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# Harmonizing Forest Conservation Policies with Essential Biodiversity Variables Incorporating Remote Sensing and Environmental DNA Technologies

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**Citation:** Lock, M.; van Duren, I.; Skidmore, A.K.; Saintilan, N. Harmonizing Forest Conservation Policies with Essential Biodiversity Variables Incorporating Remote Sensing and Environmental DNA Technologies. *Forests* **2022**, *13*, 445. https://doi.org/10.3390/f13030445

Academic Editor: Gerhard Weiss

Received: 27 January 2022
Accepted: 6 March 2022
Published: 11 March 2022



**Abstract:** It remains difficult to compare the state of conservation of forests of different nations. Essential Biodiversity Variables (EBVs) are a set of variables designed as a framework for harmonizing biodiversity monitoring. Methods to monitor forest biodiversity are traditional monitoring (according to conservation policy requirements), remote sensing, environmental DNA, and the information products that are derived from them (RS/eDNA biodiversity products). However, it is not clear to what extent indicators from conservation policies align with EBVs and RS/eDNA biodiversity products. This research evaluated current gaps in harmonization between EBVs, RS/eDNA biodiversity products and forest conservation indicators. We compared two sets of biodiversity variables: (1) forest conservation indicators and (2) RS/eDNA biodiversity products, within the context of the Essential Biodiversity Variables framework. Indicators derived from policy documents can mostly be categorized within the EBV 'ecosystem vertical profile', while 'ecosystem function' remains underrepresented. RS/eDNA biodiversity products, however, can provide information about 'ecosystem function'. Integrating RS/eDNA biodiversity products that monitor ecosystem functioning into monitoring programs will lead to a more comprehensive and balanced reporting on forest biodiversity. In addition, using the same variables and similar RS/eDNA products for forest biodiversity and conservation policies is a requirement for harmonization and international policy reporting.

**Keywords:** environmental DNA; essential biodiversity variables; forest conservation policies; indicators; remote sensing biodiversity products

## 1. Introduction

Forest are in decline globally [1]. Monitoring forest biodiversity is an important part of many local, regional, and global nature conservation policies [2–4]. Although some policies are aimed at harmonization between different regions and nations, such as the European Habitats Directive [3], it remains very difficult to compare the state of conservation of forests [5]. This hampers the monitoring of trends across regions. In Europe, harmonization difficulties arise from different definitions of forests, variation in protection categories and the activities permitted in protected areas, differences in the naturalness of forests, variation between countries in the fragmentation or continuity of forest cover and differences in protection objectives [5]. Differences in naturalness arise, amongst others, from the logging history of forests (see also Supplementary B List S1 on Forestry Backgrounds), reforestation and management. In Europe, forested areas that are now protected natural reserves were mostly planted, and rarely meet the conditions of naturalness [6].

Forests provide many ecosystem services important for biodiversity conservation and reducing the effects of climate change. A few examples are the prevention of soil erosion, carbon storage, regulation of the hydrological cycle and providing habitat for forest-dwelling species. They also have a social value as forests provide areas for recreation and economic value provided by timber production and wood-related products [7,8]. Therefore, it is important that forests are effectively managed and monitored to ensure their long-term economic, social and biological sustainability [9]. Forest conservation indicators describe several aspects of forest structure. Among the variables that are measured is the amount of coarse woody debris, tree size, vertical and horizontal structure such as vegetation layers and canopy gaps [10].

When similar variables are used in different biodiversity monitoring programs, harmonization between those programs and ultimately nature conservation policies become more apparent. To harmonize reporting, Essential Biodiversity Variables (EBVs) are developed by GEO-BON (Group on Earth Observations Biodiversity Observation Network). Much like how the Essential Climate Variables were developed to track climate change [11], EBVs are intended to define a minimum set of essential measurements to capture major aspects of biodiversity change [12]. EBVs are defined as the biodiversity measurements derived from different methods that are required to study, report, and manage biodiversity change. Thereby focusing on the status and trend of biodiversity, EBVs should play the role of brokers between monitoring initiatives and decision-makers (Figure 1) [13]. As such, they aim to form an intermediate layer between primary biological observations (field data) and indicators of biodiversity. They aim to harmonize monitoring biodiversity on a global scale while providing information for policy and decision-makers at various levels [12,14–16].

