonized information a difficult task" (Vidal et al., 2016, p. 803). Forest data is collected using several techniques, from remote sensing technology to on the ground explorations; however, such data often remains in silos and is not shared publicly (Liang & Gamarra, 2020, p. 1). Gschwantner et al. (2022) give an overview of the current methods employed by NFIs in Europe – showing that country-specific approaches exist in forest governance across Europe. Furthermore, member states commit themselves "to provide such information on a regular basis" (Baycheva-Merger & Sotirov, 2020, p. 2). Yet, forest data is still shared in many cases only on a voluntary basis, with some countries and states being known as particularly 'reluctant' in sharing their forest monitoring information openly and accessibly.

The European Commission has realized this lack of coherence and cooperation and has set up the EU Forest Strategy 2030, a strategic agenda that connects several legislative and non-legislative initiatives across policy fields to unify them under the pillar of the European Green Deal. Lier et al. (2022) have analysed the strategy and criticize that the document only "formulates objectives and commitments without specifying how progress towards each objective should be monitored" (p. 4). Nevertheless, one aspect of the strategy is the improvement of the Forest Information System for Europe (FISE), an Open data sharing platform for forest data. The system that is managed by DG Environment is, however, heavily dependent on the voluntary data and information sharing by member states. Data in FISE is also not entirely harmonized as it is collected in varying formats and in differing time cycles by the respective national and regional bodies. For instance, the latest datasets on German forests in FISE refer to Germany's third NFI from the years 2011 to 2013, published in FISE in 2018 (FISE, 2024). To counter the resulting knowledge gaps and time-lags, the European Commission (2023a) has therefore proposed a new Forest Monitoring Law in November 2023, that wants to strengthen the role of FISE and integrate different monitoring strategies coherently at EU level.

Furthermore, responding to forest ecosystem degradation and the connected loss in biodiversity, the European Commission proposed a Nature Restoration Law in June 2022 targeted at setting multiple binding restoration targets for EU member states and corresponding obligations for several ecosystem types, including forests (European Commission, 2022). The proposal has so far been adopted by the European Parliament, but it has not been ratified by the Council. The draft version foresees commitments to restore at least 30 percent of habitats that are in a poor condition by 2030, 60 percent by 2040, and 90 percent by 2050, including all remaining primary and old-growth forests. Interestingly, in the absence of a unified method for assessing the condition or resilience of forest ecosystems, the proposal names the common forest bird index and a selection of other indicators, such as tree species diversity and deadwood, as proxies for such an assessment (European Parliament, 2024). Specifically, Article 12 is set to mandate member states to "achieve an increasing trend at national level of the common forest bird index" (European Parliament, 2024, Article 12.2.) and foresees them to put in place measures that will result in a rise in at least six out of seven of the following indicators for forest ecosystems: standing deadwood; lying deadwood; share of forests with uneven-aged structure; forest connectivity; stock of organic carbon; share of forests dominated by native tree species; and tree species diversity.

Also, already in July 2023, the European Commission published a draft Soil Monitoring Law (European Commission, 2023c) which puts forward a framework for monitoring soil health and proposed parameters for soil assessment. All these ongoing legislative reforms indicate the momentum that surrounds the governance of forests. That all these legislate procedures are accompanied by intense debates shows the various interests of actors that collide here: Euractiv reports that the Nature Restoration Law has been effectively blocked by a minority of member states in the Council (Cagney & Machado, 2024). And for the Forest Monitoring Law, the ministers for environmental affairs have answered by setting up an *ad hoc* working group at the Council with further "examination […] depending on the progress made and the available time" (Council of the European Union, 2024, p. 4). This does not indicate a sense of urgency from the members states to legislate in this regard on EU level.

2.2 Forest Information Systems

Collecting information on forests has a long history and forest mapping dates back to the 16th century with remnants of woodland registries found in the kingdoms of Spain and

Lithuania. In 1919, Norway was the first country to introduce a sample based NFI and after World War II, national forest inventorying became a common practice all over Europe (Gschwantner et al., 2022, pp. 3-5). With the emergence of new technological innovations such as airborne laser scanning applications and satellite systems, new opportunities have arisen in the field of forest monitoring and innovative developments in this area are targeted towards fulfilling "'near real time' forest monitoring needs" (Nitoslawski et al., 2021, p. 10). This data is collected and stored in so-called forest information systems; socio-technical artefacts that have been designed for many different reasons. For instance, they refer to databases and systems that collect and analyse a wide range of forest-related data, such as land cover/vegetation type, vegetation height/structure, biomass, carbon sequestration, quality and size of the canopy, as well as data on fellings or deforestation and fire disturbances (Tomppo et al., 2008, p. 1983). But not all data can be recorded using remote sensing technology and some information must be collected on the ground. Such *in situ* data stems mostly from area-based sampling frame surveys: A small piece of forest is visited regularly every few years and data is collected on tree status, tree species, forest cover and the diameter at breast height (dbh) of the tree trunks in the area. *In situ* data can also include biodiversity data, such as data on the occurrence of different animal species or the composition and quality of the soil. In this field, countries and regional entities are actively involved, mostly through institutionalized land monitoring structures or model project work. According to Kühl et al. (2020), the existing structures are, however, mostly designed to assess the economic viability of forests and often leave aside biodiversity indicators. Generally, NGO and volunteer engagement plays a big role in the collection of various large-scale environmental observations. Next to these national monitoring efforts, private actors and local/regional governments operate their own forest information systems. For instance, Swedish furniture company IKEA, which is one of the biggest forest owners worldwide, operates its own forest information system in order to manage and trace its international wood procurement (Hildeman & Carlsson, 2014, p. 80).

2.2.1 Prototypes of Forest Resilience Monitoring

Pratihast et al. (2016) describe the design and implementation of an Interactive Forest Monitoring System that embraces the Open data concept and has been set up in a project in Ethiopia. It integrates Web-GIS technologies, satellite data, and community-based observations in near-real time (NRT) and monitors forest changes. Figure 1 shows an overview of how the forest information system is structured from an information system's point of view.

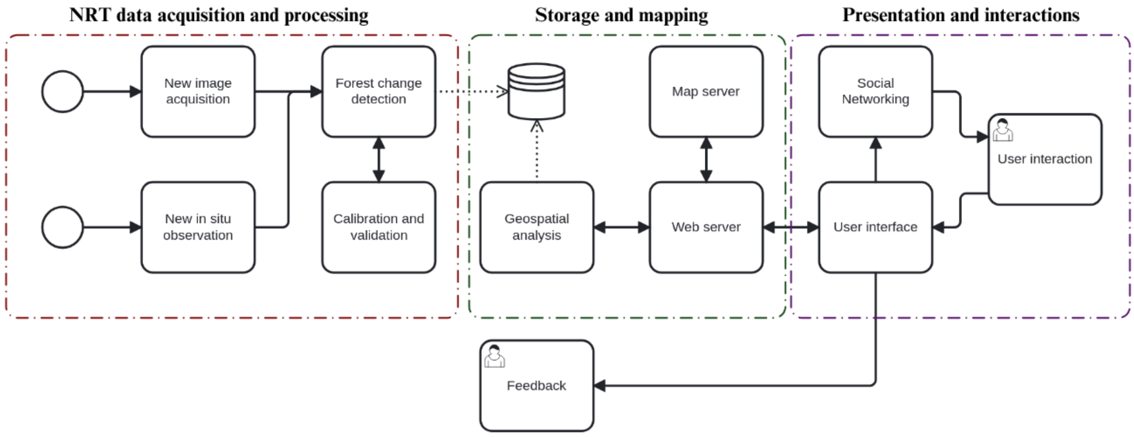


Figure 1: Diagram of an Interactive Web-based NRT Forest Monitoring System (according to Pratihast et al., 2016)

New information from both EO or *in situ* observations can be entered into the system which then detects forest changes connected to deforestation, forest degradation or reforestation. The system is a tool for local stakeholders to participate in local forest monitoring efforts collectively, for instance through the functionality to receive alerts on mobile devices, when a certain forest change is detected. This has proven to "reduce illegal activities and enhance transparency in the use of forest resources" (ibid, p. 13).

More prominently, tgloballyources Institute, together with other private, public and non-governmental actors has set up the 'Global Forest Watch' application which pools EO data on forests globally and helps to map forest changes in an area of interest, tracking forest conditions through deforestation or forest alerts, also with a mobile app (Global Forest Watch, n. d.). Users have the option to explore many spatial datasets, such as the annual forest cover change. Here, the clear focus is on tropical forests. In Spain, the EU funded 'Forest Explorer' project has helped to map all Spanish forests based on the third Spanish NFI, publishing it as Open data in an integrated data portal where users can navigate on a map, select tree species of interest and thereby explore the tree species distribution across the country in one system. The development of the system clearly identified the public sector as the main actor in providing forest information to society (Vega-Gorgojo et al., 2022). The project has shown the capacities for linking different datasets and data types, while still adhering to Open data norms. It does, however, not provide information on forest conditions, or other information related to resilience.

Focusing specifically on the disturbances that impact forest resilience, the RESONATE project has developed an interactive monitoring tool that maps the occurrence of several disturbance regimes present in forests (Senf & Seidl, 2021).[1] Using USGS Landsat satellite data, the disturbance assessments here focus on the rate of forest cover disturbed annually, the disturbance frequency, the average disturbance size as well as the maximum disturbance size annually. The analysis also considers disturbances due to biotic or wind conditions, fire impacts and harvest, all shown in hexagons of 50 x 50km size for the years 1986 to 2020 (Senf & Seidl, 2022). While this monitor already comes with some functionalities to assess regional forest resilience, a number of restrictions persist: Firstly, the tool is not very detailed due to large comp sizes. Secondly, only a limited number of disturbance factors are considered and, finally, the meaningfulness for the identification of specific threats in a regional context and the accessibility is generally limited as the research project is not meant for everyday use. Nevertheless, all these examples show that interactive forest data mapping is already implemented widely, yet varies according to functionalities and detail.

2.2.2 Innovation in Remote Sensing, Smart Forests and Data Governance

Increasingly, digital technologies are used to monitor forest conditions. Nitoslawski et al. (2021) carried out an extensive literature review on technological applications in forests showing the big potential that lies specifically in remote sensing, machine learning, and open-source technologies. Globally, such innovative technologies are already implemented in forest-related contexts. For instance, disturbance alerts are integrated into satellites that monitor forest ecosystems in the tropics "to support law enforcement actions against illegal and unsustainable human activities" (Reiche et al., 2024, p. 1). Research has also developed programmes that can estimate biomass and carbon content based on satellite-observed tree heights and canopy cover (Jucker et al., 2017) which could potentially also be used to estimate logging intensities (Welsink et al., 2023). According to Ochiai et al. (2023), EO technology will be key in assessing the global carbon stocktake in the future, referring to the UNFCCC and the associated greenhouse gas (GHG) inventories and reports at various policy levels. Satellite monitoring is based on a number of programmes, such as the National Aeronautics and Space Administration (NASA) in the US, and the European Space Agency's (ESA) Climate Change Initiative or the EU Copernicus Global Land Service. However, their resolution has so far not reached more detail than 100 x 100m. Nevertheless, research has utilized deep learning technologies to map land cover and the respective information needs more consistently and in near real time (Brown et al., 2022). Advances have also occurred in the field of virtual forests that aim at creating a digital twin of a forest ecosystem, which can help in the field of silviculture management or environmental monitoring. Here, UAVs, such as

[1] The tool 'Europe's forest disturbance regimes' can be found online here: https://tum-edfm.shinyapps.io/resonate-deliverable-2-1/ (Last accessed on June 6, 2024).

drones that are equipped with extension photogrammetry have received increased academic attention and implementation in forestry contexts (Murtiyoso et al., 2024). Digital twins of forest can model ecosystems and even “predict future remote sensing images” (Jiang et al., 2022, p. 7).

2.3 Open Data Policies

In 2009, US President Obama issued an executive order regarding the promotion of Open data in government (White House, 2009) and the Digital Agenda of the European Commission (2010) introduced Open data-sharing approaches in government also in the EU. But while the concept of Open data is applauded by scholars and practitioners of different fields, the actual provision of truly Open data is complex. Open data can be defined as “non-personal data that is accessible to all and can be freely used, re-used and distributed by anyone” (Halonen, 2012, p. 18). Pollock (2010) characterizes Open data provided by public sector organizations according to a few key features: their non-rivalry which refers to zero marginal cost, their high fixed costs due to data processing and validation, their high potential for use and re-use as well as their two-sided nature of public sector information holders referring to input and output perspectives on Open data (pp. 16-17). Here, environmental data is only one aspect as Open data can refer to socioeconomic statistics, geospatial information and many more forms. However, public sector Open data must comply with a number of principles, such as completeness, primacy, timeliness, non-discrimination and ease of access (Sunlight Foundation, 2010). According to Huijboom and Van den Broek (2011), several barriers and drivers to the provision of Open data by public sector institutions can be documented: Whereas driving forces often come from outside the government due to citizen pressure, market initiatives, emerging technologies or due to thought leaders, barriers exist particularly internally. Major barriers to Open data provision concern closed cultures in public administrations, limited quality of data, and a lack of standardization. And this is also true in terms of Open data in the field of forestry and forest monitoring.

2.3.1 Open Data in Forest Monitoring

The Aarhus Convention provides an international legal obligation for governments and public sector institutions to provide citizens with access to environmental information (UNECE, 1998). Its enforcement is, however, “tempered by the discretion accorded to Parties in implementing Aarhus obligations (Mason, 2010). Open data governance in forest monitoring specifically refers to the open sharing of data that a group of regional, national, and various other forest authorities or owners have agreed upon at a given time period. This data pool can include many different datasets with indicators on the economic productivity of land, its carbon quality, its biodiversity status or the capacity of a forest to serve as a carbon sink in relation with its environment. It can be provided "by governments, companies, academics, civil society organizations, and increasingly citizen science" (Strong, 2015). Thanks to developments towards a Web 2.0 environment, citizens are increasingly empowered to utilize spatial data collected through satellites themselves which previously required expert knowledge (Van den Homberg & Susha, 2018, p. 2). Here, also the development of common standards for geographic information systems (GIS) have been important which make it possible to locally "store, manage, analyze, edit, output, and visualize geographic data" (Chang, 2008, p. 1). However, Arts et al. (2015) show that even in the so-called 'Information Age', environmental communication faces a number of barriers referring to technical, structural, managerial, and cultural challenges. For instance, up-to-date information and resilient websites, liability issues, minimal resource allocations and lacking interdepartmental communication continue to hamper environmental communication potentials (p. 52).

Open data could be a solution to the problem of inaccessibility of data for certain potential users who do not have the resources to monitor or collect data themselves (Rantala et al., 2022, p. 753). In a best case scenario, Open data implementation can even foster a truly democratic dialogue among all forest users, taking into account the responsibilities of those who deplete the natural resources, be it directly or indirectly (Lähteenmäki-Uutela et al., 2023, p. 11). However, increasing open forest data also lays open the "tensions between forest owners, indigenous peoples as traditional users and governors, other users, non-users, future generations, and nature itself" (ibid, p. 19). Still, Open data scholars whose works investigate innovative, sustainable approaches to forestry are optimistic about the potential benefits of Open data in the forestry sector: Open forest data can be beneficial for both small and large forest managers to make decisions about harvesting, felling and reforestation strategies. It can also help in the process of selecting critical habitats to be used for the protection of endangered plants and animals (Rantala et al., 2020, p. 3), and, at best, it can empower local actors in implementing sustainable practices that benefit everyone in the community.

Possibly, opening up forest data and making it accessible easily and in real time could have the potential to make public the extent to which forests suffer from the climate crisis. Open data initiatives have massively contributed to the revelation of massive, environmental crimes such as illegal logging (Islam et al., 2019), yet many actors remain who prefer to not make accessible their most current and detailed forest information. Yet, open forest data policies could "stimulate more active forest planning and management, through better and more targeted services" (Rantala et al., 2020, p. 5) as on the input side, crowdsourcing allows more actors to share information and make data publicly accessible. On the output side, a shared forest information infrastructure allows all actors to operate on a level-playing field. This would also benefit the growing number of absentee forest owners, for instance by means of an open forest information portal. Despite these expected benefits, *in situ* forest data often remains in silos and not even a third of all in situ global forest datasets is openly accessible (Liang & Gamarra, 2020). However, thanks to the opening of the Landsat archive of satellite imagery by the U.S. Geological Survey's in 2008, scientists could establish the Global Forest Watch (GFW) platform that provides an open archive on forest changes, essentially linking datasets to one platform (Strong, 2015).

Finland is internationally renowned as a pioneer in forest data digitalization and an open forest data portal has been implemented by the Finnish government in the last years. The portal metsään.fi provides open access to forest grid data in Finland and the databases can be directly browsed by everyone, and crowdsourcing elements have been included. Even stand-level data of individual trees has been made openly accessible (Rantala et al., 2020, p. 8). The country, however, underwent lengthy political discussions on its forest information policy before. Research has observed "interlinkages between governance of forests and governance of forest information" (ibid, p. 2). This had led to a situation in which different forest actors advocated for or against open forest data. Such a decision must take into account data protection standards, particularly on forest ownership in line with the EU's General Data Protection Regulation (GDPR). In Finland, the forest owners' right to privacy and data protection regarding the forest possessions and the risks of outside interference were brought as arguments against a legal provision for Open data in the forestry sector. Unfortunately, due to a number of reasons, such as high maintenance costs and potential political disadvantages, many countries are reluctant in making their forest data openly accessible (Liang & Gamarra, 2020, p. 3) or, as Rantala et al. (2020) put it: "greater openness may result in both winners and losers" (p. 3).

2.3.2 Open Data in Environmental Monitoring on EU level

In the EU, the Open data Directive, formerly known as PSI Directive, mandates public access to environmental information. It defines EO and other environmental datasets as 'high-value datasets', focusing on the Open data provision in the fields of satellite images, mapping and *in situ* meteorological data (Official Journal of the European Union, 2019, preamble 66). Interestingly, no reference is made to forest data and hence forest data remains largely out of the scope of this directive. At EU level, the Forest Information System for Europe (FISE) serves as an Open data catalogue, but as mentioned before, it depends on the voluntary data input by member states and is hence incomplete and not up to date. Furthermore, the newly proposed Forest Monitoring Law now aims to address such flaws and inconsistencies among national and regional monitoring structures and foresees the provision of specific forest data in FISE in open format (European Commission, 2023a, Article 7). The outcome of this legislative process is still uncertain and a leap towards tighter cooperation can be questioned as common forest planning will remain a voluntary process for member states to engage in (European Commission, 2023b). Yet, while the European Commission has been outspoken on the issue for long, legal frameworks on all levels continue to place high burdens on the right to privacy and fair competition. As most European forests are private properties, diverse management interests and strategies persist. The EU has, however, created the instruments and mechanisms that already pool vast information sets. For instance, thanks to EU efforts under the ISPIRE Directive, standards for geospatial data are already in place and used within the public administrations. Enhancing Open data sharing across regions would be beneficial for the EU as a whole, institutionalizing forest decision-making at a more political battle to fight climate change. A coherent forest monitoring interface that integrates all recorded datasets on environmental monitoring of local agencies could help to empower individual and collective decisions on a local level.

2.4 Forest Resilience

As discussed, forests are facing various threats that put these ecosystems and their services under pressure. In recent academic research, the term ‘resilience’ has gained attention, yet different understandings of the concept exist. The term continues to be interpreted differently and remains a vague concept for forest decision makers. According to Carpenter et al. (2001), resilience must be defined as “resilience of what to what” (p. 779): For this thesis that means that I look at the resilience of forest ecosystems to external threats, in particular as regards climate change and other human-induced effects such as timber extraction.

Broadly, three concepts of forest resilience can be distinguished: engineering resilience, ecological resilience, and social-ecological resilience (Cantarello et al, 2024, pp. 1-2). These three conceptualizations are depicted visually in Figure 2. The first understanding, engineering resilience, refers to a natural equilibrium of an ecosystem as a reference and looks at ecological succession following a disturbance. Accordingly, this conceptualization considers how a forest ecosystem can ‘bounce back’ after a major reduction in species, and how such a natural equilibrium can be restored, (Pimm, 1984, p. 325; Cantarello et al, 2024, p. 1). Ecological resilience, similarly, looks at the ecosystem and its “ability to absorb change […] avoiding a shift to an alternative state” (Holling, 1973, as cited in Cantarello et al, 2024, pp. 1-2).

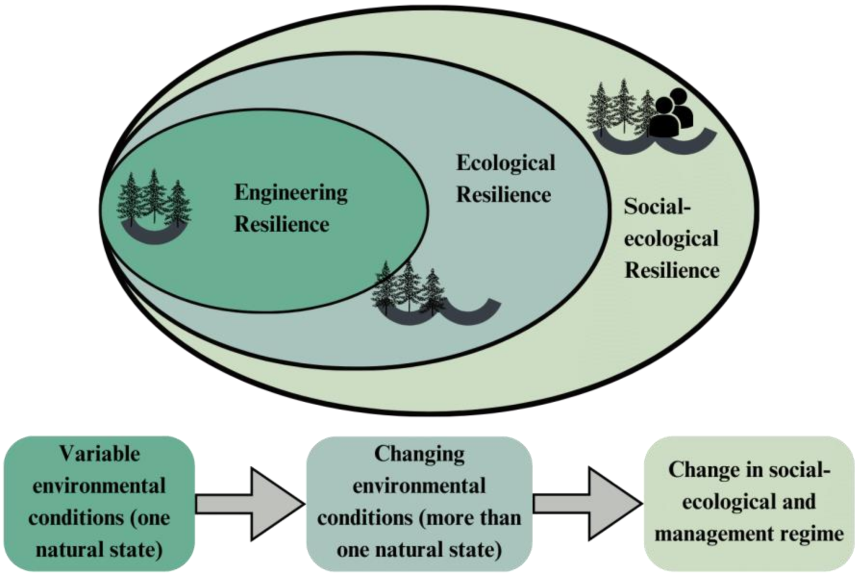


Figure 2: Conceptualizations of Forest Resilience, based on Cantarello et al., 2024

This second understanding sees ecosystems as fluid, as having more than one ideal state, which means that they can persist in more than one equilibrium, e.g. from forest to steppe or grassland. More recently, research has focussed on the third conceptualisation, social-ecological resilience. It establishes forests as connected human-natural systems. As the first two conceptualizations, this understanding focuses on the adaptive capacities of ecosystems and describes how the system is capable of self-organising and learning to counter perturbations and other stress factors, including human-induced effects (Nikinmaa et al, 2020).

2.4.1 Indicators for Forest Resilience Quantification

Being able to assess the resilience of forest ecosystems is a challenging, but indicators can help in quantifying such tasks. According to the United Nations Food and Agriculture Organization (FAO), forest indicators refer to "parameters which can be measured and correspond to a particular criterion […] and help monitor the status and changes of forests in quantitative, qualitative and descriptive terms that reflect forest values as seen by those who defined each criterion" (FAO, 2015; as cited in Hurtado, Espelta & Lloret, 2022, p. 4). Indicators can hence be tailored to measure changes or impacts in a specific situation, or indicators can more systematically monitor certain values and their different characteristics over time or in different regional contexts.

This is significant particularly in light of the climate crisis where forests have the potential to considerably help in the adaptation processes to climate change, but rarely the preparedness of forest ecosystems is known in quantifiable terms. In the urban context, researchers have estimated that a 40 percent uptake in tree cover in European cities would lead to a mean cooling effect of on average 0,5°C, which can be attributed to 41% less deaths due to urban heat islands in European cities (Iungman et al., 2023, p. 584). In this urban setting, an increase in the canopy cover of even a small 10-30m radius can yield measurable cooling effects on the surrounding area (Ziter, 2019, p. 7579). These cooling effects are, however, associated with all forests, not only in urban contexts. Yet, already today 81 percent of protected European habitats show a poor or bad conservation condition (EEA, 2020a, p. 5). The observed conditions indicate the degree of resilience a certain forest ecosystem possesses, and can lose or gain. This can help to formulate strategies that strike a balance between the different interests involved.

But how can forest resilience be measured exactly? According to research carried out by Jaime et. al. (2023) in the EU-funded RESONATE project, “forest structure, forest composition, forest management and biodiversity, followed by land use, herbivory and forest functioning” (p. 14) are the most used broad categories to predict ecological resilience of forests. Considering forests as socio-economic systems, categories for resilience prediction are extended to the broad categories of “management, regulation and institutions, economics, social features and land use, followed by value chains and trade, adaptation, education, recreational activities and working force” (ibid, p. 21). These broad categories can comprise several different indicators, e.g. forest structure can refer to canopy conditions, tree growth, tree age or stand density. Hence, when assessing resilience, it is necessary to select specific parameters that are relevant to understanding the situation at hand. In this context, Müller et al. (2016) warn that “resilience analyses can easily suffer from arbitrary indicator selections and reference definitions” (p. 38) as values in one indicator can be seen as improving resilience in one context, and they can mean the opposite in other circumstances. Unfortunately, research on forest resilience indicators is only starting to emerge, exemplified by the beforementioned RESONATE project and by individual studies, e.g. by Nikinmaa et al. (2020).

3 Methodology

To assess the openness of forest information systems in Germany and the resulting shortcomings for the development of an EU-wide Forest Resilience Monitor, this section introduces the research design and the corresponding research methods. After an overview over the analytical framework and the selected case of Germany, the methods used in the data collection stage are elaborated on. Then, the selection of the forest resilience indicators and the Open data compliance criteria is laid out and justified. The methodology section ends with methodological explanations for the data analysis stage and the limitations of this research.

3.1 Research Design and Case Study

According to Brown and Hale (2014), "[c]ase studies involve an in-depth examination of an event, geographic area, or public problem (p. 110). Following this understanding of case-based research, this thesis looks at the politico-administrative structures in Germany and aims to systematically analyze forest information systems at various policy levels. An indicative structure of the analytical framework is outlined in Table 1.

	Data existence (a)	Online availability (b)	Open license (c)	Timeliness (d)	Regular updates (e)	Accessibility, ease of use (f)	Map feature (g)
Occurrence of forest birds							
Tree species distribution							
Soil & water conditions							
Canopy cover							
Carbon sequestration capacity							

Table 1: Analytical Framework

I will focus on the case of Germany because due to the federal nature of the country, considerable differences exist between the monitoring strategies and environmental information systems employed by the *Länder*. Also, while Germany is sometimes considered to be lagging in digitalization efforts (Kairies-Lamp, 2018), the EU's 2022 Digital Economy and Society Index (DESI) assesses Germany very similarly on public digital information provision than the EU average: "Germany scores well on Open data, but interaction between the government and the public could be improved" (European Commission, 2022, p. 3). Finally, as the largest EU member state, Germany is a powerful country and is key to shaping EU policies. The internal diversity, the representativeness and the political power make Germany an interesting case to study the adherence to Open data principles. Furthermore, Germany has quite extensive forest areas, yet according to the most recent Federal Forest Inventory (FFI) of 2012, only 36 percent of forests in the country can be considered as being in a near-natural state (BMUV, 2023, p. 28). This indicates a need to restore ecosystems and invest in renaturation projects which Germany has pledged to do. Embedding this case in the methodology of a case study, "can 'close in' on real-life situations" (Flyvbjerg, 2006, p. 235). The unit of analysis therefore are public forest information systems, and connected datasets or data components.

3.2 Data collection

Turning to the question of how I collected data on forest information systems, it was essential to ensure that the process was systematically organized. As Brown and Hale (2014) emphasize, "support for our educated guesses, or hypotheses, must come from systematic observation and data collection, not from anecdotes, suppositions, or beliefs about how things ought to be" (p. 26). To this end, I chose a structured data collection strategy, primarily based on desk research of various forest information systems available online, but also taking into account legal and academic publications on the matter. According to Brown and Hale (2014), such data sources are designed for many purposes and hence pose challenges in the research process (p. 102). While the approach of desk research is complex, it was suitable for this research, as it allowed for the systematic gathering and analysis of existing forest information systems and corresponding data by various public providers in Germany, such as environmental ministries or agencies on state level on their respective websites or online portals. The nonexperimental research design was deemed appropriate for identifying and describing patterns within the data collected as indicated in the analytical framework (Table 1). As Brown and Hale (2014, p. 108) note, "when strict rules are established early on regarding data collection, and the concepts of interest are clearly operationalized and measured, nonexperimental research makes a significant contribution to our understanding of the social and political world." More detailed information on the operationalization of these concepts is detailed in section 3.5.

To enhance the depth and reliability of the data collected through desk research, I supplemented this with expert interviews and email correspondence: Five expert interviews were conducted with representatives of two German state forest authorities, a researcher from the European Forest Institute, and two interviews with representatives of the Finnish forest service, to gain some insights on how centralized countries deal with forest governance. These interviews were mainly conducted to gain some orientation in the research field more broadly. These interviews provided valuable insights and context that desk research alone could not have offered. Furthermore, via email correspondence, I engaged with respective public officials to verify and supplement the information obtained through desk research. This step was in line with van Thiel’s (2007, pp. 105-106) recommendation to apply the method of triangulation, combining information from several different data sources to increase the reliability and validity of the research findings. In total the scope of the data collection referred to 16 states plus the federal and the EU/international level, respectively for five indicator groups and about 8 criteria, leading to an analysis of more than 700 instances.

3.3 Selection of Forest Resilience Indicators

As presented previously, forest resilience can be conceptualized in three ways: engineering resilience, ecological resilience and socio-economic resilience. Which definition is chosen can considerably influence forest research and forest management, and also this work. If engineering resilience was prioritized, the potential EU Forest Resilience Monitor would emphasize rapid recovery and restoration of forests to a perceived natural equilibrium. This approach would focus on metrics related to species recovery rates and ecosystem stability. On the other hand, adopting ecological resilience would necessitate a broader range of indicators that capture the ability of forests to absorb changes and maintain functionality across multiple equilibrium states. This could include monitoring biodiversity, ecosystem services, and thresholds of change, quantifying the pressure that is present in a given forest ecosystem (Nikinmaa et al, 2020, p. 68). Lastly, if the focus was on social-ecological resilience, the Monitor would integrate human and ecological dimensions, emphasizing adaptive management practices, stakeholder involvement, and socio-economic factors affecting forest resilience. According to Nikinmaa et al. (2020), this approach likely requires more complex data on human-forest interactions, such as governance and management structures ranging from community forests to silviculture enterprises (p. 70). An EU Forest Resilience Monitor should ideally follow this last conceptualization as most forests in Europe are not only impacted by humans indirectly through climate change, but many socio-economic interests also affect forests directly. While I aimed to base my research on this socio-economic definition, I quickly realized that data and indicator sets at various levels of government in Germany and the EU do not systematically record socio-economic influences on forests. This is in line with findings by Jaime et al. (2023) who faced similar challenges (p. 10). The following paragraph describes the selection of forest resilience indicators for this thesis in more detail.

To answer the first research question to what extent data on forest resilience in Germany is publicly accessible, I first needed to develop a coherent understanding of which indicators are already used in forest research and forest legislation. Given the many actors involved in forest governance and management, it is not surprising that many different indicators are used to assess forest resilience, both in academic research and in policy-making. Hence, as a first step, I needed to choose indicators that are relevant for the desired EU Forest Resilience Monitor. To comprehend the scope of indicators utilized already, I analyzed both EU legislation in the field as well as a dataset attached to a systematic literature review on forest resilience by Nikinmaa et al. (2020). Due to the limitations of this work, I could not conduct an updated literature review myself, however the focus of Nikinmaa et al. (2020) is precisely on forest resilience and hence I saw it as a suitable proxy.

In terms of EU legislation, I looked at the proposed monitoring framework for resilient European forests (European Commission, 2023a) and the Nature Restoration Law in its last updated form by the European Parliament (2024). These two sources have been chosen as they represent a very recent glimpse into how policy-makers at European level are approaching the assessment of forest ecosystems from an ecological conservation perspective. It should be noted that neither laws have so far been adopted. Nevertheless, my investigation can help to map the extent to which relevant data is already openly available; or for which information needs the law will make the setting up of new monitoring structures necessary. Next to information on environmental targets and monitoring structures, the Forest Monitoring Law sets out who should be responsible for the collection of data, e.g. the European Commission, or the member states. Here, 32 different indicators are mentioned. Similarly, the Nature Restoration Law foresees binding targets for member states efforts in the field of ecological restoration. In the sections on the restoration of forested lands specifically, there is reference to seven indicators, of which four are already covered in the Forest Monitoring Law. Hence, the analysis of the proposals yields 35 different indicators, some with a set of sub-indicators (see a detailed overview in Appendix I.b). I then grouped these indicators according to 14 categories proposed by Nikinmaa et al. (2020): climate indicators, biodiversity, disturbance effects, and more.

Interestingly, the 35 indicators from EU nature protection legislation do not cover the whole range of indicator groups, e.g. no mention is given to climate indicators. Therefore, I supplemented the indicator long list with information from the systematic review by Nikinmaa et al. (2020): Specifically, I looked at the supplementary material[2] of their

[2] Electronic supplementary material number 4 to Nikinmaa et al. can be found here: https://link.springer.com/article/10.1007/s40725-020-00110-x#additional-information (Last accessed June 6, 2024).

research where all indicators used in 255 studies on forest resilience are contained. Of this large dataset, I omitted all indicators that were mentioned only once (e.g. aesthetic value, commercial fungi collection). I also omitted all indicators that had a clear connection to equatorial rain forests or other non-European, mostly tropical habitats and indicators that were specifically tailored to small research projects, and seemed unfit to integrate within an EU Forest Resilience Monitor. This still yielded a very large number of indicators and posed some challenges as some indicators were coded in more than one indicator group. More importantly, some referred to similar information, such as “basal values” and “basal area increment” or “mean dbh” and “dbh classes”. This yielded a long list of 140 unique indicators that are connected in one way or another to forest resilience (see Appendix Ib).

According to Müller et al. (2016), the choice of indicators must be clearly justified as the results can differ totally according to one’s choices (p. 37) and Nikinmaa et al. (2020) recommend using “a holistic set of indicators that describe both structures as well as functions of the system” (p. 71). I therefore decided to analyze not only individual indicators, but indicator groups that encompass several information sources, essentially omitting the indicator groups that referred to socio-economic values, e.g. ‘political will’ or ‘forest biomass for bioenergy’. Based on these factors, and literature on the topic, I decided to analyze the Open data compliance for the following five indicator groups:

- **Forest bird diversity (Section 4.1)**: I selected this indicator group because birds are well accepted as a bioindicator, correlating with a range of other environmental parameters (Gregory & van Strien, 2010; Mekonen, 2017). Their monitoring is quite well established at EU level already, and it is mentioned in both legislative texts, with specific reference to a ‘common forest birds’ indicator.

- **Tree species distribution (Section 4.2)**: This indicator is included because of the negative impact on resilience by monocultural management, focusing on naturalness and diversity of native species (Silva Pedro, Rammer & Seidl, 2015; Baeten et al., 2019). This indicator is also mentioned in both EU legislative texts.

- **Soil and water conditions (Section 4.3)**: I included this indicator group as soil structure and composition directly affect nutrient flow and ecosystem productivity (Bronick & Lal, 2005; Dominati, Patterson & Mackay, 2010). Recent droughts have also majorly impacted resilience of forests in Europe, yet soil and water indicators are not referred to in the chosen legislation indicating some gaps in that regard.

- **Tree cover and canopy thinning (Section 4.4)**: Including this indicator group ensures to cover the field of disturbance recovery and management variety and the impact different events have on the extent of forests (e.g. through logging or pests and fire that target vitality of crown cover). Specifically looking at defoliation was also recommended by the representative of the European Forest Institute (2024, Appendix IIIa).

- **Carbon Sequestration Capacity (Section 4.5)**: I selected this set of indicators as large-scale carbon stocktaking is already in place under the Kyoto protocol (Savaresi, Perugini & Chiriacò, 2020) and carbon stock is also mentioned in the Nature restoration law. Considering the 1.5 degrees Celsius target agreed at the 2015 UN climate conference in Paris, forest resilience assessments must therefore also consider forests' capacity to serve as carbon sinks.

The large set of indicators and the limited research process necessitated such choices. This results in limitations on the validity of my findings as many more factors can influence forest resilience assessments. Future research should therefore look into those indicator groups that I could not cover in this research. In general, the vagueness of the term 'resilience' does also provide methodical challenges in this regard as no clear boundaries can be established. For instance, "resilience in one time period or at a particular scale can be achieved at the expanse of resilience in a later period or at another scale" (Carpenter et al., 2001, p. 779) and therefore the indicators to choose for such assessments might be different in other contexts.

3.4 Selection of the Open Data Compliance Criteria

Having decided on the indicators, the next step is to assess the availability and the openness of the data in question. Several Open data assessment frameworks exist, such as the Open-o-meter for measuring openness in Open-Source hardware (Bonvoisin & Mies, 2018). However, the focus of this research is on publicly provided data, hence the Open Data Charter (ODC) that was developed in 2015 by various governmental and civic experts, fits well as a measuring tool. Accordingly, the ODC sets six foundational principles that Open data should fulfil: Data should be (1) open by default, (2) timely and comprehensive, (3) accessible and usable, (4) comparable and interoperable, as well as used (5) for improved governance and citizen engagement and (6) for inclusive development and innovation (Open Data Charter, n. d.). In a global context, these principals can be seen as aspirational norms and since their adoption, they have been endorsed by over 90 governments and organizations such as the World Bank (Brandusescu & Lämmerhirt, 2018, p. 6). As my research focuses on the availability of various forest resilience indicators, principles (1) to (4) are the most relevant because they describe the availability and characteristics of the indicators and can assessed binarily (e.g., data is up-to-date or not). Principles (5) and (6) focus more on the intended use which is harder to quantify or categorize. This is why in this research, I focus on the principles (1) to (4). Nevertheless, these principles are still quite vague. In order to achieve Open data compliance criteria for the forest resilience indicators that are easy to apply in the analysis, I also take into account the questions used by the Open data Barometer (ODB). The ODB is based on the ODC and assesses data access according to ten questions (World Wide Web Foundation, 2017):

- Does the data exist?
- Is it available online from government in any form?
- Is the dataset provided in machine-readable and reusable formats?
- Is the machine-readable and reusable data available as a whole?
- Is the dataset available free of charge?
- Is the data openly licensed?
- Is the dataset up to date?
- Is the dataset being kept regularly updated?
- Was it easy to find information about this dataset?
- Are data identifiers provided for key elements in the dataset?

Investigating all the criteria will exceed the scope of this thesis. In line with the ODC, I will therefore only analyze whether the data exists and is available online (a, b), whether it has an open license (c), whether it is up-to-date, and regularly updated (d, e), whether it is provided in machine-readable format (f) and whether was easy to find and is accessible (f). As an easy mapping functionality is an important aspect of a potential EU Forest Resilience Monitor, I decided to add an additional compliance criterion, namely the map feature (h) that indicates the integration of geospatial information.

3.5 Operationalization and Data analysis

Having selected both the forest resilience indicators and the Open data compliance criteria allows for the more detailed formulation of the research design following a deductive logic with the main data collection method being desk research. In this regard, van Thiel (2007) recommends to "find information that meets the research needs as adequately as possible" and to "use the existing information in such a manner that its contents will come to concur with the research subject" (p. 106). The following section therefore outlines in detail how the research process was operationalized, and which additional methods were creatively applied for certain aspects, such as the self-assessment of the ease-of-use-component.

