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Technical Note

Forest Inventory Data Provide Useful Information for Mapping Ecosystem Services Potential

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Abstract: The ecosystem services framework is a convenient approach for identifying and mapping nature's contributions to people, and an accurate assessment of ecosystem services potential is the first step in the decision support process of well-informed land management planning. The approach we use for forest ecosystem services potential assessment in Latvia is based on the principles of the matrix model and biophysical data of the forest inventory database, and it is comparable to other assessments previously carried out in the Baltic Sea Region. The proposed approach supports spatial planning and may be integrated with assessments of other ecosystems based on the same methodological principles. The evaluation results reflect the high spatial heterogeneity of forest types in Latvia. Future work should include integrating ecosystem services flows and demand into the assessment, developing additional indicators for culturally important ecosystem services, and introducing socio-cultural valuation to account for a broader set of stakeholders and values.

Keywords: forest management planning; ecosystem services indicators; forest structure; stand attributes; CICES; matrix model

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1. Introduction

Ecosystem services (ESs) are derived from ecosystem functions and represent the benefits people obtain from ecosystems [1]. The concept and its application have been consistently evolving and gaining ever wider popularity over the last decade, despite sometimes being criticized for their explicitly anthropocentric standpoint and related risks in promoting exploitative human–nature relationships (e.g., [2,3]). Still, if the limitations are duly considered with an inclusive approach, and the involvement of different stakeholders and integration of the available scientific knowledge in guiding management and policy decisions are ensured, this ESs approach may significantly contribute to the maintenance and restoration of ecosystems [4], efficiently fostering transdisciplinary research and allowing economic evaluations and comparisons across different ESs categories (e.g., [5]).

The Global Assessment Report on biodiversity and ecosystem services of the Intergovernmental Science–Policy Platform on Biodiversity and Ecosystem Services [6] highlights the alarming extent and speed of ESs degradation globally. The growing global population, increased consumption of resources, and altered functions of natural ecosystems necessitate further work on a closer integration of ecosystem accounts in environmental-economic accounting [7]. Consequently, scientifically sound data on the potential, flow, and demand of ESs are of utmost importance.

In European countries, the mapping and assessment of ESs, initiated in the context of Target 2 of the EU Biodiversity Strategy for 2020, have been ongoing for several years in various ecosystem types [8]. A number of national ecosystem assessments have been carried out, comprising northern, central, and southern Europe [9–12], as well as subnational case studies from the regional (e.g., [13]) to the municipality level (e.g., [14,15]). The included ecosystem types, ecosystem services, and assessment details significantly differ among the countries. Due to varying national policies and stakeholder interests, socioeconomic situations, and environmental conditions, the assessments are context specific [16]. In Latvia, no nation-wide ecosystem services mapping has been carried out so far. The existing more comprehensive assessments have focused either on individual ecosystems, such as grasslands [17], marine ecosystems [18], coastal areas [19], peatlands [20], and freshwater springs [21] or a limited set of ecosystem services, for example, those provided by soil [22].

Forests and woodlands are among the prevalent terrestrial ecosystem types in Europe, with forest cover ranging from approximately 10% in the western regions to over 60% of the land area in the north. Forests provide important economic benefits; forests harbor a significant share of terrestrial biodiversity and contribute to the general well-being of people. In 2020, the total gross value added by forestry and logging in Europe equaled EUR 23.2 billion [23]. On a European scale, more than half of Natura 2000 sites are comprised by woodland and forest ecosystems; thus, forests are significant hotspots for biodiversity retention and multiple ecosystem services provisions [8]. Urban forests in Europe have a long history and increasingly diverse ecological and social importance [24,25].

European forests are generally well described. Detailed information on forest ecosystem attributes can be derived from in situ data (typically national forest inventories on a regular grid or stand-wise inventories). An extensive and constantly growing body of scientific literature provides the necessary theoretical background and guidance for the development of indicators that are capable of capturing temporally and spatially dynamic forest ecosystem processes. Moreover, detailed and enhanced auxiliary data are being obtained using remote sensing techniques to characterize qualitative and quantitative features of forests [26].

The diverse societal demands and growing pressures on ecosystems are directing forest owners and managers towards a more inclusive and flexible management approach. A better understanding of multiple benefits provided by forest ecosystems may help forest managers to introduce novel management methods with consideration of a broad range of forest ESs, as well as find new ways to generate profit and increase the viability of the forest sector in general. Therefore, ecosystem services-based decision making has been increasingly introduced in forest management planning in Europe (e.g., [27–29]) and overseas (e.g., [30,31]).

In Latvia, the current published research on forest ecosystem services has focused on selected cases or a limited set of ESs. Biophysical indicators have been used to map ESs provided by forested dunes in two coastal areas [32]. There have been attempts at characterizing the benefits derived from riparian forest ecosystems [33,34], also in monetary terms [35]. A regional case study has analyzed societal preferences for forest landscapes among residents of rural and urban areas in the eastern part of Latvia [36]. A weighted criteria analysis has been applied for assessing forest recreational services in a model area in the western part of the country [37]. Inspiration-related cultural forest ESs have been highlighted in an analysis of landscape paintings [38]. While individual studies exist, there is still a need for a unified and flexible evaluation framework, applicable at varying spatial scales and suitable for practical forest management planning. Considering the different preferences and targets of the general society, landowners, and managers, there is an urgent necessity to demonstrate approaches and to develop protocols for comprehensive assessments of forest ecosystem services based on best available data and methods [29]. In Latvia, work in this direction is ongoing within several collaboration initiatives with the largest forest owners and managers. In addition, a short-term research project funded by the Latvian Council of Science has provided an opportunity to systematize already developed and new indicators and to calculate forest ecosystem services potential for the whole country, regardless of forest ownership.

This technical note demonstrates application of a forest ESs assessment framework, in Latvia, at the national level, and characterizes indicators and used datasets, providing a mapping example that may be applied to well-described ecosystems at a high spatial resolution.