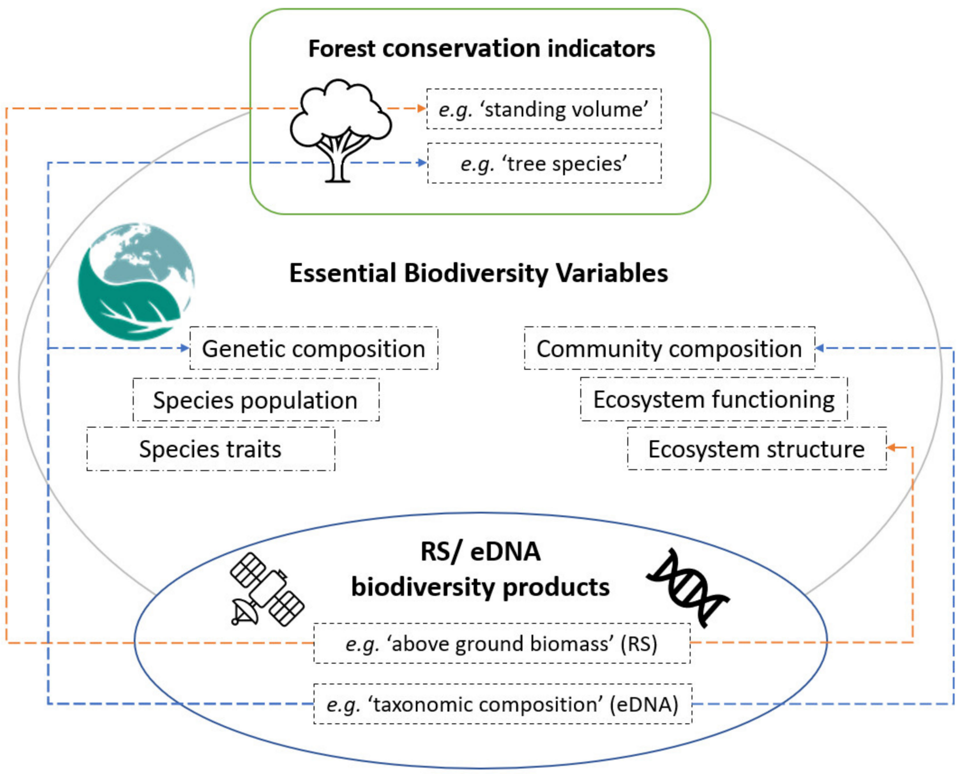


**Figure 1.** The three sets of examined variables, Essential Biodiversity Variables, forest conservation indicators and remote sensing and environmental DNA biodiversity information products (RS/eDNA-products). For EBVs, the six classes that describe aspects of biodiversity are also shown. The arrows are examples of RS/eDNA products that can feed information to EBVs but can be used for policy reporting purposes as well.

There are currently 20 EBVs, which are organized in EBV 'classes' and 'candidates' [13] (see also Supplementary A Table S2). EBVs describe different attributes of biodiversity such as community composition, ecosystem structure and ecosystem function. EBVs cover biodiversity attributes at various levels, from genetics to landscapes. An EBV class represents a general description of a biodiversity attribute. The six classes of EBVs are: genetic composition, species populations, species traits, community composition, ecosystem function, and ecosystem structure. Within an EBV class, there are multiple EBV 'candidates' that form a component of the EBV class. An example of an EBV candidate that is a component of ecosystem structure, is 'ecosystem vertical profile'. An EBV candidate itself can be composed of multiple different scientific variables that each describe part of the candidate EBV [11]. For example, vegetation canopy height (measured unit: meters) is a variable that describes part of the ecosystem vertical profile. As such, EBVs are a multi-tiered set, and can comprise different variables [15]. See Figure 2 for an example of the organization of EBVs.

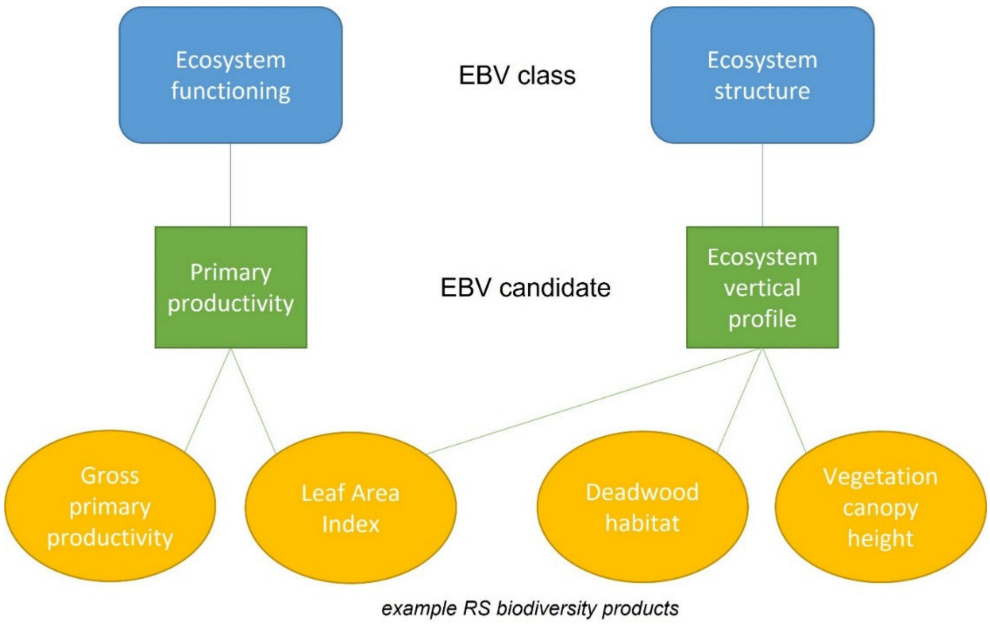


**Figure 2.** Two examples of EBV classes and candidates within the multi-tiered Essential Biodiversity Variable framework. The example remote sensing biodiversity products are variables that describe part of the EBV candidate and class (according to Skidmore et al. [11]).

Usually (forest) conservation policies have monitoring programs to track the progress towards their goals. Most monitoring programs collect their data with field observations. However, the method of gathering data in the field is laborious and costly, difficult to reproduce and hard to control [11,17]. Additionally, not all taxa of species and not all biodiversity attributes are monitored to the same extent. For example, mammals are overrepresented and invertebrates and microorganisms (e.g., *Archaea*) are underrepresented in conservation research and biodiversity reporting [18]. This is leaving much of the state of biodiversity unknown. The last decades have seen a development in techniques available for biodiversity monitoring.

Remote sensing provides high-coverage and high-resolution imagery and has the potential to provide additional biodiversity information that may aid with policy reporting, for example by mapping and monitoring ecosystem functions, ecosystem structure and species presence [15]. Skidmore et al. [11] have created a ranked list of RS products based on (among others) feasibility and product readiness. The top-ranked variables are shown in Supplementary A Table S1. These RS biodiversity products can inform about the properties of the vegetation within an ecosystem and therefore could help approximate forest conservation indicators.