To assess Data Existence (a), I searched for information online at various policy levels, starting from the highest (EU or international level) and proceeding down to national and regional levels, by online searches. If detailed data were found openly available at higher levels, all lower levels were assumed as having existing data, if no other evidence, such as personal contact or online information suggested otherwise. In cases where data were either incoherent or outdated, particularly for data pre-2018, further checks were conducted for the availability of Open data or indicator calculations at federal and state levels. The assessments with ‘yes’, ‘limited’, ‘very limited’ and 'no’ refer to a scale from sufficient to no evidence that datasets or indicator sets were produced for the respective indicator group at the respective levels.

Regarding Online Availability (b), datasets and maps were classified as ‘openly available’ if they could be accessed through direct data viewers, dashboards, or data portals, or if datasets and their metadata were provided openly. Data were classified as ‘limitedly available’ if information systems only gave limited access to the respective data or indicator sets (e.g. incompleteness or low geospatial detail). This included restrictions such as datasets only covering state forests or protected zones like Natura 2000 sites. Data that were ‘very limitedly available’ faced significant bureaucratic hurdles or access limitations: This included information that I was not able to find via online searches and were only mentioned to me thanks to personal contact with respective public authorities. This indicates an access challenge, particularly for use by common citizens. A classification of “No” indicates that information and data were not accessible at the time of research, suggesting a potential need for improved data sharing and harmonization.

Data were classified as Open data (c) if they were clearly indicated as such, and access was verified during the research process. Ideally, datasets would be under a Creative Commons license, or labeled with no restrictions. Other instances included external sources indicating open access. Data were classified as limited if copyright or usage limitations were explicitly mentioned. On a case-by-case basis, information systems and datasets were disqualified from the Open License classification if they did not provide granular data publicly (e.g., only aggregated values or blurred geospatial details). For the cases where no copyright could be found, information systems were labelled as ‘unclear’.

In terms of Data Timeliness (d), information systems were classified as timely if more recent data than 2018 was available, setting a relatively low bar of a time lag of about 6 years. 2018 was chosen as the cutoff year as Germany experienced a significant drought with detrimental effects on trees and ecosystems in general (Schuldt et al., 2020). Stricter criteria applied to data recorded continuously or in NRT, such as drought monitoring. Data older than 2018 were generally not classified as timely, although indicators based on sample locations and longer monitoring cycles that represented the best available option could be marked as such on a case-by-case basis, if sufficient justification was given. Regarding Regular Updates (e), datasets and information systems were marked as having regular updates if coherent monitoring cycles and strategies were in place. If the update frequency was unclear, representatives were contacted via email to clarify the practices. If no information on monitoring cycles was found, information systems were labelled as having no regular updates. If regular updates violated the Data Timeliness (d) component due to very long monitoring cycles, information systems were labelled as 'limited' in terms of regular updates.

Data were considered available for Machine Readability (f) if published in their original format openly. While there might have been biases towards easier-to-access data, efforts were made to contact relevant authorities to verify the information in cases of doubt. Machine-readable data here refers to data structured in a format that can be easily processed by computers without human intervention. For forest monitoring data, machine readability is crucial because it allows for efficient analysis, integration, and visualization, including datasets in CSV, GeoTIFF, JSON or GeoJSON, XML or NetCDF formats. Excel sheets and shapefiles were also considered as machine-readable formats, although some human intervention might be necessary in analyzing their contents. More restrictively, some formats are machine-readable but may present limitations due to their structure, requiring additional processing to extract and analyze the data effectively. These formats include PDFs that are primarily designed for human reading and often require specialized software to extract and parse the data accurately. In these cases, data was classified as machine-readable only to a 'limited' extent. If data was not available in all its granularity or data download did not work, information systems were coded as 'not machine-readable.'

The Accessibility and Ease of Use (g) was assessed based on personal experience and set criteria, including the availability of visualizations, timeliness, and relevance to local contexts. This involved evaluating how much information could be easily found and identifying data hidden in inaccessible geoportals intended for expert use. This is closely related to the criteria of a Map Feature (h) which describes the existence of a meaningful integrated map feature within the information system. It was classified based on its ability to visualize data implications in a local context. The term 'meaningful' required that the map functionality adds value and is up-to-date, enhancing the utility of data observations.

Furthermore, for some indicator groups, I decided to add further information on the existence of special services. For indicator group II, tree species distribution, I also included whether information systems that I looked at were compiling information on the

Naturalness of tree species composition (i) and if they were providing online tools for Tree Species Planting Advice (j). These two functionalities were included as both add value for forest managers and citizens alike, and as their existence is limited locally. Furthermore, both services require data that is necessary for the forest resilience monitor as well, namely assessments on the natural occurrence of tree species vis-à-vis monocultural plantations and predictions for climatic conditions in the future and the adaptation of different tree species. Furthermore, for indicator group III on soil and water conditions, I also included the provision of map-based and interactive climate change scenarios (k). If such interactive portals were established and provided information on likely changes in precipitation and temperature in the future, in accordance with climate change scenarios, they were coded with 'yes'. In cases where such information was not complete, or not interactively available, information systems were labelled as 'limited'. If information systems did not contain such a feature, I checked whether such service was available on a different portal or website for the respective policy level in question, particularly on state level. This also means that the rows of tables 2 to 6 which contain the results of this research do not necessarily correspond to one single information system. While I coded different information systems on international, EU or federal level on separate rows according to the respective information systems that provide the data, on state level I marked the existence of different information systems in one row. The last special service that was included is Forest Connectivity (l), describing the existence of data on landscape fragmentation which can add to the resilience assessment.

Finally, this classification was used to calculate the compliance with Open data principles in percent. Therefore, the fields with 'yes' or 'good' received 1 point respectively, fields marked with 'limited' were assessed with 0.5 points and fields marked as 'very limited' were given 0.5 points. This enabled me to calculate the total compliance scores in percent, per state. As for the EU/international level and the federal level, I looked at several forest information systems in distinct rows in the analysis. Therefore, each row received its own compliance score. The average of all forest information systems present per policy level was then taken in the final synthesized Open data compliance view.

Justifications for individual assessments can be found for most cells in the Analysis Data Sheet[3] in the form of comments.

[3] The original coding file including comments can be found on Zenodo: https://zenodo.org/records/11479358?token=eyJhbGciOiJIUzUxMiJ9.eyJpZCI6IjJmYTQ4ODYwLWIwYjYtNDU4Zi1hYjQ1LWUwZDFiMWY4ZTExMiIsImRhdGEiOnt9LCJyYW5kb20iOiI3MWYwN2E5NzZhNDA0NDAxMmNiOTNjYThiOWZiODNhYSJ9.-TM7YRDdWZbUoav6CjkLuLBZ3X6sYmmfKY4ahRygrPsgLS8ecUOb5s8ok-erwdvMXU_kgywjU4E0tYIsFdP5kw (Uploaded on June 4, 2024).

3.6 Limitations

All information and coding were done utilizing online searches and, if unsuccessful, by contacting public forest-related institutions at various policy levels. As not all representatives answered my requests, some information may be coded as non-available, although it my be provided elsewhere. However, if information can effectively not be found via online searches, it can hardly be considered as Open data. Limitations in terms of validity refer to "the extent to which we are actually measuring what we think we are measuring" (Brown & Hale, 2014, p. 100), which for most aspects of this research does not pose a challenge as the goal is to analyse what IS available openly online. Validity might be inhibited in the ease-of-use criterion, which was self-assessed. Although following clear guidelines regarding ease of access, the availability of visualizations, the timeliness, and the relevance to local contexts, bias was reduced. Further problems might have occurred concerning the reliability of the results, which refers to "the extent to which the tools we use to collect data […] are capable of yielding consistent results" (ibid, p. 100). Here, I tried to validate unclear findings through personal communication with officials. Unfortunately, not all representatives that I contacted answered my specific questions, yet only in very few cases this led me to assign the 'unclear' assessment.

Additionally, this work is to a large extent limited to the analysis of data and indicators contained in forest information systems that are used in the context of ecological resilience. While focusing on this conceptualization is compatible with environmental legislation, this choice also results in a certain bias towards ecological restoration vis-à-vis socio-economic interests in forest resilience quantifications. It might also limit the potential target groups. Still, I believe that these limitations do not outweigh the benefits that the findings entail for the future development of an EU Forest Resilience Monitor. Finally, a limitation exists in terms of forest fire indicators that were not taken into account in the selection of the indicator groups because of limited occurrences of forest fires in Germany – so far. Further research must be conducted on the already existing information systems in fire monitoring, and how specifically EFFIS could feed information into the EU Forest Resilience Monitor.

4 Analysis

The following pages describe my findings of the structured openness analysis for the indicator groups concerning Bird Species Occurrence (I), Tree Species Distribution (II), Soil Water Conditions (III), Canopy cover (IV), and Carbon Sequestration Capacity (V).

4.1 Indicator I: Forest Bird Biodiversity

The existence and abundance of birds can serve as an indicator for ecosystem health, particularly when looking at “a series of complementary indices that capture different facets of biodiversity and how it is changing” (Gregory & van Strien, 2010, p. 6). It is hence an important indicator for forest resilience. The European Environment Agency (EEA) has identified a list of 34 species that are particularly relevant in the context of forest ecosystems. Compared to the base year 1990, this common forest bird index decreased by five percent in Europe (EEA, 2023). To monitor such developments, the European Commission has also set up standardized information systems that pool data from member states, make it openly accessible and visualize trends: the Biodiversity Information System for Europe (BISE) and the Natura 2000 map viewer. Considering the biodiversity of birds in forests, a specific indicator has been established in 2018: the richness of forest-related species and habitats indicator (EEA, 2018).

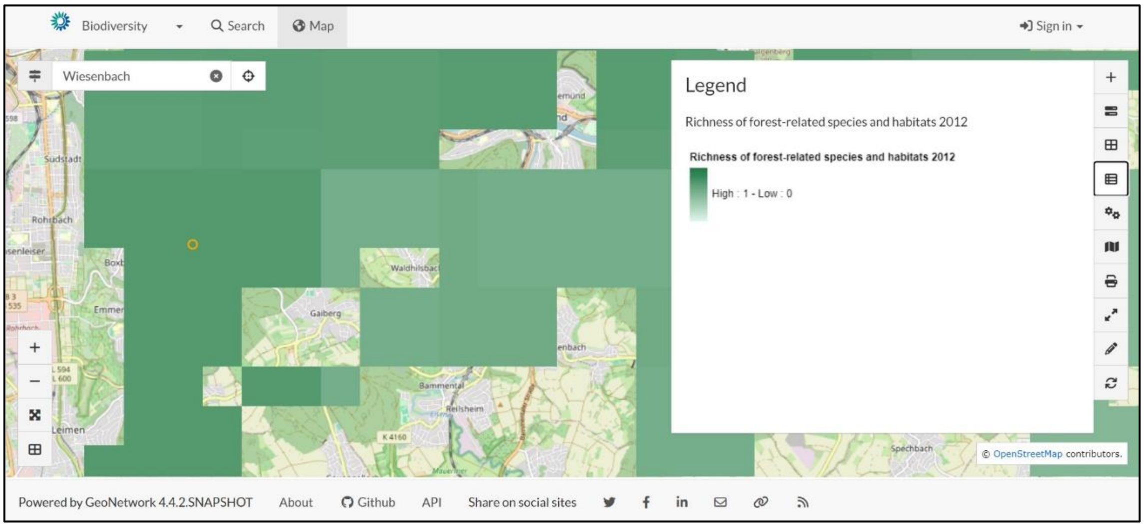


Figure 3: Screenshot of the EEA’s Geospatial Data Catalogue showing the Indicator on Richness of Forest-related Species and Habitats (2012)

As shown in Figure 3, on a scale from 0 to 1, it assesses “biodiversity values of forested areas in Europe […] at 1km resolution” (ibid, 2018, n. p.). The darker the shades of green, the higher is the presence of forest related species. While the data of indicators at EU level, such as the forest species richness indicator, is openly accessible, EU systems also face some drawbacks: All selected information systems in the biodiversity component are assessed with either limited or bad ease of use and they are mostly targeted towards experts' needs (see scores in Table 2). For instance, the EUNIS database contains information on species, habitats and sites in the EU (EEA, 2019) which has been set up to assist the Natura 2000 process, mostly to measure member states' compliance with the EU Birds and Habitats Directives. It has been coined "a major step forward […] for nature conservation survey, planning, monitoring and reporting on the international, national and regional levels" (Chytrý et al., 2020, p. 669). The information system BISE contains detailed information on species distribution, and habitat types and sites from the EUNIS database. The data is, however, mostly restricted to protected Natura 2000 sites for which member states' monitoring is mandatory. Other wooded areas that are not designated as protection zones do not fall under its scope. Hence, member states are not obliged to report such additional information. Furthermore, EU statistics can only be published once data from member states has been received. This means that the indicator on the richness of forest species, published in 2018, represents data effectively collected between the years 2006 and 2012. It can therefore not account for the climatic changes, and the possible effects on bird life, that have occurred in the meantime. Still, EU biodiversity information systems for birds provide coherent and open information, scoring on average better than national or state-level systems (see Table 2).

In Germany, the tasks of biodiversity monitoring fall within the responsibility of the *Länder* who then report to the federal level. They carry out the common breeding bird survey (MCBB), in Germany 99 species, by Directive 2009/147/EC and additional monitoring of protected areas according to the Habitats Directive (Council Directive 92/43/EEC). Additionally, Germany carries out a structured monitoring of rare breeding birds (NMB, 2024). In 6-year cycles, the structured observations carried out on state level feed into bird protection reports according to Directive 2019/1010/EU by the *Bundesamt für Naturschutz* (BfN, transl.: Federal Agency for Nature Conservation). More specifically, the MCBB information stems from double-stratified random samples of $1km^2$ sample areas that are representative of Germany's landscapes (DDA, 2024a). At least 1.000 of a total of 2,637 plots are visited and analyzed annually, for the MCBB alone. This requires many resources and is often supported by networks of voluntarily engaged people. The NGO *Naturschutzbund Deutschland* (NABU, transl.: Nature and Biodiversity Conservation Union Germany) plays an important role in facilitating this process.

	Indicator Type	Data existence (a)	Online availability (b)	Open license (c)	Timeliness (d)	Regular updates (e)	Machine readability (f)	Accessibility, ease of use (g)	Map feature (h)	Score	Average
EU (EEA, 2018)	Richness of forest-related species and habitats	Limited	Yes	Yes	No	Limited	Yes	Limited	Yes	61,11%	
	Population trend of bird species	Limited	Yes	Yes	Limited	Yes	Yes	Bad	Yes	75%	
EU (BISE & EUNIS)	Data on species, habitat types and designated sites (Natura 2000)	Limited	Limited	Yes	Limited	Unclear	Limited	Limited	Limited	44,89%	**60,88%**
EU (Natura 2000)	Data on species, habitat types and designated sites (Natura 2000)	Limited	Limited	Yes	Limited	Limited	Yes	Limited	Limited	62,50%	
National											
DDA	Breeding population development, Distribution (ADEBAR)	Yes	Yes	No	Limited	Yes	No	Limited	Limited	56,25%	
BfN	Distribution, Population trends (12y & 36y)	Yes	Limited	Yes	Limited	Yes	No	Bad	Limited	56,25%	**56,25%**
Ornitho.de	Sightings	Yes	Limited	No	Yes	Yes	Limited	Bad	Limited	56,25%	
State level											
BW	Breeding distribution, populations	Yes	Limited	No	No	No	No	Bad	Limited	25%	
BY	-	Yes	No	No	No	No	No	No	No	12,50%	
BE	-	Yes	Very limited	No	No	No	No	Bad	No	19,53%	
BB	-	Unclear	No	No	No	No	No	No	No	0%	
HB	-	Unclear	No	No	No	No	No	No	No	0%	
HH	Distribution, population	Yes	Limited	No	No	No	No	Bad	Limited	25%	
HE	Distribution	Yes	Very limited	No	No	No	No	Very limited	Very limited	21,86%	
MV	No. of breeding birds, distribution	Yes	Very limited	No	No	No	No	Bad	Very limited	18,75%	
NI	Important bird habitats	Yes	Limited	No	No	No	Limited	Limited	Limited	37,50%	**25%**
NRW	No. of breeding birds, distribution	Yes	Yes	Unclear	No	Unclear	No	Limited	Yes	43,75%	
RLP	Distribution of breeding populations	Yes	Limited	No	Yes	Yes	No	Bad	Very limited	46,88%	
SL	-	Limited	No	No	No	No	No	No	No	6,25%	
SN	Distribution	Yes	Yes	Yes	No	Yes	Yes	Limited	Yes	81,25%	
ST	-	Yes	No	No	No	Limited	No	No	No	18,75%	
SH	-	Yes	No	No	Yes	Yes	No	No	No	37,50%	
TH	-	Yes	No	No	No	No	No	No	No	12,50%	

Table 2: Compliance of Bird Monitoring Information Systems and Policies with Open Data Criteria

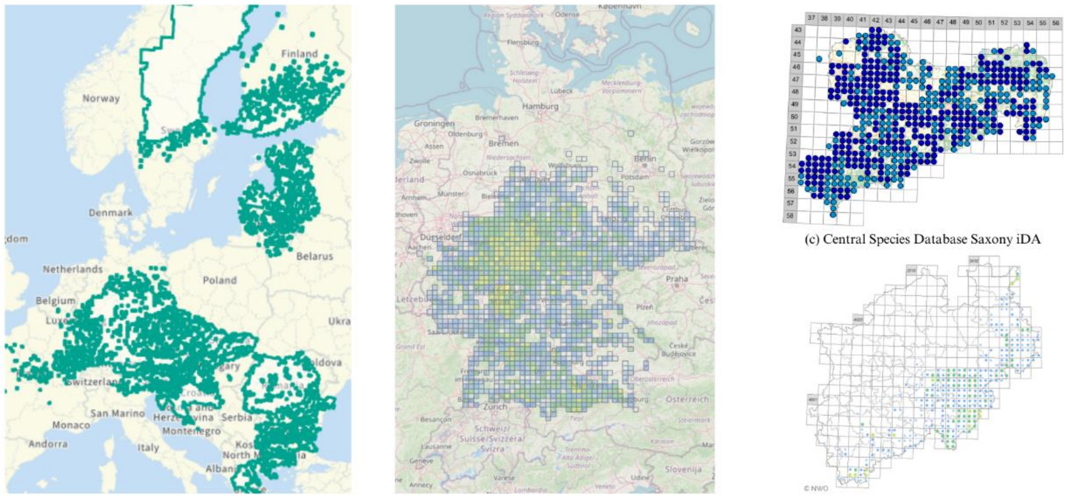
The so-called “bird race days” include lay persons and alone on one day in May 2024, 2.700 people took part in such a structured survey (DDA, 2024b). The last BfN birds protection reports from 2019 contain information on the distribution of species Germany-wide. However, these are not interactively available and published only in PDF format showing the map of Germany in a 10 x 10km grid. This inaccessibility, limited machine-readability and the considerable time-lags violate most Open data criteria. Generally, data harmonization and timeliness are a huge challenge among bird occurrence information systems. Ornithologists have, however, developed the online portal ‘ornitho.de’, which offers a platform for individual NRT data sharing on bird observations in all Germany: With more than 70 million individual observations, the portal helps to better map the occurrence of bird species (DDA, n. d.). And even beyond Germany ‘ornitho’ portals have been institutionalized in many European countries. Pooling such common observation data by birdwatchers across Europe is the mission of the European Bird Census Council (EBCC). A potential ‘EuroBirdPortal’ aims to monitor bird observations in Europe in NRT (EBCC, 2024). In Germany, these online citizen observations currently only feed into the surveys of the *Dachverband Deutscher Avifaunisten* (DDA, transl.: German Avifauna’s Association). However, they do not feed into the BfN monitoring reports on federal level. Unfortunately, data access in ‘ornitho’ is limited to very active users only. Only those that report an average of ten bird observations per month have access to free database queries. Alternatively, regional coordinators can be contacted directly for data access. Overall, the analysis reveals that the federal level and the EU level can be compared in their efforts of Open data provision of bird biodiversity datasets, both scoring at a compliance rate of about 60 percent.

The analysis in Table 2 also reveals that while most states confirm the existence of bird monitoring data, the online availability is generally poor. Only North Rhine-Westphalia (NRW) and Saxony (SN) provide online access to bird monitoring data with specific online portals. For the states of Bremen and Brandenburg (BB), data existence could not be verified as the contact persons did not reply and no information online was available. Furthermore, Saarland (SL) reports that some of its monitoring is still in a development phase. Four states have only partial online availability, for instance Lower Saxony (NI) that only produces interactive and downloadable maps that indicate important regions for large bird habitats and for breeding and visiting birds, but not for species distribution (MUEK NS, 2023). In Rhineland-Palatinate (RLP) and Baden-Württemberg (BW), ornithological groups publish aggregate reports from the locally sourced data of ornitho.de, partly with public financial funding (GNOR, 2023; OGBW, 2024). Seven states do not have their data available online and three only in limited format: In Mecklenburg-Vorpommern (MV), distribution maps of selected species are available in a rather outdated PDF reports referencing data from 2005-2009 (Vökler, 2014). In Berlin, the transmission of data must be requested from the local ornitho Steering Group by filling out an extensive form. This shows that while data may exist on state level, data access is challenging. Significant gaps in online accessibility across regions hinder effective data utilization. On top of that, most data are not clearly labelled as Open data and restrictions on the use of data persist: Only SN specifically classifies its information system with a Creative Commons license: With a score of 81,25%, SN scores considerably better than all other information systems. Its species database 'iDA' provides open access to over 7 million observations in the form of grid distribution maps and species count maps in machine-readable format (LULG SN, 2024, see also Figure 4 [c]). Such an approach could be very valuable for the potential EU Forest Resilience Monitor.

Another major challenge, as already outlined for the EU level, is the timeliness of the data. This research deems data that is less than 6 years old as timely which is already quite a stretch considering the immense effects climate change can have on biodiversity over one season alsone. Still, only for two out of 16 states, namely RLP and Schleswig-Holstein (SH), recent data was accessible online as they publish annual reports with selected distribution maps. On the downside, these reports are very inaccessible and not machine readable. Additionally, in RLP, you need to order and buy a book in physical form to receive the information (personal communication with GNOR representative, 2024, Appendix IIa). In general, the states do not have put in place regular updating cycles for bird monitoring data. And even if they do, such as Saxony-Anhalt (ST) which reports a biannual reassessment for their internally used biodiversity indicator, data on species distribution is only partially included here and not published. The analysis also reveals a pattern where almost all states do not offer machine-readable bird monitoring data. Only SN reports that its data is fully machine-readable, meaning the distribution of specific species can be downloaded as shapefiles or in Excel tables relating to the quarter as shown in Figure 4c. As mentioned before, while crowdsourced data from ornitho.de is technically available in machine-readable format, there is restricted access to it for regular users. This is a major obstacle for a potential EU Forest Resilience Monitor as data needs to be available in machine-readable formats. Yet, the openly accessible data is largely reduced to information graphics in PDF reports. In most cases, this information stems from machine-readable databases of the respective publishers, yet it is not openly accessible.

Figure 4 shows the different map features that are available online in terms of species distribution, here with the example of the distribution of the grey-headed woodpecker (*Picus canus*), a species that is included in the common forest birds index on EU level. Data by the DDA (4b), is grid data on a 10 x 10 km basis, whereas the data portals of

NRW and SN are more detailed as they show quarters of such 10km2 quadrants (4c & d), and hence give more detail on the actual habitats of the woodpecker species that mainly lives in forests.



(a) Natura 2000 Network Viewer by the European Environment Agency

(b) Information Portal "Birds in Germany" by the DDA (Umbrella organization of German avifaunists)

(c) Central Species Database Saxony iDA

(d) Information Portal Breeding Birds Atlas Northrhine-Westfalia

Figure 4: Presentation of Species Distribution of *Picus Canus* (Grey-headed Woodpecker) according to Selected Information Systems

EU data in the Natura 2000 viewer indicates those areas that are designated as protection zones where the woodpecker species has been reported to be present (4a). As illustrated, this data is incomplete as data from Poland is missing and habitats not included in the European protection framework are also not included. So far, also no aggregated visualization capabilities for the distribution of several bird species are openly available (e.g., a combined visualization of several relevant species for forest ecosystems). Such visual information could, however, be beneficial for a better quantification of forest resilience and public awareness around the topic of biodiversity loss. While a few states provide limited access to bird monitoring data, the majority exhibits significant limitations, with data either not accessible at all or very challenging to use. Of some of the websites or reports, I was only made aware of due to personal contact with local representatives. This suggests a critical area for improvement to ensure data is not only easily usable by citizens but also easily discoverable online.

To conclude, the analysis of the bird monitoring processes highlights significant disparities and gaps in data systems across the German states, particularly when compared to EU standards, which – in turn – depend on such local input as EO technology helps little in biodiversity of different animal species, including birds. Most states show deficiencies in critical areas such as online availability, openness, timeliness, and machine readability. This situation underscores the need for a concerted effort to upgrade and standardize data systems to enhance accessibility, usability, and effectiveness of bird monitoring initiatives across Germany. A notable exception among the *Länder* is SN which operates an Open data portal on all species of the state. Yet, an ideal point to address the common challenges of all states would be the DDA's existing database which already pools data from public monitoring as well as data from ornitho.de. By equipping it with machine-readability functionality, an open license, a more detailed granularity as well as with the possibility to aggregate several species' distribution in one map, it could serve as a NRT map on the occurrences of forest birds in local contexts, directly impacting regional resilience assessments. Beyond Germany, the EBCC's 'EuroBirdPortal' prototype could also serve as a valuable data pool for NRT forest bird monitoring to improve related indicators that could then feed into the determinations of forest resilience assessments.

4.2 Indicator II: Tree Species Distribution

The different climates in Europe establish different ecological environments in which various tree species find suitable habitats. According to Baeten et al. (2019), the functioning of forest ecosystems is generally enhanced by a high tree species richness. With climate change, suitable habitats for one species may, however, change as some areas will be more dry or hot. To enhance forest resilience, some researchers suggest planting trees that will be suitable for environmental conditions of the future, particularly in terms of re- or afforestation efforts. Yet, this is a very controversial debate, as others argue that only native plants are well-suited for specific environments. Non-native trees have been spread by human migration for centuries already and some species have therefore reached new continents where they successfully established (Hautala, 2024). This is particularly true for urban environments which are heating up much more considerably: For instance, city planners in Sydney have come up with guidelines to plant "the right tree […] in the right place, and at the right time" (City of Sydney, 2023, p. 3) which fits more the climate conditions of the city of Grafton, more than 450km away. In other places, rules state that trees should be mainly locally sourced because of their adaptations to blossom at the same time when native insects are active to pollinate (Hautala, 2024). This debate on climate change adaptation illustrates that simply planting trees will not help to restore resilient ecosystems. Initiatives that focus on the 'best trees' are now present in regions all around the world. To determine the local needs of a forest ecosystem, information on the current tree species occurrence in a given area is necessary. This can be done either by visiting the forest and recording *in situ* data or through arial observation. The following analysis therefore looks at datasets and information systems produced at EU level, at national level and at state level for the area of Germany, referring to their compliance with the Open data criteria. The results are shown in Table 3.

	Indicator type	Data existence (a)	Online availability (b)	Open license (c)	Timeliness (d)	Regular updates (e)	Machine readability (f)	Accessibility, ease of use (g)	Map feature (h)	Naturalness of tree species composition (i)	Future scenario recommendations (j)	Score	Average
EU (A/T4F)	Current & future potential distribution tree species	Limited	Yes	Yes	No	No	Yes	Good	Limited	No	Limited	55%	**55%**
National													
DE (Thünen)	Dominant tree species	Yes	Yes	Yes	Very limited	No	Yes	Good	Yes	Limited	No	67,50%	**45,63%**
DE (UFZ)	Current tree species distr.	Yes	Yes	No	Very limited	No	No	Good	Yes	Very limited	Unclear	45%	
DE (Waldmonitor)	Current tree species distr.	Yes	Limited	Very limited	Very limited	No	No	Good	Yes	Very limited	No	42,50%	
DE (FFI)	Pure stock per tree species	Very limited	Limited	Unclear	No	Limited	Yes	Bad	Very limited	Very limited	No	27,50%	
State level													
BW	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Very limited	Yes	22,50%	**35,78%**
BY	Tree species distribution	Yes	Very limited	Very limited	No	No	No	Bad	Limited	No	Limited	25%	
BE	Individual city trees	Yes	Limited	Yes	Yes	Yes	Yes	Good	Limited	No	Limited	75%	
BB	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	No	Limited	15%	
HB	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	No	No	10%	
HH	Individual city trees	Yes	Limited	Yes	Yes	Yes	No	Good	Yes	No	Very limited	62,50%	
HE	Biotope categories	Yes	Very limited	Limited	No	No	No	Bad	Yes	No	Yes	37,50%	
MV	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	No	Very limited	12,50%	
NI	Dominant tree species, age	Yes	Very limited	Limited	Limited	No	No	Bad	Yes	No	Limited	37,50%	
NRW	Forest habitat type	Yes	Limited	Limited	Yes	Unclear	Yes	Good	Yes	No	Yes	70%	
RLP	Biotope categories	Yes	Limited	Yes	No	No	Yes	Bad	Yes	No	Very limited	47,50%	
SL	Dominant tree species, biotope categories	Yes	Limited	Unclear	No	No	Yes	Bad	Yes	Very limited	No	37,50%	
SN	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Limited	No	15%	
ST	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	No	Yes	20%	
SH	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	No	Yes	20%	
TH	Dominant tree species & accompanying species	Yes	Yes	Yes	Yes	Limited	Limited	Bad	Yes	No	Limited	65%	

Table 3: Compliance of Tree Species Information Systems with the Open Data Criteria and the additional Capabilities of Naturalness and Planting Recommendations

Similar to the bird indicators, the EU information system scores quite well although member states, and in Germany the *Länder*, are responsible for forest monitoring practices. Here, considerable differences concerning Open data compliance exist. On EU level, the "EU-Trees4F" project has developed maps for the 67 most prominent tree species and their occurrence as well as their future potential distribution in the EU by referring to several predictions on the climatic conditions of the future due to climate change (Mauri et al., 2022)[4]. The datasets are openly available in 10 x 10km resolution; however, they do not describe the actual distribution of tree species, but – as said – their potential distribution range according to four time frames (see Figure 5). The calculations are based on data largely collected before 2017 from various sources, partly from the 21 different national NFIs (Mauri, Strona & San-Miguel-Ayanz, 2017). Unfortunately, this data is only available in a portal meant for expert data use and as raw datasets.[5]

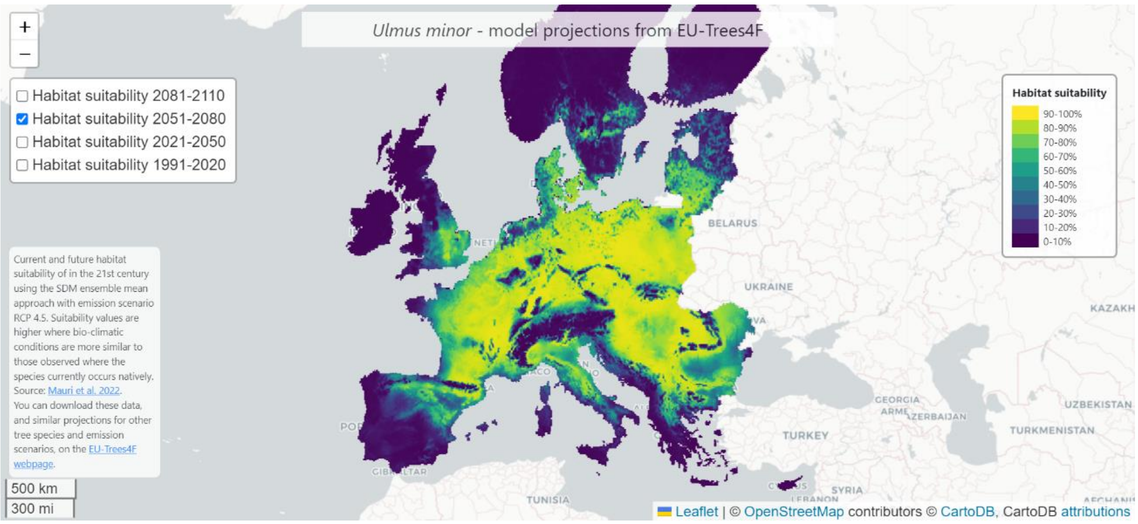


Figure 5: Screenshot of the EU-Trees4F Data on Habitat Suitability for the *Ulmus minor* Species in a Scenario for 2051-2080

Through the EU's Copernicus land monitoring service and the EU observatory on deforestation and forest degradation, the EU publishes more datasets on trees. However, these do not include individual tree species data. Generally, EU information systems only differentiate between broadleaved and coniferous forest types with "low spatial detail" and "missing information depth" (Welle et al., 2022, p. 2). While the EU level would be an ideal merging point for convergence of tree species data, the meaningfulness for individual species so far is quite limited. This necessitates looking at the availability and presentation of tree species records also in Germany, both on federal and state level.

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[4] Data is published by the European Commission's Joint Research Centre: https://forest.jrc.ec.europa.eu/en/activities/forests-and-climate-change/ (Last accessed May 14, 2024).

[5] Datasets were published by the authors on Figshare: https://figshare.com/collections/A_high-resolution_pan-European_tree_occurrence_dataset/3288407 (Lastly accessed May 15, 2024).

On German federal level, more detailed data on tree species distribution is available through four different portals: the Thünen Institute's forest atlas (Blickensdörfer et al., 2022), the UFZ's forest condition monitor, the forest monitor by RSS, and the datasets of the Federal Forest Inventory (FFI, see individual scores in Table 3). The results of the latter are published on a designated online portal, called bwi.info which contains aggregated numbers of tree species per state. As the data is not connected to geospatial information, this considerably limits its meaningfulness and accessibility. The interactive maps by the Thünen Institute, the UFZ, and RSS, however, give more insights on the actual distribution of tree species on a local scale, showcasing the detailed domination of individual species on a map (see Figure 6).

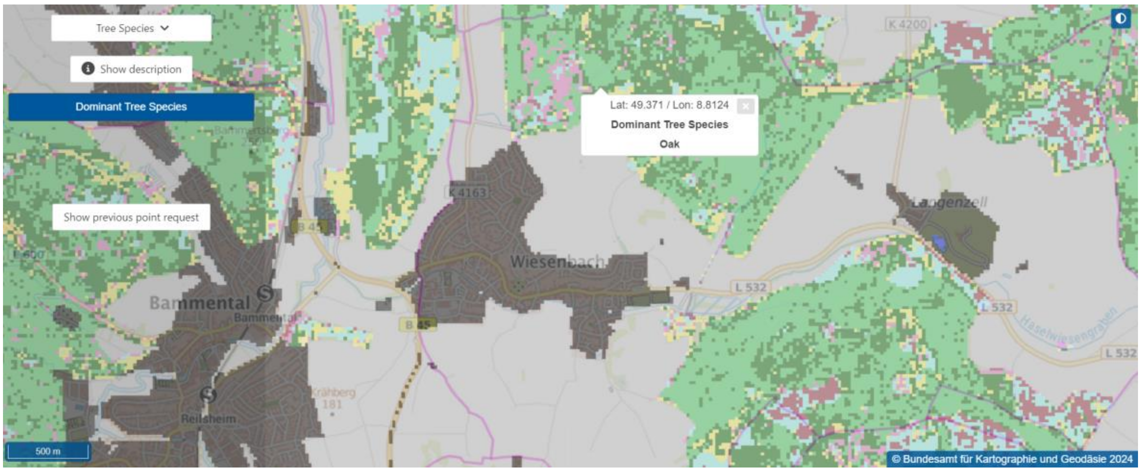

Figure 6: Screenshot of the UFZ Forest Condition Monitor's Tree Species Viewer

Yet, also these maps must be taken with caution as their accuracy lies only at around 80 (UFZ, 2024) and, according to a researcher at the Gotha Forest Research and Competence Centre, tree species were all detected before 2018, a year in which a massive forest decline occurred due to a large drought period (personal communication, 2024, Appendix IIb). Nevertheless, these data monitors provide the best sources for tree species distribution in Germany. As they are based on satellite imagery (Sentinel-2), similar processes could be established for all of Europe with the Copernicus programme (Welle et al., 2022, p. 10). The beforementioned interactive maps on federal level provide data for all states (column [a] in Table 3), but the involvement of the *Länder* in assessing and providing tree species distribution is generally limited (column [b] in Table 3), leading to a combined average score of 35, 78 percent Open data compliance. Seven states do not make any additional data or information available online in this regard. Despite all states having their own geoportals with multiple functionalities, including environmental mapping, online availability is either limited or very limited for the remaining states. And where data is available, these datasets or maps are often limited to state forests or protected sites, and generally even more outdated than satellite-based data. Their accuracy, however, can be seen as higher because such information largely stems from data recorded on the ground by field visits. For instance, in NRW, 72 different ecological habitat types were developed, based on the combination of site factors, vegetation period, overall water balance and nutrient supply. Their geographic distribution within the state is openly accessible in a dedicated forest portal, showing the locations of ecosystems such as 'wire beech forests' or 'oak-birch forest with pine' (Wald & Holz NRW, n. d.). The geoportal of the Saarland (SL) even shows information on the specific number of trees per species in a given sector with further supplementary information, but only for the state-owned forests (MUKMAV, 2024). The Thuringian geoportal has a similar feature: it contains detailed information about the tree species composition for all forested lands – delivering a complex ecosystem description via a number code. For instance, the 'BHC' number in Figure 7 refers to the area marked with the red pin and describes it as a 'coniferous pure stand forest in the middle tree phase as a single-layer structure consisting only of spruce without accompanying species, with loose canopy closure, and no special protection of the biotope'. The information can, however, only be retrieved when one has access to the document that outlines what the 'BHC' code stands for – which I could only retrieve upon personal email contact with the state forest authority. This stands exemplary for the limited accessibility of valuable information sets.