2. Materials and Methods

2.1. Study Area

Latvia is located in northern Europe, on the eastern shore of the Baltic Sea (Figure 1), and it has a cold temperate (moist) climate, with four distinct seasons. The country's area equals 64,589 km^2, the length of the border is 1878 km, and 1380 km of it is terrestrial border. Except for the flat area in the southern-central part, the terrain is undulating, with the highest point of 312 m.a.s.l. in the Vidzeme highland, the central-eastern part of the country. The elevation range in Latvia is similar to other countries in the eastern Baltic Sea Region, i.e., Estonia, Lithuania, and Poland. The average annual air temperature is +6.8 °C, and the average annual precipitation is 685.6 mm [39].

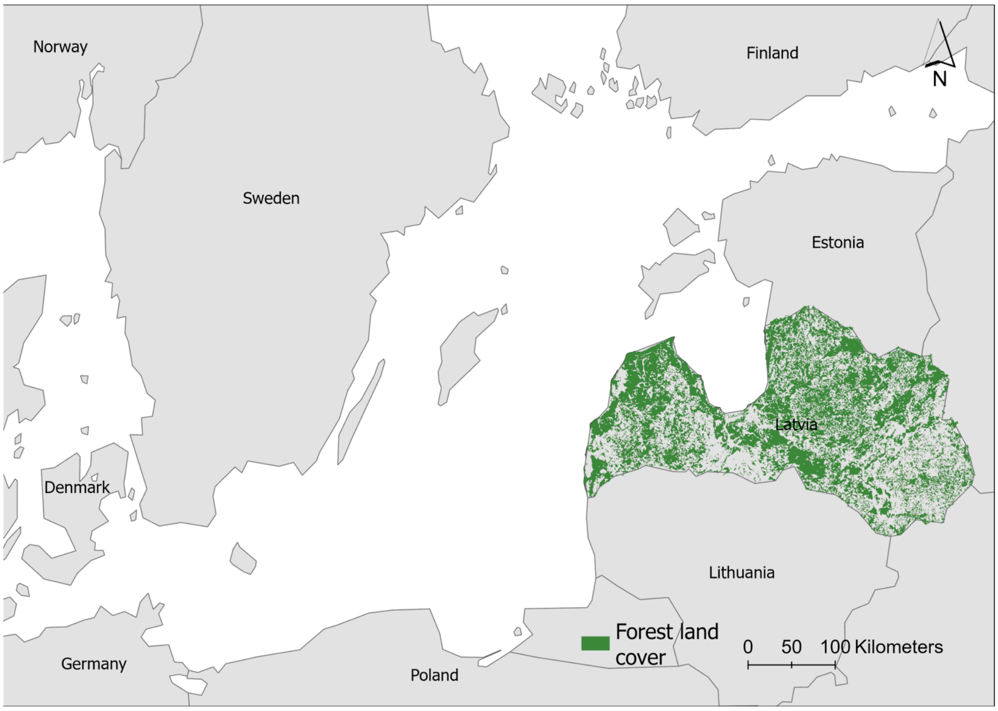

Figure 1. Location of the study area. Forest land cover is provided only for Latvia.

As a result of targeted forest management and natural afforestation of abandoned agricultural lands after World War II, the forest cover in Latvia over the last 100 years has increased more than twice, currently reaching 53%. The main tree species are Scots pine (*Pinus sylvestris*, dominates 33% of the forest area), silver and downy birch (*Betula pendula* and *Betula pubescens*, dominate 30% of the forest area), and Norway spruce (*Picea abies*, dominates 19% of the forest area) [40]. Regionally, the forest cover is unevenly spread, with the most forested areas concentrated in the north-west and east-central parts of the country, and the smallest share and largest fragmentation of forests are in the south-central and south-east parts of the country. The dominant silvicultural system is regeneration felling, with a maximum clearcut size of 5 ha (10 ha in some site types on dry mineral soils) and 1.18 ha on average [41–43]. Final felling age, depending on the tree species and site type, varies from 70 years (for broadleaves) to more than 100 years (for conifers and hardwoods). In all felled areas, forest regeneration is mandatory, either by planting or sowing, or by enhancing natural reforestation [42,44,45].

Forests in Latvia supply a wide range of provisioning, regulating, supporting, and cultural ecosystem services (Figure 2). The economic importance of forests is high; forestry, wood processing, and furniture production together constitute 6.5% of the country's GDP, and, in 2022, the share of the forest sector in export value was 22% [40,46]. Additionally, forests supply a wide range of other ecosystem services, no less important than timber and energy wood. Forests ensure habitats for rare and threatened species; 65% of Natura 2000 areas in Latvia are located in forests [47]. Riparian forests prevent erosion and leaching of nutrients into waterbodies [48,49]. Collection of non-wood forest products (NWFPs) is a traditional activity, with both economic and recreational significance [50–52]. Apart from berries and mushrooms, other region-specific products, for example, natural Christmas trees and decorative nature materials, are popular [53]. Forests, especially close to waterbodies, are favored venues for nature recreation [50,54]. They are, and historically have been, significant environments inspiring creative expression, for example, painting (e.g., [38]).

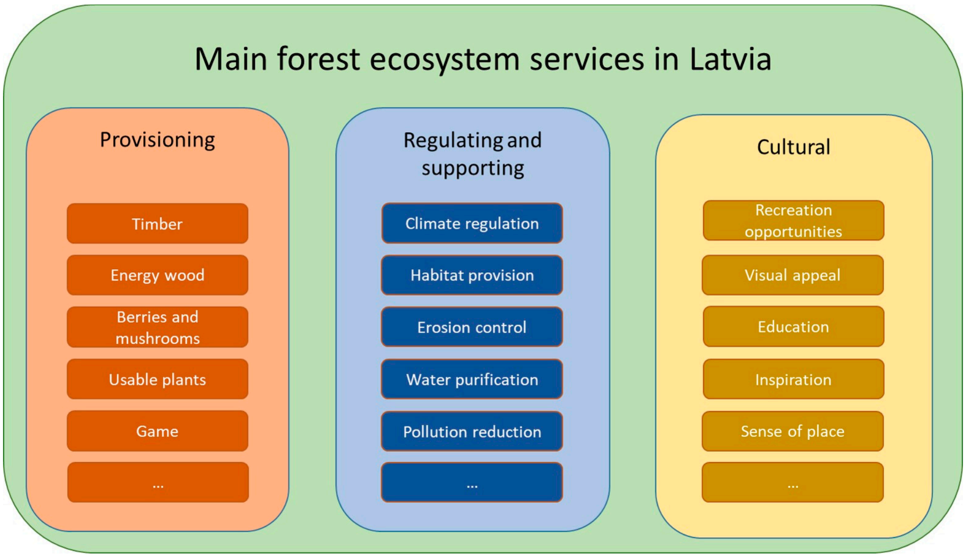

Figure 2. Main forest ecosystem services in Latvia.