At a local level, molecular approaches such as environmental DNA analysis allow genetic sequence analysis from DNA collected from field samples such as soil and water, and provide information on species in the environment [19]. In this way, environmental DNA can also provide valuable biodiversity information and can be applied for the monitoring of wildlife and park management in addition to traditional field observations [19,20]. Although the application of eDNA analyses provides many opportunities, there are still technical and social difficulties before it can be applied in continuous monitoring programs and biodiversity assessments. For example, the species DNA sequence must already be known for a species to be recognized in the eDNA sample. In other words, the database against which samples are run must contain the DNA sequence of that species, otherwise, they are not detected. Additionally, training is required for field collection and specialists are required for analysis.

To summarize, advanced scientific techniques could provide important biodiversity information relevant for biodiversity conservation policies (Figure 3). However, for the application of these techniques and the biodiversity information products thereof into forest conservation policies, it is crucial that the output data are relatable, relevant, and meaningful. The EBVs are aimed at providing a solution. We test to what extent it is possible to group forest conservation indicators and RS/eDNA biodiversity within the EBV framework, and how the framework can be improved by better alignment, using real-world national nature conservation policies. Therefore, this research aims to determine current gaps in harmonization between forest conservation indicators and RS/eDNA biodiversity products within the EBV framework and to offer suggestions to improve the use of RS/eDNA biodiversity products in policy requirements.

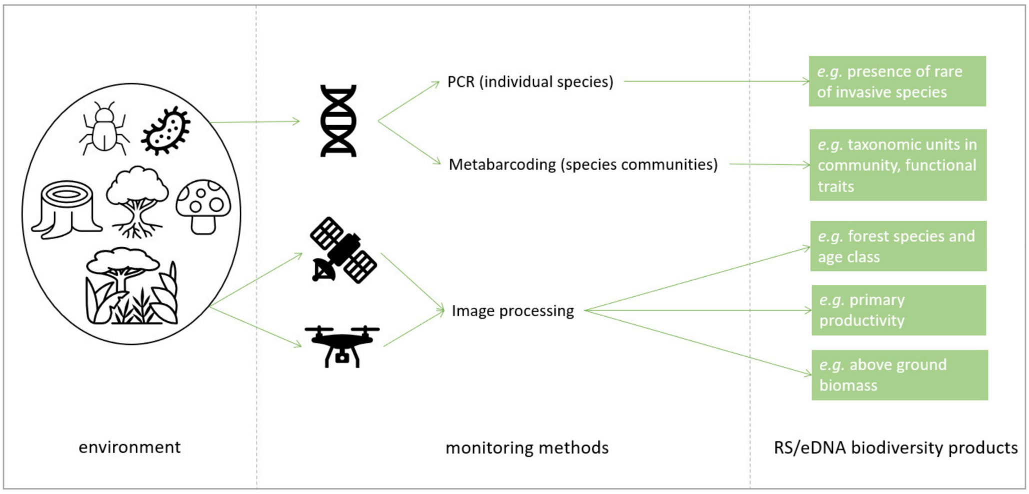


**Figure 3.** From species and landscapes, different kinds of biological information can be extracted. From environmental DNA, through PCR or metabarcoding sequencing, information about species can be obtained. Remote sensing biodiversity products are obtained from imagery or scans, e.g., taken by satellites or drones.

## 2. Materials and Methods

### *2.1. Selection of Ecosystem and Indicators*

As a target ecosystem for this study, we chose managed forests designated as natural reserves that have a function both for conservation as well as timber production (or a history thereof). This dual function makes forest conservation important and valued, by ecologists and the public alike and applies to many forests on the globe but sets them apart from solely production-orientated plantations. As described previously, for optimal comparison of forests and harmonization and policy requirements, it is pivotal that variables are used that describe similar aspects of biodiversity. This research combines variables stemming from three sources: (1) EBVs, (2) RS/eDNA biodiversity products, and (3) forest conservation policies and management-related literature. Thus, we have three sets of variables, from which we used the set of EBVs as the umbrella framework, the 'binding' set of variables with which the two other sets (RS/eDNA products and forest indicators) were compared.

EBVs were formulated with the aim to tie scientific variables to policy indicators. From this central framework, we incorporated the EBVs of five (rather than all six) classes. We excluded the EBV class 'genetic composition', which refers to intraspecific genetic diversity, which is out of the scope of this study as 'genetic composition' is not considered in any policy as well as not yet being linked operationally to remote sensing. For an overview of the EBV classes and candidates, see Supplementary A Table S2.

From policy documents, management plans and (grey) literature targeted at forest conservation, we selected indicators and variables which were relevant for conservation purposes and tracked by (governmental) monitoring programs. Search criteria were: 'forest indicators', 'forest variables', 'forest management', 'forest disturbance', and 'forest conservation policy'. We selected forest conservation indicators of three northern European countries: Finland, Germany, and the Netherlands. The forests in these three countries contain similar tree species, however, the forests are managed according to different management styles (see Supplementary B List S1). Comparing these three forest conservation policies could provide insight into what is generally important for northern European forest conservation. Additionally, these three countries must adhere to the same European Habitats Directive. We were interested in how policies of these countries that are member states of the EU compared to a country that has a similar governance structure and policy setting, but has a completely different biome. Here, we chose Australia. Australia's forests are also monitored and have regulated timber production. However, although not completely undisturbed, large areas are still covered with native forest [21] and disturbances such as fires are an integral part of Australian forest ecology. We researched whether this different background results in forest conservation indicators that were similar or different between EU member states and Australia (as well as between EU member states). See Supplementary A Table S3 for an overview of the literature and additional information on the policies.

### *2.2. Counting Variables and Indicators*

To determine the current gaps between RS/eDNA biodiversity products and forest conservation policy requirements, we counted and analyzed the variables and indicators in three different ways.