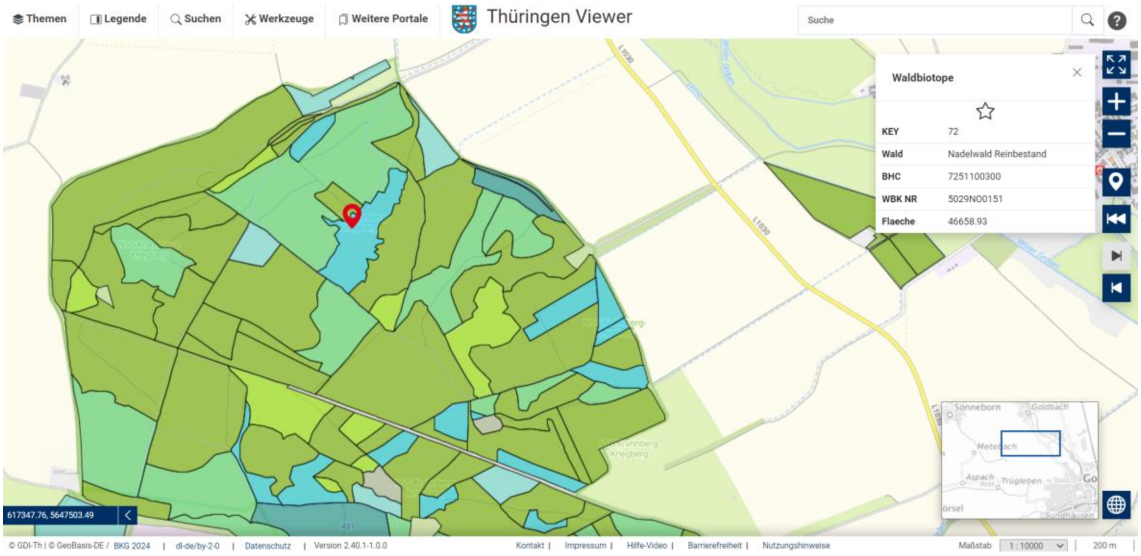

Figure 7: Screenshot of the Tree Species Map in the "Thüringen viewer"

In general, most data sets on tree species distribution are not clearly labelled as Open data, with some exceptions, such as the map by the Thünen Institute (Table 3[c]). While most datasets are technically available openly, they come with certain restrictions that may limit their use, for instance for commercial activities. In BW, only limited data is available under an open license and access to more detailed forest maps must be applied for, giving clear indications on the scope and reason of datasets (FVA-BW, n. d.). By promoting the use of open licenses across all levels of government, information on environmental conditions could be available to everyone, not only to experts involved in forest management. Even more grave are the concerns stemming from the limited timeliness and irregularity of updates: Essentially, I have coded all information systems as timely if they are based on data collected after 2018, referring to a time-lag of 6 years. This choice has been made also because the datasets then reflect the detrimental effects from the years 2018. Unfortunately, most data are older, e.g. the European Atlas of Forest Tree Species brings together data from many data sources, some as old as 2006 (De Rigo et al., 2016, p. 42). For the whole of Germany, the Thünen monitor shows data from 2017/2018, and the UFZ monitor as well as the RSS monitor are based on Sentinel-2 data from 2016 to 2018 (personal communication with UFZ representative, 2024, Appendix IIc). Hence, they all do not depict tree species distribution in NRT. While technically no big changes are to be expected within such short time frames, climate change has recently led to extreme weather conditions impacting the survival of certain species in specific regions. For instance, the 2018 drought in Germany affected millions of trees and according to the Federal Ministry on Agriculture, at least 2,450 hectares are consequently in need to be reforested (BMEL, 2020). The drought has therefore considerably impacted the species composition in German forests (Schuldt et al., 2020).

Most timely data is provided in TH through the state's geoportal as described before, with data from 2020 (Figure 7). Also, the city states of Berlin (BE) and Hamburg (HH) provide up-to-date data. Yet, it must be noted that here the focus is on the management of city trees and not on forest ecosystems. These cities have put in place tree registers, containing information on single trees. These datasets have been used to coordinate watering efforts by citizens, e.g. through the Berlin portal 'Gieß den Kiez' which visualises the locations of 885.825 metropolitan trees, as well as information on age, species and in-time watering requirements (CityLAB Berlin, n. d.). If one user waters a tree, she*he can mark the tree as 'watered', essentially leading to a better coordination of watering activities. The Open data portal might even strengthen ties within the city community and create awareness for environmental conditions. Most information that is available in state geoportals is even more outdated than the federal monitors, with data from 2011 in SL, or from 1999 in Bavaria (BY). Data from Hesse (HE) even comes from the years 1992 to 2006. The unavailability of timely forest information is most certainly linked to the absence of provisions mandating regular updates or open publishing (see Table 3[d]). Metadata of the published datasets explain that updates are only carried out 'if necessary' in some cases. It is important to point out that more recent maps certainly do exist, however they are not openly available online and rather only at the hands of regional forest offices. These are often not allowed to share updated forest maps of privately owned land outside of protected areas or state-owned lands, due to state legislations or other data protection regulations. Asked on the availability of a tree species map for the state, a representative of the forest authority in MV answered “We have it, but it will not be published”; and even to gain such information on state-owned forests, citizens need to prove “considerable interest, otherwise it is data protection” (Interview with representative Forst-MV, 2024, Appendix IIIc). The public official also compared forests to gardens – where also only the owner is in a position to know what she*he is growing. Consequently, at all levels of governance, datasets that yield information on tree species composition suffer from severe time-lags and limited meaningfulness, effectively hindering citizens’ access to information on local forests’ resilience. Modern satellite mapping technology for individual tree species recognition can certainly help to remedy these challenges, particularly for the potential EU Forest Resilience Monitor.

A more variant picture can be seen in terms of machine readability of the datasets (see Table 3[f]). At EU level, the data on tree species distribution is machine-readable, however – as stated before – it does only represent the hypothetical distribution of species and not the actual distribution. For Germany at national level, the tree species functionality of the RSS forest monitor and the UFZ forest condition monitor are not published in machine-readable format, which limits its usability for automated analysis and integration. Different geospatial restrictions apply to the data of the FFI. Conversely, the Thünen Institute's data is available openly for download in TIFF, CSV or XLSX format. Technically, these datasets could feed into the setup of an EU Forest Resilience Monitor. On the regional level, of the ten states that publish species data in one form or another, only half of them do so in machine-readable format. For instance, data from Lower Saxony (NI), cannot be downloaded but only be viewed in the geoportal and data from BW is largely only available in PDF format.

A mixed picture can also be seen in terms of the accessibility of databases and information portals (see Table 3[g]). At EU level through the interactive tree species atlas, and at national level through the monitors by UFZ, Thünen and RSS, easy-to-use applications exist which can be used by almost anyone to inform themselves about the local presence of tree species in the region of interest by a simple search function (see Figure 7). Also, the already mentioned portals on city trees in BE and HH fall within this category of good accessibility as they are targeted specifically towards an everyday usage. Beyond these, the forest information portal of NRW as well as the information portal of NI stand out as good examples on how to make tree species information more accessible: While they are both limited in their meaningfulness, particularly due to incompleteness or time-lags, their user interface is not only targeted towards experts. All other geoportals require at least some time to familiarize oneself with geospatial datasets and their proper depiction in the respective geoportals. Without professional assistance, I would not have found some of the datasets myself. Furthermore, finding the relevant datasets often requires the user to search through several functionalities and folders until the relevant data is found. Most datasets hence remain quite inaccessible. Nevertheless, the use of maps is already prevalent in forest information systems in that regard, with the notable exception of the official German FFI.

4.2.1 Naturalness of Species Composition

The analysis shown in Table 3 also records whether information is available on the naturalness of the forest ecosystem (see column [i]). This criterion was added as the occurrence of tree species data is not very meaningful on its own and must be interpreted according to the climatic context: Naturalness thereby refers to “the similarity of a biocoenosis to the presumed natural state before it was affected by man” (Reif & Walentowski, 2008, p. 64). It is relevant as most forests in Europe today have been affected by human effects and are essentially large-scale tree plantations. Monocultural plantations, sometimes labelled as ‘green deserts’ negatively affect the resilience of a forest (Bravo-Oviedo, 2018) and are hence an important aspect to consider when looking at tree species distribution. A naturally mixed species composition does, however, not mean that there is no human interference: On the contrary, due to the high density of deer that chew on broad-leafed tree seedlings in many German forests, “the natural development will often revert back to spruce, even if spruce is perhaps no longer vital everywhere”, necessitating active intervention (representative European Forest Institute, 2024, see Appendix IIIa). Therefore, naturalness of tree species composition does not refer to how species would grow without interference, but to what extent a diversity of different species is achieved that suits the respective habitats and increases environmental services: In general, naturalness indicators are not very widespread. At EU level, naturalness of tree species composition is not recorded openly. The German federal level is more aware of this indicator, which is used in its federal forest inventory. According to the latest FFI 2012, 15 percent of the German forests exhibit a composition of tree species that is ‘very near-natural’ and a further 21 percent show a ‘near-natural’ composition of tree species, with naturalness levels being particularly high in beech

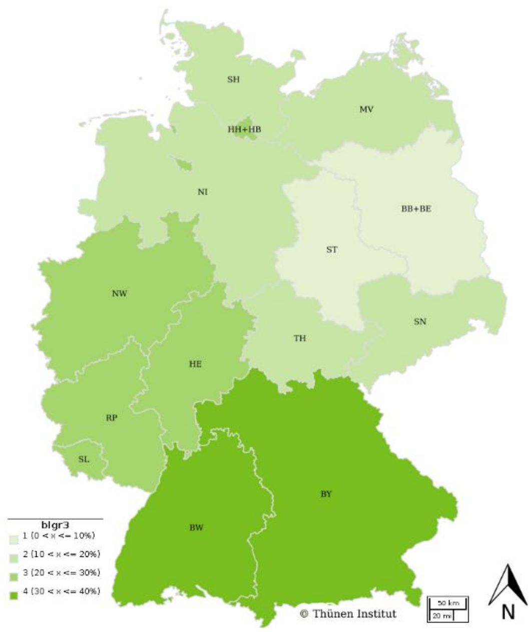

Figure 8: Share of Close-to-natural Tree Species Composition (FFI 2012)

forests and fir forests (Johann Heinrich von Thünen-Institut, 2012). However, the study reveals little information about the geographic distribution of these forests as the naturalness indexes are only available as aggregated values per state (Figure 8).

The only three states who publish information, albeit in a limited form, are BW, SL and SN. In BW, a report outlines the spatial modelling of the naturalness of tree species composition within the state-owned forests (Seebach, Michiels & Braunisch, 2020), however the machine-readable data is not openly available. For SL, the geoportal shows the number of trees per species for small pieces of state-owned forest land. Together with the open biotope mapping of the state, these datasets could be used to assess the naturalness of tree species composition. In a similarly complicated way, SN publishes information on the natural forest community and the present species as laid out in the section before through a system of codes (see Figure 7). This analysis shows that while data is published on federal level, detailed data on the naturalness of tree species composition is patchy at best, and to a large extent not openly available. A good starting point for better coherence could be the datasets of the Thünen Institute's tree species monitoring, based on Sentinel-2 observations. Given the number of trees per species in a selected area, calculations could determine the extent of the natural composition – if historical and climate change scenarios would be taken into account as well. This structured information could then feed into the forest resilience analysis for the potential EU monitoring tool.

4.2.2 Tree Species Selection Recommendation Tools

Recommendations on tree species selection are traditionally the task of local forest authorities. However, given the intensifying effects of climate change on habitat conditions, this task of forecasting has become more complex because the aim is to ensure that trees are planted in locations that fulfil good growing conditions also in the future, up to 100 years from today. To assist with species selection for specific sites, several initiatives have been set up, which is why I have chosen to add this criterion in the analysis (see Table 3[j]). There, I have analysed whether such public advice based on climatic prediction models exists per region in question. According to Bentrup and Dosskey (2022), decision support tool for tree species selection "should be intuitive to pick up and not require relearning how to use the tool" (p. 2).

At EU level, data on tree species selection for future scenarios is available through the EU-Trees4F dataset, however in a limited form due to the relatively undetailed resolution of 10 square kilometres (see Figure 5). Still, it can serve as a good basis for more accessible selection tools as a wide number of species and the whole European geographic extent is covered. Conversely, monitoring efforts on national level give very little insights in this regard, yet some states have pioneered this work: The states of BW, NRW, HE, ST and SH provide their own interactive tools for tree species selection. For instance, with the portal ‘waldinfo.nrw’, everyone can easily select a small piece of land by drawing on the map (see Figure 9). By choosing either a moderate climate change or a strong climate change impact, the user is shown the predominant habitat type in the selected area as well as the other existing location types in the area. This typification (as shown in the map through different colours, e.g. orange or green) are based on three different parameters: overall water balance, nutrient supply or base content of the soil and the vegetation period, namely the number of days with $\geq$ 10°C daily mean temperature (Geologischer Dienst NRW, n. d.). The portal then recommends different species as well as grouped species, in Figure 9 shown through the different numbers.

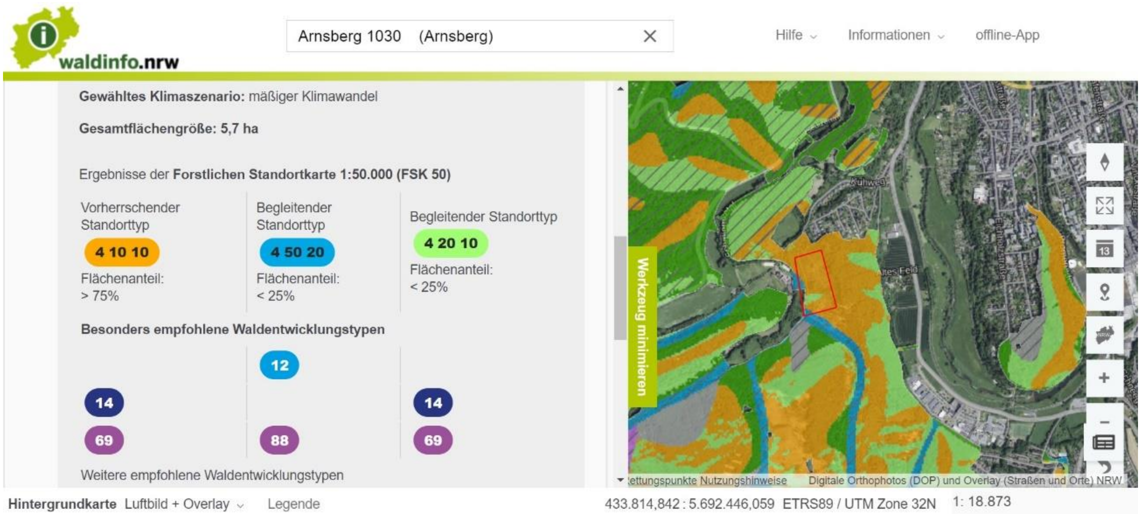

Figure 9: Screenshot of the Interactive Silviculture Recommendation Tool in the 'Waldinfo.nrw' Portal

For instance, for the orange area within the red selection frame, a grouping of oak with birch trees as well as pine trees are recommended when choosing a moderate climate change scenario. The different colours (light blue, dark blue and violet) indicate compatibility with the Habitats Directive, which prohibits the planting of non-native species in protected areas. For instance, the planting of the non-native douglas fir tree (as recommended in Figure 9 by the number ‘69’) is accordingly not allowed in protected zones. The portal also offers the possibility to show the suitability per species for all woodlands in the state. A representative of the European Forest Institute named the portal a “role model”, particularly for “small forest owners” (2024, Appendix IIIa). Similar portals have been set up in other states, while some states publish more limited guidance: The state of RLP only publishes very undetailed climate suitability maps, and in MV the information is non-interactively contained in a PDF report, hence limiting the regional applicability. Three states do not publish any recommendations on tree species planting.

To summarize, considerable data gaps have been identified through the analysis of this indicator group of tree species distribution. However, the methodology employed by the UFZ monitoring programme, if it were updated regularly and applied to the whole area of Europe, could be used to quantify resilience assessments. Specifically for a meaningful EU Forest Resilience Monitor, such information based on EO would need to be combined with datasets indicating ideal natural compositions of tree species according to different habitats, also considering the climatic conditions of the future. Naturalness mapping, however, remains a major challenge for all states.

4.3 Indicator III: Soil and water conditions

To make assessments on forest resilience, it is crucial to understand how individual ecosystems can withstand and recover from climatic disturbances such as drought periods. Soil and water conditions play a vital role in this assessment for several reasons: Firstly, the availability of nutrients is required for tree growth and regeneration which depends on the existence of soil that is rich in organic matter, minerals and microorganisms. Here, complex relationships between decomposers and the available biomass are still being researched (Gómez-Guerrero & Doane, 2018, p. 190). Secondly, the soil structure and composition directly affect root support and water retention and drainage capacities (Bronick & Lal, 2005). With climate change, forest soils are increasingly challenged during droughts and heavy rains, which can lead to soil erosion, hence decreasing resilience (Rodrigues et al., 2020). Furthermore, limited hydration or changes in the water supply of a forest ecosystem can similarly put pressure on the physiological functions of trees and other plants. In the case of droughts, groundwater levels and the replenishment of aquifers are crucial for sustaining forest ecosystems. In general, forests regulate water cycles, including transpiration, evaporation, and precipitation, contributing to stable local and regional climates. Forests with good water absorption and retention capabilities help in mitigating flood risks, protecting the ecosystem and surrounding areas from severe flood damage (Collentine & Futter, 2018). Forests with well-managed water resources also better withstand periods of drought, maintaining ecosystem functions and supporting species that are adapted to variable water availability. It is therefore important to look at soil and water conditions as interlinked entities as good soil structure improves water infiltration and retention, while adequate water availability enhances soil microbial activity and nutrient cycling. Yet, multiple threats to healthy forest soils persist, such as erosion by water, wind or harvesting activities. Anthropogenic effects also impact the soil's organic carbon content, the biodiversity of the soil, its compaction, and its sealing. Contamination of soils or the salinization or depletion of soil nutrients furthermore are challenges for forest soils.

	Indicator Type	Data existence (a)	Online availability (b)	Open license (c)	Timeliness (d)	Regular updates (e)	Machine readability (f)	Accessibility, ease of use (g)	Map feature (h)	Climate change scenarios (k)	Score	Average
EU (Copernicus Land Monitoring Service)	Soil moisture	Yes	Yes	Yes	Yes	Yes	Yes	Bad	Limited	No	72,22%	59,72%
	Land surface temperature	Yes	Yes	Yes	Yes	Yes	Yes	Bad	Limited		72,22%	
EU (Copernicus Climate Change Service)	Soil moisture	Yes	Yes	Yes	Yes	Yes	Yes	Very limited	No	Yes	80,56%	
	Climate variability	Yes	Yes	Yes	Yes	Yes	Yes	Very limited	No		80,56%	
	76 bioclimatic indicators	Yes	Yes	Yes	Yes	Unclear	Yes	Very limited	Limited		69,44%	
EU (ESDAC)	*EUSO Soil Health Dashboard**	Yes	Yes	Yes	Limited	Yes	Limited	Good	Yes	No	77,78%	
	Forest soil erosion	Limited	Yes	No	No (2006)	No	Yes	Bad	Limited		33,33%	
	Soil biomass productivity	Limited	Yes	No	No (2016)	No	Yes	Bad	Limited		33,33%	
	Soil Bulk Density	Limited	Yes	No	Yes (2024)	Unclear	Yes	Bad	Limited		44,44%	
	Topsoil physical properties	Limited	Yes	No	No (2009)	No	Yes	Bad	Limited		33,33%	
National												
DE (DWD)	Soil moisture	Yes	Yes	Yes	Yes	Yes	Yes	Good	Yes	Yes	100%	79%
	Soil temp. (5 cm)	Yes	Yes	Yes	Yes	Yes	Yes	Good	Yes		100%	
DE (Waldmonitor)	Water balance trend	Yes	Limited	No	Yes	No	No	Good	Yes	No	50%	
DE (BGR)	Soil water balance, root depth…	Yes	Yes	Yes	No (2014)	No	Yes	Good	Yes	No	66,67%	
DE (UFZ)	Soil moisture, soil drought	Yes	Yes	No	Yes	Yes	Yes	Good	Yes	No	77,78%	
State level												
BW	Soil moisture	Yes	Yes	Unclear	Yes	Yes	No	Good	Yes	No	55,56%	52,60%
BY	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Yes	22,22%	
BE	Soil moisture & temp.	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Limited	94,44%	
BB	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Limited	16,67%	
HB	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Yes	22,22%	
HH	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	Yes	22,22%	
HE	Soil moisture, groundwater level	Yes	Yes	Unclear	Yes	Yes	Yes	Good	Limited	Yes	83,33%	
MV	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	No	11,11%	
NI	-	Yes	Yes	Limited	Limited	Limited	Yes	Limited	Yes	Yes	77,78%	
NRW	Soil moisure, water balance…	Yes	Yes	Limited	Yes	Yes	Yes	Good	Yes	Yes	94,44%	
RLP	Groundwater level	Yes	Limited	Yes	No	No	Partly	Bad	Yes	Limited	50%	
SL	Soil moisture	Yes	Yes	Yes	No	No	No	Bad	Yes	No	44,44%	
SN	Plant-available water, Erosion	Yes	Yes	Limited	Yes	Yes	Yes	Good	Yes	Yes	94,44%	
ST	-	Yes	Very limited	No	No	No	No	Bad	No	Yes	25%	
SH	Water retention	Yes	Limited	Yes	No	No	No	Bad	Yes	No	38,89%	
TH	Plant-available water	Yes	Yes	Limited	Yes	Yes	Yes	Good	Yes	Yes	88,89%	

Table 4: Compliance of Soil Water Information Systems with the Open Data Criteria

The large number of challenges might be the reason why there are many different indicators employed at various policy levels. Table 4 summarises the compliance of different soil information systems with the Open data principles. As seen in the second column, the analysis includes various indicators and indicator groups that are related to soil moisture, although I was only actively searching for datasets on soil moisture and soil temperature. The different indicator types are all in one way or another measuring bioclimatic conditions or changes.

Institutions at EU level collect and publish large amounts of data, mostly thanks to earth observations by the Copernicus service. It provides comprehensive and accessible environmental data, including critical indicators such as soil moisture and land surface temperature. Soil moisture is expressed as a percentage of available water capacity and refers to the water remaining in a soil after it has been thoroughly saturated and allowed to drain freely (Zimmer, 2004, p. 71). The Copernicus climate change division also compiles secondary indicators and other datasets for climate change predictions. All these EU products are available online under an open license; with the notable exception of maps produced by the European Soil Data Centre (ESDAC) which must be manually requested. Data from Copernicus is also not only timely, but also regularly updated – almost daily. Again, at EU level, data by ESDAC is the exception which is outdated for some comprehensive soil analyses, such as the forest erosion map which is based on data from 2006. Still, ESDAC provides an important asset because it serves as a data pooling point for all soil-related data which translates, among others, into the EUSO Soil Health Dashboard, an interactive map of EU countries compiling the presence of 16 soil degradation processes that are likely to be present, in a resolution of 500m x 500m (see Figure 9, European Commission, n. d. [b]). While the EU level seems like the perfect fit to collect and publish such data in a streamlined format for all European regions, the ease of access is far from ideal and largely no map services are integrated (see Table 4 [g & h]). Still, almost all datasets are available for download and all geospatial data can then – at least in theory – be visualized on maps. However, this requires expert knowledge, a major barrier for the local utilization through citizens' action. Accessing forest soil data from EU level can be a tiring task: For instance, the data on soil moisture can only be viewed in a very outdated legacy portal or the

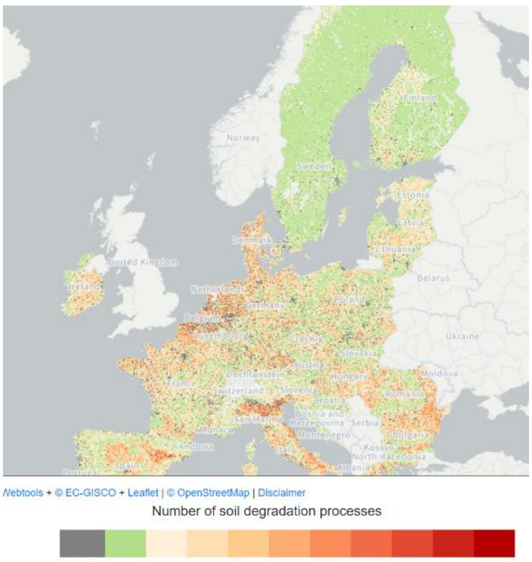

Figure 10: Screenshot of the EUSO Soil Health Dashboard

option to download the whole datasets exists, thereby effectively hindering individual citizens' information access.

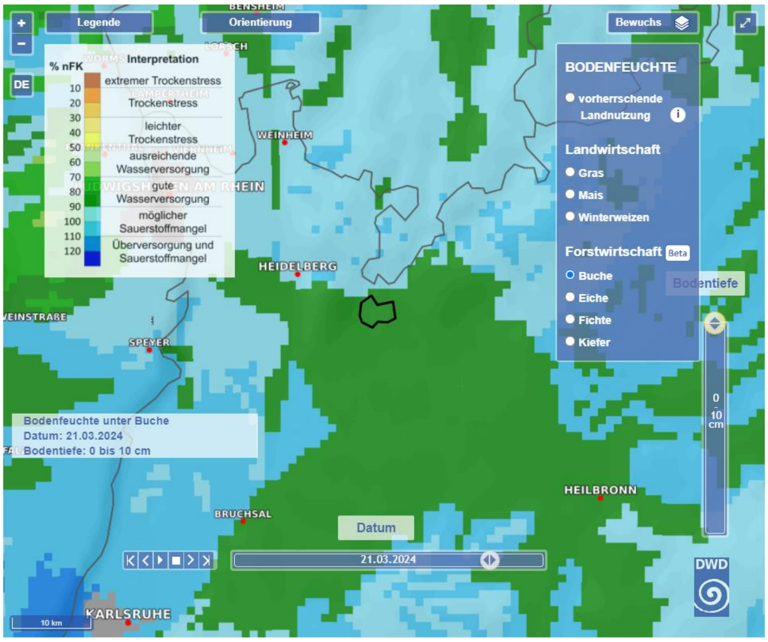

Figure 11: Screenshot of the DWD Soil Moisture Viewer

On federal level, soil moisture data is made available more easily by several institutions through data portals or dashboards. For instance, the *Deutscher Wetterdienst* (DWD, transl.: German Weather Service) offers an interactive soil moisture viewer that includes open and timely information on soil conditions in an accessible and machine-readable format. It includes a climatic forecast for soil moisture (for the next 2 - 5 weeks and 1 - 6 months), precipitation data, and other information on plant-available water and water storage. On a map, it shows the estimated soil moisture for cover with different tree species, indicating drought stress or water oversupply/ oxygen deficiency (see Figure 11).[6] DWD data is also published under an Open data license, which is also true for the geoportal of the Federal Institute for Geosciences and Natural Resources (BGR). Its usage is also quite easy and many interactive maps, such as on ground water levels and the water storage capacity are available – yet heavily impacted by being not up-to-date: Contrary to the DWD's daily monitor, the BGR maps service is based on climatic information from 1961 to 1990 and on CORINE land use data from 2006. In general, however, most data on soil and water conditions are provided timely and updated regularly, often daily. Most datasets are also available for download in machine-readable format or are published according to the OpenGIS® Web Map Service Interface Standard (WMS). For example, the DWD shares almost all their datasets in an open Climate Data Center with "various spatial, temporal and content filter functions to interactively compile a data extract from the station data for download" (DWD, n. d.). All four identified data providers in Germany also have set up interfaces that were coded as having a good accessibility and they all were shown with

[6] The soil moisture viewer can be found online: https://www.dwd.de/DE/fachnutzer/landwirtschaft/appl/bf_view/_node.html (Last accessed May 26, 2024)

integrated map features, explaining the high average scoring of 79 percent Open data compliance.

Turning to the state level reveals that the data needs are mostly satisfied by the federal data portals already and the regional monitoring stations are largely integrated into the federal monitoring structures. This might explain why five states do not process and publish soil and water condition datasets additionally. Still, some states are quite active in providing additional functionalities that are targeted towards the local needs. As regards forest resilience information needs, the soil moisture traffic light that has been developed in SN and TH is an example of that: Thanks to hydrological modelling, it provides up-to-date and historical information on the water content of forest soils for representative forest locations, also indicating the average soil water level over the last ten years for a given location (see Figure 11, Kronenberg et al., 2022). These long-term assessments are very important in resilience quantification (Müller et al., 2016). Other soil and water condition functionalities on state level are mostly linked to integrations to the states' geoportals – and these information systems generally are not as accessible, open and up to date as the information described before. Still, information systems on soil conditions generally comply with Open data criteria.

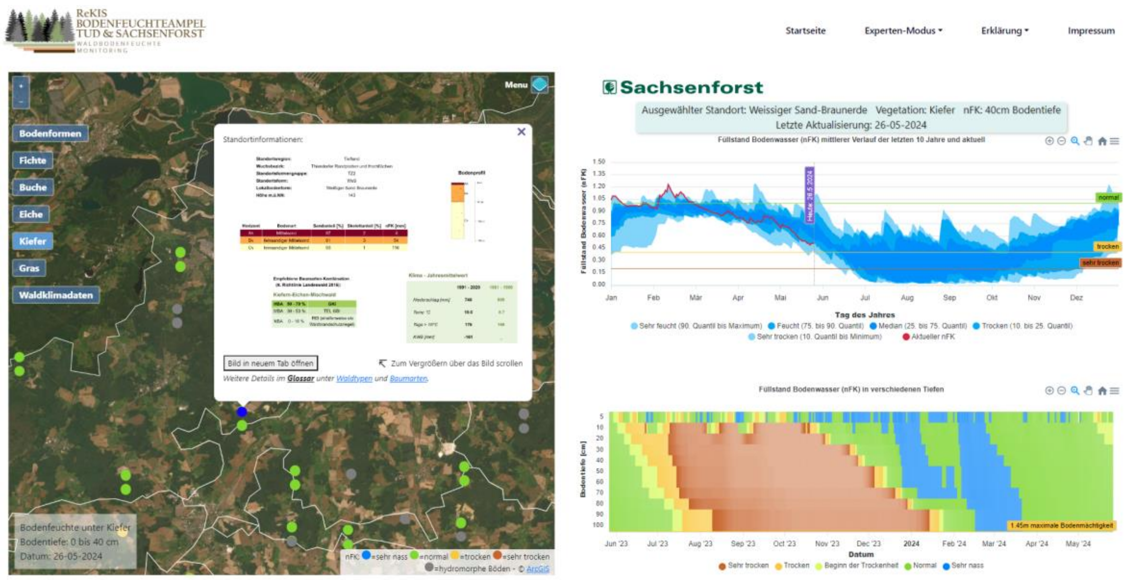

Figure 12: Screenshot of the ReKIS Soil Moisture Traffic Light Portal

4.3.1 Climate Change Scenarios

Table 4 also indicates whether information systems provide climate change predictions for the soil and water conditions of the future (column [k]). These predictions can influence the resilience of a forest, particularly if forests grow in a location in which the conditions will be considerably changed in the future, leading to erosion or other detrimental effects on forest soil. These climatic forecasting calculations are also the basis for species recommendations tools as discussed in section 4.2.2. At EU level, the Copernicus Climate Change Atlas provides projections based on different climate change scenarios for changes in temperature, precipitation and other key climate variables and for multiple datasets.[7] According to Buontempo et al. (2022), “[w]ith over 120,000 registered users worldwide, C3S [the Copernicus Climate Change Service] has rapidly become an authoritative climate service in Europe and beyond, delivering quality-assured climate data and information based on the latest science” (p. 2669). Similarly, the German Climate Atlas by the DWD shows the current deviation from historical climate records already today with predictions for future climate variables, such as air temperature and precipitation (DWD, 2024). Unfortunately, the climate change predictions in this federal monitor are only shown for the maps of the states, and one cannot utilize the current dashboard to zoom in on a detailed local context. However, nine of sixteen states have set up their own interactive climate change information systems: For instance, an online portal provides information on possible future climate developments in various regions of Bavaria up to the year 2100, also for the precipitation and temperature variables.

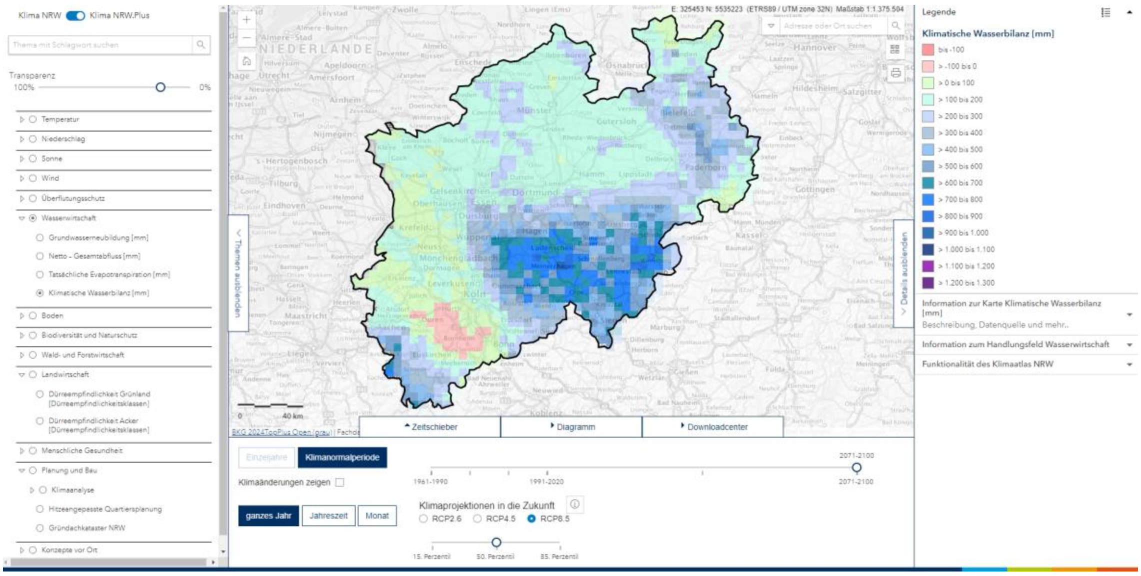

Figure 13: Screenshot of the 'Klima NRW.Plus' Portal on the Predicted Climatic Water Balance Changes for NRW in 2017-2100

NRW’s portal also contains even more predictions, including the mean climatic water balance in the actual forest growing season, the groundwater recharge capacities, actual evotranspiration, or drought sensitivity categories for forests, hence specifically tailored to the needs of forest managers and other stakeholders (LANUV, 2024, see Figure 13). For four states, no information systems are set up and for three only non-interactive maps

[7] The Copernicus Climate Atlas can be retrieved online: https://atlas.climate.copernicus.eu/atlas (Last accessed May 26, 2024.

and tables on climate predictions are available. This means that for these regions only the climate change predictors for precipitation and temperature as well as the associated variables by the Copernicus Climate Change Service and the DWD are available.

Generally, however, the information systems for soil and water conditions on EU level, but also within Germany, are very up-to-date and open and information on the climate of the future are easily available – to varying degrees of granularity according to which state is responsible. For both the states level and the federal level, the indicator group for soil and water conditions fares best with an average of 52,6 percent and 79 percent Open data compliance respectively. For the potential development of the EU Forest Resilience Monitor, this means that this category needs the least institutional changes in Germany, as most relevant data is already available openly and timely. The analysis has, however, shown that on EU level, the provision of Open data soil indicators other than moisture and temperature has room for improvement. Limited open licensing, outdated data and bad accessibility are connected to ESDAC. While the EUSO Soil Health Dashboard is its conceptualization a valuable tool also for the development of the Forest Resilience Monitor, the non-compliance of its base datasets with Open data principles, requires attention: In the political discussions around the Soil Monitoring Law, an integrated approach following the Open data principles will be key. Institutions such as the DWD, UFZ or even BGR on federal level could serve as model institutionalizations in that regard.

4.4 Indicator IV: Tree cover and canopy thinning

Data on the extent of forest cover refer to tree cover density, the extent of damaged canopy, and the general assessment of tree vitality. Information on such is accounted for on the global level through satellite observations (see Table 5). Following the methodology of Hansen et al. (2013) which mapped the extent of global forest cover for 2010, the Global Land Analysis & Discovery lab of the University of Maryland, Google, USGS, and NASA provide open access to the forest cover changes globally at 30 × 30m resolution. The datasets describe the density of tree canopy coverage in terms of global land surface. Data is continuously updated on the changes due to forest loss. Figure 14 shows a screenshot of the Global Forest Watch portal visualizing beforementioned tree cover observations. In red shade, the extent of lost tree cover over the years 2000 to 2023 is interactively and openly available. Datasets can also be found in machine-readable format for download. To supplement the recorded forest cover losses, Potapov et al. (2022), provide data on forest cover gains, however with a little time lag: data is only available for the period of 2000 to 2022.

	Indicator type	Data existence (a)	Online availability (b)	Open license (c)	Timeliness (d)	Regular updates (e)	Machine readability (f)	Accessibility, ease of use (g)	Map feature (h)	Forest Connectivity (l)	Score	Average
Global (Hansen et al., 2013)	Tree cover loss	Yes	Yes	Yes	Yes	Yes	Yes	Good	Yes	No	88,89%	**86,11%**
Global (Potapov et al., 2022)	Tree cover gain	Yes	Yes	Yes	Yes	Yes	Yes	Good	Yes	No	88,89%	
Global (Turubanova et al., 2023)	Tree height changes	Yes	Yes	Yes	Yes	Yes	Yes	Good	Yes	No	88,89%	
EU (Copernicus)	Tree cover density	Yes	Yes	Yes	Limited	Unclear	Yes	Good	Yes	Limited (2015)	77,78%	
National level												
DE (UFZ)	Forest condition anomaly index	Limited	Yes	No	Yes	Yes	No	Good	Yes	No	61,11%	**48,61%**
DE (Waldmonitor)	Forest vitality trend	Yes	Yes	No	Yes	Yes	No	Good	Yes	No	66,67%	
DE (FCS/Thünen)	Canopy thinning	Limited	Limited	No	Yes	Yes	No	Limited	Very limited	No	41,67%	
DE (BfN)	Habitat connectivity	Yes	Limited	No	No	No	No	Bad	Very limited	Limited (2012)	25%	
State level												
BW	Mean canopy thinning	Limited	Limited	No	Yes	Yes	No	Bad	Very limited	Limited (2013)	47,22%	**34,20%**
BY	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	Very limited	13,89%	
BE	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	No	11,11%	
BB	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	No	11,11%	
HB	-	Limited	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	No	5,56%	
HH	-	Limited	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	No	5,56%	
HE	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	Limited (2009)	16,67%	
MV	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	Limited (2002)	16,67%	
NI	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	Limited (2015)	16,67%	
NRW	Tree cover density, calamity areas	Yes	Yes	Limited	Limited	Yes	Yes	Good	Yes	Yes (2021)	88,89%	
RLP	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	Yes (2024)	22,22%	
SL	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	Limited (2009)	16,67%	
SN	Vitality changes	Yes	Limited	Yes	Yes	Yes	Yes	Bad	Yes	Yes (2013)	83,33%	
ST	-	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	No	Limited	16,67%	
SH	Forest cover changes	Yes	Yes	Yes	Yes	Yes	Limited	Good	Yes	Very limited (2001)	86,11%	
TH	Vitality changes	Yes	Limited	Yes	Limited	Yes	Yes	Yes	Yes	Yes (2015)	88,89%	

Table 5: Compliance of Canopy Information Systems with the Open Data Criteria and the additional Capabilities of Forest Connectivity

Furthermore, Turubanova et al. (2023) provide additional data on the height changes in tree canopy cover in Europe for the years 2001 to 2021, also accessible via the Global Forest Watch portal. However, also the EU is engaged in monitoring and mapping global forest cover through its Copernicus Land Monitoring Service: High Resolution Tree Cover Density data are available for the years 2012, 2015 and 2018, including data on the forest cover changes between these years, most recent data even available in 10 × 10m resolution (European Environment Agency, 2020b). While the data is not as up to date as the beforementioned datasets, the tree cover detection on EU level is still very useful. For instance, contrary to the soil and water condition mappings, the tree cover dataset is accessible via the Copernicus data viewer and hence easy-to-use.