2.2. Framework of the Forest ESs Assessment

The framework for the forest ecosystem services assessment in Latvia follows the conceptual model proposed by Burkhard et al. [55]. This framework acknowledges the link between ecosystem functions, ecosystem services supply, and ecosystem services demand (Figure 3).

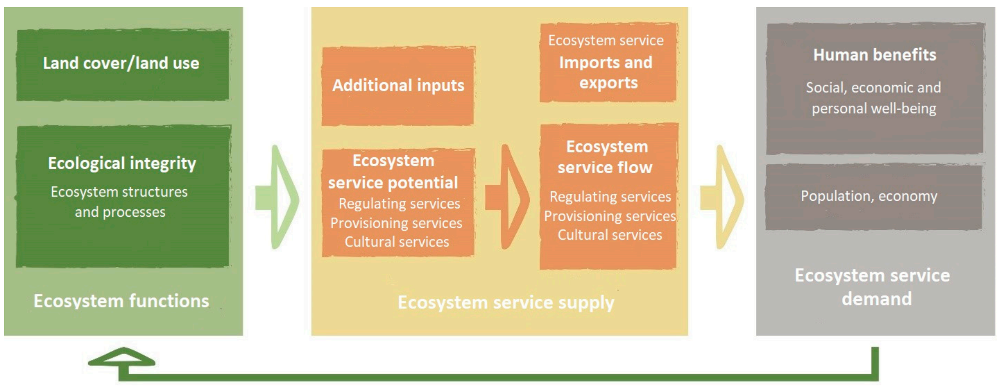

Figure 3. Conceptual model of the relations between ecosystem functions and services (from Burkhard et al. [55]).

According to this framework, ecosystem functions emerge as a combination of land cover/land use and ecological integrity of the respective ecosystems, forming the basis of ecosystem services supply. Ecosystem services potential is affected positively or negatively by added inputs and further creates the ecosystem services flow that directly contributes to the social, economic, and personal well-being of people. The resulting societal benefits and their distribution have impacts on consequent management decisions that, via direct and indirect feedback, influence ecosystem functions, by altering either land use/cover or ecosystem structures and processes.

2.3. The "Matrix" Model

For convenient mapping and evaluation of ESs, we applied the "matrix model", developed to provide spatially defined estimates of ESs in land use or land cover classes [56,57]. ESs are evaluated in semi-quantitative units (supply capacity classes), distinguishing between a high supply and a low supply of the respective service. Zero denotes its absence (Figure 4).

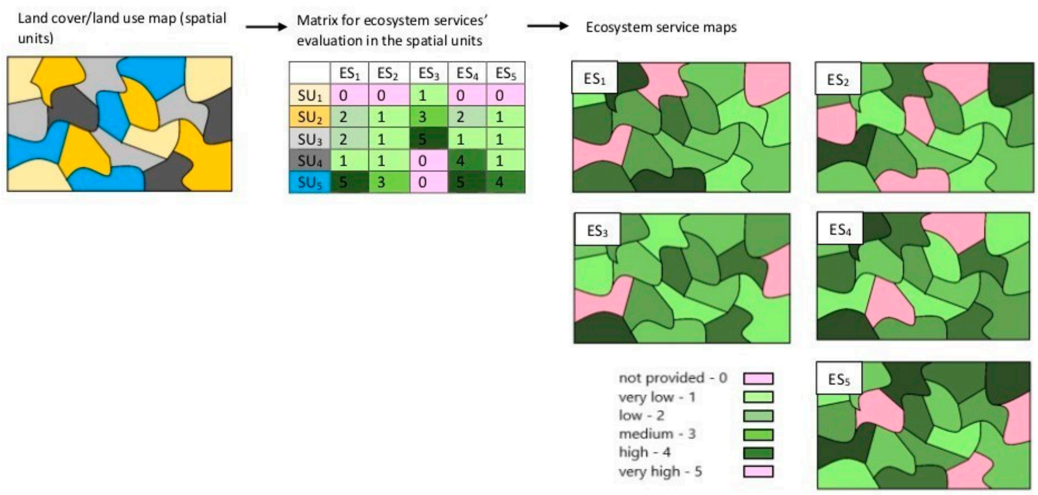

Figure 4. Basic principle of the "matrix model" application (from Burkhard et al., 2009 [57]).

The main advantages of the matrix model are simplicity and speed of application and the possibility to include diverse types of indicators (statistical, biophysical, and expert knowledge based), normalized in the same scale, and thus easily comparable across different classes of ESs and land use/land cover types. Due to frequent involvement of expert opinions, the method is sometimes criticized as lacking methodological transparency and providing data that are often difficult to reproduce [56,58,59]. Despite the validity of the stated concerns, the possibility to include a broad set of ESs in the evaluation and to easily compare across different ESs classes was a convincing argument in favor of this approach. Also, the progressively growing number of published studies on its application over recent years [60] contributed to our choice.

It is important to stress that our country-wide assessment used indicators derived from biophysical data characterizing the spatial units. Thus, we mapped the ecosystem services potential, the basis for the ecosystem services-based decision-making process. Potential supply of ESs refers to the hypothetical maximum yield of ESs in a specific ecosystem [61]. Detailed and accurate data used for this first step of the assessment ensured a solid basis for further evaluation steps and, consequently, well-informed decisions.