#### 2.2.1. Distribution of Forest Indicators and RS/eDNA Biodiversity Products across EBVs

We used the EBV framework (without the EBV class 'Genetic composition') as an umbrella approach for a pairwise comparison with forest indicators and RS/eDNA biodiversity [15]. The overview created by Skidmore et al. [11] listing the RS-biodiversity products linking to EBV candidates was used to count the RS-biodiversity products that could be categorized with a particular EBV candidate. For both the set of forest indicators and the set of RS/biodiversity products, we counted the number of variables from RS/eDNA products and indicators from (scientific) monitoring programs that could be categorized with a particular EBV candidate. eDNA metabarcoding has to date been used to determine taxonomic units which tells something about species presence and species indices, such as richness [22]. The categorization of RS/eDNA biodiversity products with EBV candidates can be seen in Supplementary A Table S1. In a similar fashion, forest conservation indicators from policies and (grey) literature were categorized within an EBV as well. The measured unit and description of an indicator were used to determine the placement within an EBV candidate. For a few examples see Figure 4. Another example is the forest conservation indicator 'percentage of area surface covered by mixed forest type' [2]. This indicator is categorized within the EBV candidate 'live cover fraction' within EBV class 'ecosystem structure'.

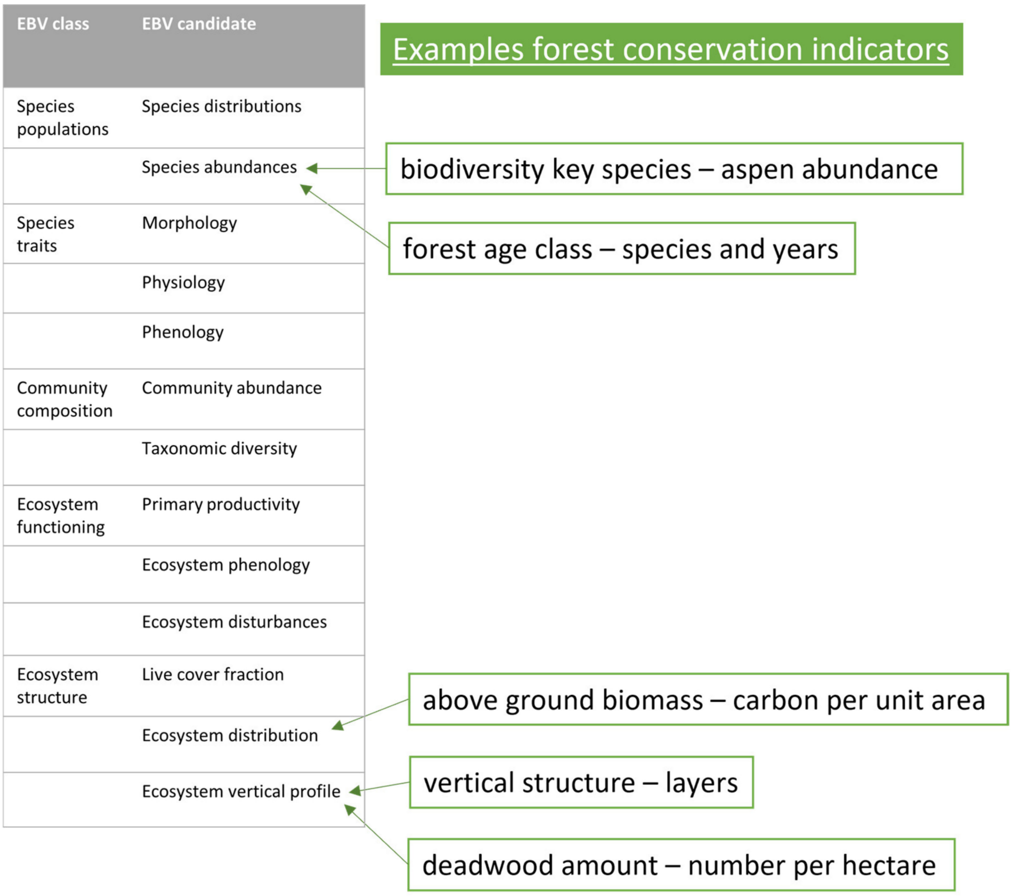


**Figure 4.** Examples of forest conservation indicators that may be linked with an EBV candidate.

We then counted how many variables and forest conservation indicators were linked with each EBV candidate. A Kruskal–Wallis test was used to test if the counts were equally distributed across all EBV candidates for both variable sets: (1) indicators and variables taken from policy and scientific literature, and (2) the variables from RS/eDNA biodiversity products. This determines whether all EBVs were addressed equally, or if some EBVs were favored over others by a variable set.

### 2.2.2. Potential Use of RS/eDNA Biodiversity Products in Forest Conservation Policy

Secondly, we wanted to know to what extent the total number of current forest conservation indicators used in this study could be monitored with RS/eDNA biodiversity products. Here, the EBV framework played no part in the analysis.

For each country, we counted how many forest indicators were or could (likely) be monitored with a RS/eDNA biodiversity product and noted this as 'current use'. We counted how many times a RS/eDNA biodiversity product had no demand with respect to policy statements or management plans. For instance, there is no requirement in policy for the four studied countries to monitor 'productivity' (or even more variables aligned to productivity such as leaf area index and chlorophyll content). These variables describe traits that relate to structure and function but are not specifically mentioned in policy or management plans. These RS/eDNA products were noted as 'available for use'. We then counted how many times there were forest conservation indicators in the literature for which there was no (suitable) RS/eDNA product. This was undertaken to determine the hypothesized proportion of forest conservation indicators for which RS/eDNA products could be used. Finally, we counted the total number of forest conservation indicators, for all countries. There was just one set of RS/eDNA biodiversity products. For each country, the forest conservation indicators that could be monitored with an RS/eDNA product could differ. Thus, the RS/eDNA biodiversity products were summed, to account for these differences. This was the entire 'population' of indicators. Then, a one-sample z-test for proportion was used to test if policies currently make less use of RS-eDNA biodiversity products than potentially possible.