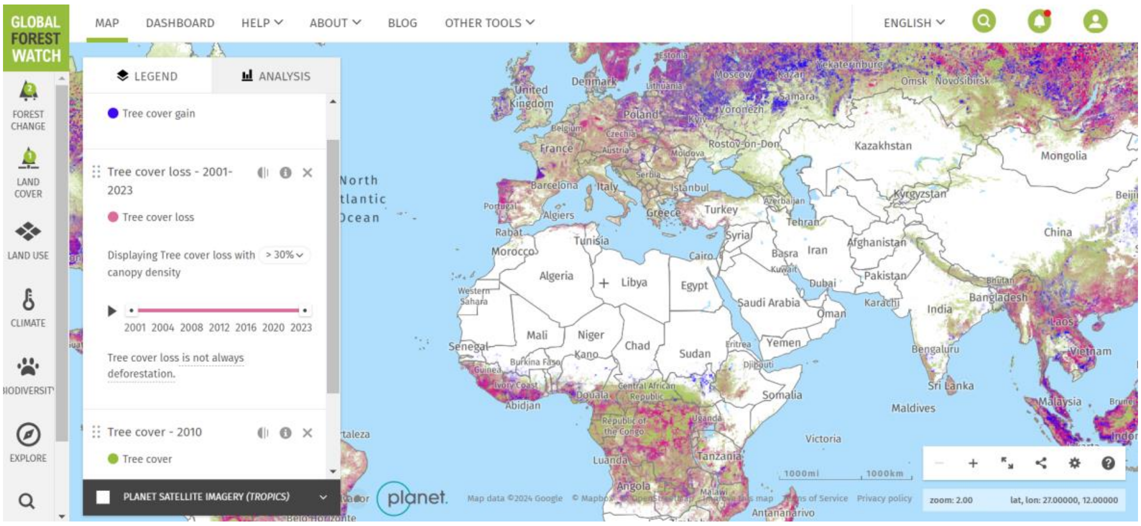

Figure 14: Screenshot of the Global Forest Watch Map on Tree Cover Loss (Hansen/UMD/Google/ USGS/NASA, accessed through GFW)

Additionally, maps are provided on German federal level. These yield more detailed information, such as the Forest condition anomaly index provided by the UFZ. In a timely and accessible way, it shows deviations of forest conditions from long-term observations since 2016, indicating positive as well as negative forest canopy anomalies, based on Sentinel-2 data (UFZ, 2024). The analyses are particularly relevant as they depict anomalies yearly, seasonally or even monthly, and the assessments can help to assess forest resilience in general. Similar information can be retrieved from the Waldmonitor which shows a forest vitality index, indicating damage events/wood removal in red and vitality improvements in green. Its analysis is also based on Sentinel-2 observations (Naturwald Akademie gGmbH, n. d.). In the official German Forest Condition Surveys, you can also find data on the extent of canopy thinning, however only in the form of PDF reports. The extent of canopy thinning is based on data from over 420 sample grids that are representative for the most important tree species in the country (Johann Heinrich von Thünen-Institut, 2024).

The results of these official statistics are, however, only limitedly accessible online as only aggregated values without a clear geospatial connection are disclosed, e.g. only aggregated values for the extent of canopy thinning per species per state. This does not disclose where the most harmed regions are exactly. Furthermore, none of these services are indicated as Open data. This has to do with the fact that this information is simply a collection of datasets collected at state level.

Here, while international reporting structures through satellite observations clearly show the data existence for all states, additional forest cover mapping by the state authorities is rare or not openly available: Only two states publish their data on forest cover. All other states simply publish annual reports on the state of forests. These reporting obligations are mostly covered by sample surveys that yield information on the average percentages of tree cover damages, such as canopy thinning. Due to the reliance on sample sites only, there is no complete geospatial information. In terms of coordination among the *Länder*, a common indicator for assessing the forest conditions has been agreed upon, namely the percentage of significantly damaged trees on the basis of canopy assessments with the following damage levels: 0=undamaged, 1= slightly damaged, 2= moderately damaged, 3= severely damaged, 4= dead. Referring to level 2 and higher, these values, based on the annual state reports on forest conditions, make up the harmonized forest condition indicator in Germany (LiKi, 2023, see Figure 15). How individual states draw up these values is, however, based on observations in sample sites that do not serve well the needs of a seamless forest resilience monitoring system that refers to all forests.

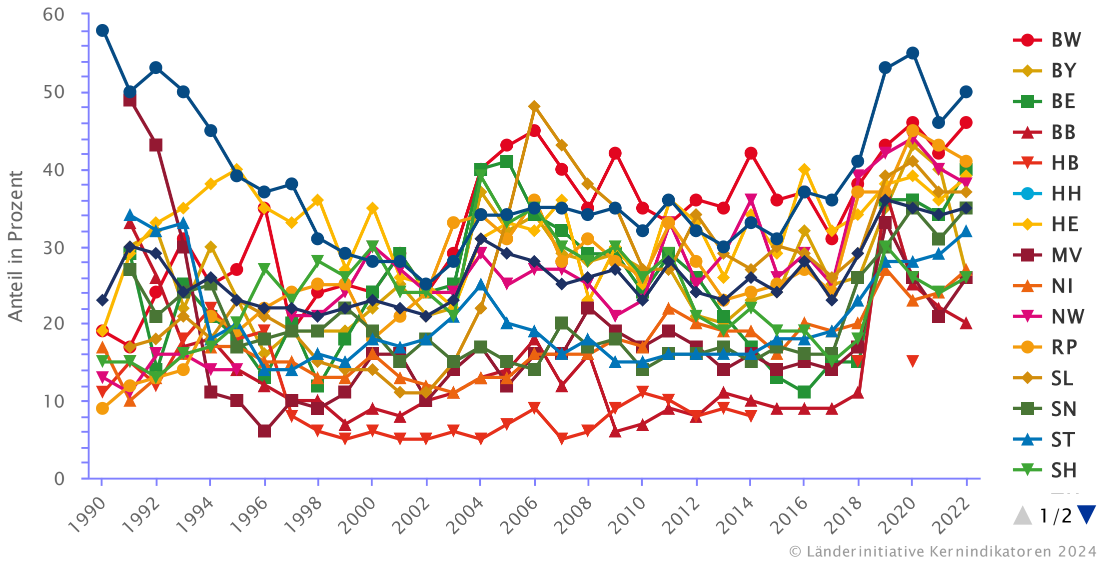

Figure 15: Percentage of Significantly Damaged Trees of Level 2 and Higher (combination damage level 2-4), (Source: LiKi, 2023)

Among the states, SH stands out with forest cover data available: In SH, based on Copernicus data, forest areas and their changes in the state were detected and displayed on maps using Artificial Intelligence (Schmidt, 2021). The results can be interactively viewed in the state's geoportal. Similarly, the 'waldinfo.nrw' portal in NRW, integrates the EU's Copernicus Tree Cover Density Monitor and in SN the results of the monitoring of damaged areas based on Sentinel-2 data can be accessed by all citizens in the state's geoportal. In TH, the forest cover analysis is connected to the data on tree species distribution as discussed in section 4.2.1 and as shown previously in Figure 7: Here, the state-wide forest condition survey was condensed to a 4 × 4km grid and harmonized to show the results in a timely and open way in the state's geoportal. The meaningfulness of that is, however, only limited as the data is restricted to the sample sites and not available for all forest areas.

In general, annual reporting duties for all states on the extent to which forest cover is damaged, the results are largely not openly available. This is in line with the statement by the representative of the forest agency in Brandenburg who mentioned that the phenomenon of non-published data occurs "en masse" in Germany (2024, Appendix IIIb). Eleven of 16 states do not publish the extent of forest cover or canopy thinning as a map-based service and every state faces some limitations, regarding either timeliness, accessibility or the availability of machine-readable data.

4.4.1 Forest Connectivity

As an additional indicator, I have included the availability of forest connectivity information in this regard. Information on the fragmentation of forest ecosystems is important as the dissection of landscapes, e.g. by streets, residential areas or other human structures, effectively limits the ability of forests to produce ecosystem services and depreciates their resilience. It also has negative effects on the accessibility of habitat for different species, hence negatively affecting biodiversity. This makes connectivity "an important element of resilience when managing ecosystems" (Craven et al., 2016, p. 506).

In this field, the Effective Mesh Surface Index has emerged as a parameter with high potential for analysing and evaluating the fragmentation of landscapes (Oehmichen & Köhl, 2006). For Germany since 2000, a report by the BfN indicates a "spatially differentiated increase in fragmentation" (Walz, Schumacher & Krüger, 2022). The assessments are largely based on the definition of large, unfragmented and open areas for habitats of a size of over 100 km² or 50 km² (Lassen, 1990). On this basis, the availability of such information on the respective policy levels is shown in column (l) of Table 5: On EU level, the EEA published an assessment of the effective mesh density and the corresponding connectivity assessments for European landscapes in 2015 (see Figure 15).

While the dataset is easily accessible and openly usable, potentially for an EU forest resilience monitor, the data takes not into account the newest available details: In the last 9 years, much infrastructure was possible added, contributing to an even higher fragmentation of forest landscapes. However, this could serve as an additional factor to take into account when designing the EU Forest Resilience Monitor.

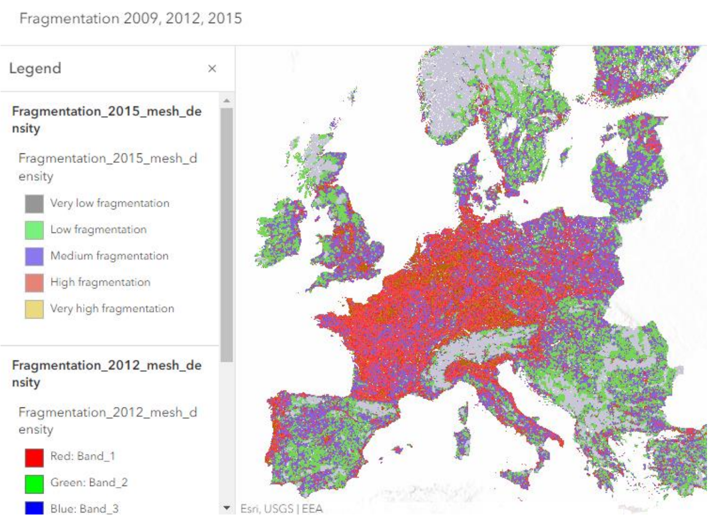

Figure 16: Screenshot of the EEA's Measure of Effective Mesh Density on Landscape Fragmentation in Europe (2015)

On the federal level, the network of forest habitats was surveyed in 2012 by the BfN and priorities for connecting habitat corridors were developed on the basis of supra-regional road network. Yet, since then no more updates have been published on federal level. The engagement of the *Länder* in providing such maps is different from state to state: four states do not publish any information on that, and most other datasets are even more outdated than the EEA's or BfN's maps, e.g. the information provided by the state of SH is from the year 2001. Positive examples come from NRW which publishes the data from 2021 in a dedicated web portal;[8] and from RLP where a map is available from the year 2023, referring to undissected, low-traffic areas.

In general, for data on tree cover, canopy thinning and connectivity of ecosystems, very good information systems on the global level are set up that comply with the Open data principles. However, the analysis of the German perspective showed some grave Open data inconsistencies. Here, the institutionalized Forest Condition Surveys focus on sample sites to measure the vitality and the extent of canopy thinning; but it is now possible with EO technologies to monitor all areas and supplement this information with *in situ* information. Yet, Germany seems to be unwilling to give up path dependencies on how forest monitoring is decentralized and organized among different stakeholders. The focus of forest information systems on federal level is not tree cover and tree cover loss, but more specifically the analysis of forest condition anomalies: The UFZ forest monitor is a

[8] Information on undissected low-traffic areas in North Rhine-Westphalia can be found on this dedicated website: https://uzvr.naturschutzinformationen.nrw.de/uzvr/de/start (Last accessed May 27, 2024).

good example of how EO technology can be integrated in forest monitoring. Unfortunately, this data is not fully integrated into forest monitoring processes. Restrictions exist in the provision of machine-readable data and open licensing which limits the further utilization of the information, e.g. in a potential EU Forest Resilience Monitor. On state level, the analysis has shown that despite annual reporting duties for all states, data on the extent of forest loss and forest vitality loss is rarely openly available and most information is compiled in PDF reports based on sample site results. Hence the state level was assessed with a low Open data compliance score of on average 34,2 percent while on global level all Open data criteria were fulfilled. The only aspect that is so far not taken into account here is the connectivity of ecosystems: on EU level, however, some assessments on the mesh density are available which could be integrated into resilience assessments.

4.5 Indicator V: Carbon Sequestration Capacity

The last indicator group refers to the capacity of forests to sequester carbon. In this regard, NFIs are relevant as they contain information on the growing stock of a forest (in timber volume in m^3/ha), or other biomass assessments. For woody matter such as stems, branches and roots the carbon share is about 50 percent, "which consists mainly of polysaccharides such as cellulose, lignin and hemicellulose" (Lamlom &Savidge, 2003; McGroddy et al., 2004; as cited in Neumann et al., 2016, p. 398). Generally, four classes of carbon storage in a forest can be distinguished: living biomass above and below ground, deadwood, mineral soil and litter cover (Klein et al., 2013). Via photosynthesis, carbon dioxide is removed from the atmosphere and bound as carbon in the biomass, such as the tree stems. Dead biomass supplies deadwood and the litter layer which subsequently create the mineral soil reservoir via humus formation. Through natural processes such as microbial respiration, forests can release carbon back into the atmosphere. This slow process is however most evident when wood is burnt. In that case, bound carbon is released. Yet in Europe, the carbon sequestered by forests has steadily increased over the last 50 years thanks to new silvicultural management strategies and multi-purpose forest policies (Ciais et al., 2008). The carbon storage potential is thereby impacted by tree species or different habitats. Often overlooked are the so-called substitution effects that occur through the use of long-lived harvested wood products, as carbon remains stored in wooden furniture for instance (Bösch et al., 2017). Based on investigations in Bavaria (BY), the carbon sequestration of one hectare forest in a suitable habitat makes up about 6.5 t CO^2 per year which can be compared to the annual emissions of about 1 to 2 persons living in BY (Klein et al., 2013, p. 63). According to the 2017 federal carbon forest inventory, 1.264 Mio. t of CO^2 is sequestered in all forests in Germany (Riedel et al., 2019, p. 16). These calculations are done for the reporting duties under the Kyoto protocol; and numbers might be even higher as only the top humus soil and the 30cm of the mineral soil below are considered in the inventory. Yet, the forest soil can go down to a depth of 90cm, including the humus layer (BMEL, 2024). This underlines the big potential of forests in fighting global warming. According to Mo et al. (2023), reforestation and restoration of degraded as well as the sustainable forest management could make available an additional 226 gigatonnes of carbon for sequestration globally. Biomass and carbon assessments are also closely linked to timber extraction and can serve as a proxy measurement. In Germany, timber extraction amounted to a total of 70.6 million cubic meters in the year 2023, 10.3% lower than in the previous year with 78.7 million cubic meters (Destatis, 2024). A bit more than half of logging was due to forest damage, but more generally timber extraction has been decreasing since 2020.

Turning to the analysis of information systems concerning carbon storage in forests, the detailed assessment can be found in Table 6. As shown in the second column, the indicator types encompass a range of measurements for evaluating forest carbon, including aboveground biomass and gross stock, which measures the total volume of timber or wood resources. Additionally, GHG emissions and carbon removals are tracked, alongside net flux, which indicates the balance between carbon emissions and absorption. Another crucial indicator is biomass density, reflecting the concentration of biomass in a given area. Soil carbon stock measures the carbon stored in soil, and carbon sequestration assesses the process of capturing and storing atmospheric carbon dioxide. These indicators are assessed in order to gain a comprehensive understanding of forest carbon dynamics, enabling informed policy-making and effective forest management practices. On average, the international/EU level sees the highest rates of accordance with the Open data principles (64 percent), with considerable Open data violations on German federal and state level. Particularly for the latter, carbon monitoring is still quite limited.

Globally, the availability of forest carbon assessments varies significantly across different organizations and platforms. The UN Economic Commission for Europe (UNECE), in collaboration with the Food and Agriculture Organization (FAO), publishes aggregate values for aboveground biomass, growing stock, and wood removals. This data, accessible through the UNECE/FAO website, is user-friendly and allows for easy comparison between countries and regions, although it lacks a geospatial component and is hence not suitable for map-based information needs.

	Indicator type	Data existence (a)	Online availability (b)	Open license (c)	Timeliness (d)	Regular updates (e)	Machine readability (f)	Accessibility, ease of use (g)	Map feature (h)	Score	Average
UNECE/FAO	Abovegr. biomass, Gr. stock, Wood removals	Limited	Yes	Yes	Yes (2020)	Yes	Yes	Good	No	81.25%	64%
GFW (Harris et al., 2021)	GHG emissions, carbon removals, GHG net flux	Yes	Yes	Yes	Yes ('01 - '23)	Yes	Yes	Good	Yes	100%	
	Abovegr. Live Woody Biomass Density	Yes	Yes	Yes	No (2000)	No	Yes	Good	Yes	75%	
NASA	Abovegr. biomass density	Incomplete	Yes	Yes	Yes ('19 - '23)	Yes	Yes	Good	Yes	87,50%	
EU (ESA/FCM)	Abovegr. biomass, Gr. stock volume	Yes	Yes	Yes	Yes (2021)	No	Yes	Good	Yes	87,50%	
EU (EC-JRC)	Carbon sequestration	Yes	Yes	Yes	No (2012)	No	Yes	Bad	Very limited	53,13%	
	Abovegr. biomass	Yes	Yes	No	No (2006)	No	Unclear	Bad	Very limited	28,13%	
	Above and below-ground carbon	Yes	Yes	No	No (2006)	No	No	Bad	Very limited	31,25%	
	EFA FRA CBM Data	Yes	Yes	Yes	Yes ('00 - '19)	Unclear	Yes	Bad	No	62,50%	
	Biomass density	Yes	Yes	Yes	No (2010)	No	Yes	Bad	No	50%	
National level											
DE (FFI/Thünen)	Abovegr. Biomass with sub-indicators	Yes	Yes	No	No (2012)	Limited	Limited	Limited	Limited	50%	44%
	Soil carbon stock	Yes	Yes	No	No (2006)	Limited	Limited	Limited	Limited	50%	
DE (GGI/Thünen)	Growing stock, carbon sequestration (aggr.)	Yes	Limited	No	No (2017)	Limited	Limited	Bad	No	31,25%	
State level											
BW	Soil carbon stock	Yes	Very limited	No	No (2008)	No	No	Bad	Very limited	18,75%	14,26%
BY	Soil carbon stock	Yes	Very limited	No	No ('06 - '09)	No	No	Bad	Very limited	18,75%	
BE	Above and below-ground carbon	Yes	Very limited	No	No (2010)	No	No	Bad	No	15,63%	
BB	Above and below-ground carbon	Yes	Very limited	No	No (2010)	No	No	Bad	No	15,63%	
HB	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
HH	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
HE	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
MV	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
NI	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
NRW	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
RLP	Soil carbon stock	Yes	Very limited	No	No ('06 - '07)	No	No	No	No	15,63%	
SL	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
SN	Carbon content top soil	Yes	Very limited	No	No ('12 - '14)	No	No	No	No	15,63%	
ST	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
SH	n.a.	Yes	No	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	12,50%	
TH	Carbon content biomass	Yes	Very limited	No	No (2010)	No	No	No	No	15,63%	

Table 6: Compliance of Forest Carbon Information Systems with the Open Data Criteria

More useful for local context analysis is data available on the Global Forest Watch portal which is based on research by Harris et al. (2021), The platform offers comprehensive data on forest GHG emissions, forest GHG net flux, and forest carbon removals for the years 2001 to 2023. It also provides an assessment of aboveground live woody biomass density, referring to the base year 2000. All these datasets are available in a machine-readable format with an open license, also providing automated geographical analyses (see Figure 16) and the option to keep updated on regions of interests – users are notified when changes in the respective forest region are recorded. While the data for aboveground live woody biomass density from GFW is outdated, a new monitoring regime by NASA provides recent data from 2023. This data offers a high resolution of 1 x 1 km, although it is limited to regions south of latitude 52.00, excluding areas in Northern Europe, hence its usefulness is rather low for an EU forest resilience monitor.

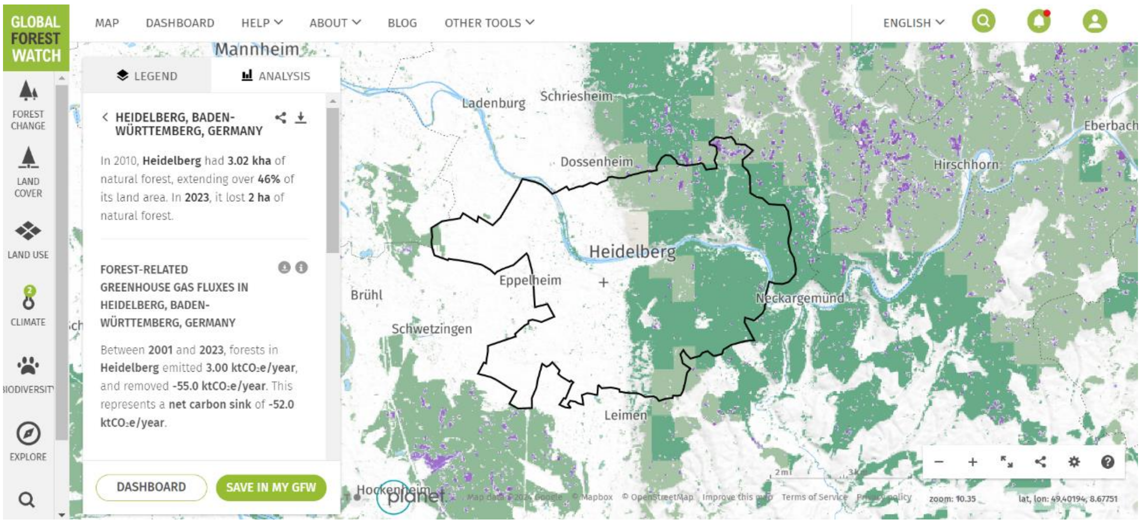

Figure 17: Screenshot Forest GHG Emissions View of the Global Forest Watch Portal

At the EU level, significant efforts have been made to report and monitor carbon data through organizations like ESA and the Joint Research Centre (JRC) of the European Commission. The ESA's Biomass Climate Change Initiative (Biomass_cci) has produced global datasets of forest above-ground biomass for the years 2010, 2017, 2018, 2019, and 2020, derived from a combination of earth observation data. These raw datasets are openly available. Complementing this, the EU-funded 'Forest Carbon Monitoring Project' has created an accessible prototype for carbon data mapping, providing an interactive and easy-to-use map that includes above and below-ground biomass, a biomass decrease mask, and data on the growing stock for 2020 and 2021, which can be easily viewed, downloaded, and used without restrictions. Figure 18 depicts the map view, easily making the zones visible where clearance considerably diminished a forest’s carbon sequestration potential.

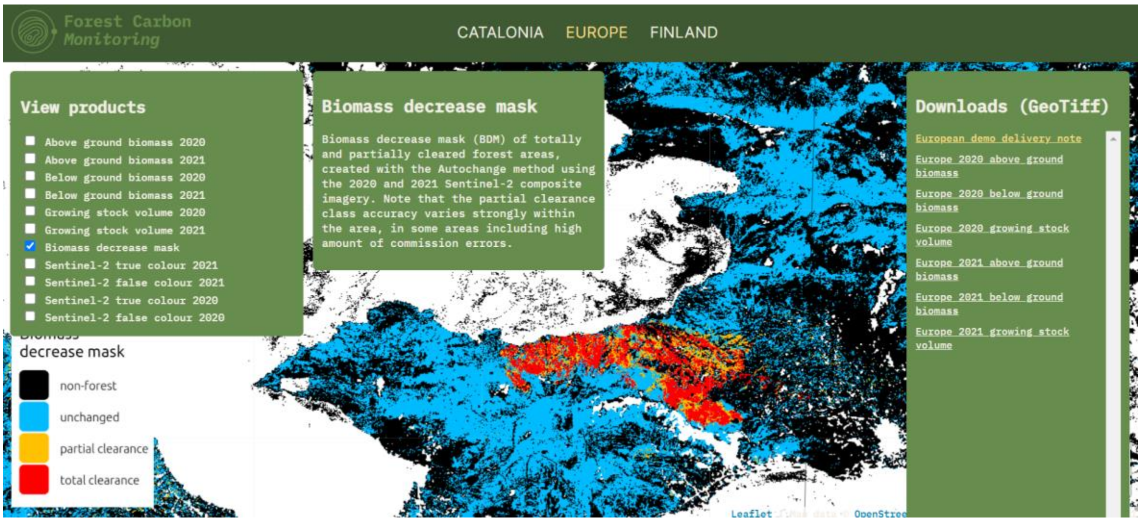

Figure 18: Screenshot of the Biomass Decrease Mask of the Forest Carbon Monitoring Project

Additionally, the JRC has published numerous datasets, such as the reported carbon sequestration capacities of 2012 by forests and woodland for the LULUCF statistics, integrated into an estimated 1 x 1 km grid cell mapping (Vallecillo et al., 2019); a map of living forest above-ground biomass following the IPCC Tier 1 method based on data from 2006 (European Commission, 2014a); a map that combines above and below-ground biomass and carbon stocks following the same methodology, also with data from 2006 (European Commission, 2014b); and a dataset that contains information on growing stock, increment, and removals of the EU for the years 2000 to 2019, which is part of a Carbon Budget Model but lacks a geospatial component for mapping (Pilli, 2021). Lastly, there is a forest biomass density map available at 100m resolution for the year 2010 (Avitabile, Pilli & Camia, 2020). The primary issues with these datasets are their outdated nature and their inaccessibility to non-expert users. Therefore, the EU's investment in the 'Forest Carbon Monitoring Project' is commendable, as it enhances public accessibility and usability of carbon data. Generally however, data provided on the GFW portal is more accessible and up to date.

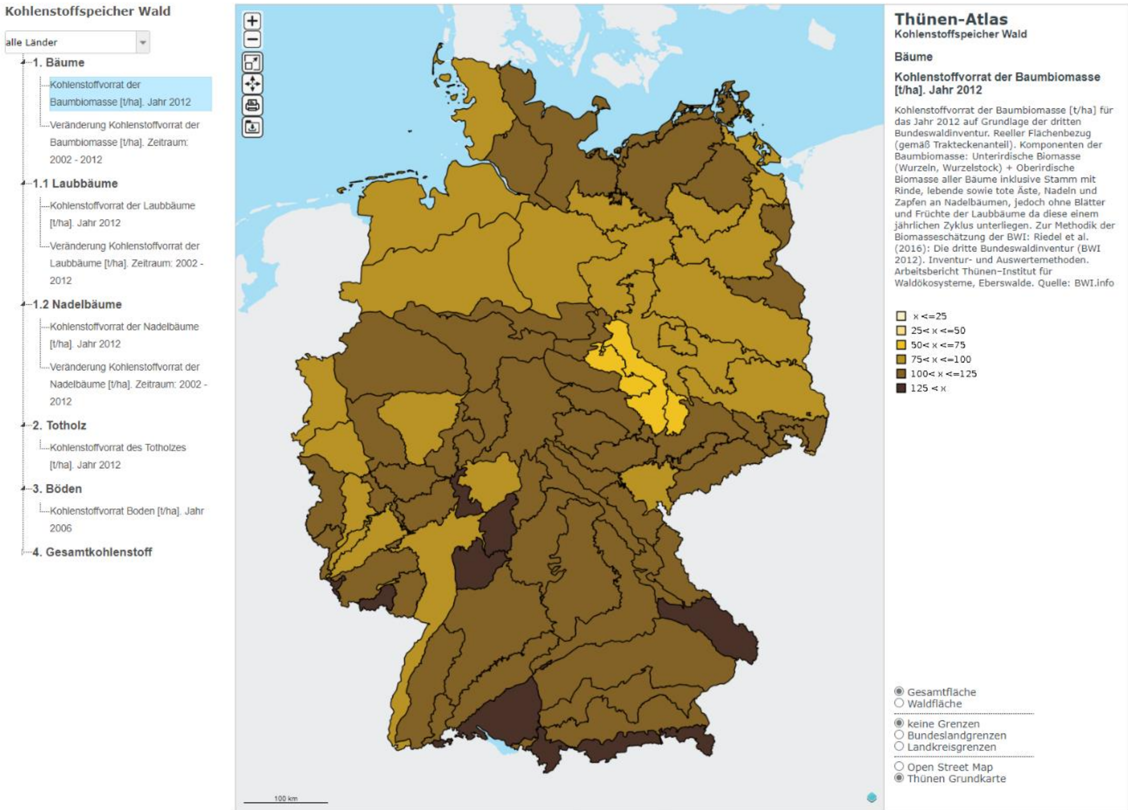

Figure 19: Screenshot of the Thünen-Atlas on Carbon Stock of Tree Biomass

Availability of forest carbon assessments in Germany on federal level is connected to the Thünen Institute which is generally responsible for accumulating forest data on the federal level in the frameworks of the FFI and the Greenhouse Gas Inventories (GGI). Corresponding to the FFI, Thünen Institute provides a map of the carbon stock of forests in tons/hectare for 2012, including changes to the year 2002 when the FFI was carried out before (see Figure 19). The results of the current survey are currently being assessed but will only be published later this year. The mapping provides for viewing and accessing data also for carbon stored only in trees (coniferous and/or broadleaved trees), deadwood, as well as for carbon in soil (data only from 2006). Unfortunately, the datasets only contain information on aggregate values for forest landscapes and do not contain more geospatial details. Datasets are also not all available in the corresponding data portal bwi.info and more specific carbon statistics would need to be manually requested at the Thünen Institute – clearly violating Open data principles. In terms of the GGI data, the data is provided in the same inaccessible web portal, however with no map functionalities available, yet a bit more recent with data from the year 2017. Datasets refer to the growing stock and the change thereof, the wood increment and timber harvesting, as well as data on deadwood. These *in situ* observations based on sample sites can be more accurate than assessments based on data collected through EO technology. These official statistics are, however, only available as aggregated values per state and hence not very helpful for a potential EU Forest Resilience monitor which requires detailed geospatial information. For these federal datasets, the same restrictions in terms of Open data principles apply as mentioned before. Accordingly, information on the capacity of forests to store carbon is hardly openly available openly through institutions at the federal level. Even more scarce is the situation in the *Länder* where only seven states provide some information online, all classified as ‘very limited’. None of these are machine-readable, published under an open license, up-to-date or are easily usable. Most information is restricted to reports that show local trends and are connected to model projects or sample data collection sites.

To sum up, carbon sequestration assessments are most effectively carried out on an international scale, as EO technology can take on this task quite well. Here, Open data criteria are fulfilled and relatively recent data is available – yet not in NRT. The same applies to the European Commission which has set up its own forest cover mask and projects in forest carbon mapping. Here, Open data challenges persist, particularly on terms of timeliness and ease-of-use. Germany faces even bigger restrictions and datasets cannot be considered as openly available. The latest data by the Thünen Institute is from 2017 and only limitedly available. Even more restrictions apply for the states whose involvement in carbon quantifications from forests are even more limited.

4.6 Summarized results: Open data Compliance Analysis

Firstly, bird monitoring across Europe revealed a mixed picture in terms of Open data compliance. While overall compliance is highest at EU level, the EU itself is not directly involved in data collection processes. Instead, data is collected by the *Länder*, which generally exhibit low Open data compliance, scoring only around 25%. These states report their data to the federal level (BfN), which subsequently distributes the data to the EU level. As there is no mechanism for states to provide their data directly to the EU in NRT, the reporting process is hampered by time lags. Moreover, there is limited knowledge about bird populations in non-protected zones, such as forests under general management, as reporting obligations mostly exist for protected Natura 2000 zones and are based on sample plots. The development of an EU Forest Resilience Monitor, which includes bird biodiversity as one of its indicators, faces significant challenges under the current system. Although the existing EU indicator on richness of forest-related species is a good fit, it requires more frequent updates: Individual *Länder* should be enabled to share their data directly with the European Commission through a pan-European monitoring system. Furthermore, integrating general observation data from portals such as ‘ornitho’ could enhance the timeliness and comprehensiveness. As it stands, bird biodiversity indicators are not well-suited to represent NRT data on forest biodiversity. This inadequacy limits accurate forest resilience quantifications.

Secondly, information systems on the actual distribution of different tree species are generally heavily restricted by Open data violations. Information systems on EU level are so far not capable of showing the occurrences of tree species based on satellite data alone and this analysis is here limited to the distinction between coniferous and broad-leafed trees. In Germany, datasets by the Thünen institute and the associated map make the dominant species class of nine trees visual and available in machine-readable format, however the map does not include the changes after the 2018 drought and is therefore not yet fit for NRT monitoring. The *Länder* themselves are quite reluctant to make available tree species distribution maps openly, but good practices include NRW & the city tree portal of Berlin as well as the geoportal in TH with limited accessibility. These datasets could feed into an EU Forest Resilience Monitor directly. To make a meaningful impact within such a monitor, data on the actual distribution would need to be combined with ideal states of natural composition, also considering the climates of the future. Efforts to prepare forest ecosystems for the climatic challenges of the future are, however, present in most states in Germany, often through specific tree species selection tools. The underlying analyses could be used to establish the ideal naturalness targets.

Indicators in the field of soil and water, the third indicator group of this study, are widely implemented and ready to utilize in the scope of a potential EU Forest Resilience Monitor, although more specific datasets, such as on erosion or soil densities require a more structural and accessible approach, ensuring better timeliness. This should be targeted in the discussions surrounding a European soil monitoring law in the next EU legislature. Meanwhile, geohydrological datasets follow the Open data principles quite well in Germany both on the federal level and in the states, scoring high average values compared to the other indicator groups. Good examples include the DWD's 'Climate Data Center' with a wide range of open datasets, and regionally implemented projects such as the soil moisture traffic light. Particularly relevant in this context is also the wide availability of climate adaptation portals or scenario forecasts that have been developed all over Germany, indicating the climatic conditions of the future in a regional context. Dramatic regional changes in temperature and precipitation directly influence the resilience of forest ecosystems and hence must be considered when designing a coherent monitoring system.

Table 7 shows all the scores in a synthesized view, indicating Open data compliance best at EU level, and lower compliance rates at German federal level, with notably good scores by the states of NRW, SN and TH overall.

	Bird Species Occurrence		Tree Species Distribution		Soil Water Conditions		Canopy Cover		Carbon Sequestration		TOTAL AVERAGE
	Score	Average	Score	Average	Score	Average	Score	Average	Score	Average	
EU		60,88%		55,00%		59,72%		86,11%		64,00%	**65,14%**
DE		56,25%		45,63%		79,00%		48,61%		44,00%	**54,70%**
State level											
NRW	43,75%	25,00%	70%	35,78%	94,44%	52,60%	88,89%	34,20%	12,50%	14,26%	**61,92%**
SN	81,25%		15%		94,44%		83,33%		15,63%		**57,93%**
TH	12,50%		65%		88,89%		88,89%		15,63%		**54,18%**
BE	19,53%		75%		94,44%		11,11%		15,63%		**43,14%**
SH	37,50%		20%		38,89%		86,11%		12,50%		**39,00%**
RLP	46,88%		47,50%		50%		22,22%		15,63%		**36,45%**
NI	37,50%		37,50%		77,78%		16,67%		12,50%		**36,39%**
HE	21,86%		37,50%		83,33%		16,67%		12,50%		**34,37%**
BW	25%		22,50%		55,56%		47,22%		18,75%		**33,81%**
HH	25%		62,50%		22,22%		5,56%		12,50%		**25,56%**
SL	6,25%		37,50%		44,44%		16,67%		12,50%		**23,47%**
ST	18,75%		20%		25%		16,67%		12,50%		**18,58%**
BY	12,50%		25%		22,22%		13,89%		18,75%		**18,47%**
MV	18,75%		12,50%		11,11%		16,67%		12,50%		**14,31%**
BB	0%		15%		16,67%		11,11%		15,63%		**11,68%**
HB	0%		10%		22,22%		5,56%		12,50%		**10,06%**

Table 7: Synthesized Open Data Compliance Scores

In terms of tree cover and vitality, also regional discrepancies in Open data provision were detected. Global tree cover and ecosystem monitoring systems adhere to Open data principles, but Germany's approach shows significant inconsistencies. While global systems leverage EO technologies for comprehensive monitoring, Germany still largely relies on traditional, decentralized Forest Condition Surveys focusing on sample sites, limiting data integration and accessibility. Despite tools like the UFZ forest monitor, Germany's forest monitoring data is not fully integrated or openly licensed, hindering broader utilization. At the state level, annual reports on forest loss and vitality are often limited to non-machine-readable PDF formats, resulting in low Open data compliance (34.2%). While global data sets, like Hansen et al.'s forest change data and Copernicus's Tree Cover Density data, are ready for integration into an EU Forest Resilience Monitor, German state-level data remains underutilized. Improved Open data practices could enable matching local sample data to broader forest conditions, enhancing resilience monitoring efforts.

Finally, the analysis of information systems in the field of carbon storage revealed that the global level is already carrying out carbon quantification assessments on forests according to the Open data criteria. This means that data is available for a potential EU Forest Resilience Monitor already, with a few restrictions in terms of timeliness. More local assessments of the carbon capacity in the German states are very outdated and not very helpful; and the carbon assessments on federal level are also quite unfit for the task of geospatial forest monitoring. Here, also a number of Open data violations have been observed. Still, EO technology and the EU's capacities in that regard could be integrated in a resilience monitor, taking into account the findings of the Forest Carbon Monitoring Project.

Based on this extensive analysis, the initial part of the research question, namely to what extent data on forest resilience in forest information systems in Germany is publicly accessible, can be answered: The extent to which Open data compliance is achieved varies across different regions and indicator groups. In terms of regions, forest information systems provided on EU level or by international organizations score best on all indicator groups, except for soil and water conditions. Here, the federal level scores better. On average, the states have the lowest scores concerning Open data compliance. Forest information systems in NRW and SN, however, score on average better than the federal level (see Figure 19). In terms of indicator groups, open data compliance has generally not reached its full potential across all indicator groups, with particular limitations in the biodiversity areas of bird monitoring and tree species distribution, with the best values scoring only around 61 percent and 55 percent respectively.