2.4. Development of the Base Map and Identification of Spatial Units

The base map distinguishes land cover classes, preferably specific land use classes that are understood as ecosystem services providing units [62]. We used the State Forest Register of Latvia for 2021 [43], a geospatial database containing a detailed description of forest land types (forest stand, wet area, mire, bog, etc.). For all the identified ESs classes and indicators, we used forest compartment as the smallest spatial unit for the ESs value calculation. In the database, each forest compartment is characterized by 173 inventory entries, describing stand properties (e.g., location, size, site type, age, dominant and other tree species, volume, basal area, tree dimensions, etc.), previously performed management and its timing, as well as nature conservation requirements and restrictions for management. In total, the 2021 database holds information about ~2.7 million individual forest compartments (Table 1).

Table 1. Characteristics of forest compartments by site-type group and dominant tree species (all forests of Latvia), i.e., Pine—*Pinus sylvestris*, spruce—*Picea abies*, and birch—*Betula pendula*, *Betula pubescens*. Other tree species include mainly broadleaves and hardwoods—*Populus tremula*, *Alnus incana*, *Alnus glutinosa*, *Quercus robur*, *Fraxinus excelsior*, *Acer platanoides*, *Tilia cordata*.

Site Type Group	Forests on Dry Mineral Soils	Forests on Wet Mineral Soils	Forests on Wet Peat Soils	Forests on Drained Mineral Soils	Forests on Drained Peat Soils	Total
Number of compartments	1,512,580	298,942	239,170	358,409	252,368	2,661,469
Average compartment area, ha (±S.D.)	1.14 ± 1.30	1.10 ± 1.16	1.30 ± 1.86	1.17 ± 1.16	1.36 ± 1.54	1.18 ± 1.36
Share of pine-dominated forests, % (mean age, years)	32 (75)	29 (77)	40 (90)	29 (73)	32 (84)	32 (77)
Share of spruce-dominated forests, % (mean age, years)	22 (46)	18 (50)	5 (56)	21 (46)	12 (52)	19 (47)
Share of birch-dominated forests, % (mean age, years)	23 (44)	34 (48)	39 (55)	32 (48)	45 (50)	30 (47)
Share of forests dominated by other species, % (mean age, years)	22 (35)	19 (40)	15 (52)	18 (37)	11 (43)	19 (38)

Forests on dry mineral soils take up more than half of the total forest area, while forests on wet peat soils are the least represented. Scots pine stands occupy around one third of all site-type groups, except in forests on wet peat soils where their share is higher. Pine-dominated forests are, on average, the oldest, while forests dominated by "other" species (mostly alders and aspen) are the youngest.

Inventory data characterizing individual stands serve as basic information for calculating ecosystem services potential indicators. Forest site type is one of the main proxies, as it holds information about moisture conditions, trophic level, possible stand composition, typical ground vegetation species, and other parameters. In Latvian forest typology, there are five main site-type groups representing various hydrological conditions, including those altered by forest drainage. Each site-type group contains four to six individual site types, aligned in order of trophic level increase [63] (Figure 5).

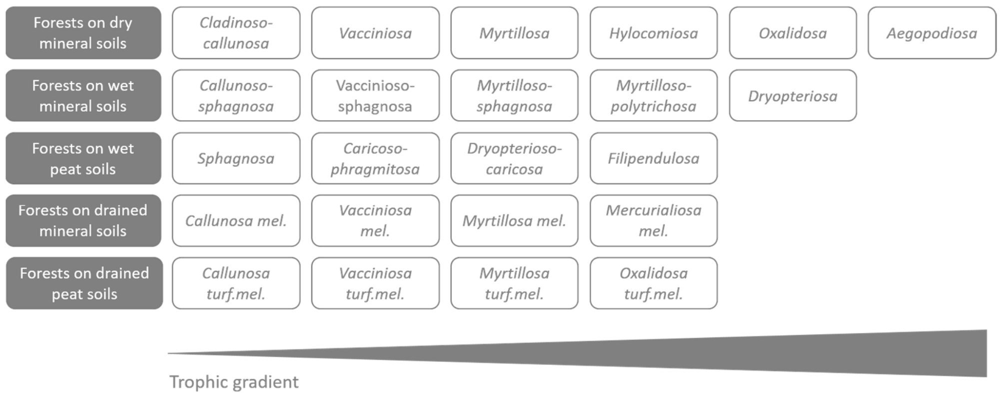

Figure 5. Site-type groups and site types used in Latvian forest typology. The peat layer thickness border between forests on wet mineral soils and wet peat soils is 30 cm, but between forests on drained mineral soils and drained peat soils, it is 20 cm.

2.5. Identification of ESs of Interest and Development of Indicators

We classified the forest ESs according to the Common International Classification of Ecosystem Services (CICES) version 5.1. [64] which distinguishes between provisioning, regulating, and cultural ESs, and is further subdivided into divisions, groups, classes, and class types. We developed indicators in three classes of provisioning ESs, three classes of regulating ES, and two classes of cultural ESs (Supplementary Material, Table S1). All these indicators reflect the potential supply of ecosystem services [61]. This paper focuses on less frequently described services in all ESs divisions, and we excluded several commonly mapped ecosystem services, such as timber, energy wood, and carbon storage, from this demonstration example, even though they would certainly be included in the assessment for management planning purposes.

All ESs values are expressed as scores from 0 (ESs not provided in the respective spatial unit) to 5 (ESs value in the respective spatial unit is very high). The information needed for assigning the scores was derived from earlier and ongoing studies. During recent decades, several research projects have been striving to develop algorithms for quantification of non-wood forest products and services and regulatory functions of forest ecosystems. Not all results and equations are yet published in scientific journals; some are included only in research reports. In the descriptions, we give references to all sources, regardless of their type (peer-reviewed publications and "grey" literature). Score confidence is evaluated following Geange et al. [65], distinguishing between local and foreign peer-reviewed and "grey" sources (Supplementary Material, Table S1).