By 'could be monitored', we mean that an indicator is similar to an output variable of a RS/eDNA biodiversity product. By 'could likely be monitored', we mean that a RS/eDNA biodiversity product has a different output variable than the conservation indicator, though with a minor adaptation (such as an improved definition and clear link to policy requirements), the indicator could be monitored with a RS/eDNA biodiversity product and the indicator could be adopted into policy. See Box 1 for examples of the forest conservation indicators that 'could likely be monitored' with a RS/eDNA biodiversity product.

**Box 1.** Some examples of forest conservation indicators that could be already monitored with RS/eDNA biodiversity products. When an indicator could likely be monitored, the adaptation that is needed to monitor the indicator is listed. When 'n/a' (not applicable), no adaptation is needed and the RS/eDNA product is ready for use as the indicator is aligned.

**RS/eDNA Biodiversity Product**
Vegetation canopy height (RS)
Ecosystem structural Variance (RS)
Forest species and age class (RS)
Ecosystem fragmentation (RS)
Fraction of vegetation cover (RS)
Canopy cover (RS)
Deadwood habitat (RS)
Biological effects of pest and disease outbreak (RS)
Species diversity richness (eDNA)
Relative abundance of taxonomic unit (eDNA)
**Forest Conservation Indicator**
Vertical structure—layers
Horizontal structure
Stand diversity—species and age
Interconnectedness—fragmentation
Retention trees after cutting—volume
Canopy gaps
Deadwood volume
Scale and impact of agents and processes affecting forest health and vitality
Polypore species richness
Bryophyte species—abundance
**Adaptation Needed**
Layers in height (not in number)
Define measured units
n/a
n/a
Align measured units
Align measured units
n/a
Define measured units
n/a (DNA of polypore species has to be known)
n/a (DNA of bryophyte species has to be known)

2.2.3. Similarity of Forest Conservation Policies

A similarity in conservation policy requirements for biodiversity monitoring improves the comparison and monitoring of conservation status between countries. Thus, we were interested in whether forest conservation policies of the four countries were similar or different in the type and number of indicators that were categorized within the EBVs. Here, we compared countries directly and did not include RS/eDNA biodiversity products. For example, we tested whether Dutch policy is similar to German policy in the number of indicators that address 'live cover fraction'. We expected the three northern European policies to be similar in the count of indicators across the different EBVs. In other words, the policies of these countries monitor similar biodiversity attributes, such as species composition and vegetation structure. Although these are important variables for all forest types, we expect that forest conservation indicators listed in a forest biodiversity policy from a country with a different biome and natural history have a different set of indicators that are relevant for management. Here, we used a chi-square test to compare countries and their number of indicators categorized within EBV candidates.

## 3. Results

Table 1 details the number (counts) of RS/eDNA-biodiversity products and forest conservation policies that could be categorized into the different EBV classes and candidates. In this study, the EBV class 'genetic composition' is out of the scope of this research (see also Section 2.1 Selection of ecosystem and indicators). There were 62 RS/eDNA biodiversity products, of which 55 were remote sensing-based and 7 were eDNA based. From Dutch, German, Finnish, and Australian policy documents we sampled 49, 55, 68, and 34 indicators, respectively.

**Table 1.** The number (counts) of RS/eDNA biodiversity products and forest conservation indicators from the four countries that could be categorized into the different EBVs classes and candidates.

| EBV Class | EBV Candidate | *n* Biodiversity Products | | *n* Indicators | | | |
|---|---|---|---|---|---|---|---|
| | | RS | eDNA | The Netherlands | Germany | Finland | Australia |
| Species populations | Species distribution | 2 (4%) | 3 (43%) | 0 (0%) | 7 (13%) | 6 (9%) | 2 (6%) |
| | Species abundances | 3 (5%) | 1 (14%) | 6 (12%) | 3 (5%) | 15 (22%) | 4 (12%) |
| Species traits | Morphology | 3 (5%) | 0 (0%) | 0 (0%) | 3 (5%) | 0 (0%) | 0 (0%) |
| | Physiology | 2 (4%) | 0 (0%) | 0 (0%) | 3 (5%) | 0 (0%) | 0 (0%) |
| | Phenology | 9 (16%) | 0 (0%) | 0 (0%) | 1 (2%) | 0 (0%) | 0 (0%) |
| Community composition | Community abundance | 1 (2%) | 0 (0%) | 1 (2%) | 0 (0%) | 0 (0%) | 0 (0%) |
| | Taxonomic diversity | 3 (5%) | 2 (29%) | 2 (4%) | 1 (2%) | 0 (0%) | 0 (0%) |
| Ecosystem functioning | Primary productivity | 12 (22%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) |
| | Ecosystem phenology | 3 (5%) | 0 (0%) | 0 (0%) | 1 (2%) | 0 (0%) | 0 (0%) |
| | Ecosystem disturbance | 3 (5%) | 0 (0%) | 0 (0%) | 0 (0%) | 0 (0%) | 4 (12%) |
| Ecosystem structure | Live cover fraction | 3 (5%) | 0 (0%) | 7 (14%) | 7 (13%) | 9 (13%) | 6 (18%) |
| | Ecosystem distribution | 5 (9%) | 1 (14%) | 6 (12%) | 5 (9%) | 3 (4%) | 2 (6%) |
| | Ecosystem vertical profile | 6 (11%) | 0 (0%) | 27 (55%) | 24 (44%) | 35 (51%) | 16 (47%) |
| Total | | 55 | 7 | 49 | 55 | 68 | 34 |

*3.1. Distribution of RS/eDNA Biodiversity Products and Forest Conservation Indicators across EBVs*

As mentioned before, the set of EBVs aims to define a minimum set of essential measurements to capture major aspects of biodiversity change. These major aspects involve ecosystem composition, structure and function. We used the counts listed in Table 1 to determine if the counts of RS/eDNA biodiversity products and forest indicators categorized with an EBV candidate are equally distributed across the candidate EBVs. The counts of indicators are pictured in Figure 5. There is no significant difference in the number of RS- and eDNA biodiversity products across the EBV candidates ($p$ = 0.998). It can be observed that the number of forest conservation indicators is unequally distributed across the EBV candidates. A pairwise comparison (Kruskal–Wallis test) shows that a significant difference is found between EBV candidates 'ecosystem vertical profile' and 'primary productivity' ($p$ = 0.002). There are many forest conservation policy indicators that describe structural elements within a forest, such as tree height, presence of deadwood or above-ground biomass. However, there were no policies that incorporate ecosystem function indicators such as primary productivity.