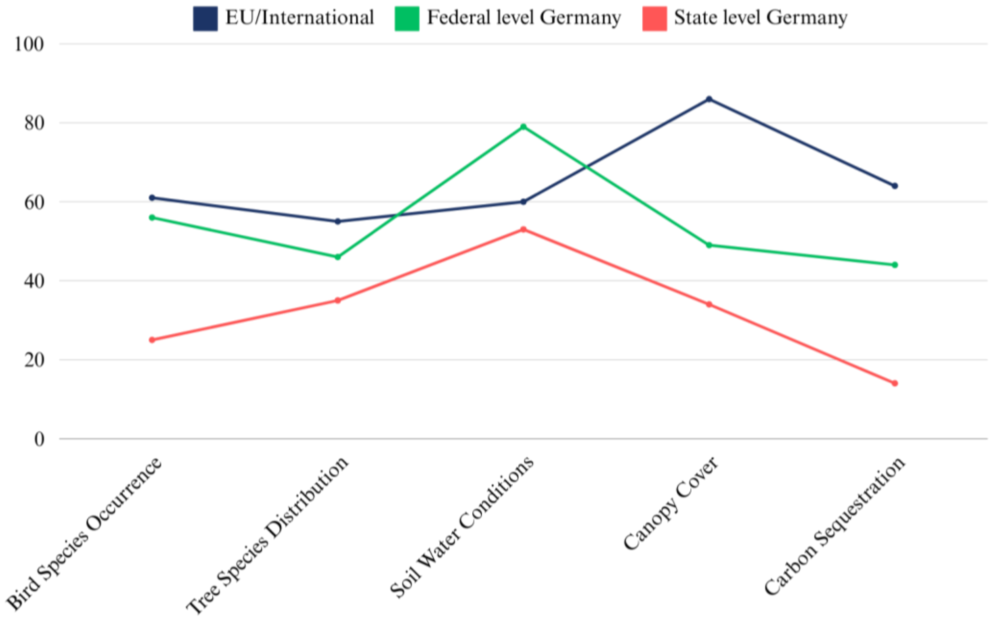

Figure 20: Visualization of the Open Data Compliance Scores

Before discussing these findings in the context of the design and the establishment of an EU Forest Resilience Monitor, more findings on the German case can be summarized that go beyond answering the initial research question: Firstly, good practices of open forest data monitors are already implemented, e.g. through the ‘Waldinfo.NRW’ portal on state level, the DWD ‘Climate Data Center’ on German federal level or ESA’s Biomass Climate Change Initiative on European level. Secondly, discrepancies in Open data provision are structural as the German states are responsible for most forest policies and they manage most forest information systems. Thirdly, Germany relies on traditional forest condition surveys carried out independently by the *Länder* which focus on sample sites. EO is only integrated into these monitoring duties in patches across states. The following section will explore in detail what these findings mean for the potential development of an EU Forest Resilience Monitor.

5 Discussion

The discussion section sets the findings from the Open data compliance assessment into perspective in line with the second part of the research question, focusing on how shortcomings of open accessibility could be overcome, and what sort of European Forest Resilience Monitor could be established. Therefore, I will start by briefly discussing the desirable functionalities and target user groups of such a tool. Having established such a vision, I discuss the repercussions of the analysis of the German case for the monitor in more detail. Specifically, I turn to the specific data sources in the five analyzed indicator groups, and how they could interact. Finally, I will more broadly discuss the structural governance components of Open data violations in the forest policy field, turning to the EU, the federal and the states level. From my findings, I aim to give some practical recommendations on how Open data compliance could be enhanced respectively.

5.1 Functionalities and Target Groups of an EU Forest Resilience Monitor

Assuming that the technological artifact of the monitoring tool was to include the five indicator groups described in this thesis, functionalities could include a range of features. The monitor could show birds, and potentially other animal taxa, present in an area, indicating whether abundance is decreasing or increasing and laying out potential reasons for negative developments. On a policy-making level, it could inform better environmental conservation strategies, identifying important migratory routes of fauna and flora, connecting habitats and species while considering future climatic projections. This could be better achieved as an Open data monitor lays bare the degree to which climate change and human land use already affect our forests today, increasing transparency and allowing the public to act as watchdogs for the successful implementation of ecosystem restoration projects. The monitor could also include specific advice for forest owners, such as recommendations on tree species or other site-specific recommendations for increasing the water retention potential of soils to avoid erosion effects Europe-wide and identify forest areas where specific management could help to minimize flood risks. Additionally, the forest resilience monitor should more generally serve educational purposes for the local population, giving them knowledge about their nearby forests. If local citizens are well-informed about the challenges in neighbouring forests, they will be more active in community exercises such as the planting of seedlings or watering efforts during drought periods, contributing to forest resilience. In terms of tree cover and vitality, the monitor could offer actionable insights for active management to increase the health and vitality of forest ecosystems.

Furthermore, Open data is already playing a role in uncovering environmental crimes through the actions of dedicated NGOs. However, an easily usable monitor would make the instruments to detect such practices available to everyone. Timber extraction and harvesting interests can be united with sustainable management if only selected trees are extracted and trees are left behind that can quickly rebuild a resilient forest ecosystem (Interview with representative European Forest Institute, 2024, Appendix IIIa). However, the extent of nature exploitation, for instance by furniture giant IKEA, is often unknown and requires intensive media work, for instance by a TV documentary last year (ARTE DISTRIBUTION, 2023). With a Forest Resilience Monitor, the mass cutting through large-scale silviculture operations could more easily be made public, adding to such communication efforts. Finally, functionalities could include the monitoring of the carbon budgets set out in the legislation of the EU's Green New Deal, indicating which forests are best suited for implementing management decisions that lead to a better carbon sequestration capacity, as increasing the carbon stock requires active management. Such a monitor would also provide a better overview of local timber and biomass availability, which is essential for meeting the future demands for heating or use in bio carbon fuel. By incorporating these functionalities, such tool could enhance forest resilience through greater public engagement and transparency.

The EU Forest Resilience Monitor could serve a diverse range of stakeholders, with citizens and local communities being primary users. Local communities and citizens could benefit from the monitor, if accessibility was a major focus in the design process. The final tool could be utilized to gain increased awareness and education about nearby forests, biodiversity, and the importance of sustainable forest management. Community groups could engage in local conservation efforts, directly contributing to forest resilience. Policy makers and government agencies at both the EU and national levels would also be significant users. Based on the openly shared input data, they could utilize the monitor to ensure compliance with environmental regulations, assess the effectiveness of current forest management policies, and make informed decisions about future legislative measures. Local forest authorities could use the monitor for planning and implementing localized forest management strategies and conservation projects. Public and private forest managers could receive site-specific recommendations for sustainable practices, while private forest owners would have access to practical advice on tree species selection, soil and water management, and carbon sequestration techniques. This is particularly relevant in the context of largely fragmented ownership (Interview with representative BrandenburgForst, 2024, Appendix IIIb). Environmental organizations and NGOs could leverage the monitor to track biodiversity changes in species populations and identify critical habitats and migratory routes or uncover and report environmental crimes, advocate for policy changes, and engage in ecosystem restoration projects.

Researchers could find the monitor an essential tool for accessing comprehensive data needed for studies on forest resilience, climate impact, and biodiversity. Potentially, also business and industry stakeholders, particularly those in the timber and biomass industries, could even benefit and use the monitor to ensure sustainable harvesting practices and to plan for future biomass needs. Sustainable business initiatives could integrate forest resilience data into their sustainability strategies and corporate social responsibility programs, such as the existing licensing schemes such as FSC or PEFC. Lastly, educational institutions could employ the monitor as a teaching tool to educate students about forest ecosystems, biodiversity, and environmental stewardship. By serving these diverse user groups, with a primary focus on citizens and local communities, the EU Forest Resilience Monitor would play a critical role in enhancing sustainable forest management and increasing forest resilience.

5.2 Potential Data Inputs for an EU Forest Resilience Monitor

Following the data flow for an interactive web-based NRT forest monitoring system (Pratihast et al., 2016), as introduced in the theoretical background section, data sources for the potential EU Forest Resilience Monitor can be based upon EO imagery input and on direct observations, be it through systematized surveys or through decentralized citizens observation inputs. In the following, I discuss the potential data inputs for a forest resilience mapping tool, based on the findings of the analysis on the five indicator groups.

For the biodiversity component, trends on the abundance of a range of species indicate increasing or diminishing resilience of specific ecosystems. The EEA's richness of forest-related species and habitats indicator would be an ideal data input, however major time lags and information limitations in terms of non-protected zones limit its meaningfulness. Still, EUNIS and the Natura 2000 information systems, that are the basis for the beforementioned indicator, provide an important source for the EU Forest Resilience Monitor as biodiversity indictors are so far not included in most other forest resilience monitoring tools. However, one could also tap into the potential of crowdsourced bird monitoring data in the 'ornitho' framework. Possible points of data access are the DDA's 'Birds in Germany' portal (which so far does not provide data in machine-readable format openly), and the 'EuroBird' portal by the EBCC which is still in its development phase. Both information systems could look to the 'iDA' database in SN which provides bird monitoring data in open and machine-readable format. Hence, several coordinated steps are still necessary to gain a reliable NRT information basis on the occurrence of individual bird species as well as aggregate species indeces. In terms of tree species distribution, Thünen Institute, UFZ and RSS provide tree species monitoring systems based on EO datasets, mostly through Sentinel data. However, timeliness is a major obstacle here.

Nevertheless, the methods employed could be used not only for Germany, but also for a Europe-wide assessment. Still, only knowing the dominant tree species is only of limited importance for resilience quantifications, as more structural information on accompanying species, the extent of canopy closure/tree density and information on the tree growing phases impact such assessments. From a climate adaptation viewpoint, biotope scenarios that are based on climate suitability projections (e.g. through the EU-Trees4F projects) are very relevant in formulating the desired target conditions. However, such biotope mapping is done differently across states in Germany and is often very inaccessible, outdated and not available in machine-readable formats. Considerable knowledge gaps exist as EO information systems and systems that rely on *in situ* data are not interlocked. Hence, the best data input for the EU Forest Resilience Monitor would come from integrating the dominant species measurements based on Sentinel-1 and -2 imagery. Where interoperable data on the naturalness and species diversity targets exists, this should be taken into account, yet more efforts in standardization of such information is needed to have in place a Europe-wide framework.

Measuring the soil and water properties of the land surface is already well established in the EU, and more specifically in Germany. Datasets that can be utilized for an EU Forest Resilience Monitor are readily available at the Copernicus Land Monitoring Service (Soil moisture and Temperature) the Copernicus Climate Change Service in terms of associated changes in the future through climate models. This can be reflected in resilience quantifications as well: Forest areas that are in locations where climatic conditions of water availability and mean temperature will be considerably changed in the future, and which do not exhibit environmental adaption (e.g. in more heat robust tree species) could receive lower resilience values. To better assess soil health, the existing EUSO Soil Health Dashboard by ESDAC could be integrated into the resilience monitor, however updated base data would need to be collected first. In that regard, specifically relevant is data on erosion, soil bulk density and topsoil properties that indicate forest resilience. Generally, however, data sources on climate and soil are most ready at EU level already.

In general, in the area of tree cover assessments, many tools and monitoring strategies are already implemented that can be used in the EU Forest Resilience Monitor. Global forest change data by Hansen et al. as well as the High Resolution Layer Tree Cover Density by the EU's Copernicus Land Monitoring Service are available for an integration into such a resilience assessment tool. But also, the data from the sample sites of the German official monitoring schemes could be utilized further: By publishing the data collected on state level openly, forest vitality data could be matched to all representative sites. This means that the results from the local sample monitoring could feed into an index that can be applied to all forest sites that showcase similar climatic or silvicultural conditions. This could be important in balancing bias that might come from EO data sources. Simply defining higher tree density with higher resilience is a wrong assumption as this can also refer to densely planted monocultural sites. Conversely, sites with sustainable management practices might even exhibit lower tree densities as selected trees are felled, leaving behind only some trees that can then build up a diverse forest again. Finally, the EU Forest Resilience Monitor could also be based on the analysis of the effective mesh density on undissected habitats. Fragmented forest ecosystems would likely be assessed with lower resilience values as they are more exposed to changes, e.g. through erosion and limited fauna and flora connection. On EU level, updated assessments are required in this regard as the last version displays information from 2015.

Figure 21 summarizes all recommended data inputs for the EU Forest Resilience Monitor, notwithstanding that some of these are not yet ready for implementation.

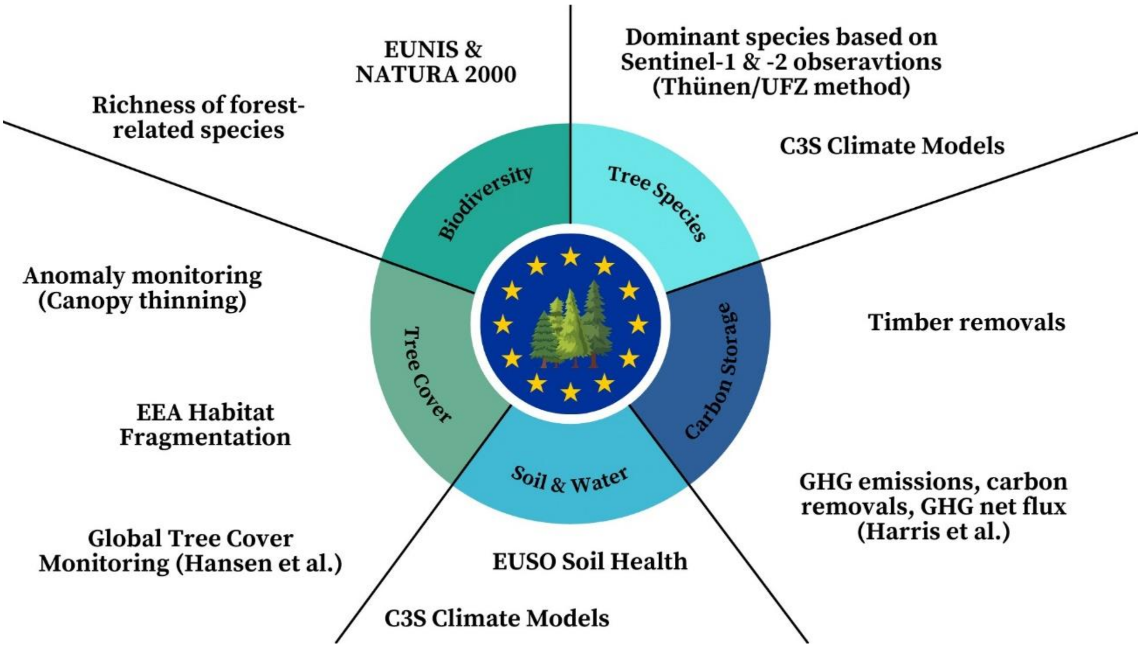

Figure 21: Recommended Data Sources for an EU Forest Resilience Monitor

Finally, the carbon sequestration potential of forests is best summarized through EO data by the ESA's Biomass Climate Change Initiative, and by datasets on GHG emissions, carbon removals, and GHG based on Harris et al. (2021), via the Global Forest Watch map. Both could be used as potential data sources for an EU Forest Resilience Monitor. Inaccuracies of measurements through EO could be balanced with the data that is collected on the ground on state or federal level in Germany. So far, data on the timber removals cannot be displayed as a geospatial form, because they are only collected in aggregate forms per state. Stricter legislation, as already formulated to some extent in the EU Regulation on Deforestation Free Products, might potentially make an origin mapping of timber possible. This information could then supplement the resilience monitor.

5.3 Repercussions for Muli-Level Governance

The analysis has identified some data gaps for the quantification of NRT assessment of forest resilience. The case of Germany exemplifies that many actors on various policy levels are involved in monitoring strategies, that follow Open data practices very differently. According to the representative of the European Forest Institute, forest inventory data continues to be handled very differently among member states, and the "understanding of Open data has not really arrived everywhere" (2024, Appendix IIIa). The person even went as far as calling some behaviour 'embarrassing' and 'ridiculous', because of blockades for further harmonization and the rejection of further reporting obligations at EU level. However, one avenue of change that the representative was very hopeful about were research projects that carry out their own measurements Europe-wide, e.g. in the area of EO. Pan-European initiatives could help to overcome national egos when they prove to be operable and successful. The EU Forest Resilience Monitor could be such a project – however it also severely depends upon the input by member states and regions. In the next legislative period at EU level, the Forest Monitoring Law will be discussed and potentially adopted. In its current form, there is reference to many indicators, most of which are already systematically recorded on either EU or member state level, at least in Germany. However, there is no mention in the current legislative proposal whether such assessments can continue to be based on sample surveys, or whether these results should be available in more geospatial extent by unifying *in situ* observations and EO datasets. A requirement for data on the respective indicators to be available as Open data and in geospatial form would help to make a forest resilience tool reality. Furthermore, the Nature Restoration Law has not been adopted finally and in the current form some indicators are mentioned where this thesis has identified challenges: for instance, on the coherent monitoring of tree species diversity (European Parliament, 2024, Article 12. 3 [g]), and in terms of the monitoring of common forest birds (ibid, Article 12.2). Legislation should ensure that new monitoring requirements take into account the capacities of forest authorities on the ground and integrate them better in monitoring structures.

For the federal level, this means that some degree of autonomy might be given to EU institutions to better connect the states that collect data and those that produce the final assessments, which happens increasingly at EU level. At federal level, there are currently discussions on an update of the federal forest law from 1975. A draft report that was published in November 2023 includes a passage stating that "[t]he results of the [forest survey] shall be made public" (BMEL, 2023, § 68 [2]) – a phrase that was not contained in the old bill. Still, other transparency laws already require such publication of results and only time will tell if this brings about some change in Open data forest data provision in Germany. The findings of this thesis support the view that if federal legislation was to provide a one-stop shop where states can openly share their collected data, better timeliness and better data reuse can be achieved, for instance for forest resilience quantifications. Requirements that data must be made openly available, at best in geospatial form, could help to increase digitalization efforts in forest monitoring. According to the representative of the forest agency in Brandenburg, digitization is still a major hurdle for German forest administrations and many forest directorates still require forest management plans by private owners on paper, and not in digital form which often leads to data being only available in non-machine-readable formats, such as pictures of maps (2024, Appendix IIIb). The current federal forest law proposal, however, puts forward little new mechanisms in that regard.

Finally, the draft law does not include a major change of responsibilities and the 16 Länder will continue to play the most important role in forest governance and forest monitoring in Germany. Similar to the already established cooperation system on core indicators, as spelled out in the section on canopy thinning (LiKi, 2023), the *Länder* should be empowered to better pool their forest observation data, and also report data directly to the European Commission, reducing time lags and improving data availability. This research supports the view that Open data sharing, however, must consider the target users. If focus is on everyday application by citizens, a one-stop shop for open forest data-pooling, as suggested before, must give priority the ease-of-use and the online searchability of such a tool. Here, initiatives like the 'waldinfo.NRW' portal can serve as good examples that other states are recommended to join.

6 Conclusion

The structured Open data analysis has shown mixed data availability on different forest indicator sets in Germany. NRT forest monitoring continues to be hampered by structural data gaps and limited timeliness. Open data adherence is generally patchy. The analysis has shown that biodiversity monitoring, exemplified by birds, still lacks in terms of Open data compliance in Germany. Generally, while the EU level has high compliance, it relies on data collected by member states and therefore the *Länder*, which score low on Open data compliance. Tree species distribution information is also restricted by Open data violations, with only limited good practices seen in some German regions. Soil and water indicators are generally well-implemented but require more structured and timely data for effective use in an EU Forest Resilience Monitor. Lastly, while global systems meet Open data criteria for carbon storage, German state-level data, that is partly more accurate than data from EO is largely outdated and not available in machine-readable formats. Nevertheless, various reliable sources for the establishment of an EU-wide Forest Resilience Monitor could be selected.

The question now is whether we go from the *status quo*, namely inconsistent data provision, access and accessibility and try to synchronize this information into a monitoring system on forest resilience that fits our needs; or do we start new forest data collection instruments to build the framework that we need. Both paths have their upsides, but one thing in common: To achieve an Open data Forest Monitor in Europe and beyond, many forces must work together. Global Forest Watch already exemplifies that to some extent: an advanced, NRT forest information system that is based on satellite technology, big data analytics, and crowdsourcing to track changes in forest cover globally. Such Open data sharing alliances will be key in protecting forests as carbon sinks. Where Open data policies are implemented, they make compliance with sustainable forestry practices transparent or expose illegal logging activities and other impacts on forest resilience. Nevertheless, this research has shown that this potential is not fully utilized, at least in the case of Germany where Open data principles are still violated across sectors and policy levels. A Forest Resilience Monitor could institutionalize Open Data structures across the EU and – by pooling data and providing an easily usable interface – it could influence management practices in communal and private forest planning. This could help to better balance the diverse interests in forest governance and involve local communities in forest decision-making. Referring to the broader picture of centralization and decentralization, a structured European approach to forest governance that follows resilience parameters must ensure that European forests are actively managed in garnering their climatic potentials to protect local populations. Open data accessibility can be strengthened through an institutionalized EU Forest Resilience Monitor.

As laid out before, this research has some inherent limitations: The selection of indicator group might have a certain bias towards ecological resilience factors. Future research should therefore explore the availability of coherent social-ecological indicators that influence forest resilience. Furthermore, while this thesis has identified possible data sources for an improved resilience monitoring of forests, it has not analysed how these components should be weighted and how quantifications of forest resilience are reliably done in practice, without over- or underestimating certain management practices. This requires further academic attention. Finally, with new innovations from the field of EO, a better understanding of the interoperability and interlocking of data and datasets with *in situ* data is necessary.

References

Aggestam, F., & Pülzl, H. (2018). Coordinating the uncoordinated: The EU forest strategy. *Forests, 9*(3), 125.

Agrawal, A., & Ostrom, E. (2001). Collective action, property rights, and decentralization in resource use in India and Nepal. *Politics & Society, 29*(4), 485-514.

Arts, K., Ioris, A. A., Macleod, C. J., Han, X., Sripada, S. G., Braga, J. R., & van der Wal, R. (2016). Environmental communication in the Information Age: Institutional barriers and opportunities in the provision of river data to the general public. *Environmental Science & Policy, 55*, 47-53.

Avitabile, V., Pilli, R., Camia, A. (2020). Forest Biomass Map of Europe for 2010. *European Commission, Joint Research Centre (JRC)*. [Dataset]. Lastly retrieved on May 28, 2024 from http://data.europa.eu/89h/d1fdf7aa-df33-49af-b7d5-40d226ec0da3.

Baeten, L., Bruelheide, H., van Der Plas, F., Kambach, S., Ratcliffe, S., Jucker, T., ... & Scherer-Lorenzen, M. (2019). Identifying the tree species compositions that maximize ecosystem functioning in European forests. *Journal of Applied Ecology, 56*(3), 733-744.

Barredo, J. I., Brailescu, C., Teller, A., Sabatini, F. M., Mauri, A., & Janouskova, K. (2021). Mapping and assessment of primary and old-growth forests in Europe. *Publications Office of the European Union*, Luxemburg.

Bentrup, G., & Dosskey, M. G. (2022). Tree advisor: A novel woody plant selection tool to support multifunctional objectives. *Land, 11*(3), 397.

BLE. (n. d.). EU-Holzhandelsverordnung. Bundesanstalt für Landwirtschaft und Ernährung. Lastly retrieved on May 2nd, 2024 from https://www.ble.de/DE/Themen/Wald-Holz/Handel-Holz/EU-Holzhandelsverordnung/eu-holzhandelsverordnung_node.html.

Blickensdörfer, L., Oehmichen, K., Pflugmacher, D., Kleinschmit, B., & Hostert, P. (2022). Dominant Tree Species for Germany (2017/2018). *Thünen-Institut, Institut für Waldökosysteme: Eberswalde, Germany*.

BMEL. (2020, February 26). Waldschäden: Bundesministerium veröffentlicht aktuelle Zahlen. [Press release]. *Bundesministerium für Ernährung und Landwirtschaft*. Lastly retrieved on May 18, 2024 from https://www.bmel.de/SharedDocs/Pressemitteilungen/DE/2020/040-waldschaeden.html.

BMUV (Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz). (2023, February 14). Aktionsprogramm Natürlicher Klimaschutz. *Bundesministerium für Umwelt, Naturschutz, nukleare Sicherheit und Verbraucherschutz*. Lastly retrieved on May 1st, 2024 from https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Naturschutz/aktionsprogramm_natuerlicher_klimaschutz_2023_bf.pdf.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2023). Entwurf eines Gesetzes zur Neuordnung des Bundeswaldgesetzes. [Draft bill]. *Forstpraxis.de*. Lastly retrieved on June 6, 2024 from https://www.forstpraxis.de/sites/forstpraxis.de/files/2023-11/231110_Referentenentwurf_BWaldG.pdf.

BMEL (Bundesministerium für Ernährung und Landwirtschaft). (2024, Jan 29). Gesündere Waldböden: Bodenzustandserhebung. [Gov. article]. Bundesministerium für Ernährung und Landwirtschaft. LAstly retrieved on May 28, 2024 from https://www.bmel.de/DE/themen/wald/wald-in-deutschland/bodenzustandserhebung.html.

Bonvoisin, J., & Mies, R. (2018). Measuring openness in open source hardware with the open-o-meter. *Procedia CIRP, 78*, 388-393.

Bösch, M., Elsasser, P., Rock, J., Rüter, S., Weimar, H., & Dieter, M. (2017). Costs and carbon sequestration potential of alternative forest management measures in Germany. *Forest policy and Economics, 78*, 88-97.

Bourgoin, C., Ameztoy, I., Verhegghen, A., Carboni, S., Colditz, R., Achard, F. (2023). Global map of forest cover 2020 - version 1. *European Commission, Joint Research Centre (JRC)*. [Dataset]. Lastly retrieved on May 14, 2024 from https://forobs.jrc.ec.europa.eu/GFC.

Bravo-Oviedo, A. (2018). The role of mixed forests in a changing social-ecological world. *Dynamics, silviculture and management of mixed forests*, 1-25.

Bronick, C. J., & Lal, R. (2005). Soil structure and management: a review. *Geoderma, 124*(1-2), 3-22.

Brown, C. F., Brumby, S. P., Guzder-Williams, B., Birch, T., Hyde, S. B., Mazzariello, J., ... & Tait, A. M. (2022). Dynamic World, Near real-time global 10 m land use land cover mapping. *Scientific Data, 9*(1), 251.

Brown, M., & Hale, K. (2014). *Applied research methods in public and nonprofit organizations*. John Wiley & Sons.

Buontempo, C., Burgess, S. N., Dee, D., Pinty, B., Thépaut, J. N., Rixen, M., ... & de Marcilla, J. G. (2022). The Copernicus climate change service: climate science in action. *Bulletin of the American Meteorological Society, 103*(12), E2669-E2687.

Cagney, D. & Machado, B. (2024, May 17). Supporters rally for Nature Restoration Law, but no sign of movement in Council. [News article]. *Euractiv Media Network BV.* Lastly retrieved on June 6, 2024 from https://www.euractiv.com/section/biodiversity/news/supporters-rally-for-nature-restoration-law-but-no-sign-of-movement-in-council/.

Cantarello, E., Jacobsen, J. B., Lloret, F., & Lindner, M. (2024). Shaping and enhancing resilient forests for a resilient society. *Ambio*, 1-14.

Carpenter, S., Walker, B., Anderies, J. M., & Abel, N. (2001). From metaphor to measurement: resilience of what to what?. *Ecosystems, 4,* 765-781.

Chang, K. T. (2008). *Introduction to geographic information systems* (Vol. 4). Boston: McGraw-Hill.

Chytrý, M., Tichý, L., Hennekens, S. M., Knollová, I., Janssen, J. A., Rodwell, J. S., ... & Schaminée, J. H. (2020). EUNIS Habitat Classification: Expert system, characteristic species combinations and distribution maps of European habitats. *Applied Vegetation Science, 23*(4), 648-675.

Ciais, P., Schelhaas, M. J., Zaehle, S., Piao, S. L., Cescatti, A., Liski, J., ... & Nabuurs, G. J. (2008). Carbon accumulation in European forests. *Nature Geoscience, 1*(7), 425-429.

CityLAB Berlin. (n. d.). Gieß den Kiez. *Technologiestiftung Berlin*. Lastly retrieved on May 18, 2024 from https://citylab-berlin.org/en/projects/giessdenkiez/.

City of Sydney. (2023, June). Tree Species List: Development and Use. Lastly retrieved on May 5, 2024 from https://www.cityofsydney.nsw.gov.au/strategies-action-plans/urban-forest-strategy.

Colantoni, L., Sarno, G. S., Bianchi, M. (2022, September 08). Fighting Illegal Logging in Europe. An Overview of Trends, Players and Action. *Istituto Affari Internazionali*. Lastly retrieved on December 16, 2023 from https://www.iai.it/en/pubblicazioni/fighting-illegal-logging-europe.

Collentine, D., & Futter, M. N. (2018). Realising the potential of natural water retention measures in catchment flood management: Trade-offs and matching interests. *Journal of Flood Risk Management, 11*(1), 76-84.

Copernicus. (n. d.). COPERNICUS: EUROPE'S EYES ON EARTH. *European Commission, Directorate-General for Defence, Industry and Space Unit*. [Information sheet]. Lastly retrieved on May 30, 2024 from https://www.copernicus.eu/sites/default/files/2023-07/Copernicus%20General%20EN.pdf.

Cortina-Segarra, J., García-Sánchez, I., Grace, M., Andrés, P., Baker, S., Bullock, C., ... & Ventocilla, J. L. (2021). Barriers to ecological restoration in Europe: expert perspectives. *Restoration Ecology, 29*(4), e13346.

Council of the European Union. (2024, March 18). Current legislative proposals: Proposal for a Regulation on a monitoring framework for resilient European forests – Information from the Presidency. [Note]. 7699/24. *General Secretariat of the Council*. Lastly retrieved on May 30, 2024 from https://data.consilium.europa.eu/doc/document/ST-7699-2024-INIT/en/pdf.

Craven, D., Filotas, E., Angers, V. A., & Messier, C. (2016). Evaluating resilience of tree communities in fragmented landscapes: linking functional response diversity with landscape connectivity. *Diversity and Distributions, 22*(5), 505-518.

DDA. (no date). ornitho.de. *Dachverband Deutscher Avifaunisten e.V*. Lastly retrieved on May 1st 2024 from https://www.dda-web.de/ornitho/info.

DDA. (2024a). Monitoring häufiger Brutvögel (MhB). *Dachverband Deutscher Avifaunisten e.V*. Lastly retrieved on May 8, 2024 from https://www.dda-web.de/monitoring/mhb/programm.

DDA. (2024b). Rückblick auf das Birdrace 2024. *Dachverband Deutscher Avifaunisten e.V*. Lastly retrieved on May 8, 2024 from https://www.dda-web.de/aktuelles/meldungen/rueckblick-auf-das-birdrace-2024.

Deleu, X., & Kerfriden, M. (2023). IKEA, THE TREE HUNTER. *ARTE DISTRIBUTION*. Lastly retrieved on June 5, 2024 from https://distribution.arte.tv/fiche/Ikea__l_arbre_qui_cache_la_foret.

De Rigo, D., Caudullo, G., Houston Durrant, T., & San-Miguel-Ayanz, J. (2016). The European Atlas of Forest Tree Species: modelling, data and information on forest tree species. *European Commission Joint Research Service*. Lastly retrieved on May

Destatis. (2014, April 15, 2024). Weniger Schadholz aufgrund von Waldschäden: Holzeinschlag 2023 um 10,3 % gesunken. *Statistisches Bundesamt*. Lastly retrieved on May 2nd, 2024 from https://www.destatis.de/DE/Presse/Pressemitteilungen/2024/04/PD24_154_41.html.

Dominati, E., Patterson, M., & Mackay, A. (2010). A framework for classifying and quantifying the natural capital and ecosystem services of soils. *Ecological economics, 69*(9), 1858-1868.

DWD. (Deutscher Wetterdienst). (n. d.). CDC-Portal. *Deutscher Wetterdienst, Offenbach, Germany.* Lastly retrieved on May 26, 2024 from https://www.dwd.de/EN/ourservices/cdc_portal/cdc_portal.html.

DWD. (Deutscher Wetterdienst). Deutscher Klimaatlas. *Deutscher Wetterdienst, Offenbach, Germany*. Lastly retrieved on May 26, 2024 from https://www.dwd.de/DE/klimaumwelt/klimaatlas/klimaatlas_node.html.

EBCC (European Bird Census Council). Introduction EuroBirdPortal. *European Bird Census Council.* Lastly retrieved on May 31, 2024 from https://www.eurobirdportal.org/ebp/en/about/.

European Commission. (2022, June 22). Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on nature restoration. *EUR-Lex.* Lastly retrieved on April 12, 2024 from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52022PC0304.

European Commission. (n. d.). Regulation on Deforestation-free products. *Directorate-General for Environment*. Lastly retrieved on May 2nd from https://environment.ec.europa.eu/topics/forests/deforestation/regulation-deforestation-free-products_en.

European Commission. (n. d. [b]). EU SOIL OBSERVATORY: EUSO Soil Health Dashboard. *Joint Research Centre of the European Commission / European Soil Data Centre (ESDAC).* Lastly retrieved on May 25, 2024 from https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/.

European Commission. (2010, May 19). A Digital Agenda for Europe. [Communication]. *European Commission; Directorate-General for the Information Society and Media, INFSO*. Lastly retrieved on May 30, 2024 from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52010DC0245&qid=1717098159432.

European Commission. (2014a): European map of living forest above-ground biomass. *European Commission, Joint Research Centre (JRC).* [Dataset]. Lastly retrieved on May 28, 2024 from http://data.europa.eu/89h/cbfbf540-e90c-447d-aaeb-d424a350af44.

European Commission. (2014b): European map of forest above and below-ground carbon. *European Commission, Joint Research Centre (JRC)*. [Dataset]. Lastly retrieved on May 28, 2024 from http://data.europa.eu/89h/8dcd61eb-c97f-4c92-886f-5027bad233ed.

European Commission. (2021, July 16). New EU Forest Strategy for 2030. [Communication]. *EUR-Lex*. Lastly retrieved on June 6, 2024 from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52021DC0572.

European Commission. (2022). Digital Economy and Society Index (DESI) 2022 Germany. *Directorate-General for Communications Networks, Content and Technology*. Lastly retrieved on May 30, 2024 from https://digital-strategy.ec.europa.eu/en/policies/desi-germany.

European Commission. (2023). Progress Report 2023 Climate Action. *European Commission*. Lastly retrieved on December 17, 2023 from https://climate.ec.europa.eu/system/files/2023-11/com_2023_653_glossy_en_0.pdf.

European Commission. (2023a). Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on a monitoring framework for resilient European forests. *Directorate-General for Environment*. Lastly retrieved on December 17, 2023 from https://ec.europa.eu/transparency/documents-register/detail?ref=COM(2023)728&lang=en&lang=en.

European Commission. (2023b). Questions and Answers on Forest Monitoring Law. *European Commission*. Lastly retrieved on December 17, 2023 from https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_5910.

European Commission. (2023c). Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Soil Monitoring and Resilience. *Directorate-General for Environment*. Lastly retrieved on May 25, 2024 from https://environment.ec.europa.eu/publications/proposal-directive-soil-monitoring-and-resilience_en.

European Commission, Joint Research Centre, Beck, P., Caudullo, G., Forzieri, G. (2023). Tree species distribution data and maps for Europe, *Publications Office of the European Union*. Lastly retrieved on May 13, 2024 from https://data.europa.eu/doi/10.2760/602977.

EEA (European Environment Agency). (2018). Richness of forest-related species and habitats indicator 2012 dataset, Nov. 2018. Lastly retrieved on May 8, 2024 from https://sdi.eea.europa.eu/catalogue/biodiversity/api/records/81754d01-8bc3-49aa-a52c-86b3d212f94e.

European Environment Agency. (2019a, April 22). About the European Nature Information System, EUNIS. Lastly retrieved on May 8, 2024 from https://eunis.eea.europa.eu/about.

EEA (European Environment Agency). (2019b, May 27). Annual European Union greenhouse gas inventory 1990–2017 and inventory report 2019. *European Commission, DG Climate Action*. EEA/PUBL/2019/051.

EEA (European Environment Agency). (2020a, October). *State of nature in the EU: Results from reporting under the nature directives 2013-2018.* Lastly retrieved on April 12, 2024 from https://www.eea.europa.eu/publications/state-of-nature-in-the-eu-2020.

European Environment Agency. (2020b, December). Tree Cover Change Mask 2015-2018 (raster 20 m), Europe, 3-yearly, Dec. 2020 (01.00) [Dataset]. *European Environment Agency*. Lastly retrieved on May 27, 2024 from https://doi.org/10.2909/9723D33F-AC36-49D0-B2C7-80710D377A7D.

European Environment Agency. (2023, June 08). Common bird index in Europe.

EFI (European Forest Institute). Who owns the forests and how are they managed? *European Forest Institute*. Lastly retrieved on May 30, 2024 from https://efi.int/forestquestions/q2_en.

European Parliament. (2024, February 27). European Parliament legislative resolution of 27 February 2024 on the proposal for a regulation of the European Parliament and of the Council on nature restoration (COM(2022)0304 – C9-0208/2022 – 2022/0195(COD)). Lastly retrieved on April 26, 2024 from https://www.europarl.europa.eu/doceo/document/TA-9-2024-0089_EN.html.

FAO (Food and Agriculture Organization of the United Nations). (2020). *Global forest resources assessment 2020: Main report*. Food & Agriculture Organization of the UN.

FISE (Forest Information System for Europe). Data Catalogue. [Search query]. Lastly retrieved on May 30, 2024 from https://forest.eea.europa.eu/datacatalogue?source=%7B%22track_total_hits%22%3Atrue%2C%22query%22%3A%7B%22bool%22%3A%7B%22must%22%3A%5B%7B%22term%22%3A%7B%22COUNTRY%22%3A%22Germany%22%7D%7D%5D%7D%7D%2C%22display_type%22%3A%22list%22%2C%22size%22%3A50%2C%22sort%22%3A%5B%7B%22YEAR_PUBLISHED%22%3A%7B%22order%22%3A%22desc%22%7D%7D%5D%2C%22highlight%22%3A%7B%22fields%22%3A%7B%22*%22%3A%7B%7D%7D%7D%7D.

Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative inquiry, 12*(2), 219-245.

FOREST EUROPE. (2020). State of Europe's Forests 2020. *Ministerial Conference on the Protection of Forests in Europe - FOREST EUROPE*. Retrieved from https://foresteurope.org/wp-content/uploads/2016/08/SoEF_2020.pdf (14.11.2023).

FVA-BW (Forstliche Versuchsanstalt Baden-Württemberg). Bestellformular Standortskartierung. Lastly retrieved on May 17, 2024 from https://www.fva-bw.de/daten-tools/geodaten/bestellformular-standortskartierung?no_cache=1.

Geologischer Dienst NRW. (n. d.). Forstliche Standortkarte für den Wald der Zukunft. *Landesbetrieb Geologischer Dienst Nordrhein-Westfalen*. Lastly retrieved on May 18, 2024 from https://www.gd.nrw.de/bo_dk_forst-standortkarten.htm.

Global Forest Watch. (n. d.). Forest Watcher. [Online Article]. *World Resources Institute*. Lastly retrieved on May 29, 2024 from https://www.globalforestwatch.org/help/forest-watcher/.

GNOR (Gesellschaft für Naturschutz und Ornithologie Rheinland-Pfalz e. V.). (2023). Vogelmonitoring-Bericht 2022 für Rheinland-Pfalz. Lastly retrieved on May 9, 2024 from https://vogelmonitoring-rlp.de/wp-content/infomaterial/vogelmonitoring-bericht_2022.pdf.

Gómez-Guerrero, A., & Doane, T. (2018). The response of forest ecosystems to climate change. In *Developments in soil science* (Vol. 35, pp. 185-206). Elsevier.