From the division of provisioning services, we chose six indicators for characterizing the provision potential of non-timber forest products: potential yield of two most popular wild berries, i.e., bilberry (*Vaccinium myrtillus* L.) and lingonberry (*Vaccinium vitis-idaea* L.), and habitat suitability for large game species, i.e., roe deer (*Capreolus capreolus*), red deer (*Cervus elaphus*), moose (*Alces alces*), and wild boar (*Sus scrofa*). The compartment database supplies all the necessary information for the calculation. Berry yields are directly related to their projective cover depending on site type, as well as stand age and stand density as proxies for light conditions [66]. Habitat suitability for large game species is calculated according to land cover/land use class, forest site-type group, and stand age group [67,68]; this methodology is formalized in the legislation [69].

The indicators for regulating services included the phytoremediation potential of trees and ground vegetation, noise attenuation potential, stabilization potential of toxic heavy metals (Hg, Pb, Cd), and ecosystem resilience against recreational pressure. The phytoremediation potential of trees and ground vegetation plants depends on the ability of different tree and ground vegetation species to decrease the toxicity of the environment [70] and the occurrence of the respective species in specific site types (Straupe, unpublished data [71], see Table S2). The stabilization potential of toxic heavy metals depends on the organic layer thickness in the soil of different forest site types [72]. The resilience against recreational pressure depends on the site type, stand age, dominant tree species, and slope [73,74]. Noise attenuation potential depends on stand density and tree species, and it is higher for conifers as they retain the needles all year round and have overall higher crown density [75–77].

Cultural ecosystem services included in the mapping relate to forest recreation and visual attractiveness of forest landscapes. Forest recreational value potential is expressed as the suitability of spatial units to provide environment for recreation. The indicator is based on the methodology initially developed in Lithuania by Riepšas [78] and adapted to Latvian conditions by Donis [79]. The recreational value of the spatial unit depends on the dominant tree species, site type, age group, location (proximity to cities, waterbodies and equipped resting places), as well as pollution level and presence of logging residues. The indicator expressing the visual quality of a forest is based on sociological survey data about visitor preferences. Visual quality depends on tree species, stand age, type of view (open/closed), and presence/absence of logging residues. According to this principle, fresh clearfelled areas with logging residues score lowest, while older pine stands with unobstructed view and without logging residues score highest [80].

The indicator value scales are mostly based on local (national) or, in some cases, regional data, and thus reflect forest conditions and capacities to deliver specific ecosystem services that are characteristic to Latvia. For other geographic contexts, the scales need adjustment, considering place-specific conditions. Initial indicator values were assigned separately to each spatial unit (compartment). For an overview at the national or regional level, the evaluation was carried out at a 10 × 10 or 5 × 5 km grid, calculating median values of the particular ES in the grid.

The presented approach has been previously tested and validated in a ~3000 ha forested catchment of state forests where business-as-usual management has been implemented [81]. It is expert approved [82], and it has been included in the Interreg Europe project PROGRESS second handbook of good practices for the policy theme "Support the horizontal integration of the ecosystem concerns into the sectoral policies and plans at regional and/or national level" [83].

3. Results and Discussion

3.1. Calculating and Mapping the ESs in Spatial Units

The summary of the mapping results is presented as the percentage of forest area characterized by different ecosystem services potential scores (of the assessed ESs). Figure 6 shows an overview of all forests, by major ESs categories and site-type groups, while Tables S3–S7 in the Supplementary Materials provide more detailed information on the level of the assessed ESs and dominant tree species.

Generally, the potential of the assessed regulating services tends to be better than that of cultural and especially provisioning services; the area with high and very high regulating service potential varies from 34% to 65%, depending on the forest-type group, while the area of forest with high and very high provisioning service potential varies from 28% to 37%, and the area of forest with high and very high cultural service potential varies from 28% to 27% (Figure 6). In forests on dry mineral soils, the area with no (assessed) provisioning service potential is comparatively lower than in the other site-type groups, and the same is true for regulating services. All site-type groups are characterized by at least some potential to provide cultural ESs (no 0 scores were assigned), but in forests on wet mineral and wet peat soils, the potential for provision of cultural ESs is significantly lower than in other forest site-type groups.

Areas with average or above average wild berry yield potential are located only in pine and spruce forests on dry mineral soils, wet mineral soils, and drained peat soils (Supplementary Material, Tables S3–S7). Forests on wet peat soils have zero potential for supplying bilberries and lingonberries, and on drained mineral soils this potential is negligible. Mostly, the scores are low because in each site-type group there are site types that are unsuitable for bilberry and lingonberry. All forest site-type groups and dominant tree species' groups support habitats for game animals, but spruce-dominated forests, regardless of site type group, score low for moose.

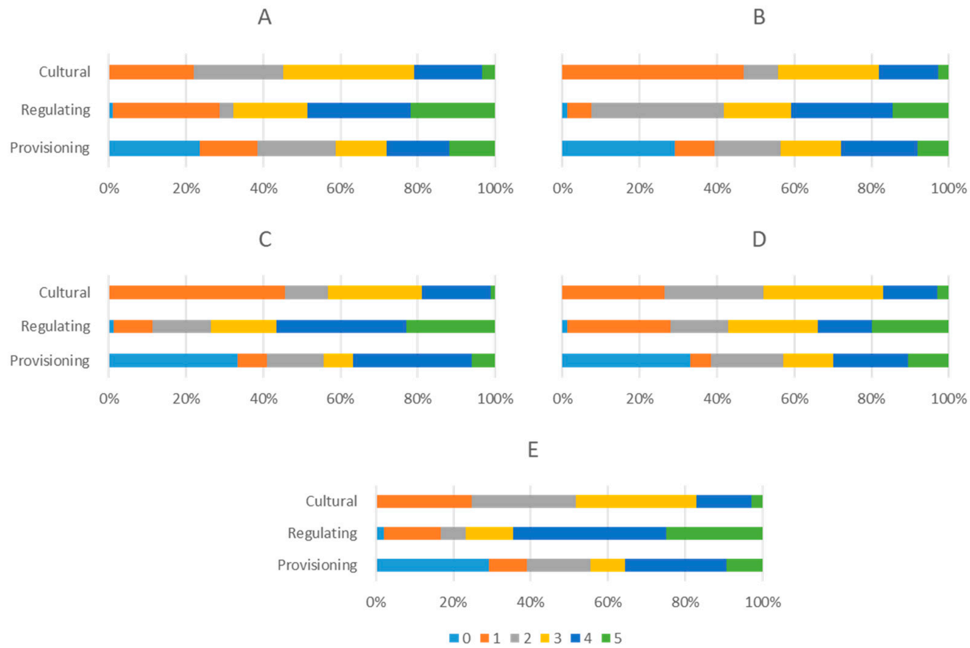

Figure 6. Forest area (%) characterized by different ESs scores, by ESs group and site-type group: (**A**) Forests on dry mineral soils; (**B**) forests on wet mineral soils; (**C**) forests on wet peat soils; (**D**) forests on drained mineral soils; (**E**) forests on drained peat soils. 0—ES not provided; 1—ES value very low; 2—ES value low; 3—ES value average; 4—ES value high; 5—ES value very high.