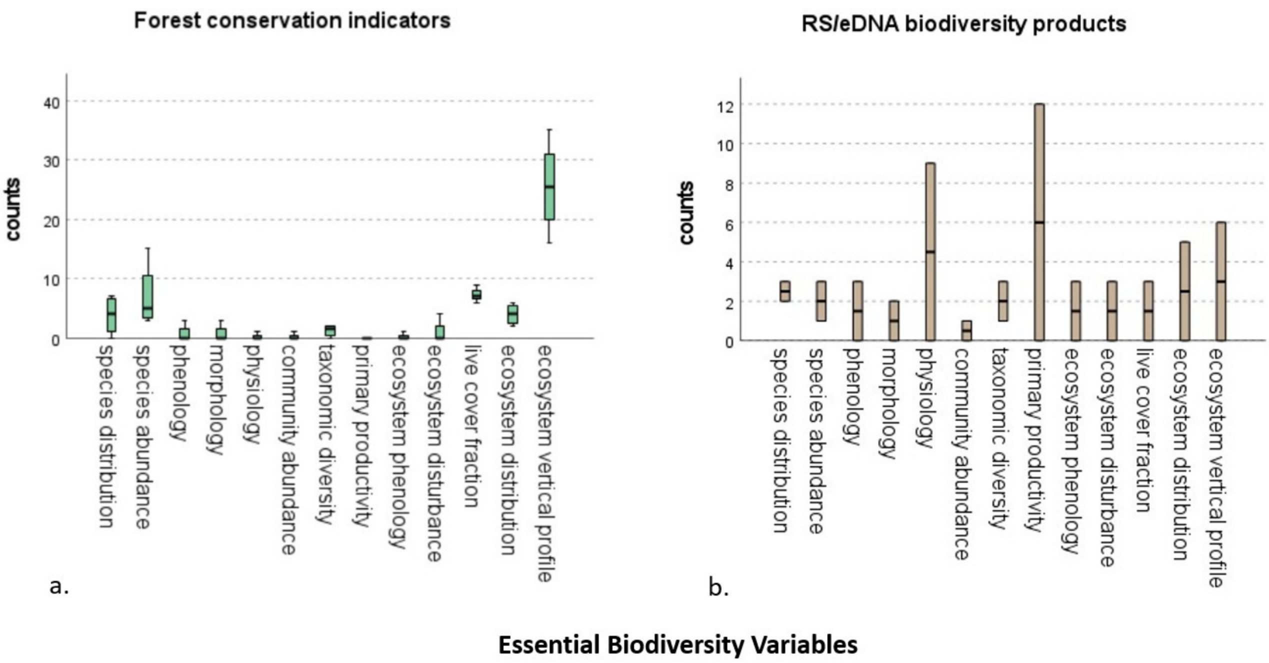


**Figure 5.** Distribution of the number of (**a**) forest conservation indicators and (**b**) RS/eDNA biodiversity products across the different Essential Biodiversity Variable candidates.

*3.2. Potential Use of RS/eDNA Biodiversity Products in Forest Conservation Policy*

The proportion of forest conservation indicators that can currently be monitored with RS/eDNA biodiversity products is significantly different than the potential use (one-sample z-test, $p$ = 0.000) (Table 2). In other words, there are more opportunities to monitor the indicators with RS/eDNA biodiversity products than are currently utilized. This indicates an underuse of RS/eDNA biodiversity products within forest conservation policies.

**Table 2.** The proportion of current forest conservation indicators that can be monitored with RS/eDNA biodiversity products ($p$ values from one sample z-test).

| Population Parts | $n$ | Proportion |
|---|---|---|
| Total number of indicators | 394 | 1 |
| Current/potential use of RS/eDNA product (current) | 187 | 0.47 ($p$ = 0.00) |
| RS/eDNA product, but no policy demand (availability) | 194 | 0.49 ($p$ = 0.00) |
| No suitable RS/eDNA product for indicator | 13 | 0.03 |
| Potential use of RS/eDNA product (=Total—no suitable RS/eDNA product) | 381 | 0.97 |

### 3.3. Difference between Policies in Indicator Distribution across EBVs

For each country, the number of forest conservation indicators that could be categorized with an EBV candidate was counted (Table 3). The differences in number across the EBVs were compared with a chi-square test. As can be seen in Table 4, there is no significant difference between the northern European countries in the number of forest conservation indicators that can be categorized within the different EBVs. Differences in the number of forest conservation indicators used in the policies across EBVs were found between Germany and Australia ($p$ = 0.04), as well as Finland and Australia ($p$ = 0.00) (Table 4). Germany and Finland have a higher number of indicators for species distribution, species abundance (Finland) and taxonomic diversity, whereas Australia has a higher number of indicators for ecosystem disturbance.