Gregory, R. D., & van Strien, A. (2010). Wild bird indicators: using composite population trends of birds as measures of environmental health. *Ornithological Science, 9*(1), 3-22.

Gschwantner, T., Alberdi, I., Bauwens, S., Bender, S., Borota, D., Bosela, M., ... & Tomter, S. M. (2022). Growing stock monitoring by European National Forest Inventories: Historical origins, current methods and harmonisation. *Forest Ecology and Management*, *505*, 119868.

Halonen, A. (2012). Being open about data. Analysis of the UK Open data Policies and Applicability of Open data. *London: Finnish Institute in London*.

Hansen, M. C., Potapov, P. V., Moore, R., Hancher, M., Turubanova, S. A., Tyukavina, A., ... & Townshend, J. R. (2013). High-resolution global maps of 21st-century forest cover change. *Science, 342*(6160), 850-853.

Hautala, L. (2024, April 24). As the climate changes, cities scramble to find trees that will survive. [News Article]. *Grist Magazine Inc*. Lastly retrieved on May 14, 2024 from https://grist.org/agriculture/climate-change-tree-urban-city-arborists-heat-drought-native-species/.

Harris, N. L., Gibbs, D. A., Baccini, A., Birdsey, R. A., De Bruin, S., Farina, M., ... & Tyukavina, A. (2021). Global maps of twenty-first century forest carbon fluxes. *Nature Climate Change, 11*(3), 234-240.

Hildeman, A., & Carlsson, M. (2014). A furniture company's view on wood. *Forests and Globalization: Challenges and Opportunities for Sustainable Development*, 77.

Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual review of ecology and systematics, 4*(1), 1-23.

Huijboom, N., & Van den Broek, T. (2011). Open data: an international comparison of strategies. *European journal of ePractice*, 12(1), 4-16.

Hurtado, P., Espelta, J.M., Lloret, F., (2022). Deliverable 1.1. Inventory of forest resilience indicators and metrics reported in the literature with an assessment on their applicability to RESONATE case studies. *Horizon 2020 project RESONATE, project no. 101000574*, CREAF and EFI (coordinator). Lastly retrieved on April 26, 2024 from https://resonateforest.org/resources/#deliverables.

Islam, K. N., Rahman, M. M., Jashimuddin, M., Hossain, M. M., Islam, K., & Al Faroque, M. (2019). Analyzing multi-temporal satellite imagery and stakeholders' perceptions to have an insight into how forest co-management is changing the protected area landscapes in Bangladesh. *Forest Policy and Economics*, *101*, 70-80.

Johann Heinrich von Thünen-Institut (2012). Dritte Bundeswaldinventur (2012): 12.17 Waldfläche [ha] nach Land und Naturnähe der Baumartenzusammensetzung der Hauptbestockung. *Johann Heinrich von Thünen-Institut*. Lastly retrieved on May 31, 2024 from https://bwi.info/inhalt1.3.aspx?Text=12.17%20Nativeness%20of%20tree%20species%20composition%20of%20the%20primary%20forest%20stand&prRolle=public&prInv=BWI2012&prKapitel=12.17.

Johann Heinrich von Thünen-Institut (2024). Waldzustandserhebung. [Website]. *Johann Heinrich von Thünen-Institut, Bundesforschungsinstitut für Ländliche Räume, Wald und Fischerei, Institut für Waldökosysteme*. Lastly retrieved on May 17, 2024 from https://blumwald.thuenen.de/wze.

Jucker, T., Caspersen, J., Chave, J., Antin, C., Barbier, N., Bongers, F., ... & Coomes, D. A. (2017). Allometric equations for integrating remote sensing imagery into forest monitoring programmes. *Global change biology, 23*(1), 177-190.

Iungman, T., Cirach, M., Marando, F., Barboza, E. P., Khomenko, S., Masselot, P., ... & Nieuwenhuijsen, M. (2023). Cooling cities through urban green infrastructure: a health impact assessment of European cities. *The Lancet, 401*(10376), 577-589.

Jaime, L., Espelta, J.M., Hurtado, P., Lloret, F. (2023). *Deliverable 1.2. Resilience indicators and metrics assessment*. Horizon 2020 project RESONATE, project no. 101000574, CREAF and EFI (coordinator). Lastly retrieved on April 12, 2024 from https://resonateforest.org/wp-content/uploads/2023/09/RESONATE_D1.2.pdf.

Jiang, X., Jiang, M., Gou, Y., Li, Q., & Zhou, Q. (2022). Forestry digital twin with machine learning in Landsat 7 data. *Frontiers in Plant Science, 13,* 916900.

Kairies-Lamp, N. (2018). Innovation Labs: Katalysator für die Digitalisierung. *Public Governance des Instituts für den öffentlichen Sektor*, 12-16.

Kishor, N., & Lescuyer, G. (2012). Controlling illegal logging in domestic and international markets by harnessing multi-level governance opportunities. *International Journal of the Commons, 6*(2).

Klein, D., Höllerl, S., Blaschke, M., & Schulz, C. (2013). The contribution of managed and unmanaged forests to climate change mitigation—a model approach at stand level for the main tree species in Bavaria. *Forests, 4*(1), 43-69.

Kölling, C., Knoke, T., Schall, P., & Ammer, C. (2009). Überlegungen zum Risiko des Fichtenanbaus in Deutschland vor dem Hintergrund des Klimawandels. *Forstarchiv, 80*(2), 42-54.

Kühl, H. S., Bowler, D. E., Bösch, L., Bruelheide, H., Dauber, J., Eichenberg, D., ... & Bonn, A. (2020). Effective biodiversity monitoring needs a culture of integration. *One Earth*, 3(4), 462-474.

Kronenberg, R., Luong, T. T., Müller, M., Andreae, H., & Petzold, R. (2022). Die Bodenfeuchteampel – Ein webbasiertes Informationssystem für die tagaktuelle Bewertung der Wasserverfügbarkeit in Wäldern. *Waldökologie, Landschaftsforschung und Naturschutz–Forest Ecology, Landscape Research and Nature Conservation*. Lastly retrieved from https://www.afsv.de/images/download/literatur/waldoekologie-online/waldoekologie-online_heft-21-2.pdf.

LANUV. (Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen). Klima NRW.Plus. [Web application]. Lastly retrieved on May 26, 2024 from https://www.klimaatlas.nrw.de/klima-nrw-pluskarte.

Lassen, D. (1990). Unzerschnittene verkehrsarme Räume über 100 km2-eine Ressource für die ruhige Erholung. *Natur und Landschaft, 65*(6), 326-327.

Liang, J., & Gamarra, J. G. (2020). The importance of sharing global forest data in a world of crises. *Scientific Data, 7*(1), 424.

Lier, M., Köhl, M., Korhonen, K. T., Linser, S., Prins, K., & Talarczyk, A. (2022). The new EU forest strategy for 2030: a new understanding of sustainable forest management?. *Forests, 13*(2), 245.

LiKi (Länderinitiative Kernindikatoren). (2023, May 28). Waldzustand: Anteil der deutlich geschädigten Bäume der Stufe 2 und größer (Kombinationsschadstufe 2-4). [Online article]. *Länderinitiative Kernindikatoren, Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen*. Lastly retrieved on June 6, 2024 from: https://www.liki.nrw.de/natur-und-landschaft/b4-waldzustand.

LULG SN (Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie). (2024). iDA. [Application]. *Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie*. Lastly retrieved on May 31, 2024 from https://www.umwelt.sachsen.de/umwelt/infosysteme/ida/index.xhtml.

Mason, M. (2010). Information disclosure and environmental rights: The Aarhus Convention. *Global environmental politics, 10*(3), 10-31.

Mauri, A., Girardello, M., Strona, G., Beck, P. S., Forzieri, G., Caudullo, G., ... & Cescatti, A. (2022). EU-Trees4F, a dataset on the future distribution of European tree species. *Scientific Data, 9*(1), 37.

Mauri, A., Strona, G., & San-Miguel-Ayanz, J. (2017). EU-Forest, a high-resolution tree occurrence dataset for Europe. *Scientific data, 4*(1), 1-8.

Mekonen, S. (2017). Birds as biodiversity and environmental indicator. *Indicator, 7*(21).

Mo, L., Zohner, C. M., Reich, P. B., Liang, J., De Miguel, S., Nabuurs, G. J., ... & Ortiz-Malavasi, E. (2023). Integrated global assessment of the natural forest carbon potential. *Nature*, 1-10.

MUEK NS (Niedersächsisches Ministerium für Umwelt, Energie und Klimaschutz). (2023, October 23). Für Brut- und Gastvögel wertvolle Bereiche. Lastly retrieved on May 9, 2024 from https://www.umwelt.niedersachsen.de/service/umweltkarten/natur_landschaft/weitere_den_naturschutz_wertvolle_bereiche/brut_und_gastvoegel_wertvolle_bereiche/wertvolle-bereiche-9098.html.

MUKMAV (Ministerium für Umwelt, Klima, Mobilität, Agrar und Verbraucherschutz des Saarlandes). (2024). Staatswald Bestände Saarland. [Dataset]. *Landesamt für Vermessung, Geoinformation und Landentwicklung (LVGL)*. Lastly retrieved on May 17, 2024 from https://geoportal.saarland.de/map?WMS=36794.

Müller, F., Bergmann, M., Dannowski, R., Dippner, J. W., Gnauck, A., Haase, P., ... & Theuerkauf, M. (2016). Assessing resilience in long-term ecological data sets. *Ecological indicators, 65*, 10-43.

Murtiyoso, A., Holm, S., Riihimäki, H., Krucher, A., Griess, H., Griess, V. C., & Schweier, J. (2024). Virtual forests: a review on emerging questions in the use and application of 3D data in forestry. *International Journal of Forest Engineering, 35*(1), 29-42.

NMB (Nationales Monitoringzentrum zur Biodiversität). (2024). Monitoring seltener Brutvögel (MsB). *Bundesamt für Naturschutz*. Lastly retrieved on May 8, 2024 from https://www.monitoringzentrum.de/steckbriefe/monitoring-seltener-brutvoegel-msb.

Nikinmaa, L., Lindner, M., Cantarello, E., Jump, A. S., Seidl, R., Winkel, G., & Muys, B. (2020). Reviewing the use of resilience concepts in forest sciences. *Current Forestry Reports, 6*, 61-80.

Nitoslawski, S. A., Wong-Stevens, K., Steenberg, J. W. N., Witherspoon, K., Nesbitt, L., & Konijnendijk van den Bosch, C. C. (2021). The digital forest: Mapping a decade of knowledge on technological applications for forest ecosystems. *Earth's Future*, *9*(8), e2021EF002123.

Oehmichen, K., & Köhl, M. (2006). Weiterentwicklung von Indikatoren zur Erfassung der Fragmentierung von Wäldern unter Berücksichtigung der Datenverfügbarkeit (No. 2006/2). [Report]. *Johann Heinrich von Thünen-Institut*. Lastly retrieved on May 27, 2024 from https://literatur.thuenen.de/digbib_extern/dk038949.pdf.

Official Journal of the European Union. (2019, June 20). Directive (EU) 2019/1024 of the European Parliament and of the Council of 20 June 2019 on Open data and the re-use of public sector information (recast). *EUR-Lex*. Lastly retrieved on December 17, 2023 from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L1024.

OGBW (Ornithologische Gesellschaft Baden-Württemberg). (2024). Vögel Baden-Württembergs. Lastly retrieved on May 9, 2024 from https://www.ogbw.de/voegel/brut.

Pilli, R. (2021). EFA FRA CBM Data analysis. *European Commission, Joint Research Centre (JRC).* [Dataset]. Lastly retrieved on May 28, 2024 from http://data.europa.eu/89h/d4be2da6-54a1-4767-a262-dcebf66bf10b.

Pimm, S. L. (1984). The complexity and stability of ecosystems. *Nature, 307*(5949), 321-326.

Pleger, M., & Schiering, I. (2023). Digital Transformation in Forestry-Stakeholders and Data Collection in German Forests. *INFORMATIK 2023 - Designing Futures*. (Conference Paper for UINW 2023). Retrieved from https://dl.gi.de/items/796dfaf3-fec9-4bd4-a2d6-5a15f1eb4124 (10.12.2023).

Pollock, R. (2010). The economics of public sector information. *Sydney University Press*.

Potapov, P., Hansen, M. C., Pickens, A., Hernandez-Serna, A., Tyukavina, A., Turubanova, S., ... & Kommareddy, A. (2022). The global 2000-2020 land cover and land use change dataset derived from the Landsat archive: first results. *Frontiers in Remote Sensing, 3*, 856903.

Pratihast, A. K., DeVries, B., Avitabile, V., De Bruin, S., Herold, M., & Bergsma, A. (2016). Design and implementation of an interactive web-based near real-time forest monitoring system. *PloS one, 11*(3), e0150935.

Rantala, S., Swallow, B., Paloniemi, R., & Raitanen, E. (2020). Governance of forests and governance of forest information: Interlinkages in the age of open and digital data. *Forest Policy and Economics*, *113*, 102123.

Rantala, S., Swallow, B., Lähteenmäki-Uutela, A., & Paloniemi, R. (2022). Forest data governance as a reflection of forest governance: institutional change and endurance in Finland and Canada. *Environmental Science & Policy, 136*, 751-760.

Reiche, J., Balling, J., Pickens, A. H., Masolele, R. N., Berger, A., Weisse, M. J., ... & Carter, S. (2024). Integrating satellite-based forest disturbance alerts improves detection timeliness and confidence. *Environmental Research Letters, 19*(5), 054011.

Reif, A., & Walentowski, H. (2008). The assessment of naturalness and its role for nature conservation and forestry in Europe. *Waldökologie, Landschaftsforschung und Naturschutz, 6*(3), 63-76.

Riedel, T., Stürmer, W., Hennig, P., Dunger, K., & Bolte, A. (2019). Wälder in Deutschland sind eine wichtige Kohlenstoffsenke. *AFZ-Der Wald, 14*, 14-18.

Rodrigues, A. R., Botequim, B., Tavares, C., Pécurto, P., & Borges, J. G. (2020). Addressing soil protection concerns in forest ecosystem management under climate change. *Forest Ecosystems, 7*(1), 34.

Naturwald Akademie gGmbH. (n. d.). Waldmonitor Deutschland. *RSS - Remote Sensing Solutions GmbH & Naturwald Akademie gGmbH*. Lastly retrieved on May 27, 2024 from https://waldmonitor-deutschland.de/.

Savaresi, A., Perugini, L., & Chiriacò, M. V. (2020). Making sense of the LULUCF Regulation: Much ado about nothing?. *Review of European, Comparative & International Environmental Law*, *29*(2), 212-220.

Schlueter, A. (2008). Small-scale European forestry, an anticommons?. *International Journal of the Commons*, *2*(2).

Schmidt, R. (2021, Sept). KI4Forst – Mit Satellitendaten und KI den Wald monitoren. INTERGEO 2021 Hannover. [Presentation]. *Landesamt für Vermessung und*

Geoinformationen Schleswig-Holstein. Lastly retrieved on April 20, 2024 from https://www.adv-online.de/Veroeffentlichungen/Vortraege-Praesentationen/binarywriterservlet?imgUid=a5b30fc1-bfa9-0c71-b7ac-a853f4bff7b6&uBasVariant=11111111-1111-1111-1111-111111111111&isDownload=true.

Schuldt, B., Buras, A., Arend, M., Vitasse, Y., Beierkuhnlein, C., Damm, A., ... & Kahmen, A. (2020). A first assessment of the impact of the extreme 2018 summer drought on Central European forests. *Basic and Applied Ecology, 45*, 86-103.

Senf, C., & Seidl, R. (2021). Mapping the forest disturbance regimes of Europe. *Nature Sustainability, 4*(1), 63-70.

Senf, C., & Seidl, R. (2022). Deliverable 2.1. Online map of hotspots of disturbance at the continental scale. *Horizon 2020 project RESONATE, project no. 101000574, Technical University of Munich*. Lastly retrieved on June 6, 2024 from https://resonateforest.org/wp-content/uploads/2023/09/RESONATE_D2.1.pdf.

Silva Pedro, M., Rammer, W., & Seidl, R. (2015). Tree species diversity mitigates disturbance impacts on the forest carbon cycle. *Oecologia, 177*, 619-630.

Society for Ecological Restoration International. (2004). The SER international primer on ecological restoration. *Society for Ecological Restoration International*, Tucson, Arizona. Lastly retrieved on April 23, 2024 from https://cdn.ymaws.com/www.ser.org/resource/resmgr/custompages/publications/SER_Primer/ser_primer.pdf.

Strong, A. (2015, August 20). 3 Ways Open data Can Help Forests. *World Resources Institute, Washington DC*. Lastly retrieved on May 1st, 2024 from https://www.wri.org/insights/3-ways-open-data-can-help-forests.

Sunlight Foundation. Ten Principles for Opening Up Government Information. *Sunlight Foundation*. Lastly retrieved on December 17, 2023 from https://sunlightfoundation.com/policy/documents/ten-open-data-principles/.

Tomppo, E., Olsson, H., Ståhl, G., Nilsson, M., Hagner, O., & Katila, M. (2008). Combining national forest inventory field plots and remote sensing data for forest databases. *Remote Sensing of Environment, 112*(5), 1982-1999.

Tucker, C. (2010). Learning on governance in forest ecosystems: Lessons from recent research. *International Journal of the Commons, 4*(2).

Turubanova, S., Potapov, P., Hansen, M. C., Li, X., Tyukavina, A., Pickens, A. H., ... & Stolle, F. (2023). Tree canopy extent and height change in Europe, 2001–2021, quantified using Landsat data archive. *Remote Sensing of Environment, 298*, 113797.

UFZ (Helmholtz-Zentrum für Umweltforschung). (2024). UFZ Forest Condition Monitor (2016-2022). *Helmholtz-Zentrum für Umweltforschung GmbH – UFZ, Department Remote Sensing*. Lastly retrieved on May 17, 2024 from https://web.app.ufz.de/waldzustandsmonitor/en.

Umweltbundesamt, (2023, Nov). Monitoringbericht 2023 zur Deutschen Anpassungsstrategie an den Klimawandel. *Interministerielle Arbeitsgruppe Anpassungsstrategie der Bundesregierung*. Lastly retrieved on June 4, 2024 from https://www.umweltbundesamt.de/sites/default/files/medien/376/publikationen/das-monitoringbericht_2023_bf_korr.pdf.

UNECE (United Nations Economic Commission for Europe). Convention on Access to Information, Public Participation in Decision-making and Access to Justice in Environmental Matters (Aarhus Convention). *United Nations Economic Commission for Europe.* Lastly retrieved on May 30, 2024 from https://unece.org/environment-policy/public-participation/aarhus-convention/text.

UN General Assembly (2019) Resolution adopted by the General Assembly on 1 March 2019. 73/284. *United Nations Decade on Ecosystem Restoration (2021–2030).* Lastly retrieved on April 15, 2024 from https://undocs.org/A/RES/73/284.

Vallecillo, S; La Notte, A.; Garcia Bendito, E.; Maes, J. (2019). INCA - Carbon Sequestration. *European Commission, Joint Research Centre (JRC).* [Dataset]. Lastly retrieved on May 28, 2024 from http://data.europa.eu/89h/3509c9d0-a51f-4bce-8b02-e1738e7ffc2d.

Van Den Homberg, M., & Susha, I. (2018). Characterizing data ecosystems to support official statistics with open mapping data for reporting on sustainable development goals. *ISPRS International Journal of Geo-Information, 7*(12), 456.

Vega-Gorgojo, G., Giménez-García, J. M., Ordóñez, C., & Bravo, F. (2022). Pioneering easy-to-use forestry data with Forest Explorer. *Semantic Web, 13*(2), 147-162.

Vidal, C., Alberdi, I., Redmond, J., Vestman, M., Lanz, A., & Schadauer, K. (2016). The role of European National Forest Inventories for international forestry reporting. *Annals of Forest Science*, *73*(4), 793-806.

Vökler, F. (2014). Zweiter Brutvogelatlas des Landes Mecklenburg-Vorpommern. *Ornithologische Arbeitsgemeinschaft Mecklenburg-Vorpommern e.V.* Lastly retrieved on May 9, 2024 from https://www.oamv.de/fileadmin/oamv/documents/Brutvogelatlas /Brutvogelatlas_OAMV_2014_Passeres.pdf

Wald & Holz NRW. (n. d.). Die Forstliche Standortkarte für Nordrhein-Westfalen. *Landesbetrieb Wald und Holz NRW*. Lastly retrieved on May 17, 2024 from https://www.wald-und-holz.nrw.de/wald-in-nrw/forstliche-standortkarte.

Walz, U., Schumacher, U., & Krüger, T. (2022). Landschaftszerschneidung und Waldfragmentierung in Deutschland-Ergebnisse aus einem Monitoring im Kontext von Schutzgebieten und Hemerobie. *Bundesamt für Naturschutz; Natur und Landschaft, 97*. 85 – 95. Lastly retrieved on May 27, 2024 from https://bfn.bsz-bw.de/frontdoor/deliver/index/docId/1114/file/NuL2022-02-04a.pdf.

Welle, T., Aschenbrenner, L., Kuonath, K., Kirmaier, S., & Franke, J. (2022). Mapping dominant tree species of German forests. *Remote Sensing, 14*(14), 3330.

Welsink, A. J., Reiche, J., De Sy, V., Carter, S., Slagter, B., Suarez, D. R., ... & Herold, M. (2023). Towards the use of satellite-based tropical forest disturbance alerts to assess selective logging intensities. *Environmental Research Letters, 18*(5), 054023.

White House. (2009, Dec 8). Open Government Directive. [Government Directive]. *Executive Office of the President; Office of Management and Budget. Washington D.C.* Lastly retrieved on May 30, 2024 from https://obamawhitehouse.archives.gov/open/documents/open-government-directive.

World Wide Web Foundation (2017). Open data Barometer: Country Detail Germany. World Wide Web Foundation. Lastly retrieved on May 6th, 2024 from https://opendatabarometer.org/country-detail/?_year=2017&indicator=ODB&detail=DEU.

Zimmer, T. (2004). Die Karte der nutzbaren Feldkapazität. *gut, 176*, 200.

Ziter, C. D., Pedersen, E. J., Kucharik, C. J., & Turner, M. G. (2019). Scale-dependent interactions between tree canopy cover and impervious surfaces reduce daytime urban heat during summer. *Proceedings of the National Academy of Sciences, 116*(15), 7575-7580.

References for Figures

Figure 1: Pratihast, A. K., DeVries, B., Avitabile, V., De Bruin, S., Herold, M., & Bergsma, A. (2016). Design and implementation of an interactive web-based near real-time forest monitoring system. *PloS one, 11*(3), e0150935.

Figure 2 based on: Cantarello, E., Jacobsen, J. B., Lloret, F., & Lindner, M. (2024). Shaping and enhancing resilient forests for a resilient society. *Ambio*, 1-14.

Figure 3: European Environment Agency. (2018). *Richness index of forest - related species and habitats*. Lastly retrieved on June 7, 2024 from https://sdi.eea.europa.eu/catalogue/srv/api/records/5e834abf-808e-40f0-a32c-2a70d326f4fc.

Figure 4:

(a) European Environment Agency. (2024). *NATURA 2000 Viewer: Grey-headed Woodpecker - Picus canus*. Lastly retrieved on May 17, 2024 from https://natura2000.eea.europa.eu/?views=Species_View.

(b) Dachverband Deutscher Avifaunisten (DDA). (2024). Grauspecht Verbreitung nach ADEBAR. Lastly retrieved on May 17, 2024 from https://www.dda-web.de/voegel/voegel-in-deutschland/Grauspecht/verbreitung.

(c) Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie. (2024). *iDA (interdisziplinäre Daten und Auswertungen): Grauspecht*. Lastly retrieved on May 17, 2024 from https://www.umwelt.sachsen.de/umwelt/infosysteme/ida/q/5PbVMyG7Wc9iXMWm5omlWS.

(d) Nordrhein-Westfälische Ornithologengesellschaft e.V. & Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen. (2024). *Die Brutvögel Nordrhein-Westfalens: Grauspecht*. Lastly retrieved on May 17, 2024 from https://brutvogelatlas.nw-ornithologen.de/artkapitel/Grauspecht/verbreitung.

Figure 5: Mauri A., Girardello M., Strona G., Beck P. S. A., Forzieri G., Caudullo G., Manca F. & Cescatti A., 2022. EU-Trees4F, a dataset on the future distribution of European tree species. *Scientific Data 9*, 37. DOI: 10.1038/s41597-022-01128-5. (Lastly retrieved on May 18, 2024 from https://forest.jrc.ec.europa.eu/media/EU-Trees4F/EU-Trees4F_Ulmus_minor.html).

Figure 6: UFZ – Helmholtz Centre for Environmental Research. (2024). UFZ Forest Condition Monitor. *Department Remote Sensing*. Lastly retrieved on May 18, 2024 from https://web.app.ufz.de/waldzustandsmonitor/en?area=6&layer=45.

Figure 7: Kompetenzzentrum Geodateninfrastruktur Thüringen (GDI-Th), Thüringer Landesamt für Bodenmanagement und Geoinformation. (2024). *Thüringen Viewer: Waldbiotope*. Lastly retrieved on June 7, 2024 from https://thueringenviewer.thueringen.de/thviewer/?Map/layerIds=10001005,10105002,10

601017&visibility=true,true,true&transparency=0,0,0&Map/center=[654817.6138025918,5638769.873899416]&Map/zoomLevel=6.

Figure 8: Johann Heinrich von Thünen-Institut. (2024). Dritte Bundeswaldinventur (2012): *Naturnähe der Baumartenzusammensetzung der Hauptbestockung=naturnah (Map view)*. Lastly retrieved on May 8, 2024 from https://bwi.info/Karten.aspx.

Figure 9: Ministerium für Landwirtschaft und Verbraucherschutz des Landes Nordrhein-Westfalen. (2024). *Interaktive Waldbau-Werkzeuge: Unterstützungssystem Wiederbewaldung*. Lastly retrieved on May 8, 2024 from https://www.waldinfo.nrw.de/waldinfo2/?lang=de.

Figure 10: European Commission. (n. d. [b]). EU SOIL OBSERVATORY: EUSO Soil Health Dashboard. *Joint Research Centre of the European Commission / European Soil Data Centre (ESDAC)*. Lastly retrieved on May 25, 2024 from https://esdac.jrc.ec.europa.eu/esdacviewer/euso-dashboard/.

Figure 11: DWD. (Deutscher Wetterdienst). Interaktive Bodenfeuchtekarten und -profile. Lastly retrieved on May 26, 2024 from https://www.dwd.de/DE/fachnutzer/landwirtschaft/appl/bf_view/_node.html.

Figure 12: Kronenberg, R., Luong, T. T., Müller, M., Andreae, H., & Petzold, R. (2024). *Bodenfeuchteampel. Lehrstuhl für Meteorologie TU Dresden - Sachsenforst*. Lastly retrieved on May 15, 2024 from https://life.hydro.tu-dresden.de/BoFeAm/dist_bfa/index.html.

Figure 13: Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen. (2024). *Klimaatlas NRW: Mittlere klimatische Wasserbilanz in der tatsächlichen forstlichen Vegetationszeit [mm]*. Lastly retrieved on May 18, 2024 from https://www.klimaatlas.nrw.de/klima-nrw-karte.

Figure 14: Hansen, M. C., P. V. Potapov, R. Moore, M. Hancher, S. A. Turubanova, A. Tyukavina, D. Thau, S. V. Stehman, S. J. Goetz, T. R. Loveland, A. Kommareddy, A. Egorov, L. Chini, C. O. Justice, and J. R. G. Townshend. 2013. "High-Resolution Global Maps of 21st-Century Forest Cover Change." Science 342 (15 November): 850–53. Data available on-line from:http://earthenginepartners.appspot.com/science-2013-global-forest. Accessed through Global Forest Watch on June 6 2024. www.globalforestwatch.org.

Figure 15: LiKi (Länderinitiative Kernindikatoren). (2023, May 28). Waldzustand: Anteil der deutlich geschädigten Bäume der Stufe 2 und größer (Kombinationsschadstufe 2-4). [Online article]. *Länderinitiative Kernindikatoren, Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen*. Lastly retrieved on June 6, 2024 from: https://www.liki.nrw.de/natur-und-landschaft/b4-waldzustand.

Figure 16: European Environment Agency. (2019). *Landscape fragmentation Effective Mesh Density time-series, 2015: major and medium anthropogenic fragmenting elements (FGA2-S) - version 1.0, Nov. 2019*. Lastly retrieved on May 20 from: https://sdi.eea.europa.eu/catalogue/idp/api/records/2e842c1e-d914-4533-8db0-039bfbaffaff.

Figure 17: Harris et al. (2021). *Global maps of 21st century forest carbon fluxes*. Lastly retrieved on June 7, 2024 from Global Forest Watch: https://gfw.global/3Rgxue7.

Figure 18: Forest Carbon Monitoring Consortium. (2021). *Forest Carbon Monitoring Platform: Biomass decrease mask*. Lastly retrieved on June 3rd, 2024 from https://portal.forestcarbonplatform.org/.

Figure 19: Johann Heinrich von Thünen-Institut. (2024). *Thünen-Atlas Kohlenstoffspeicher Wald – Bäume – Kohlenstoffvorrat der Baumbiomasse [t/ha] 2012*. Lastly retrieved on June 7, 2024 from https://gdi.thuenen.de/wo/waldatlas/?workspace=waldatlas_kohlenstoff_wald&instanz=wo.

Figure 20: own representation.

Figure 21: own representation.

Appendix

I. Supplementary information on the research design

I.a Explanation on the coding

Criterion	Yes/Good	Limited	Very Limited	No/Bad	Unclear
Data existence (a)	There is sufficient evidence that datasets or indicator sets are produced in the respective category (notwithstanding their accessibility or openness)	There is evidence of datasets or indicator sets, yet their meaningfulness is limited (e.g. incomplete or low granularity)	There is evidence of datasets or indicator sets, yet major restrictions exist that considerably limit their meaningfulness (e.g. very incomplete or only aggregated data)	No evidence that data is recorded systematically	Existence could not be determined without doubt.
Online availability (b)	Datasets or maps can be accessed through direct data viewers, dashboards, or data portals, or datasets and their metadata are provided online.	Information systems only give limited access to the respective data or indicator sets (e.g. incompleteness or low geospatial detail)	Significant hurdles in accessing datasets or maps exist, e.g. through access limitations, or hidden datasets only made known to me after personal contact.	Datasets or maps are not available online.	Availability could not be determined without doubt.
Open license (c)	Clearly indication though a Creative Commons attribution or 'no restrictions'. Data access and existence was verified during the research process.	Refers to cases where no information on licensing but also no restrictions to usage are mentioned. Also refers to some cases where some use cases require the permission of the copyright holder.	Data is effectively not openly available contrary to suggestions; or available open data is irrelevant or outdated (case-by-case basis).	Restrictions on the usage of data exist, including on the commercial utilization.	No coyright information could be found.
Timeliness (d)	Datasets or maps refer to data collected in 2018 or later.	Refers to cases where data is partly from before 2018, but more recent data is fed into information systems as well.	Data is from the year 2017, not taking into account the effects of the 2018 drought in Germany (only case-by-case).	Data is considerably older than from 2018.	No information on the temporal scope could be found.
Regular updates (e)	If coherent monitoring cycles and strategies were in place (e.g. updates all 5 years).	If monitoring cycles of more than 6 years were in place.	Not coded.	Refers to no cyclical updates of datasets or maps, often indicated through 'updated upon request'.	No information on regularity of updates.
Machine readability (f)	Datasets are published in their original format, best in CSV, JSON or GeoJSON, GeoTIFF, XML or NetCDF formats	Some formats are machine-readable but may present limitations due to their structure, e.g. Excel files.	Some formats are machine-readable but may present strict limitations due to their structure, e.g. PDF files.	Data was not available in all its granularity or data download did not work.	Machine-readability could not be determined.
Accessibility, ease of use (g)	Good: Data is easily found online and the presentation of datasets and maps is meaningful; this refers to interactive portals that show relevant, up-to-date information. Based on personal assessment.	Refers to restrictions in the accessibility of datasets, e.g. limited geospatial meaningfulness or expert knowledge required to understand data portal.	Refers to restrictions in the accessibility of datasets or maps that are so major that they effectively hinder its widespread utilization, e.g. only raw data available.	Bad: Access requires a deep understanding of the functionality of the information system. Also coded when information is irrelevant or not up-to-date. Based on personal assessment.	Not coded.
Map feature (h)	A meaningful map feature that is easy to use is integrated into the information system.	Map feature exists but restrictions in terms of detail, time or functionality inhibit meaningfulness.	Restrictions in terms of detail, time or functionality majorly inhibit the meaningfulness of the map feature.	Dataset has no geopatial component or no in-built mapping functionality is available online.	Map existence could not be determined.
Additional indicators (i, j, k, l)	Datasets are available openly, timely, in machine-readable format and are easily accessible.	Restrictions are so major that the meaningfulness of the information is inhibited.	Restrictions are so major that the meaningfulness of the information is inhibited.	No data or maps exist.	Existence could not be determined without doubt.

n.a.	Not applicable: Refers to cases where data does not exist additionally on the respective policy level and hence no assessment on the detailed data provision can be made.

I.b Explanation on the indicator selection

The following list names all indicators per indicator group according to their source. The original analysis file can be retrieved on Zenodo: https://zenodo.org/records/11517505?token=eyJhbGciOiJIUzUxMiJ9.eyJpZCI6ImQyODA3ODAzLWMwYjktNDViNi1iMDY0LTZkZWZhNDZhMDAxNiIsImRhdGEiOnt9LCJyYW5kb20iOiJiYjc1MDMwYzI0NTkxNWVlMTVjYTgzNThkMTVlYzM3MSJ9.2oKkNOgqQJpSoElUjHOd83_YI0yeQgTCEp9AN_5xyZ8A_0Z_GwbNMZXGihy0qHejAgmbS7s0M55jlcUgjWAl5Q.

Climate indicators (all from Nikinmaa et al., 2020):

- Basal area increment,
- Precipitation (mean annual or standardized precipitation index [SPI]),
- Temperature (monthly or degree days sum),
- Vapour pressure deficit,
- De Martonne Index (aridity)

Soil property indicators (all from Nikinmaa et al., 2020):

- Available nutrients/ nutrient reserve,
- Soil aggregate size,
- Soil type,
- Relative plant-available water in the root area,
- Post-fire soil organic layer,
- Mycorrhizal network,
- Thornthwaite index,
- Microbial biomass,
- Topsoil without vegetation cover,
- Soil water content/ soil water deficit.
- Erosion depth,
- Intensity of traffic,
- Carbon utilisation profile,
- Soil organic matter,
- Soil depth. Humus horizon depth

Indicators to measure disturbance effects (from the proposed EU Forest Monitoring law [European Commission, 2023a]):

- Defoliation (see Annex I [e] in European Commission, 2023a),
- Forest fires (see Annex I [f] in European Commission, 2023a) consisting of 5 sub-indicators (fire events, burnt forest areas, fire severity, post-fire soil erosion & post-fire event recovery),
- Wildfire risk assessment (see Annex I [g] in European Commission, 2023a) consisting of 3 sub-indicators (dead & live fuel moisture content, fuel type map),

- Tree cover disturbances (see Annex I [h] in European Commission, 2023a),
- Removals of tree volumes (see Annex II [g] in European Commission, 2023a),
- Forest disturbances caused by factors other than fires (Annex III [a] in European Commission, 2023a)

Indicators to measure disturbance effects (from Nikinmaa et al., 2020):

- Palmer Drought Severity Index,
- Population density/ increase of population density,
- Timber harvest intensity,
- Grazing intensity,
- Organic matter removal,
- Cover removal,
- Standardised Precipitation-Evapotranspiration Index (SPEI),
- Tree mortality,
- Stress or strain level,
- Disturbance severity/intensity

Indicators on forest structure (from the proposed EU Forest Monitoring law [European Commission, 2023a]):

- Forest area (see Annex I [a] in European Commission, 2023a),
- Tree cover density (see Annex I [b] in European Commission, 2023a),
- Forest type (see Annex I [c] in European Commission, 2023a),
- Forest connectivity (see Annex I [d] in European Commission, 2023a),
- Stand structure (see Annex II [d] in European Commission, 2023a),
- Tree species composition and richness (see Annex II [e] in European Commission, 2023a),
- European Forest Type (see Annex II [f] in European Commission, 2023a),
- Standing and lying deadwood (see Annex II [h] in European Commission, 2023a),
- Primary and old-growth forests (see Annex II [k] in European Commission, 2023a),
- Aboveground biomass (see Annex III [b] in European Commission, 2023a),
- Forest structure (see Annex III [c] in European Commission, 2023a),
- Forest naturalness classes (see Annex III [f] in European Commission, 2023a)

Indicators on forest structure (from the latest version of the EU Nature Restoration law proposal [European Parliament, 2024]):

- Forest connectivity (see Article 12. 3 [d] in European Parliament, 2024), Stand structure (see Annex II [d] in European Parliament, 2024),
- Tree species diversity (see Article 12. 3 [g] in European Parliament, 2024)
- European Forest Type (see Annex II [f] in European Parliament, 2024)

- Standing and lying deadwood (see Article 12. 3 [a;b] in European Parliament, 2024)
- Primary and old-growth forests (see Annex II [k] in European Parliament, 2024)
- Aboveground biomass (see Annex III [b] in European Parliament, 2024)
- Forest structure (see Annex III [c] in European Parliament, 2024)
- Forest naturalness classes (see Annex III [f] in European Parliament, 2024)
- Uneven-aged structure (see Article 12. 3 [c] in European Parliament, 2024)
- Stock of organic carbon (see Article 12. 3 [e] in European Parliament, 2024)
- Share of forests dominated by native tree species (see Article 12. 3 [f] in European Parliament, 2024)

Further indicators on forest structure (from Nikinmaa et al., 2020):

- Basal values, basal area increment
- Tree density, stem density,
- Species density, stems per hectare (SPH)
- Tree diameter class, mean dbh
- Large trees
- Terrain indicators: aspect, slope, and slope position
- Phytomass
- Canopy height, tree height
- Ground vegetation cover
- Herbaceous cover, canopy and total crown cover, tree cover

Indicators referring to Forest Regeneration (from Nikinmaa et al., 2020):

- Number of surviving trees and resprouting trees
- Number of seedlings
- Rate of biomass accumulation after damage
- Vegetation recovery index
- Tree mortality
- Seedling abundance

Indicators referring to Tree and ecosystem production and transpiration (from Nikinmaa et al., 2020):

- Standardised Precipitation-Evapotranspiration Index (SPEI)
- Above ground net primary production/ biomass accumulation
- Difference between actual evapotranspiration (AET) and potential evapotranspiration (PET)
- De Martonne Index (aridity)
- Basal area increment
- Climate-Vegetation-Productivity-Index

Biodiversity indicators (from the proposed EU Forest Monitoring law [European Commission, 2023a]):

- Common forest birds (see Annex II [j] in European Commission, 2023a)
- Presence of invasive species (see Annex III [g] in European Commission, 2023a)
- Diversity of non-tree vegetation (see Annex III [h] in European Commission, 2023a)
- Presence of threatened species (see Annex III [i] in European Commission, 2023a)

Biodiversity indicator (from the latest version of the EU Nature Restoration law proposal [European Parliament, 2024]):

- Common forest birds (see Article 12.2 in European Parliament, 2024)

Further biodiversity indicators (from Nikinmaa et al., 2020):

- Species composition (Shannon Diversity Index)
- Abundance of species, species richness, species number/population size
- Species dominance, species evenness
- Species density, increase of population density
- Keystone species
- Native species richness, non-native species richness (non-native plant cover, native plant cover)

Indicator from the field of land use (from the proposed EU Forest Monitoring law [European Commission, 2023a]):

- Availability for wood supply (see Annex II [a] in European Commission, 2023a)

Further indicators from the field of land use (from Nikinmaa et al., 2020):

- Land-use classes, forest type (active pasture, succession forest, old-growth forest)
- Normalized Difference Vegetation Index (NDVI)
- Enhanced Vegetation Index (EVI)
- Vegetation map category
- Shade normalized green vegetation fraction images
- Proportion of natural habitat
- Carbon isotopes
- Vegetation Optical Depth (VOD)
- Remotely sensed tree cover
- Habitat connectivity (within an elevational band)
- Natural and built environment

Indicators on ecosystem management objectives (from the proposed EU Forest Monitoring law [European Commission, 2023a]):

- Natura 2000 sites (see Annex II [i] in European Commission, 2023a)

- Protected forest areas (see Annex II [l] in European Commission, 2023a)
- Location of forest habitats outside Natura 2000 sites (see Annex III [e] in European Commission, 2023a)

Further indicators on ecosystem management objectives (from Nikinmaa et al., 2020):

- Management diversity (societal trade-offs)
- Harvest rates (annual net revenue, and net present value)
- Agroforestry: Management interventions on crop cultivation & keeping livestock (percentage of forest surface with management interventions)
- Type of management goal
- Fire adaptive planning
- The amount of forest and connectivity of ecosystems

Indicators on the socio-economic capacity (from the proposed EU Forest Monitoring law [European Commission, 2023a]):

- Growing stock volume per hectare (see Annex II [b] in European Commission, 2023a)
- Net Annual Increment per hectare (see Annex II [c] in European Commission, 2023a)
- Production and trade of wood products (see Annex II [m] in European Commission, 2023a)
- Forest biomass for bioenergy (see Annex II [n] in European Commission, 2023a)

Indicators on the socio-economic capacity (from Nikinmaa et al., 2020):

- Local communal knowledge, community cognitive
- Social network connectivity and social capital (number of voluntary membership organizations per capita)
- Quality of Life
- Human health
- Demography
- Population size and density (amount of resource competition)
- Infrastructure (transportation, residential, but also level of optimization/sustainability in forestry)
- Indigenous practices

Indicator on socio-economic diversity (from the proposed EU Forest Monitoring law [European Commission, 2023a]):

- Value of non-wood forest products (see Annex III [d] in European Commission, 2023a)

Further indicators on socio-economic diversity (from Nikinmaa et al., 2020):

- Lifestyle/ livelihood diversity

- Management diversity, commercial plant use diversity
- Diversity, capacity to innovate
- Economic diversity
- the proportion of a county's total employment within a specific natural resource based industry

Indicators in the field of finance and technological infrastructure (from Nikinmaa et al., 2020):

- Stability of median house-hold incomes
- Financial incentives (such as environmental service payments)
- Annual net revenue and net present value (NPV)
- Community assets (physical, financial, social, human, natural)
- Dependency on forestry (proportion of a county's total employment within a specific natural resource based industry)
- Access to financial capital/credits

Governance indicators (from Nikinmaa et al., 2020):

- Land ownership
- Effective institutions and organisations
- Political will
- Collective actions, strategic actions
- Networks and connections

Other indicators

- Other wooded land (see Annex III [j] in European Commission, 2023a)

II. Emails that were used for citations in the text

The information that I retrieved via personal email contact with various representatives is contained as comments in anonymized form in the original coding file including that can be retrieved on Zenodo:
https://zenodo.org/records/11479358?token=eyJhbGciOiJIUzUxMiJ9.eyJpZCI6IjJmYTQ4ODYwLWIwYjYtNDU4Zi1hYjQ1LWUwZDFiMWY4ZTExMiIsImRhdGEiOnt9LCJyYW5kb20iOiI3MWYwN2E5NzZhNDA0NDAxMmNiOTNjYThiOWZiODNhYSJ9.-TM7YRDdWZbUoav6CjkLuLBZ3X6sYmmfKY4ahRygrPsgLS8ecUOb5s8ok-erwdvMXU_kgywjU4E0tYIsFdP5kw (Uploaded on June 4, 2024).