The scores of the regulating ESs vary by service. Phytoremediation potential is medium to high in pine-dominated stands in all forest site-type groups. Noise attenuation potential is high or very high in most of the assessed categories. Heavy metal stabilization potential typically increases with increasing organic matter content in the soil; thus, in forests on dry mineral soils the value of this ES is low, and most stands with high and very high scores are located in forests on wet and drained peat soils. Resilience against recreational pressure tends to be higher in forests on dry mineral soils, with birch stands as the most resilient; all birch-dominated compartments on dry mineral soils are characterized by high or very high potential to withstand recreational pressure.

Visual quality is medium to very high for pine stands and low to medium for spruce stands in all site-type groups. Most stands dominated by birch and other species score medium to high in this ES. Recreational suitability of spruce forests, regardless of the site-type group, is low. For other tree species, the score varies by site-type group. Forests on wet mineral and peat soils mostly have very low potential for recreational activities, except for those dominated by pine that are characterized by low potential for this ES.

Spatial visualization of the indicator values (Supplementary Material, Figures S1–S12) reveals some challenges for the spatial evaluation of aggregated compartments. The comparison of potential wild berry yields, calculated on a compartment scale and on a 5 × 5 km grid scale, demonstrates that forest-type diversity has a large impact on the mapping result (Figure 7).

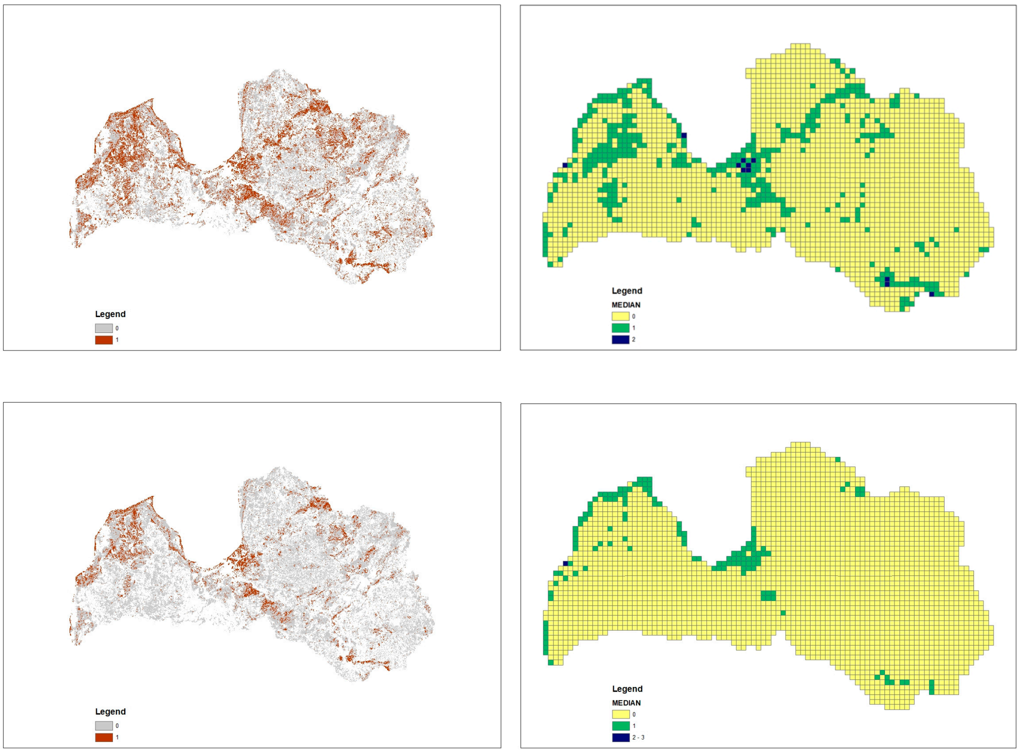

Figure 7. Spatial distributions of bilberry (upper maps) and lingonberry (lower maps) potential yields. The maps on the left side show individual compartments suitable for the respective species (marked as 1, forest compartments where respective species does not occur are marked with 0). The maps on the right show aggregated ESs values in a 5 × 5 km grid. The legend represents ESs median scores from low (1) to average (3) potential supply of the respective ecosystem service. There are no grids with high and very high ESs potential values for berry yields.

In Latvia, due to spatially variable soil and hydrological conditions and management history, the heterogeneity of forest compartments is very high, consequently, a 5 × 5 km grid unit will only rarely contain a set of homogeneous site types. Forest berry yields are a good example for demonstrating this, as bilberry and especially lingonberry grow only on a subset of site types. Consequently, while mapping of aggregated spatial units is useful for an overview on a country scale or regional scale, compartment-based assessments are recommended for practical planning.

The grid maps of other calculated ESs (Supplementary Material, Figures S3–S12) confirm the same pattern. The higher the number of site types where the respective service is delivered at all, the higher the possibility of a higher value in the aggregated unit. Site-type dependent services tend to score lower when spatially aggregated, in contrast to those determined by other stand attributes, for example, noise attenuation potential which depends on the tree species and stand density.