**Table 3.** The number of indicators of the examined policies per country across the candidate EBVs.

| EBV Class | EBV Candidate | The Netherlands | Germany | Finland | Australia |
|---|---|---|---|---|---|
| Species populations | Species distribution | 0 | 7 | 6 | 2 |
| Species populations | Species abundance | 6 | 3 | 15 | 4 |
| Species traits | Phenology | 0 | 3 | 0 | 0 |
| Species traits | Morphology | 0 | 3 | 0 | 0 |
| Species traits | Physiology | 0 | 1 | 0 | 0 |
| Community composition | Community abundance | 1 | 0 | 0 | 0 |
| Community composition | Taxonomic diversity | 2 | 1 | 2 | 0 |
| Ecosystem functioning | Primary productivity | 0 | 0 | 0 | 0 |
| Ecosystem functioning | Ecosystem phenology | 0 | 1 | 0 | 0 |
| Ecosystem functioning | Ecosystem disturbance | 0 | 0 | 0 | 4 |
| Ecosystem structure | Live cover fraction | 7 | 7 | 9 | 6 |
| Ecosystem structure | Ecosystem distribution | 6 | 5 | 3 | 2 |
| Ecosystem structure | Ecosystem vertical profile | 27 | 24 | 35 | 16 |

**Table 4.** Result of the chi-square comparison between countries in the distribution of forest conservation indicators across EBVs.

| *p*-Value | The Netherlands | Germany | Finland | Australia |
|---|---|---|---|---|
| The Netherlands | - | - | - | - |
| Germany | 0.97 | - | - | - |
| Finland | 0.56 | 0.22 | - | - |
| Australia | 0.16 | 0.04 | 0.00 | - |

## 4. Discussion

For the harmonization and comparison of forest conservation policies, a standardized set of biodiversity variables is necessary [5,11,23]. The EBV framework, EBV classes, and candidate EBVs provide an opportunity for harmonized biodiversity assessment and policy reporting [11]. However, the description of EBVs remains rather abstract. The terminology used and classification of the indicators among the EBV classes can be confusing to policymakers, as the EBV terminology may not equate to the terms used in specific regions or scientific domains by policy analysts [11]. For example, it is not always clear whether indicators describe a biodiversity aspect or correlate with and influence other biodiversity aspects. Alternatively, a variable is an environmental variable and not biological, such as soil moisture. Currently, there is a poor alignment between the information that is delivered by RS/eDNA biodiversity products and the information required for forest conservation policies. This poor alignment between RS/eDNA biodiversity products and forest conservation indicators manifests itself in various ways.

### *4.1. Alignment of Forest Biodiversity Indicators and RS/eDNA Biodiversity Products within EBVs*

Our results show that RS/eDNA biodiversity products provide much information about ecosystem functioning, whereas currently formulated forest conservation policies call for information about community composition and ecosystem structure. This finding concurs with another study showing that functional biodiversity attributes are often overlooked by conservation policies [24]. Conservation indicators of taxonomic groups often serve as a proxy for large scale functional ecological changes. However, changes in community composition do not necessarily correlate with changes in ecosystem functioning [25,26]. Thus, having a good understanding of the functional processes of an ecosystem is equally important as understanding compositional and structural attributes. Even if they are not included as 'target' variables in a conservation policy or management operations, changes in functional processes provide a strong signaling function. Monitoring forest health by monitoring photosynthesis, productivity or tree properties that are indicative of healthy growth and functioning of the trees is very useful for policymakers and conservation area authorities. Especially the latter will benefit by being able to respond to early warnings of changes in ecosystem functioning due to drought stress, pollution or pests, e.g., bark beetle infestation. Adding variables that track ecosystem function will result in a more 'balanced' reporting on the biodiversity of forests with regards to the composition, structure, and function of an ecosystem. Additionally, RS/eDNA biodiversity products can also obtain a more complete picture of taxa that are not easily monitored with traditional field monitoring. Environmental DNA analysis mostly informs about 'species distribution', 'species abundance', and 'taxonomic diversity'. Adding eDNA analysis to the 'monitoring mix' may provide insight into previously undetected species [27]. Thus, the combination and integration of both RS biodiversity products and eDNA biodiversity products into monitoring programs will lead to more comprehensive and balanced monitoring across all biodiversity attributes as described by the EBVs. As such, the use of environmental DNA for consistent biodiversity monitoring and reporting shows potential. However, the technique is still in early development and for practical applications for conservation policy, some hurdles must be overcome [19]. The application of the technique requires specialized training [19]. No standardized protocol for all ecosystems exists [28]. Additionally, because eDNA is a relatively new technology, and an integrated effort between scientists, local and federal agencies is required to ensure the data meets legal standards to be useful for policy [29–31]. Therefore, the application of eDNA for consistent monitoring is still limited. However, for single species detection and aquatic environments, there is evidence that eDNA is a promising technique and that it could be possibly more broadly applied in the future [28,31].

Secondly, when looking at the current use of RS/eDNA biodiversity products in conservation policies we conclude that they are not used to their full potential. The results in Table 2 show that the proportion of forest conservation indicators that are or could potentially be monitored with remote sensing techniques and eDNA analysis is significantly lower than the total number of variables available in this study for monitoring forest biodiversity. This is partially explained by the observation that most of the current conservation indicators have different units of measurement than the output variables of a RS/eDNA product. For example, the indicator 'diversity in structure', listed for the Veluwe National Park in the Netherlands had no defined units, though using LiDAR, vegetation structure can be quantified in SI units. However, the measurement unit required by policy is not stated. These RS/eDNA biodiversity products are mostly categorized within functional EBV candidates such as (ecosystem) phenology, physiology, ecosystem disturbance and primary productivity. For some variables (such as species richness indices and leaf area index), neither the variable nor its proxy is yet a requirement for policy. We note that some policy 'indicators' are identical to remote sensing biodiversity products commonly used in the remote sensing literature [11] while some indicators are based on ecological terms. We recommend that practitioners in ecology, remote sensing and policy align to a standard set of terminology to avoid confusion (see [11]) though finding agreement on a standard set of terms is not straightforward.