Note: Please contact the author directly if you want to have access to anonymized versions of the email conversations with the other representatives.

II.a Email by GNOR Representative, RLP

Hello Mr Hergl,

Thank you for your enquiry. Where are you studying, are you focussing specifically on Rhineland-Palatinate in your Master's thesis or on Germany as a whole? Regarding your questions:

There is no current overview of the occurrence and distribution of bird species relevant to forests. There is the ‘Birdlife of Rhineland-Palatinate’, which shows the distribution of all bird species ever recorded in Rhineland-Palatinate on a TK25 basis as of around 2014. There are also the annual ornithological reports written by Christian Dietzen (e.g. here), in which the ‘ornitho’ reports of the respective year are analysed for each bird species and the breeding distribution is shown in maps on a TK25 basis. The last volume summarises the year 2022.

The annual reports of the bird monitoring project are available as pdf downloads on the homepage. Here is the latest report, also for the year 2022, the one for 2023 is expected to be published in June.

We do not have an online portal with data from the breeding bird monitoring in RLP. Instead, we have the annual report, which summarises the data from the previous year and is therefore very up-to-date.

I hope I have been able to help you a little. If you have any further questions, please do not hesitate to contact me.

Best regards

[redacted]

II.b Representative Gotha Forest Research and Competence Centre, TH

Dear Mr Hergl,

Thank you for your enquiry. I will try to answer shortly:

Apart from this map from the Thünen Institute, are there any publicly accessible maps showing which tree species can be found where in Thuringia? (I found this data set in the geoportal, but I can't open the map online).

In general, there is no clear and conclusive answer on the subject of ‘tree species’. Yes, the Thünen map is okay, but it has its weaknesses (e.g. tree species for the period 2017-2018 detected from satellite data (without the massive tree mortality since 2018), 10m resolution (thus no individual tree detection possible, delimitation of some tree species not precise enough). There is also a remote sensing product from RSS (https://www.remote-sensing-solutions.com/waldmonitor-deutschland/#baumartenkart), which was also created on the basis of BWI data, and a product from the UFZ: web.app.ufz.de/waldzustandsmonitor/de?area=6&layer=45. ThüringenForst has its own (internal) tree species map, which corresponds to the data set they found. However, the dataset you found (which can be opened in any GIS) is outdated and partially updated. Unfortunately, I cannot provide you with the current dataset. However, ThüringenFrost is constantly working on updating this layer.

Are there also publicly accessible maps on the naturalness of the tree species composition in Thuringia?

Yes, these can be found in the tables of the tree species recommendation. The site unit (roughly corresponds to the site area) can be found in the forest topics of the Thuringia Viewer (https://thueringenviewer.thueringen.de/thviewer/). As a rule, all geodata from ThüringenForst AöR (which can be made accessible to the public) is always displayed here.

With regard to tree species suitability maps: Is there an interactive advisory portal in Thuringia, similar to the one in NRW? (Unfortunately I could not find it online)

ThüringenForst is currently working on an amendment and an interactive tool for tree species recommendations. Until then, our recommendations apply, which you can view as PDFs: https://www.waldbesitzerportal.de/waldbewirtschaftung/waldbau-waldumbau/der-waldumbau/.

I hope I have been able to help you and wish you every success with your thesis!

Yours sincerely

On behalf of

Dr [redacted]

II.c Email by representative of the UFZ

Hello Mr Hergl,

thank you for the enquiry, an interesting topic for a master's thesis! For the tree species classification, the satellite data of the years 2016-18 are used. So - especially with regard to forests that have died in the meantime dead forest after the drought years - something can already change in terms of Forest - non-forest. The data is currently not yet downloadable, as it has not yet published in a journal. However, we could potentially make it available after consultation. Alternatively, there is also Blickensdörfer's map, which is very similar and available (as it has published in the meantime).

The future distribution of tree species is now available in WebGIS. Just have a look.

Perhaps you can keep me up to date with the results of the work.

Best regards,

[redacted]

III. Transcribed Interviews

III.a Interview with a representative of the European Forest Institute, 11.04.2024 [in German, translated]

MH:
I would like to hear from you or I can give you a brief overview of my research and then I would ask you to perhaps introduce yourself and tell me about your work. I am writing my master's thesis at the University of Tallinn on the possibilities of open data in the field of forestry or in the protection of biodiversity or forest resilience and to what extent open data could help to increase this or generally to look at how different countries or regions in Europe are already using open data in the management of forests and whether this makes sense at all. I think the assumption is that open data is a good thing if the data is publicly accessible.

But the question I'm asking myself is what exactly can open data actually achieve in the area of forest protection? So far, I have focussed on Finland and Germany because there are already very good approaches in Finland. In Germany, it's still very opaque to some extent because every federal state has different implementations. Exactly, and I hope to learn a bit from them, not more about the European co-operation of data on forests. So my view is not really from the forestry science side, but rather from policy research, from the political side. But perhaps you could start by introducing yourself in terms of your work and link this to whether you have ever dealt with open data.

EFI Representative:
Okay, so I'm trying to grasp it somehow. It's quite a complex topic. So yes, I've already written an email saying that I'm not a specialist for Germany or Finland, but that I'm more familiar with the pan-European area. I haven't worked specifically on open data, but of course we have open data as a very clear requirement of the Commission projects and our work at the EFI is very much based on third-party funded research and a large part of the research is actually funded by the Commission through its research programmes. And there has been a very clear trend for a long time that data collected with public funds should be made available to the public. It is therefore quite clear that we are of course aware of the goal that data should be made open and shared.

We have also worked on this ourselves with our EFI tools. Which of the things can we now also make source code public, for example? Where can we simply make things public and simply fulfil these requirements? But that's a bit of a general context. In the forest sector, of course, we have the international issue of inventory data in particular, because if we want to create any reports, such as I don't know, you've already heard something about Forest Europe or the ministerial process, where the corresponding reporting on forest data takes place. Does that mean anything to you?

MH:
Yes, that tells me something. So at least I read through the last report.

EFI Representative:
Yes, yes, because it is also clearly regulated that, in principle, data should be provided by the member states and then made accessible. There are not only the reports, but also corresponding databases where the information is accessible. And this is very aggregated information data, a source of very highly aggregated information, where indicators are ultimately compiled on a national scale. The inventory data, i.e. national forest inventory data, is of course very, very relevant for more detailed statements. And it is actually the case that each country handles this differently and a whole series of countries continue to handle it very restrictively, so that you can usually only request the data from the responsible institutions in advance and then often only on request and often not really get the source data.

Other countries are completely unproblematic. Germany, for example, has now made all the BWI data public, I believe. You can simply download it and work with it yourself. So a lot has already happened from there. Waldinfo.NRW.de really serves as a role model. This is a portal that has been set up by the state government here in North Rhine-Westphalia. A very wide range of information on forests has been compiled there and the aim is clearly that the data provided by state institutions should also be made publicly accessible. Many services are also offered, so to speak, where, for example, forest owners can look at their own areas, see which protected areas they are located in or which soil data they are based on. A whole range of other secondary information on biodiversity or I don't know, many attributes are also compiled there, but I don't think other countries necessarily do it in the same form. I believe that this has been repeatedly sold by them as a kind of pioneering role in Germany.

MH:
Yes, I've actually seen the portal briefly before, but it's good that you mentioned it, so I'll take a closer look.
I've just started looking at what they've published. And they deal a lot with forest resilience, in other words the resilience of forests. I asked myself what data could be used to determine or measure resilience? What data or measurements provide information about how healthy a forest is?

EFI Representative:
Yes, these are the level one data on forest condition. These are the defoliation or leaf discolouration data collected by ICB Force. That is one possible source of data. We did this one study ourselves where we collated the disturbance data on top of the inventory-based disturbance data. That was the Global Change Biology publication last year, where we then also made the data available accordingly. This is a database that is also maintained in the EFI and where the data can be accessed from the EFI. This is information about the quasi stress factors that affect the forest. But to really make an assessment of how resilient the forests are, we need concrete indicators, at least for the time being.

And we are currently running a project, the RESONATE project, in which methods are being developed for precisely this area to assess and measure resilience. And we will also be carrying out case studies for nine different regions, where we will at least carry out modelling and then carry out corresponding assessments. But if you now want to retrieve data somewhere as a forest owner, then something like Waldinfo NRW would perhaps provide some of the information. But of course that's not really the information you need. So you need, you have to first understand what forest-free means, for example, the tree species composition, of course, very critical, very important, structural diversity, perhaps also the degree of foliage or where is forest, where has forest been disturbed? Where has crown loss been recorded? This is information that is compiled by Copernicus, for example.

I think you can download the forest map there. But these are many of the application products where the data is ultimately processed and interpreted. Some of them are not freely available, I believe. But the Copernicus satellite data is at least made available for researchers to process.

MH:
Now the availability of data is one thing, the other thing is that in my research I mainly look at owners of smaller forest plots or small forest owners, who often have little interest in their forest or sometimes simply don't have the means to manage their forest or simply hire subcontractors to manage the forest. Now perhaps from their point of view, there is an interest among the owners of forests, i.e. smaller forest plots, to look at data about their forest at all, to inform themselves about it and then perhaps to act on the basis of the data. So I would say planting new trees or pushing back invasive species, etc.

EFI Representative:
Well, I don't have that much contact with the practitioners themselves, with the owners themselves. We have stakeholder engagement activities in our North Rhine-Westphalia case study of superb project, which is about forest restoration, i.e. restoring forests after bark beetle calamities. And this Waldinfo NRW DE is actually a very good opportunity to show small forest owners in particular, because, as I said, they can find their own plot in the system and then see which tree species recommendations have been made for this location, so to speak. And the forestry planning in North Rhine-Westphalia has actually all been fed into this digital system. This allows the forest owner to see, even with small areas, which forest management types or forest development types, WETs, could be suitable for an owner's management objectives. So this is of course a very good way of obtaining information.

I've been to at least one workshop where this platform was presented and I don't think the owners necessarily have it on their radar. So how would they know? I think even the representatives of owners' associations, for example, don't necessarily know that these specific data services are available online. So there is certainly a lot of educational work needed to find out whether the forest owners could really be interested in something like this. So I don't think there's a generalised answer to that. I would think that it varies greatly depending on whether someone is very tech-savvy or not, and then people certainly use such tools nowadays because they can perhaps find them relatively quickly if they know what to look for. But I would assume that the vast majority won't use them.

MH:
How are there other ways of motivating people or motivating forest owners to strengthen the resilience of their forests? How do you go about this or what is your role at the institute?

EFI Representative:
Yes, so what we are actually doing in one project is that we have created demonstration areas where it is shown how this reforestation can be done with adapted tree species mixtures. And excursions are then offered, e.g. so that the trainee foresters, for example, can look at these areas, so that if another practitioners' conference is taking place somewhere, an excursion is offered to look at such areas. Well, I think there are many points that are very important for assessing resilience. But there are also many problem areas where this is actually a very difficult topic. For example, the topic of game density and browsing. Because of all these forest losses we are experiencing, regeneration through natural regeneration is of course particularly desirable.

And if the deer density is unfortunately as high as it currently is in many areas, then of course it is somehow very difficult to get a mixed forest to grow at all. So the natural development will often revert back to spruce, even if the spruce is perhaps no longer really vital everywhere, but everything else is unfortunately being selectively chewed out by deer and roe deer.

MH:
Yes, I was actually in the Harz Mountains recently and there you can see how large areas are simply being reforested. But I can imagine that it's a big challenge to get the trees to grow at all. Another question, because I don't come from a forestry background, is it still possible to manage a forest effectively? In other words, cutting down trees, turning them into timber and selling them, while at the same time strengthening the resilience of the forest. Is that possible?

EFI Representative:
Definitely, definitely. As I said, there are various criteria that are very important for resilience. One is the mixture of tree species, that we don't just have monocultures, like the spruce trees that have just been so badly attacked by bark beetles, but that we create mixed stands that are adapted to the climate. And in order to make this possible, of course, we also have to actively intervene, because where the spruce has now died off, the desired mixture will not necessarily re-establish itself. You have to plant first, but then, when the natural reduction is there, when the competitive forces take effect later, you have to regulate the mix and later, so I think the trend should also be towards more permanent forest stocking, where you then allow structurally rich forests to develop.

And you can only do that through active management. That means always using the somewhat stronger trees, so to speak, which can also be utilised economically, but then always keeping in mind that a forest stand remains that continues to be productive and resilient. But managing the mix is very important here, because if I only remove spruce trees, I can't necessarily control what other tree species will establish or develop in the stand. But in any case, you can combine the two.
So many, I think the problem is rather that if you now use or not use this paradigm, somehow just say across the board, yes, this is far too intensive forest management everywhere and we should manage much less, then I rather see the problem is then these stands in the natural or not only natural selection process then partly also impoverish themselves in the tree species diversity. For example, mixed deciduous forests are totally important, especially now with climate change, but in the short term beech is much more competitive than oak, although oak is the driest species. Normally, we want to have mixed forests with a mixture of different types of trees. But that's exactly what you have to support through active management, because otherwise such mixed stands can quickly become segregated again, because an oak can tolerate less shade than a beech. And if there is no thinning at all, then there is a risk that the oak will be thinned out by the beech.

MH:
My research started when I discovered this Global Forest Watch portal, which focusses primarily on rainforests. And I then wondered whether there was something similar in Europe. And my question was a bit more about the regulation or control of forests. It's always all very well to say that we are protecting our forests, that we have drawn up various action plans, but then you really have to look at what is actually happening. In recent years, there have been repeated reports in the Carpathian Mountains, for example, that large areas of forest that were actually under protection have simply been cut down or in the east of Poland. Now, I would like to come to the European Forest Monitoring System, which was proposed by the Commission. How do you assess the regulation of forestry or forest protection in Europe in general? Is it something that actually works well or is it a very large, broad, scattered field between different countries?

EFI Representative:
Now I don't know what I mean by forest protection, because protection in itself is something like insect monitoring and suchlike and possible control of bark beetle outbreaks and suchlike. And that is purely a management task that is carried out by the relevant owners or forestry authorities on various scales. Protection in the sense of compliance with sustainability principles or forest laws is a completely different level of governance. That's probably what you mean. Of course, there is no generalised answer to that. So the examples of Romania in particular and the conflict back then in Bielovescha in Poland, I wouldn't consider those to be typical examples for Europe, but rather a glaring exception. But I also recently watched this documentary about Ikea and the practices of how they deal with their own forests in Romania.

And I was very shocked to see that the problem is much more differentiated and that it's not just a few black sheep who are making illegal cuts, but also large players who are somehow implementing unsustainable practices and that this is not really being curbed. But I would also like to refer to something else, namely, as you said, this monitoring legislation, which is not directly linked to this, but there is also this Forest Information System Europe (FISE). And one of the Commission's concerns is that more such information should be processed there. And there is a very large project called FORWARDS. I don't know if you've heard of it before, but I'm sure you can google it. A forest observatory is currently being set up there at quite great expense.

These are data routines that are then developed, e.g. from intensive monitoring areas in almost near casting, i.e. almost up-to-date data is provided, which can then also be retrieved accordingly. On the one hand, this concerns intensive monitoring, where individual trees, e.g. diameter time series, are then also transmitted in the current now casting, but where other information content is also to be processed and then shared via this platform in the future.

MH:
I'll take a closer look at that. Because you just mentioned this FISE. I had been looking at the site for a while and the problem there, or at least that's what I had seen, is that the member states are not obliged to forward current data to the European Commission, but that this is voluntary.

EFI Representative:
That's the old problem. I already mentioned earlier that the inventory data is handled very differently and that there are some countries that just completely block it and it really is totally ridiculous. 100 years. Yes, there are projects where the inventory institutions have been given the task of harmonising and sharing data and then methods are developed, but the correct data is still not shared because some people simply block it. That's totally embarrassing.

MH:
What is the motivation for blocking it? Well, I myself had already spoken to a representative from Finland who simply said that a European system wouldn't help anyway because they already have the best. But that's no reason for me to say no, we don't share that.

EFI Representative:
No, there is simply a lot of investment from the institutions and they have created time series and they simply believe that they themselves want to be involved in any research that uses this data and always want to get a piece of the pie and they simply don't understand that you can also enable new approaches by sharing data and then perhaps develop a better understanding and get feedback. So this understanding of open data hasn't really arrived everywhere.

MH:
Somehow, I don't know, I think last autumn there was a proposal from the Commission for new European Forest Monitoring, but there is actually exactly the same problem. There, too, it was not stipulated that there would be mandatory monitoring, i.e. mandatory monitoring requirements. Is there anything to be gained anyway?

EFI Representative:
That will also be blocked again and again. It will always be blocked because the countries themselves don't want to commit to measuring and sharing more and more. This is also blocked by countries as a matter of principle, quite often, and the Commission must then somehow try to deal with this again and again. In the end, it is made formally voluntary or certain things only have to be shared on a mandatory basis to cover certain reporting obligations. But yes, the way things have gone over the last 10-20 years is unlikely to change completely in the future. Unfortunately, that's very bitter.

But that's why initiatives like FORWARDS, where this Forest Observatory is being set up, could perhaps have an impact, also because projects that carry out measurements themselves can also incorporate them there. Then you can also see that measurements are being taken here, monitoring is being actively carried out here and products can be retrieved here, so to speak, which can then provide information on certain issues. Yes, but that will still take quite a while and whether that is now on these European scales is of course not what affects small forest owners. It's simply a matter of being able to call up climate trends or see where the deforestation problem has been due to bark beetle damage, for example, and whether many areas in the vicinity of my farm are affected. You can then call that up. But the fact that you can really get information for management, for example, is still a long way off, I think.

MH:
These forestry planning offices are particularly important...

EFI Representative:
Yes, they are the providers who can do this as a service provider. Mr Hergl, it's taken us half an hour now, so do you have any specific questions? I have another media right now that I would like to switch to.

MH:
I'm sorry. So thank you in any case so far. I have one more question, and that is that I have mainly looked at Finland and Germany in detail so far. Would you have any suggestions for me regarding certain countries in Europe that have perhaps already made a special effort in the area of open data or as negative examples, I should say?

EFI Representative:
I always have the feeling that the Austrians are totally stonewalling, that they are very unwilling to share things. So Finland and Austria have often set a bit of a bad example. I think Switzerland is quite good when it comes to data access. But I'm not an important data user either. I think Norway and Switzerland have often had fewer problems sharing data, but neither of them are in the EU. I don't know if they are related to the EU countries now.

MH:
Okay, then I'll definitely have a look at it, so I won't keep you any longer. Thank you in any case.

EFI Representative:
I then have to download the transcript or recording, then the recording, then transmit it to them.

MH:
Or send me the link to the recording. That would be very nice. Thank you very much.

EFI Representative:
Yes, I will. Yes, then I hope I was able to help a little and good luck with your Master's thesis.

MH:
Thank you. Thank you very much. And I hope it would be okay, if I have a question that falls specifically in your area, that I contact you again by email.

EFI Representative:
Yes, of course, sure, I'd love to.

MH:
With pleasure. Thank you very much. Thank you for your time.

EFI Representative:
Okay, you're welcome. Bye. Have a nice afternoon.

III.b Interview with a representative of BrandenburgForst, the forest authority of the state of Brandenburg, Germany;

Representative BrandenburgForst:
So it has completely different interests than Department 4, which is the Eberswalde State Competence Centre for Forestry, which is the department for applied forestry research.

MH:

Okay. There are now regular monitoring systems or reporting systems in Germany, such as the Federal Forest Inventory, the Forest Condition Survey and the Soil Condition Survey. Are there any other monitoring systems in Brandenburg?

Representative BrandenburgForst:
Yes, the monitoring systems are in Department 4 in Eberswalde and this is where the inventories are carried out. The Federal Forest Inventory is coordinated by the Thünen Institute on behalf of the BMEL and the federal states are the executing organisations. This means that there is a coordination centre in Eberswalde with a forest inventory supervisor. In addition, there is also a regeneration status in wildlife monitoring and then status surveys in the Level 1 area. The soil condition survey is then comparable with the national forest inventory and not to be forgotten is the forest protection monitoring, which also runs through Department 4. In addition, there is also more specific research, which is realised to a greater or lesser extent depending on the personnel and financial resources available, such as natural forest research.

MH:
If you now look at the data collected in this monitoring process, is there an online portal where all this data flows together or is it scattered on different websites, or are these results all openly available?

Representative BrandenburgForst:
There are now several questions. Unfortunately, there is no data platform, whatever you want to call it, where all the data comes together. Most of the information is freely available, some of the data is available as open data and we now have the information portal bwi.info for the Federal Forest Inventory, where you can also download the data freely, albeit in a reduced form without the geodata. Yes, exactly, I've already seen the party. And then there are also various websites from Brandenburg, such as Brandenburg Forst, where you can also look at different things.

MH:
Yes exactly, I have already seen this portal and then there are also other websites, for example from Brandenburg Forst, where you can also look at various things.

Representative BrandenburgForst:
For example, the WZE has a special website for forestry environmental monitoring, and there is a special website for the soil condition survey, but it is all available in a heterogeneous form, i.e. at different addresses and in different states. And generally as information and not as data. And that brings us back to the initial question: What are we actually talking about?

MH:
What would you say is the aim of these applications? Is the aim more to fulfil legal obligations or is it really aimed at certain target users?

Representative BrandenburgForst:
Which applications? We haven't talked about any applications yet...
MH:
I'm talking about this site brandenburg-forst.de with a map where you can display different growth areas, for example.

Representative BrandenburgForst:
So there is the geoportal.

MH:
Yes, I think that runs via the geoportal.

Representative BrandenburgForst:
But then let's be more specific.

MH:
Okay, then I'll ask the other way round.

Representative BrandenburgForst:

These are really two different pairs of shoes. One is data and the other is information. You have to separate the two, please. If you want to think about research in this direction, you have to make a distinction between data and information. Then we have to talk about what we are talking about with regard to the provision of information. The term "portal" is used inflationarily for all sorts of things. There is the so-called geoportal, which is a web viewer at brandenburg-forst.de, where various information is displayed as a map view. And what is the specific question here?

MH:
Okay, so the idea behind my research, I'll say, is to analyse what information small or medium-sized forest owners need and to what extent this is available online.

Representative BrandenburgForst:
Yes, but then I'm the wrong person to ask, I'm not a forest owner.

MH:
Perhaps I have one more question. Is there...

Representative BrandenburgForst:
In the forestry sector in particular, there is usually no distinction between information and data. As a rule, the provision of information is formulated as the provision of data and there is hardly any ability to talk about use cases. And if we want to look at what information a forest owner needs, then we first have to define which forest owners we are talking about. If we are talking about small forest owners, then that is also an exciting question because, as a rule, we say that all those under 20 hectares are small. But you have to differentiate again, because there is a very large group under 5 hectares that probably has no need for information at all. What you could then put forward as a hypothesis is that it could then be difficult to manage the forest area at all. And there have been various programmes and attempts to approach the topic in the past. So how do I specifically address the small private forest owner?

MH:
And there was also a strategy to make more data publicly available. In other words, precisely under open data. Or was that another motivation?

Representative BrandenburgForst:
I don't know if that's the motivation. There's no point in talking about it like that if we're not talking about a specific use case. And if we now want to look at a specific use case and consider the small private forest owner who somehow still has the ability to manage the forest and who doesn't usually do it alone because he has usually come to the forest by chance. Every year, 65,000 people in Germany come to the forest by chance, namely through inheritance, and they usually have something completely different to do. They simply need a forestry advisor of some kind, which can be the district forester provided by the administration. In the past, however, there was a political interest in reducing this and leaving it to the market.
Here we are with freelance forestry contractors and now we have a freelance forestry contractor who wants to help this forest owner to manage his forest. And now the question is, what does he need? I can highly recommend that you talk to the forestry planning offices, because as a forestry consultant, the first thing you need is planning. For that you need an inventory. And on the basis of the inventory, depending on the mapped forest functions and the site data, he is then in a position, or would be in a position, to make recommendations for the current silvicultural treatment.

MH:
And this silvicultural treatment, to what extent, ok of course that also depends on the individual case, but to what extent would you say that economic interests are the top priority?

Representative BrandenburgForst:
Yes, but that brings us back to another topic. How is this relevant to the issue of providing information?

MH:
Yes, I would say that it is striking that there is no single portal where all this data flows together. And then perhaps the question is why this data is so scattered around.

Representative BrandenburgForst:

Yes, you can ask yourself that question. But does it make sense to only think in one direction here? If I understand it correctly, the thesis behind the question is that there is an economic interest in not providing information, perhaps even data.

MH:
Yes, you could accuse me of that.

Representative BrandenburgForst:
Yes, you could imply that in the question, but you can also ask: Where is data available in which field is there freely accessible data and how did it come about there and then you can ask the question, where is there no freely accessible data and information?

MH:
Is there any data that is collected but not published?

Representative BrandenburgForst:
Yes, en masse, of course.

MH:
And what are they in particular?

Representative BrandenburgForst:
You can't say what that is above all. Do you mean in terms of megabytes or time?

MH:
So what kind of data is not made publicly accessible? I mean, certain data cannot be published because it is private data. I'm trying to find out why certain data is available online and other data is not. And one reason that often comes up is...

Representative BrandenburgForst:
But let's go back to the question of what information and data is freely accessible and available.

MH:
So, for example, is the data available on the state of the forests...?
Representative BrandenburgForst:
Is that the case?

MH:
Yes, only minimally in the end.

Representative BrandenburgForst:
Yes, I also get some data on the condition of the forests via the IPvL. But what I get on the condition of the forests is information on the forest condition reports. However, these again relate to the country, i.e. they are large-scale information and are of no use to me as a forest owner. So beta data is available. The DWD is exemplary in making almost all beta data available.
But there is an organisation, and also an answer, there is an organisation that coordinates both the data collection and the provision of data. And there is reasonably balanced funding.

MH:
Which organisation is that?

Representative BrandenburgForst:
The German Weather Service.

MH:
Ah, okay. Is it possible in Brandenburg for forest owners to make their data on the condition of their forests available to the public authorities? So is there such an aspect of crowdsourcing?

Representative BrandenburgForst:

Firstly, why should forest owners collect their data on the condition of their forests and secondly, why should forest owners pass their data on to anyone? And thirdly, what overriding interest is there as to why there should be such a collection function?

MH:
I interpret that as a no. In other countries, this is sometimes the case. In Finland, for example, there are certain obligations that you have to answer questions online about your piece of forest. Or when you last carried out any work.

Representative BrandenburgForst:
However, this is not data on the condition of the forests, but on the management of the forests, and this works differently in other countries, especially with regard to management. There are also countries where the tax declaration is completed in advance, but I don't think that's the issue here. There is absolutely no interest on the part of forest owners to collect any information on the condition of the forests. There is no data model for this and there is also no overriding interest in somehow making condition data available. There are approaches that go in the direction of NGOs in the nature conservation sector, but even there I cannot construct a concrete use case that benefits the forest owner and the forest.

MH:
Yes, the forests are not doing very well at the moment, or haven't been for a long time. To what extent does open data have the potential to contribute to climate protection? Or to environmental protection?

Representative BrandenburgForst:
I would really strongly recommend doing your homework when it comes to separating data and information and also separating the condition of the forests, the condition of the individual trees and the management and carrying out a stakeholder analysis. In other words, who is actually pursuing which interests and where. Then we can talk about this in a structured way. This is a really great and important topic. There is the Digitalisation 2.0 working group in the specialist department for renewable raw materials, which has been working intensively on the topic of digitalisation and the provision of data within the forestry industry for almost 10 years now, and you can go there and take part. There is a meeting in Fulda on 9 April. The FNR also has a website and regularly publishes documents and videos on this topic. Then there is the Competence Centre Forest and Wood 4.0 in North Rhine-Westphalia, which was also created as part of the Digital Forest project. They have focussed in particular on data and data models. And here you have to differentiate between the respective use cases with regard to management and there is an immense need for data and I would strongly recommend that you speak to a forest management office, for example the German Association for Forest Management or Waldkontakte KFG. And they have the problem that they have to obtain the data relevant for forest organisation from many different sources. Fortunately, in most federal states, with the exception of Bavaria and Baden-Württemberg, the parcels of land, which are super important for creating a plan in the first place, are open data. And you can download and edit it and only with the land reference, i.e. with the land ownership, can you then start to think about the inventory. And at the moment, the recognised procedure for forestry is stocktaking, which means that they still have to go out and measure the forest on site to collect the economic data of this forest. Now the question regarding open data would be: Does it make sense to publish this data? You should answer this question in your work. Because you don't necessarily have to publish the economic data, but you also have to separate which data is actually relevant. Planning data is certainly not worth publishing. In the case of inventory data, you can certainly consider whether it serves a greater interest, which brings us back to the use case of a small forest owner who wants to manage his forest. He goes to a forestry consultant and says, give me some advice here, what can I do here. He needs a forestry planning office to do this and they need data, first of all they need the parcels of land, secondly they need the site mapping. The site mapping is not freely available in Germany, let alone in a standardised data model, let alone that it can be downloaded in a way that conforms to the target.
This is often the case in many federal states, where the data is published in accordance with INSPIRE as DNS or as an image. This means that in many forestry offices, the image is displayed in GIS and then the employees digitise the location data and we are then in the problem area of digitisation in Germany that information has to be collected several times or has to be copied. And then we only have the forest function mapping, which is collected by our forestry offices and should actually be freely available as open data, for download as data and not just as an image. This is more or less the case in most federal states, you just have to search for it for a very long time. Then the forest planning office has to take an inventory and go out into the forest to carry out certain measurements. And according to the current state of the art, many of these measurements are actually no longer necessary. For example, it is relatively easy

to derive the average height, stand height and top height from LIDAR data. To do this, however, this LIDAR data would have to be made available. As a rule, this is done by the Land Surveying Office and we see different qualities and different time intervals. And when the plan is finally drawn up, the private forest owner has to submit the plan to the higher staff directorate and they still want it on paper. As a result, there is still no sensible data model for forest organisation data. And then we talk about data structures and standards and if these are not demanded top-down, then they simply don't exist.
If the upper forestry directorate doesn't say that they want the forest organisation data as XML or whatever, and the information in this or that form, then this model won't exist either. This has nothing to do with any economic interests or conspiracy theory nonsense, but with the general problems of digitalisation in Germany, federalism and political will.

MH:
Now I have one last question, which I hope follows on from that. There are now plans at European level to introduce European forest monitoring. Could this help to harmonise standards within Germany?

Representative BrandenburgForst:
No, because these are completely different use cases. So, in theory, it could help to simplify certain information situations. There was also this hope with INSPIRE. The INSPIRE implementation has not yet materialised. Then came the PSI and the PSI implementation is also only rudimentary. And a purely political demand that certain information must be made available will not ultimately lead to data being available in a sensible way and even if a data model is specified, as is the case in Bavaria, this will not lead to a compliant, uniform and standardised data model. It often just creates a lot of work at different levels because data has to be processed again and again in order to provide the information in accordance with the model. So that didn't work and now back again, you can only do this kind of work and ask this kind of question with a specific use case and if you are now somehow looking at the small private forest and how should the data aka information be used for the difficult considerations, which are anything but simple. So with regard to what has been considered so far, it is a political goal. It's about what information, what data does a forest owner need and where does a forest owner get this data? You also have to ask yourself what he needs for what.

MH:
That's right. Do you have an approach where you say that would be a small solution or a larger solution that could make a big difference so that small forest owners have access to information that is relevant to them for the management of their forest? You probably know better than me if.

Representative BrandenburgForst:
It is important that I can get down to the stand in the spatial resolution. So I would need data sizes significantly smaller than half a hectare. Once again, the question of which data is actually relevant for the forest owner and I would say in a rough first step, yes, the site mapping should be available as open data, a standardised data model. Just like the conclusions, just like the forestry operation routes and the elevation data at least should also be made available nationwide according to a standardised model.

MH:
Yes, yes. Okay, thank you in any case so far. I'm sorry, you were my first interviewee, but it's definitely given me a lot of new food for thought. Yes, as I said, I'm also a bit motivated by the fact that I'm currently in Estonia and there's a data portal about the forests in Estonia where you can actually view everything that's collected as long as it's not somehow private data and that's still a long way off in Germany. Yes.

Representative BrandenburgForst:
And that is very important with regard to the data model and structuring.

MH:
Yes, I'll start looking for that over the next few months. Thanks in any case so far and I'm happy to take it, if I have any further questions, I'll get back to you.

Representative BrandenburgForst:
Yes, with pleasure.

MH:
Okay, thank you. I'll do some more digging and if I find anything that I think might help me, I'll get back to you. But for now I wish you a happy Easter and yes, thank you. Have a good weekend. Bye.

III.c Short interview with representative of 'Wald-MV', the forest agency of the state of Mecklenburg-Vorpommern

MH:
I could just call you back. Does it suit you right now?

Representative Forst-MV:
Yes, that's fine. Then we can discuss it briefly.

MH: Basically,
that's what my Master's thesis is about.
Or I take a look at the Federal Forest Inventory, which collects a lot of data. But it can only be accessed online in an aggregated version. So you can see the figures for each federal state. But without geoinformation. Without geodata. And that was the problem I started with, so to speak. And I wanted to know from them whether there are other portals in Mecklenburg-Vorpommern, let's say, where they publish information about the forests.

Representative Forst-MV:
Yes, well, if you go to the Geoportal MV, you can call up the Mecklenburg-Vorpommern forest map, for example.
Okay, but what's not there is the factual data regarding the distribution of tree markets, that's not stored there.

MH:
What data can you find there? I can also look for myself, but...

Representative Forst-MV: You can find
the basic forest map there. The forest map, i.e. where the forest is located in Mecklenburg-Vorpommern and so on. And there you'll find the forest fire deployment map. What else do we have there? I'll have to have a look now.

MH:
Yes, I'm also looking at it right now. The problem is that I'm looking at all 16 federal states and it's actually the case that it's different in every federal state.

Representative Forst-MV:
Yes, of course, we are in federalism. Yes. So, on the subject of agriculture and forestry: forest compensation probably doesn't play a major role for you, that's also from us, I said the forest map, then the habitat types, the FFH action planning, the forest protection areas, the basic forest map is now being taken out, the forest structure, the forest utilisation map, then the rescue points...

MH:
Yes, and everything comes together in this geoportal. So you don't have any other portals where data is published in Mecklenburg-Vorpommern. Okay, that's something.

Representative Forst-MV:
So I'll put it this way, this is the portal where we publish our data to the outside world. But that's not all the data we have.

MH:
Do you have any data on biomass or wood growth?

Representative Forst-MV:
Yes, of course, but we don't give them out.

MH:
Okay.

Representative Forst-MV:
Yes, because these are data protection issues. That's tax law. That's the big crux of the matter.

This is operational data that we have, so to speak, which we also have as a sovereign authority, but which we do not disclose ourselves and which we also do not disclose to third parties.