The spatial distribution of the ES scores for recreational suitability and, to some extent, visual quality of forest landscapes, correspond to the results previously obtained by Jūrmalis et al. [54] about the location of the hotspots of nature visits. These hotspots, mapped during a public participatory geographic information system survey, are concentrated around major cities and largest national parks, and in some cases, they coincide with areas that are less resistant to recreational pressure. Combining the mapping results of different forest ESs with other data sources may help to identify areas where additional care is needed during forest management operations and may also contribute to spatial planning and land management more broadly, for example, in directing the visitor flows in nature areas.

It must be emphasized that the results in this section are aggregated for the sake of presentation brevity, i.e., the actual ecosystem value potential scores are calculated on a compartment basis. The equations are based on the site type (Figure 5), not the site-type group, and take into consideration a broad set of stand attributes. It should also be stressed that several significant services, such as timber and energy wood production and carbon sequestration, were omitted from this example.

3.2. Method Suitability

Our choice of ESs mapping method was influenced by the main advantages of the matrix model, i.e., the simplicity of application, the possibility of using both quantitative and qualitative input data of various levels of detail, and the possibility of combining biophysical and expert evaluation. The latter may present difficulties with respect to data validation [84], but expert-based ecosystem services scores may also yield comparable results to those derived from quantitative biophysical models [85]. Moreover, the matrix model presents opportunities for a unified evaluation, as spatially determined score values are comparable between regions and, to an extent, between countries.

In the neighboring countries, i.e., Lithuania and Estonia, a country-wide mapping of ecosystem services has been carried out, with forest ecosystems included in both cases. In Lithuania, the matrix model with expert evaluation has been applied to CORINE land cover classes, mapping the potential supply of 31 ecosystem services [86]. The Estonian assessment included a set of 27 ecosystem services from grasslands, wetlands, forests, and agro-ecosystems, classified according to CICES v5.1. Only potential supply was mapped, and the indicator types varied from measurable biophysical attributes to unitless indices [87]. In Finland, a set of indicators for 28 ecosystem services, classified according to CICES, has been developed [11]. The Finnish ESs assessment system follows a modified cascade model [88], which characterizes the structure of the ecosystem, ecosystem function, the benefit obtained from the ES, and the value of the benefit. Similarly, Hansen and Malmaeus [89] analyzed the ESs provided by Swedish forests, based on the CICES classification and the cascade model.

The forest ESs mapping method we have applied at a national scale is comparable to other assessments carried out in the Baltic Sea Region. All of them classify ESs according to CICES, and include or are limited to ecosystem services potential assessments, either directly or indirectly. When comparing data to the Finnish and Swedish assessments, the ESs potential may be derived from the interactions of ecosystem structure and function of the cascade model, as demonstrated by Mononen et al. [11], where, for example, ecosystem structure is expressed by suitable berry and mushroom habitats and ecosystem function is expressed by the change in annual production.

3.3. Data Sources and Spatial Scale

Forest ecosystem service provision primarily depends on the structural elements of the forest stand [90], and forest inventories are able to provide information about these elements. The general approach of a forest inventory-based ecosystem service assessment should be widely applicable in countries where detailed forest inventory data exist. European forest inventories are built upon similar methodologies [91], moreover, during recent decades, there have been persistent harmonization efforts, within the frameworks of several COST Actions and collaboration projects [92,93], to ensure data comparability. In countries with less comprehensive forest data, however, problems with detailed biophysical evaluation may occur, and other methods, for instance, expert assessment, should be used.

An issue of possible concern for wider application of the framework is that different forest typology systems are used in different countries. Application of a generalized typology, such as European forest types, developed by the European Environment Agency [94], would, on the one hand, facilitate a comparison at the regional and global level. On the other hand, we would lose some essential information for the ESs evaluation, as the classification units of European forest types do not provide sufficiently detailed information on, for example, the nutrient status of the ecosystem. Latvian site types are identified according to soil moisture conditions and trophic level, and harmonization with at least other Baltic Sea Region countries should be possible. For example, Avis [95] noted the similarities of the Latvian system with the Finnish typological principles, established by Cajander [96], despite the heavy reliance of the latter on floristic composition. Moreover, as stressed by Wang [97], plant communities reflect soil moisture conditions and nutrient status. Consequently, transitions between both systems should be possible by applying ecological knowledge on vegetation indicator values.

We used two broad types of data sources for indicator development and assessment: monitoring data (forest inventory and game inventory) and research results, based either on biophysical measurements and modeling (e.g., for berry yields, potential for stabilization heavy metals) or population surveys (e.g., for recreational attractiveness, visual quality of forest landscape). Thus, we obtained comparable score values of provisioning, regulating, and cultural ESs. These score values may be further applied for identification of ES hot and cold spots, as well as for the analysis of ES synergies and trade-offs.

A forest compartment may be directly used as a spatial unit for ESs value calculation. Compared to the broader land use and land cover (LULC) types, compartment descriptions also provide data about some components of forest condition (for example, stand structure, soil type, etc.), which is valuable information when assessing the capacity of ecosystems to provide ESs [60]. The main stand-level forest attributes for ESs assessment in our study were site type, dominant tree species, standing volume, stand age, and stand density. Applying a similar approach, Jūrmalis et al. [98] identified forest stand age and tree species structure as the main factors influencing ESs score values in a forested model area. Several of the ESs-defining stand attributes are dynamic, i.e., they change with time, requiring a systematic update of the respective databases to ensure correct evaluation results.

For the presentation of country-wide results, in the current paper, we aggregated forest site types by dominant tree species and site-type group, and, by such aggregation, some accuracy was inevitably lost. The detailed analysis, further applied for practical management purposes and typically comprising much smaller areas, will include factors affecting the stand ecological functions. The calculation algorithms of indicators use more detailed information than reflected in the overview, for example, noise reduction potential depends on the presence of the second canopy layer, and habitat provision services (not included in this overview) consider such factors as tree age in the stand, complexity of the horizontal structure (canopy layers), presence of old-growth trees, small scale wetlands, and others.