### 4.2. Differences between Countries

EBVs form a framework that provides opportunities for harmonization between conservation policies of different regions/nations. Differences in the forest conservation policies between countries are expected, as biomes, as well as natural and cultural history, vary. We found that northern European countries are very similar in the amount of and type of biodiversity indicators that can be linked with EBVs. This contrasts with the finding of Parviainen and Frank [5], who found that forest conservation indicators are different between countries in Europe, and argued that forest certification (and forest certification links with policy) were needed to achieve harmonization. In contrast to Parviainen and Frank [5], we did not compare the policies and their targets/definitions directly with each other in this study. Rather, we looked at the indicators for each policy and to which EBV candidates these indicators could be classified. However, the counts of indicators categorized within the EBV candidates from Australian policy differs from two of the Northern European policies, namely those of Germany and Finland. There are a few explanations as to why. For example, Australia has a different biome. In addition, Australia has a relatively high number of indicators that can be classified with the EBV ecosystem disturbance. This may be the result of forest fires (ecosystem disturbance), which are integral to Australian forest ecology.

As mentioned previously, the Netherlands, Germany, and Finland all adhere to the European Habitats Directive, and Australia does not. The European Habitats Directive has likely caused the northern European forest conservation policies to converge over time. For more background information on the history of forest management of the four countries, see Supplementary B List S1 Forestry background. Based on the observed difference between the European Union and non-European Union countries, we propose that the EBVs may provide a framework to better align and compare biodiversity assessments between countries, and therefore make upscaling possible at a global level.

### 4.3. Suggestions for Further Integration of RS/eDNA Biodiversity Products into Policy Targets

Based on these results, we suggest the following to improve the comparability and harmonization of forest conservation policies:

1. The variables used for monitoring forests should be similar, or at a minimum, a core set of common and universal forest conservation indicators useful for management and policy should be implemented that are applicable for all forest environments.
2. Redefining and separating environmental variables from biodiversity variables within the EBV framework will likely facilitate the discussion between ecologists, policy-makers and the remote sensing community and help in harmonizing biodiversity conservation policies.
3. Monitoring programs should incorporate variables that track ecosystem functioning.
4. RS biodiversity products should be integrated into monitoring programs that track ecosystem vertical profile, as these products align well with current policy requirements.
5. Similarly, integrating eDNA analysis into monitoring programs could theoretically be undertaken using eDNA biodiversity products to yield information about ecosystem functioning as well as additional knowledge about taxa presence and relative abundance. However, since eDNA is a relatively new technology, we suggest an initial focus on RS biodiversity products.

## 5. Conclusions

To inform on global and regional policy of forests conservation status, variables and indicators that track the biodiversity and conservation status of a forest need to be comparable and similar. Currently, there is an underuse of RS/eDNA biodiversity products. Integrating RS/eDNA biodiversity products into monitoring programs will lead to more comprehensive biodiversity monitoring. By providing a) additional means and variables for biodiversity monitoring of ecosystem functioning such as primary production, as well as b) more information about taxa species present, a more complete and balanced picture of biodiversity in a particular area appears. Structuring forest conservation policies such as the EBV classes and candidates could aid with harmonization and international policy reporting. However, clear definitions, tighter links with policy variables mentioned in policy documents and ecologically sound classification of indicators is needed. RS/eDNA biodiversity products provide the opportunity to measure biodiversity across different EBVs, as well as add more in-depth knowledge to already existing forest conservation indicators.

**Supplementary Materials:** The following are available online at https://www.mdpi.com/article/10.3390/f13030445/s1, Table S1: Essential Biodiversity Variables and RS/eDNA biodiversity products, Table S2: Essential Biodiversity Variables and their description, Table S3: Overview of the examined policies, Table S4: Indicator List, List S1: Forestry backgrounds of The Netherlands, Germany, Finland and Australia.

**Author Contributions:** Conceptualization, formal analysis, M.L.; methodology, M.L. and I.v.D.; resources, N.S.; writing—original draft preparation, M.L.; writing—review and editing, N.S., I.v.D. and A.K.S.; supervision, N.S., I.v.D. and A.K.S.; funding acquisition, A.K.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This study is part of Horizon 2020 research and innovation programme—396 European Commission 'BIOSPACE Monitoring Biodiversity from Space' project (Grant 397 agreement ID 834709, H2020-EU.1.1).

**Institutional Review Board Statement:** Not applicable.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** Indicator list is attached as Supplementary Materials C Table S4.

**Acknowledgments:** Not applicable.

**Conflicts of Interest:** The authors declare no conflict of interest.

## Glossary

Biodiversity
The term biodiversity is subject to different definitions. Here, we use the term as describing a property or characteristic of a natural environment or ecosystem. These properties and characteristics can be subject to change, which can be monitored.
eDNA biodiversity products
Environmental DNA biodiversity products can provide information about the biodiversity of an ecosystem. Samples of soil, leaves or water are collected from the environment. Apart from microbes that live in the environment, different species leave feces, skin cells, eggs, etc., in the environment. DNA within the samples is isolated and DNA sequences determine the species present in the sample. This result can be translated into species richness indices and assessment of functional groups.
Essential Biodiversity Variables (EBVs)
A set of complementary variables that are aimed at measuring different aspects of biodiversity and capturing biodiversity change. These variables can be derived from various methods, including both in situ data collection and remote sensing-based methods. The latter offer great possibilities. However, field monitoring (e.g., lab. analysis of plant nitrogen content) must supply the validation data for the remote sensing-based methods. Some EBVs, e.g., species abundance, are still often depending on field observations only.
Forest conservation indicators
Variables that measure aspects of a forest and are used to assess the conservation status of that forest. Examples are species present (both endemic and invasive), tree size and fragmentation. Indicators usually track progress towards a goal, or act as a benchmark.
RS biodiversity product
Data output from remote sensing techniques. Based on reflectance per pixel (or point returns when using LiDAR), biological information is extracted from the image. NDVI (a vegetation index) for example, can distinguish between vegetation and non-vegetation. When used in time series analyses, it can express the dynamics in an ecosystem. This information can be used to assess (a part of) the biodiversity in an ecosystem.

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