MH:
Yes, also for the forests that belong to the state?

Representative Forst-MV:
Only, so to speak, if you can now demonstrate a legitimate interest. Because we are, after all, a state forest, we are an institution under public law and this is our operating organisation. And that closes the circle again, so to speak. It's nationwide, but that's just what's operational and yes.

MH:
Okay, then they've helped me a lot, actually.

Representative Forst-MV:
And they also had another question, they wanted to know something else, if I remember correctly. There was also something else.

MH:
Yes, the composition of tree species, that's what they said they had.

Representative Forst-MV:
We have, but it will not be published.

MH:
Okay.

Representative Forst-MV:
Well, we have all that, we have that and we have the data, but as I said, they are not published.

MH:
And the reason why it's not published is simply because it's technically very demanding, isn't it?

Representative Forst-MV:
Nope, because nobody wants that, so to speak. And in our case, they have the map visualisation and they have the data storage forest, so they have the factual data, so to speak, and they can combine them. This is only done if there is a legitimate interest.

MH:
Okay.

Representative Forst-MV:
And so far, as I said, there has been hardly any interest, so to speak, only for ourselves. And at the moment, we're not doing the work of putting something out there that isn't in demand at all.

MH:
Okay, that means, as an interested citizen, if I were to look at what information I can find out about my forest, I could either look at this geoportal and find the limited information there, or I would have to contact the forestry office in my neighbourhood.

Representative Forst-MV:
Yes, exactly. Well, let me put it this way, it's not really right, so to speak, if you are the owner of the forest, then you have information about your forest yourself.

MH:
Yes, that's true, at best.

Representative Forst-MV:
And the other, so to speak, is the interested citizen, so to speak, but who then wants information that, let's put it this way, via third parties.

MH:
Yes.

Representative Forst-MV:
And that's just like wanting to know what I'm growing in my garden, so to speak. Yes, yes, I know what I grow myself, the owner also knows what he grows, so to speak, and he must also have a forestry organisation and so on. He already knows what he has.

Well, there are those who think they have to have information and, as I said, they have to prove that they have a considerable interest. Otherwise it's data protection.

MH:
Yes, that almost brings us to the philosophical question of who owns the forest, or rather who owns private landowners in particular.

Representative Forst-MV:
Yes, exactly, the owner owns it, so to speak. And there is, that's why the forest map is so limited, you can see where the forest is in Mecklenburg-Vorpommern, so to speak, to the owner, what he wants to give out.

MH:
Yes, okay. It's still interesting to find out how different, so it's similar in different federal states, but then there are different methods of publishing some of the data.

Representative Forst-MV:
Yes, I know, because we all know each other, so to speak.

MH:
Okay, then at least I have the two pieces of information I wanted from you and thank you.
Thank you very much.

III.d Interview with a management representative of the Finnish Forest Service ‘Metsakeskus’,

MH:
First of all, thank you for talking to me. I'm just going to quickly sum up my research. I'm researching the use of open data in the forestry sectors in Europe, and I'm specifically looking at Finland and Germany and the implications for a common European forest monitoring system if it is set up. Could you give me some information about yourself and your work background?

Metsakeskus representative:
Yes, my name is Ari Eini, I work as the director of Finnish Forest Centre. Finnish Forest Centre is an organisation working under the supervision of the Ministry of Forestry and Agriculture. So we implement the forest policy into practice.

MH:
Yes. What is your understanding of open data?

Metsakeskus representative:
Open data, one of the main tasks of Metsakeskus, so forest centre, is to gather and process the forest data. That includes the data concerning the nature, but also the timber and wood. And basically all the information is available publicly that we produce. We are a public organisation and in that sense, basically, all we do is public. Of course, not the personal details of the owners. But all the information that we produce is open. And the idea is that the forest sector would better, that it would increase the quality of the operations. Also the silvicultural work, forest management, but also from the natural side, to be able to see what's important habitats and the diversity of the nation. And we also use the forest information actively ourselves, because another task for us is to implement the forest legislation. So we use the forest data to implement the legislation and we try and also, how do you say, I'll use it automatically as much as possible. And the third job for us, the legislation, the forest data, the third one is to help and promote forest-based businesses and economies in Finland. So this forest data serves ourselves, it serves the nature and it serves the forest owners and forest actors.

MH:
So from an organizational perspective, is Metsakeskus the only organization in Finland that does that and that gathers all the information, or are there any other organizations involved in forest monitoring?

Metsakeskus representative:
There are, I would say that under the Ministry of Agriculture and Forestry, there are three organizations which are involved with the forest, not forest management but forests, let's put it that way. Metsakeskus is one, second one is the Metsähallitus, which governs the stately owned forest and land and water areas. So they have two sides, they operate as they make business, they take care of the business side but then there's a fireball and on the other side is also the natural issues, sustainability, protecting issues. And the third organization is LUKE, Luonnonvarakeskus, which is a natural research institute. So they do both agricultural and forestry studies and investigation, national forest inventory. So the LUBKE makes the large-scale inventing of the forests, which serves political level decision making. Or, let's say, for example, when we look at the European Union, that is like large-scale information. Whereas the data that Metsakeskus supplies that is for operational work. So it goes to the details of the compartment and forest holding. And we can make recommendations on the forest management, for example, tending of seedling stand based on this information.

MH:
So these three organizations, do they have the same standards in terms of the data collection on forests? Or is there, because I talked to someone from Germany earlier and there it's basically you have 16 states and in all of the states it's done in different, a little bit of a different way.

Metsakeskus representative:
Well I would say that yes and no. I mean the National forest inventory, as I said, that is for larger scale forest inventory. And I don't know all the details about that. Well, I don't know the details of our own system either, because there are specialists doing that. But basically, as I said, when it comes to this operational forest data, we have the national forest data standard. So not only forest center, but also Metzahamnitus and the companies. And everyone works with the same standard. So the data can move easily between the various actors. And the idea is that when we have our, when we produce our information, we used LIDAR scanning, you know, laser scanning. Then there is aerial pictures, aerial imaginary and field sample plots. And then all the result of these three things are then combined and modeled and that forms the information. And this standard is common for the forest sector. And when we get the data ready, we release it, it's open for anyone to use. And we also combine some other information, for example from Finnish museum agency, you know, there are some old things which need to be reserved. And then also from the environment side, because there are two ministries, there's the Ministry of Agriculture and Forestry, and then there's the Ministry of Environmental Issues. They have some information there on the threatened species, for example and all that information we use and combine it to our data when we serve it to our customers.

MH:
So you collect the data and then which regular monitoring or reporting systems are in place or which reporting systems do you have on forests that are the most important?

Metsakeskus representative:
When you say report system, do you mean the technology? How we supply it?

MH:
I mean more, do you have like a study that you do every year on the forests? The quality or the state of the forest? I mean what maybe more like what publications do you make? Because for instance in other countries, some countries have like every year they publish one report on the state of the forest, or they do it every 10 years or every 5 years.

Metsakeskus representative:
Yes, that report on the state of the forest is supplied by the Luke, by the National Research Institute. Okay. So they supply that report on the national forests and they report it. But this, our information, I would say we don't report it anywhere, we just publish it.

MH:
Okay, let's move to maybe you have this online portal, the metsään.fi. Yes, sorry, my Finnish is not...

Metsakeskus representative:
No worries, your pronunciation was very good. You have been to Finland, haven't you?

MH:
So you have it for forest owners and forest operators. What is the main goal of this portal?

Metsakeskus representative:
The main goal of this Metsään.fi is that that is one of the channels what we use to distribute the information. And when we published the Metsään.fi in 2012, I guess it was for the first time, it was first that kind of service, internet service for forest information.We try and make it easy for the forest owner to increase his willingness to manage his forest. So at one side he can see what are the options, what should I do, there are recommendations, and there are also channels to contact the forest operators. And so it started from information channel to the forest owners, but during the years it has enlarged and it's sort of a place to meet between the forest operators and forest owners. And that is one of the distribution channels. Then there are, you can also see the open forest data through our internet pages, where we have made sort of ready-made packages. And then the big companies, they use this information directly, how do you say. They can use Metsään.fi, but they basically have an electrical connection between the forest and the information. So there are basically three different ways to use it.

MH:
Is there an aspect, or I read on the website, I translated it, but I'm not sure if everything was super correct. Is there an aspect of crowd sourcing that individual forest owners, they can upload data or information on the forests in the portal or is it more like the other way around?

Metsakeskus representative:
They can, private forest owner can contact us and say that this is wrong, I mean this is wrong information, this should be this and that and then it's up to us to double check it and correct. Not anyone can supply us the information because we, Metsäkieskus is responsible, the forest, the act of Finnish Forest Centre that states that we are responsible for the correct information. So we cannot take the information just like that, okay this is okay and that is all right. So but for example we also get information from the forest operators like for example, if you have this final harvesting area, the company can supply us information telling that we have now made the harvesting, you can change the setting and we use that information actively. So it's not only supplying from us, but we try and circulate the information as much as possible, because whenever someone uses the information, that's a chance to correct and make it better.

MH:
So now the portal, you need to log in and it's only accessible to forest owners and the operators. Yes. Why is it not open data in the sense that you don't have to log in and it's just there?

Eini Ari:
Because there are also the forest owners name and address and everything, the details, personal details. So

according to the GDPRs we cannot open that data. But the same data is available through the map service in our webpage. But there are not the names of the forest owners.

MH:
I also saw that there's this open data portal by the Finnish government. Avoindata? And there you can find access to the Metsakeskus data on forest resource patterns and grid materials. So do you know how the cooperation is with the Avoyne data portal?

Eini Ari:
We have.Yes, the idea is that we try and bring our information to all different platforms, if you put it that way. And that's why it's also available through that AVOID data. But what was your question?

MH:
Okay, maybe I'm going to reach out to one of someone from there.

Eini Ari:
But we have one more thing, when we produce this information, we do it, one actor which has an important role in this play is the Finnish Land Survey to them. So of course this land survey has, they have a very crucial role when it comes to anything that happens in the in registration so we have very close, we get all the forest owner information from them and we also supply our data to them so wherever their data is available they also have our data.

MH:
Okay, so in Finland and in many other countries, there are a lot of small forest owners. So now you have the metsään.fi portal for them. Do you have any other experience how you can motivate these people to actually care about their forest and manage their forests. Because I think it can sometimes be hard to reach them because they might not have an interest in managing their forests.

Eini Ari:
Yes. Yeah. In our portfolio of services, it has been advising and educating forest owners has been on very top of the list. So we run different kind of lectures, lessons and courses. You can find information on various issues from our webpage. But of course, that already assumes that you have interest to go to our webpage. So the problem is the silent forest owners, which are not interested. Until recently, we used to choose every year, sort of 10,000, 20,000 forest owners. And we have certain criteria. I mean, if you have lots of silvicultural needs in your forest, or if we can see that there is lots of important natural habitats in your forest, we made a list of that kind of forest owners and called them and try to improve that of forestry. And until last year we did something between, we reached with telephone six to ten thousand forest owners, so-called silent forest owners. Of course the idea is that we work with the public money, with the state money, so we don't want to contact those forest owners which already have a contact with some operator or forest owners association. So we just try to find those restaurant owners are not listed, if you put it.

MH:
Do you think, or I'm not sure if you can tell, but do you think that these small scale forest owners are interested in data about the forests? Or if the data on the forest was, if they could check it online, do they not really care about it?

Metsakeskus representative:
I think forest and forestry sector, as you probably know, is a big issue for Finland. Almost 20% of our export sales are forest-based products. And so there's lots of every... We are five and a half million people in this country, and I think everyone has a personal opinion on the forests. Either you are a forest owner or not. But the fact is that there is so much debate nowadays on the papers about forestry that makes people interested. So I think we have... Say if you go 50 years back, 50 years ago, most of the forest owners were farmers. But now most of the forest owners live in the towns. They are teachers or engineers or whatever. But forestry is getting sort of a hobby for them. And if you increase your interest that look even if you have a 20 hectare piece of land that may pay you a salary for a 13th month. And I can see that if we compare the situation 20 years ago and now the people are more interested in the forest ownership now than 20 years ago. And when I say I told you we have decided to finish calling them. But we try and improve more and more e-services. So that every year we supply new information for one sixth part of the country. So we have a six year program to go through the whole country. And whenever we get certain

areas ready, we contact that area forest owners and forest operators. Now there's new information on this area. Please go and check. How do you think about this and that?

MH:
Do you have an information or do you have information of how many people or how much percent of forest owners use digital services?

Metsakeskus representative:
We haven't. I mean, there are, depending on how you, a little bit how you calculate, there are over 600,000 forest owners in Finland. So about every 10th person is a forest owner. Yes. And I think people more and more, anyone, I'm getting 60 in two weeks time. And I mean, the average age of forest owner is pretty high, but still more and more people use digital services. And there's also electrical timber exchange where you can place your offers on this harvesting area, companies, the offers. And that is also based on this information.

MH:
Okay. One aspect of open data is also the hope maybe that it can help to protect the forests which are important ecosystems, like where important species live, and that are especially good in storing carbon, like old growth forests. And this concept has mainly been used in like tropical rainforests to use open data to kind of monitor that these places are not locked. But this idea has mostly been worked on by NGOs and like the tropical rainforest. Would you see that this could also work in Finland or is there something that is already happening? Like similarly that actually the satellite pictures are recorded and if there's an illegal logging somewhere, there's an alarm.
Metsakeskus representative:
Yeah, that's exactly what we do. I mean, when you do harvesting in Finland, you don't need a permit, but you need to make a forest use notification to Metsakeskus. So you usually do over 90 percent make it electronically, you give the notification. And we have, according to the law, we have 10 days time to react. I mean, if he doesn't hear anything from us, he can basically go ahead. But what happens when he makes the notification electronically, our system automatically compares the notification, the area, to our forest data. And if there's nothing special, if it's just ordinary forest, it sends immediately back a message that, please go ahead. That's all right. But if our forest act, there's clause number 10, which there's a list of important habitats. And we have tried to locate all those important habitats of our forest data. It's not 100% ready yet. I mean, they may be on the map, but we need to go to the forest and double check it physically. But basically if the notification meets one of those areas, or if there's something else special, or a threatened species in that area, then our system sends a message to the forest owner and operator that please make sure that there, please be aware that there is this or that kind of special thing in this area. And we also send a message to environmental authorities who are responsible for a different legislation. And then after the harvesting, we use satellite pictures. And if there is an area which hasn't given a notification at all, we immediately find it out. Okay. Or if the harvesting has gone to one of these important habitats, that's also visible on this satellite's picture. So that's what we do every day in our office.

MH:
We're coming to the end already, but there are currently plans for a common European forest monitoring system. Yes. Would you generally support this initiative? Or let's ask maybe a bit more differently. Which aspects of transferring the power, so to say, on the European level come with concerns from your side?

Metsakeskus representative:
Yes, yes, they are. I mean, I think the problem really is that the different countries have so different systems and somewhere for us are better monitored than elsewhere. And now European Union and the Commission wants to use the Copernicus program. But we believe that Copernicus has not the information they are trying to use it for, I mean, the Copernicus program is not, I mean, they can't, the information is not detailed enough for that kind of decisions that they are going to use it for. So, I mean, you can't say all those pictures. I think their hopes are how the targets are too tight or what they think they can do. And basically our formal opinion is that we should use the information that we already have. I mean, I can't, for our country, I can't say. It's very difficult to see that the Commission's ideas would bring anything. We have already established a connection with the forest owners. So why should that change? And we have, I would say that during the last 10 years, the technique has improved so much that we are really going to the right direction.

MH:
And I mean, you also already transmit a lot of information to the European Commission.

MH:
Yes. And of course, then another question is that... Yeah, this is a very tricky debate that basically the European Union doesn't have a common forest policy. There are so many other policies, like environmental policy, climate policy, trade policy. And the decisions of those DGs are also involved in the forests. So that's a bit of a tricky course. We see that the forest policy should be in hands of the national decision making. But the decisions from other polices are knocking the door all the timec. And also when it comes to monitoring policy and the targets of that, the fact is that we shouldn't go further. I mean, it's getting to some areas which belong to the national decision making and not to commission. Yes.

MH:
Maybe to end this interview again with talking about open data. Do you already have plans maybe to make even more data available as open data? Are there any new initiatives that you are talking about, maybe also collecting new data that you have so far not collected? Are there any recent developments in open data? Well, the forest data, the building of the forest data system started from the economical need, I mean, to help the operators to better plan the harvestings and logistics and stuff like that.
But during the last five or ten years, we have seen that the environmental issues have grown very much. So what we are doing about the, if you call it raw data, we are trying to utilize it more and more to find what's important climate-wise or age-wise.

MH:
Biodiversity.

Metsakeskus representative:
Yeah biodiversity details, those are something which we are very much improving right now. So let's put it that way, for the economical use the data is very good already, but we need more and more different things concerning the biodiversity. And then we can find those spots in the woods and help the forest owner and the operator to take them better into account. And basically, as I said, all the data already is open from our side. So even when it comes to these field sample plots that we do every year. They are also available for you, for example, science.

MH:
Yeah, no, it's really good to see because I mean, I also saw the portal here in Estonia. There's also a lot of free available data, but then, like I'm German, when I go back there, I mean, the data is technically available, but the geo coordinates are missing. So it's you can look at the data on state level, but it doesn't help you with anything.

Metsakeskus representative:
What we try and do is to make it as easy as possible to use it. And that's why we try to make it, you know, when we make it open, we really want to make it usable.

MH:
You said that in Europe, there's very different approaches already. Do you have maybe a country case, which you would recommend me to look into more? Where they also use open data very well?

Metsakeskus representative:
To be honest, I don't know. I think that we are pretty much in the front row. Yeah. I would probably, I don't know if you have talked to our Swedish colleagues, because they also, traditionally they have lots of effort.

MH:
Yes, all right. Thank you so much for your time and your answers!

Metsakeskus representative:
It has been a pleasure. Have you been to Finland yourself? I have, yes. Yeah, but I don't know, would it be helpful if I sent you a few pictures or presentation on the forest data?

MH:
I would love to have some more information. If you have some reports or even presentations, I would like to have a look, yes.

Metsakeskus representative:
I can ask one of the guys who works with this forest data if he has sort of a general presentation on collecting the forest data.

MH:
Yes, that would really help me. Thank you so much. Then I'm going to stop the recording here.

III.e Interview with a data manegement representative of the Finnish Forest Service 'Metsakeskus',

MH:
All right, so maybe you can tell me a bit more about yourself and what you do at Metsakeskus.

Representative Metsakeskus:
Yes, yes. My name is [redacted]. I work as a forest manager and my responsibilities is to work with the collection of forest data. One of my main tasks and also the staff that for whom I work as a foreman, works also with legal forest act things and legislation in the forest sector. But my main task is to collect and produce forest data. And our organization is founded by the government, so it's public fund organization, and we are, how do you say, controlled by the ministry for Agriculture and forestry. So they say what to do with the money they gave to us.

MH:
Okay, who do you work with normally? Do you work with people from the owners or do you mostly work with the people that collect the data?

Representative Metsakeskus:
Maybe. Well, more in my work, we work more with the companies that are issued in the forest collecting the forest operators and not forest operators. It's different companies that are specialized in the techniques of the collecting of forest data by remote sensing. And so, and also other public organizations are involved in the collection. Like the. Is it land survey.

MH:
Yes. Can you maybe give me like an overview of what data you collect and from which sources this data comes from?

Representative Metsakeskus:
How do you specify what is forest data for you? I mean, what are you interested about? Because forest data, what we have, how we have.

MH:
Like you can have the more economic data in terms of civic culture, how the trees like the growing conditions, basically, yes.

Representative Metsakeskus:
And then I think also we contain in the term forest data, also like the forest. Oh, my english is so bad today when you don't use it, when you do forest use declarations, you have to do them to us and we then inspect them and also they are part of forest data in our terms. But then maybe what you more think about forest data is data about the forests, trees in the self, the vegetation and the soil and the production, how it grows and how it will develop. But you can also think forest data as bigger as all things that is connected to the forest.

MH:

Yes, because actually my question was also going to be if you also collect data on biodiversity in the forest.

Representative Metsakeskus:
Yeah, yeah. But our main data is the data that is connected to the legislation, like this forest declaration data that you have to give to us. And also we have this stub deduce forestry that you can apply for. It's called camera and new legislation is Metca in Finland, and therefore example for the terms in English. Sorry. When you do operations in small seedling stands. Yeah. You can get substitutes for. For those kinds of operations in the forest. So they have to apply for the subsidies from us. And then it's a kind of data that is collected and stored in our forest database. And then we have this real forest data, as I think it is then collected by remote sensing. So we have a national inventory plan for the whole country, where there is several organizations that share the costs for the inventories, or not the inventories, but the collecting of the remote sensing data, that is lidar data and auto photos.

MH:
And so you use the Lidar?

Representative Metsakeskus:
Yes.

MH:
Not the Copernicus satellite data?

Representative Metsakeskus:
No, no. Yes. We also use two other supporters, those, but we use for the production of forest data, Lidar data and orthophotos. And the land server is the organization that. That is the main partner, and they have the responsibility of organizing the collection of this data.

MH:
So, okay, maybe this is a stupid question, but I'm still finding my way into this field. Do you, from the satellite data, do you have new photos every day?

Representative Metsakeskus:
Well, from Sentinel two, you almost have every day, but there's, of course, so much clouds and so on, so you can't get a clear picture of the whole country each day. But now the whole country, we have a program where the whole country now gets laser scanned in six years. And we have this year and next year left of this cycle, inventory cycle, or data collection cycle. Auto photos are taken every third year. And that's now, for this moment, the ground for our forest data production.

MH:
And this data is also publicly available?

Representative Metsakeskus:
It's public available, yes. And it's then the LAN server where you can get the data. But we are then a user also putting our own money for the data and the areas that are scanned every year. There are about 20 to 24, 23 inventory areas, blocks that are scanned every year. And the same year, when they are scanned for lidar data, they also take ortho photos from the same areas during the summer. And these inventory areas are then the blocks where we do forest inventories and for our use. Then, when we are interested of the trees there, then we, with other companies, also the same companies does these laser scannings and auto photos. But there are also different companies that are specialized then inventories. And for the inventories, we need reference sample plots, reference data from the ground. So we measure from each inventory areas, inventory area, then field sample plots, and with help of these field sample plots, then the company that does then the inventory data for us, then they do, with help of the leader data and the ortho photos and the sample plots, they can do then models that for the whole inventory areas where we then what is my term, my english so bad today. I'm sorry. They do them models that describes the end product is 16 times 16 meters squares inventory units. And for each unit that we will define for each three species, broadly red trees, pine and spruce, then diameter, breeze, tight mean height and what else.

MH:
Yeah, I think I found the information online.

Representative Metsakeskus:
So we do the inventory for these three tree species, and we get then from this 16 x 16 units, how much of these trees and what is the diameter on each tree species and length. And of course the basal area. And then from that information we produce then stand level data. So we produce stands. So we are trying to keep updated a stand data for the whole country. So we have then bigger areas that are quite similar to each other in forest terms. And then these units are then calculated to these larger areas. And that is then the forest data. One kind of forest data that we keep updated and then also uses as open forest data. And this data is also then the stand level data. And also the forest units data today is also updated. So we calculate we have, of course, the ground data, is the inventory dates data, what was there when the laser scanning and the auto photos were done. But then we also calculate to that data the annual growth every year. And also then possible cuttings and thinnings that we know of will also be calculated into account. When we get to know things that has happened or maybe will happen in the forest, then we will update the data. And probably, or let's hope that then in the future, within some years, then there will be a new inventory. And then we will continue to update the data.

MH:
Do you have a warning system in place? If there is, let's say like illegal logging taking place?

Representative Metsakeskus:
Yes, that's a kind. That's again a different process. Because when we you have to do this forest use declarations to us. And then, and there again we use satellite change, satellite image change analysis. So we analyze changes from the satellite data and then compare it to where the cuttings have been told to happen. And if we found. If we will find cuttings, for example, where the forest act is in place, and where we haven't had any forest use declaration, then we will start investigation of that case. If there has happened something illegal.

MH:
And is this data openly available freely?

Representative Metsakeskus:
That data is more background process of ours. But I think also that change detection data is in that case it's just date of areas where some cuttings have been taken. So yes, you could have it if you ask for it, but we don't produce it or deliver it as open data that you can download or look at whenever you want to.

MH:
Yeah, I get. So basically the raw data would be available, but the process for internal process.

Representative Metsakeskus:
Yeah, you should then apply for it differently and maybe it would cost something to produce the data so that you could use it. Yeah, but open data today is of course, all these forest units, 16 times 16 meters squares, that is open data today you can go into our website site and download them in different blocks or the whole country. And also the stand data, these like bigger areas are open data. And we also have old and collect and produce soil and soil data, because you need the soil data when you estimate how it will grow in the future.

MH:
So when you are just an ordinary citizen and you want to know about the conditions of your local forest…

Representative Metsakeskus:
Local forest on your own forest, then we have also a website where you can log into and look at your own forest. And we newly renewed the site, so it works better nowadays, also on Ipads and telephones.

MH:
So. But this is only forest owners.

Representative Metsakeskus:
Forest owners and actors. Yeah, forest actors. But here again, we have the forest data and the ownership connected to the same data. So here, if a forest actor wants data, then he has to. He needs the permissions from the forest owner to look at his data. But if you. If you just take the raw material, like the open data,

but then you will get all the data, the same data, but you don't know who owns it. So that's the difference. Because when, as soon as you connect an ownership to real person, as an ownership to the forest data, then it's not open anymore.

MH:
Yes. Is there in the data collection in general, do you also ask forest owners to provide or can they provide their own data? Or their own, maybe not like raw data, but their own information.

Representative Metsakeskus:
We have a forest data act in Finland, that precisely is for our data. And there the forest owner has the permission to correct things that are wrong in our data. So then we have of course take to accept is this that big error that we have to correct it? But for example, he has the permission to correct the wrong if we have wrong data about him or his forests.

MH:
Does that happen often?

Representative Metsakeskus:
Of course, those that uses the data more intensively, they often want things to be corrected. But of course we have also some things that are more that maybe is okay. It's wrong in sense, because the forest owner might know that I was. This was cut 2020 and now you say that it is 20 years old. It can't be. But there are of course, things with the inventory errors. So we can't promise to correct everything because something comes from the method that we do the inventory. So we can't promise it to be more exact than the method is. But if there are, it's a little bit. The law doesn't say like exactly that this is an error that we have to correct, but so we have to like see with it where our standard goes at what do we correct and what we do not correct.

Then if a forest owner says that you have to correct this, then all that we have is our data and his words that it should be like this. So for example, another data that we have and update is data about important habitats of the forest act. And there we are trying to be more exact because those data again is of course might be a problem for the forest owner, that it might affect how, what he can do with his forest. So if we are there uncertain about how exactly our data is, so then maybe we. And he can also beg us for what is it like a real paper where we really say that this is an object by the forest act? And of course, maybe for that paper we maybe need to go to the forest and really check it once more. Yeah.

MH:
Yes. Okay, so I'm jumping a bit to the questions now because, I'm sorry, but I talked to some people in Germany and they said that a lot of the surveys, especially for the sample plots, they're still done by going to the forest, to the sample plots and recording everything manually on paper.

Representative Metsakeskus:
Yes.

MH:
Do you still do that?

Representative Metsakeskus:
Yes. This forest data inventory is done like this, I said, by modeling and by remote sensing. But then when we check the forest laws, then we do more for field work. So if we, for example. Yeah, but when we do field inspectations, you maybe would tell them. So then we have to measure in the field. Yeah, but nowadays we also use, for example, drones and such data in the inspection work.

MH:
But is there some sort of data that you can only collect by physically visiting the forest?

Representative Metsakeskus:
For example, we have an act about forest damages. And when you do, for example, a thinning in the forest, then the basal area is not allowed to go too low in the area and you may not damage the other trees too much, either the root or the stems. And today, for example, there is no remote sensing or drone that can collect the data of how is the stems looking? Is there a lot of damages on the stems after the thinning,

for example, maybe the trees, you can calculate from the drone data how many trees there are left in the area.

MH:
But from the data you had before and then from the data how much?

Representative Metsakeskus:
No, you always have to take new data because the data that is taken out, we will not get.

MH:
Okay. Okay.

Representative Metsakeskus:
Yeah. So, for example, we have been trying to collect these kind of data nowadays, but with drones. So the drone then takes a picture and you can then analyze how many trees there are left. And then after that you will go in and just check at the forest damages in the trees and collect data separately in the field. And then all days you went into the forest and then you make sample plots and collected the whole data in the forest. But now we have tried to do like hybrid inspections when you use drones and you use field work together, for example, for this use. But the problem a little bit with the data from the sky is that it's not so easy to see all trees. So today it's maybe more, I don't know if it's more exactly, but it's more easier for the other part to accept the data if you do it in the field still today. But of course, when you go to the field also, you have to do sample plots. So it's just, it's not the fact, because you can't. We don't have resources to count all trees.

MH:
Now, I'm curious about the use of the drones. Yeah, so the drones, do you use them, they just record videos or are they equipped with software that already measures.

Representative Metsakeskus:
They are equipped with a lot of sensors. That is also something that we buy from operators. So we get the ready data. For example, we do a lot of drone inspections after the cuttings. So, for example, easy task for the drone. If you have important habitat that has to be without the cuttings, then we put the drone and it will fly and collect the data from the trees. And of course, we will get a really good quality of the image from the drone and the drone data. I'm not really into it, but one kind of thing is that it takes a lot of auto photos, and then from the auto photos you can produce a point cloud, and from the point cloud then calculate each tree's diameter and height and so on.

And also there are scanners nowadays, so there is a lot of different technologies and sensors on the drones, but the operator then does the analysis for us. So we will get our data is then the photo and a point data where each tree that is analyzed is then on the map, and then we have the tree data and then we have the picture. And from the picture, for example, we can then check quite exactly, is the habitat then intact? Or has there something happened? And if it seems that it's not intact, then we can then maybe do some hearing. Or then we have to go to the forest and check it again more exactly, or already then after the hearing, then send it to the police for further investigations. And then from.

From the pictures also we can measure, for example, dead tree, and if there are some water elements, how they have been taken into account in the cuttings, or for example in the soil preparation and so on. So we can check a lot from the very exact image that we get from the drone.

MH:
There are also these international monitoring reports on the land use and the capacity of forests to store like carbon and to service carbon sinks, basically. Are you at Metsakeskus also responsible for these reports? Or is that someone else?

Representative Metsakeskus:
That's someone else. It's LUKE.

MH:
I've heard, look. But do they collect their own data or do they correct your data?

Representative Metsakeskus:
They collect their own. They don't use these datasets in their collection, but they use more satellite data, I think.

MH:
Okay, interesting. I thought they used the same data as you.

Representative Metsakeskus:
Yeah. And for them we also have then the Finnish National Forest inventory, and that's a different thing. And that's also open data. And also in 16 x 16 square meters units produced data, but these are different locations. It's the same location, but it's a whole other method. How it's produced. It's produced by satellite data and the sampling is otherwise done. So the accuracy on the stand level, the accuracy is not that good as our data, but for the whole country it gives like a better and with less error estimate for bigger areas. Again, so it's their data and their methods then, that are used for. For these kinds of analysis.

MH:
And now we've talked about open data quite a while. I've actually wanted to ask this in the beginning, but what do you understand as open data in forestry?

Representative Metsakeskus:
Yes, but I understand this is maybe data that you easy can access without asking anything. And what we produce, I think open data is these datasets that you can download and then do whatever you want with. And also we have, if you know, data set provided on your server that you can connect to and look at your own data, so you don't need to download the data. I can't remember the terms in English.

MH:
Okay, yeah. So it's like web based?

Representative Metsakeskus:
No, I can't remember the terms. But for example we have the land survey, they provide. I can't get it into my mouth. They provide open. What is it? Open. Okay. They have a server that provides a service so that you with your computer and your GIS program can connect to the server and then look at the data. Yeah. So we have these open services for example for the forest use declarations for the forest data stands and also other kinds. And also, then you can download them if you want to your own database. Yeah.

MH:
So you already said that the data that is only in the Metsään portal is the data that is like private data where you can find like information about ownership also.

Representative Metsakeskus:
Yeah, yeah. So there it is in Metsand fi. There everything is connected to the forest owners. So. And that services is today at least it's not a place where anybody would go and look at our open forest data because there it is then connected to the forest owner and you need to log into it with these procedures that protects the forest owner.

MH:
But then in the portal you find the same information?

Representative Metsakeskus:
Open data. Yeah, it's open data but just like already like tailored to the specific needs. Yeah. So if you as a forest owner login, then you will only see your own properties and the data from your properties.

MH:
Yeah, but there's no extra data that is not openly available.

Representative Metsakeskus:
There are extra services because in the medicine alpha fi is also a portal for the services to us. So you can send electronically your forest use declarations and your applications to us and so on. And also the actors

can do it. Yeah. So it's more than a place to see all open data. It's also like a public service to where you can do your business with us.

MH:
So as I've kind of realized now, Finland is pretty advanced in this field and pretty, they're, yeah. Already doing quite a lot.

Representative Metsakeskus:
Which other countries are you investigating? You said Germany.

MH:
I'm also looking at Estonia because Estonia has also a very open system and then I'm also looking at Spain. But then Spain is very different so I might end up not taking Spain. Okay. And Sweden is also quite similar probably to.

Representative Metsakeskus:
Yeah, it's quite same. But, but maybe the difference is that they have almost the same data sets provided openly. But one big difference is the forest stand data that we produce and the accuracy also that they produce isn't as good as our. But they don't provide forest stand information they have in their open apps, they have a system where you can draw a stand and then it will tell you how much it forest there is inside that area that you draw. But then it's also the inventory date data, so they don't do any updates or something like that. So they just have this 16, I don't remember, is it 16 times 16 meters squares and it's a static data that isn't updated or anything. And it's also only the total for the forest totals.

So total volume, total basal area, total mean height, mean diameter. And we are like trying to produce then separately for at least these three different tree species, the data and then produce from these three species, then the total for the area.

MH:
Going back to the open data. Do you have any clue how this is used or if it is used, the open data?

Representative Metsakeskus:
It hasn't been open since. Was it now I don't really remember. Was it 2017 or 2018? And after that, I think the real use of our data production has like really got to the field and is used today. And it's more and more in use. So it's a really good thing that it got opened. Before we started in Finland with this remote sensing inventory in 2010. Before that we did only inventories in field. And also, then there were 13 independent forest centers. And the total inventory area in field was one point, was it over 1 million ha every year were inventory in the field. And then in those days, the forest center also sold forest management plants to the forest owners, like for, for this business. Like, like for like a business.

And, and maybe 30% of the forest area that was inventory where then done into forest data, forest management plans. So then they of that data, of course, when to use. But the other 80, 70% for a time, nobody almost used that data. But now, today, all data, every day someone downloads the data and uses it in their own organizations and operations.

MH:
Do you have statistics of numbers? How many downloads you have on this?

Representative Metsakeskus:
There are some statistics, yes, but I can't remember them really myself. But, but the usage, the download usage, we don't know who downloads and who are in contact with our servers, but the usage has gone upwards all the time since 2018 and are still going really a lot upwards.

MH:
And do you know who, like, I mean, you don't know from the data, but maybe from personal experience who these people are that download the data?

Representative Metsakeskus:
Mostly. Mostly forest organizations. Yes. Okay. And then they also have, I think, like in their own systems, then some kind of routines that tells that they know, there's new data there and then they will

automatically then download it and so on. Or then they download it each month or each some procedures, how often they download it.

MH:
Okay, so as I see, you already have quite a good system in place.

Representative Metsakeskus:
Yeah. And working system. Yeah. And the big deal in the system is also the forest data standardization. So we have standards for the forest data, all data. So that helps also the usage.

MH:
And they are all the same all over the country.

Representative Metsakeskus:
Yes. And we are the organization that has a task to maintain the standards. But there are in the work for the standards. There are people from the whole sector that is then updating the standards if needed.

MH:
So if you could say what could other countries maybe learn from this Finnish approach of how data on forests is utilized by a public institution?

Representative Metsakeskus:
Difficult. I think the standardization is maybe a quite big thing because without that it's not so easy to use the data. And of course we as an agency, it's important for us that everything is digitalized. For example, when you send us forest use declarations or other applications that everybody has the possibility to produce services their own, that they can send it to us digitally.

MH:
Yeah. I've talked to some German forest officials and there it's really complicated, but you have to get like the forest usage, like the approval of operations in your forests. You have to do a lot of paperwork, print it out and send it by mail. And then.

Representative Metsakeskus:
Here. Now you can do it in metsään.fi yourself or usually the forest operator does it for you. So when you do a contract, then the forest operator do it and then they can send it into us in their own system. They then have a connection to our server that takes the message from them.

MH:
And the only way to do that is online. You cannot do this with paper.

Representative Metsakeskus:
You can do it by paper. But today 94% of all declarations comes by digitally. But of course there are a lot of these declarations. So this 6% is a quite, makes a quite big work for us because then we have to digitalize them ourselves.

MH:
I see.

Representative Metsakeskus:
Yeah. And in Finland we have ten days to react. So after ten days, if they don't hear anything from us, then it's fine to go and start cutting.

MH:
Okay.

Representative Metsakeskus:
I don't, I don't know any other country where you that fast after sending the declaration is allowed to go out and do the cuttings after ten days.

MH:
From your personal experience, is there something that you would like to change in the system?

Representative Metsakeskus:
Yeah, but maybe more about money, use and so on. But it doesn't belong to this.

MH:
I mean, it already seems like a system that is working quite well. Yeah, but I guess there's always room for improvement all of a sudden could.

Representative Metsakeskus:
Make the data better. But of course resources are always a… You have to say the finnish government have put in the days and also still puts a lots of money into this data and to the production of data. But of course, if you would have more data, the data would better. But of course you have to what is. What is then enough.

MH:
Yes. All right, thank you. I think I already asked most of my questions.

Representative Metsakeskus:
My questions and if you need you, I didn't read your paper too much. But if you need more about the strategies and so on those you will find that the ministries sites and I saw that they are also almost everything there were also in English.

MH:
Yes. And I was also on the Metsakeskus website and I just translated. Yeah, translator. So it worked.

Representative Metsakeskus:
Yeah.

MH:
And do you have any recommendations maybe what I could still look into for my research. I guess my main argument will be Finland as a good example. And like, so you said maybe one thing, that you used to have 13 independent forests.

Representative Metsakeskus:
Agencies and organization, yeah. But now we are on a countrywide organization nowadays. Yeah.

MH:
And that you don't need to mention.

Representative Metsakeskus:
Yeah.

MH:
Okay. No, because I was just thinking in German you have like 16 different forest authorities and they all do different things.

Representative Metsakeskus:
Yeah, we had those less 13 or some. There has been also organizations before that, but of course they all then had the same agenda and so on. But of course, also when you have two workers, they don't do the same thing. So I think it's more equal now than what it was before 2012.

MH:
All right, thank you so much. Yeah, maybe if I have a more specific question and find the answer, I'm going to maybe send you just an email.

Representative Metsakeskus:
Yeah, yeah.

MH:
Great.

Representative Metsakeskus:
Good luck with your papers.

MH:
Thank you. And yeah, wait, I'm going to stop the recording and then you are free to continue your working day.