The spatial units in our ESs assessment were small; the average size of compartments by the forest site-type group in Latvia varies from 1.10 to 1.36 ha. On the one hand, it allows for a more detailed spatial evaluation. On the other hand, the high spatial heterogeneity presents added challenges. The ESs flow is not necessarily bound to individual spatial units, even for all provisioning services. For example, while it is possible to calculate the amount of timber and non-timber forest products by compartment, for other ESs, this kind of calculation may become extremely laborious and often meaningless. This is true especially when assessing the flow of and demand for ESs. People harvest forest berries disregarding the compartment boundaries. Hunting districts, for which the information on the number of hunted game animals is available, include not only forest areas, but also other land use classes. Compartment borders are also impractical for evaluating several regulating and cultural ESs. For instance, a habitat of some rare or threatened species may encompass only part of a compartment or several compartments; recreation, depending on the activity, often encompasses wider forest areas; heritage values may be attributed to objects of different scale, from individual trees to landscapes.

3.4. Directions for Future Research

In recent years, the ecosystem services framework has steadily gained interest and acceptance among scientists as well as among spatial planners and land managers. Still, knowledge gaps remain, especially those related to the identification of the drivers of change and quantification of their impact. This is complicated by the natural dynamics of ecosystems in time and space, the mutual interactions between the drivers of change, the uncertainty of projections under the rapidly changing climate, and the complicated interactions between the ESs themselves [99–101]. Future studies should, therefore, carefully consider these aspects by including the management effects and land use change-induced shifts of ecosystem functions.

A combination of evaluation methods can significantly improve the practical applicability of ESs assessments, especially when evaluating ESs flows and demand [102]. While an accurate biophysical assessment of ESs potential is of crucial importance, the next assessment steps require additional methods. The attitude towards ESs largely relies on cultural constructs and individual preferences, and links between modeled and perceived value may be weak [103]. At the same time, the public's understanding of ecosystem conditions is often limited [104], consequently, a value-based approach may not be the best long-term solution. Socio-cultural valuation may render different results than biophysical data, also concerning synergies and trade-offs of ESs, as suggested, for example, by Plieninger et al. [105]. Moreover, different stakeholder groups will have differing demands for ESs, depending on social, economic, and cultural factors [106,107].

A combination of social and biophysical assessments may present added benefits for environmental resource management planning. An ecosystem service approach may support sustainable use of resources, but it is challenged by multiple sources of uncertainty, which are related to incomplete data, knowledge gaps concerning ecosystem processes and functions, demand fluctuations, social trade-offs, as well as normative and value-laden arguments [56]. Integration of social research methods into an ESs assessment allows for inclusion of a broader set of values and perspectives and helps to elucidate the facets of human–nature relationships that go beyond the utilitarian use of natural resources [108].

The directions for future research also include further work on less represented ESs groups, especially cultural, by expanding expert teams to include social scientists and integrating these ESs groups more tightly into assessments. Recreation is one of the most frequently described and evaluated cultural ESs [109], but including only that or even, as in our case, recreation and aesthetic value which cover, to an extent, active and passive interactions with nature, leads to an underestimation of the rich cultural significance of forest ecosystems. Development of additional indicators in this group would help to raise representation of culturally embedded aspects of nature's contributions to people and would reduce the overall uncertainty of the assessment. Innovative methods for the assessment of cultural ecosystem services are often developed within frames of individual studies, for example, remote sensing- and social media-based approaches (e.g., [110–113]), and a broad range of stakeholders would benefit from the integration of these methods into assessments that support management decisions. Further work on quantification and interpretation of ESs simultaneously belonging to several categories (e.g., provisioning and cultural, foraging for NWFPs as a distinct example) will help to further disentangle the complex relationships between people and nature, and therefore, reduce the risk of double accounting in national, regional, and global assessments.

4. Conclusions

The combination of the matrix model and CICES classification of ESs is a suitable approach for the mapping and assessment of ecosystem services potential of forest ecosystems in Latvia. Detailed information on stand-level spatial units allows different classes of ecosystem services and indicator types to be included in the evaluation. A country-level assessment in spatially aggregated compartments shows medium to high values of the evaluated regulating services and medium to low values of the evaluated provisioning and cultural services. A biophysical evaluation of recreational suitability and visual quality spatially corresponds to stated visitor preferences. However, due to the high heterogeneity and small size of forest compartments, aggregated scores may lead to underestimation of the ESs values.

In the further steps of ESs assessment, the biophysical indicators of ecosystem services potential should be complemented with information on ESs flow and demand. To cover these aspects, additional methods, such as socio-cultural valuation, are needed to encompass the diverse significance of forest ecosystems for the well-being of society. A broader range of indicators that describe cultural ESs should be included in the assessment to also integrate those services that are difficult or even impossible to quantify, such as intellectual development, health benefits, cultural identity, sense of place, and symbolic appreciation.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/land12101836/s1, Table S1. Indicators for evaluating the potential of selected forest ecosystem services in Latvia (ES section, group and class according to CICES version 5.1), Table S2. Trees and ground vegetation species suitable for phytoremediation. The first number shows possible habitat (1—oligotrophic sites, 2—mesotrophic sites, 3—eutrophic sites), the second—occurrence (1—rarely, 2—sometimes, 3—often) (based on Straupe, unpublished data), Table S3. Area of forests on dry mineral soils in each ES potential class, % by dominant tree species group. 0—ES not provided, 1—ES value very low, 2—ES value low, 3—ES value average, 4—ES value high, 5—ES value very high, Table S4. Area of forests on wet mineral soils in each ES potential class, % by dominant tree species group. 0—ES not provided, 1—ES value very low, 2—ES value low, 3—ES value average, 4—ES value high, 5—ES value very high, Table S5. Area of forests on wet peat soils in each ES potential class, % by dominant tree species group. 0—ES not provided, 1—ES value very low, 2—ES value low, 3—ES value average, 4—ES value high, 5—ES value very high, Table S6. Area of forests on drained mineral soils in each ES potential class, % by dominant tree species group. 0—ES not provided, 1—ES value very low, 2—ES value low, 3—ES value average, 4—ES value high, 5—ES value very high, Table S7. Area of forests on drained peat soils in each ES potential class, % by dominant tree species group. 0—ES not provided, 1—ES value very low, 2—ES value low, 3—ES value average, 4—ES value high, 5—ES value very high. Figures S1–S12: Aggregated values of ecosystem service indicator values, 5×5 km grid.

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