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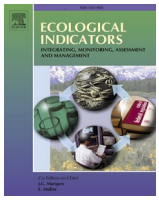

Evidence-based alignment of conservation policies with remote sensing-enabled essential biodiversity variables

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ABSTRACT

Nature conservation policies require up-to-date and accurate biodiversity monitoring. Innovative synoptic information products such as Remote Sensing-enabled Essential Biodiversity Variables (RS-enabled EBVs) could complement field observations in biodiversity monitoring. It is not clear however, how these scientific remote sensing products can be utilized for policy reporting. Agreement on the monitored geographic extent (area size and scale), as well as biodiversity attributes (composition, structure, and function), may provide a common'point of departure' for policymakers and the scientific community to develop and further improve monitoring. In this study, biodiversity indicators of 10 nature conservation policies and 50 RS-enabled EBVs were compared using non-parametric tests (chi-square and Mann-Whitney U). Our main finding is that policy indicators and RS-enabled EBVs are very similar in the spatial extent they address (mapping scale). However, most policy indicators are related to ecosystem structure while most of the RS-enabled EBVs are related to ecosystem function and ecosystem structure. RS-enabled EBVs have added value in monitoring of biodiversity, especially when looking at ecosystem functioning. Information on ecosystem functioning and structure provides evidence needed as input for policy development and management of biodiversity. However, to make this happen, a stronger focus on ecosystem functioning and structure with appropriate variables is needed, in policy requirements and targets.

1. Introduction

Nature conservation policies require up-to-date and accurate biodiversity monitoring. Traditional biodiversity monitoring usually consists of gathering *in situ* data during fieldwork. However, the problem with *in situ* data is that they are very fragmented in space and time (Geijzendorffer et al., 2016) as well as being costly, hard to control, laborious and difficult to reproduce (Skidmore et al., 2015). Innovative information products such as Remote Sensing-enabled Essential Biodiversity Variables (RS-enabled EBVs) could complement field observations in biodiversity monitoring. Such remote sensing enabled EBV products can be derived from modern technologies such as aerial photography, satellites, and UAVs (unmanned aerial vehicles, drones) (Skidmore et al., 2015). EBVs are developed by GEO-BON (Group on Earth Observations Biodiversity Observation Network). They form an intermediate abstraction layer between primary observations (field data) and biodiversity indicators and define a minimum set of essential measurements to capture major aspects of biodiversity change. EBVs can be divided

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into 6 classes: genetic composition, species populations, species traits, community composition, ecosystem function, and ecosystem structure (in this study we focus on the last three since these EBVs have a better link with RS products than the other EBV classes). EBVs aim to harmonize monitoring biodiversity on a global scale while providing information for policy- and decision-makers at various levels (Geijzendorffer et al., 2016; O'Connor et al., 2015; Pereira et al., 2013; Pettorelli et al., 2016). Remote sensing technologies have mostly been developed from a scientific point of view, to explore and understand the world (Khorram et al., 2012; Nagendra, 2001). Because remote sensing offers such a broad range of quantified data and with a high spatial and temporal resolution, it is well suited to contribute to evidence-based decisions (Skidmore et al., 2015). There are many remote sensing research initiatives approaching biodiversity monitoring in various ways (Jongman, 2013). However, the new technologies introduce a whole set of concrete, scientific variables without clear links to policy requirements (Skidmore et al., 2015). Thus, it is not clear where scientific products from RS-enabled EBVs may best serve policy requirements of various national and international policies and treaties. This lack in clarity stems from a few different, but interlinked factors (for an overview see Fig. 1).

To start with, nature conservation policy is multidisciplinary due to its complexity. Policy requires decision-makers, ecologists, and GIS/remote sensing experts to agree and understand one another. However, each expert has a different perspective on the issue, and alignment is necessary to understand each other. GIS and remote sensing experts describe (natural) areas with maps and imagery derived from aerial photography, drones and/or satellites. The use of algorithms that calculate and classify pixel values results in information products. A well-known example is NDVI, Normalized Difference Vegetation Index. NDVI allows detecting areas covered with vegetation and areas that are not, as well as changes in phenology and biomass over time. Other examples of variables are Leaf Area Index (a measure of ecosystem structure as well as ecosystem function), chlorophyll content (physiological trait) and vegetation height (structure). For more examples see supplementary material 'Table Indicator List'. Most variables track vegetation characteristics. Modelling animal movement with satellite imagery is still limited (to very high-resolution satellite imagery) and is largely based on vegetation mapping (Neumann et al., 2015; Remelgado et al., 2018), although remote sensing has been combined with species modelling for animals and insects (Cord et al., 2013; Pöyry et al., 2018). Other limitations when using publicly available data from satellites is the temporal and spatial resolution. This can be resolved by using other platforms such as drones, but then other limitations occur such as the area size that can be monitored. Going back to the available information products, policymakers and nature managers do not directly use NDVI or leaf area index when designing policies or deciding upon nature conservation measures. Rather, such variables derived from remote sensing have been primarily developed as a technical solution to explore the world, and not necessarily in response to conservation policy (Skidmore et al., 2015). Thus, although remote sensing information products may be of great value, they might not relate well to policy requirements (Geijzendorffer et al., 2016; O'Connor et al., 2015) or ecological indicators (Peterson & Soberón, 2018; Vihervaara et al., 2017).

Another perspective is that of ecologists. Currently, biodiversity is mostly described with biodiversity levels and biodiversity attributes (Franklin et al., 1981; Norse et al., 1986; Noss, 1990), by using various ecological models, *in situ* observations and, increasingly, spatial and temporal data. Biodiversity levels are seen as levels of organization: (1) genetic diversity within a species, (2) species diversity and (3) ecosystem diversity (Norse, 1986). Apart from these three levels of biodiversity, biodiversity 'attributes' are also recognized (Franklin et al., 1981): (1) composition, (2) structure and (3) function. Composition tells ecologists about the identity and variety of the elements in an ecosystem, such as which species are present. Structure is about the organisation or patterns, such as vegetation height. Function involves underlying processes, such as nutrient cycling (Noss, 1990). Both the levels and the attributes have been consolidated into a 'nested hierarchy' of biodiversity by Noss (1990), who also added the 'landscape' level to the levels of organization. The 'nested hierarchy' has evolved into a widely accepted framework for biodiversity research. Noss (1990)

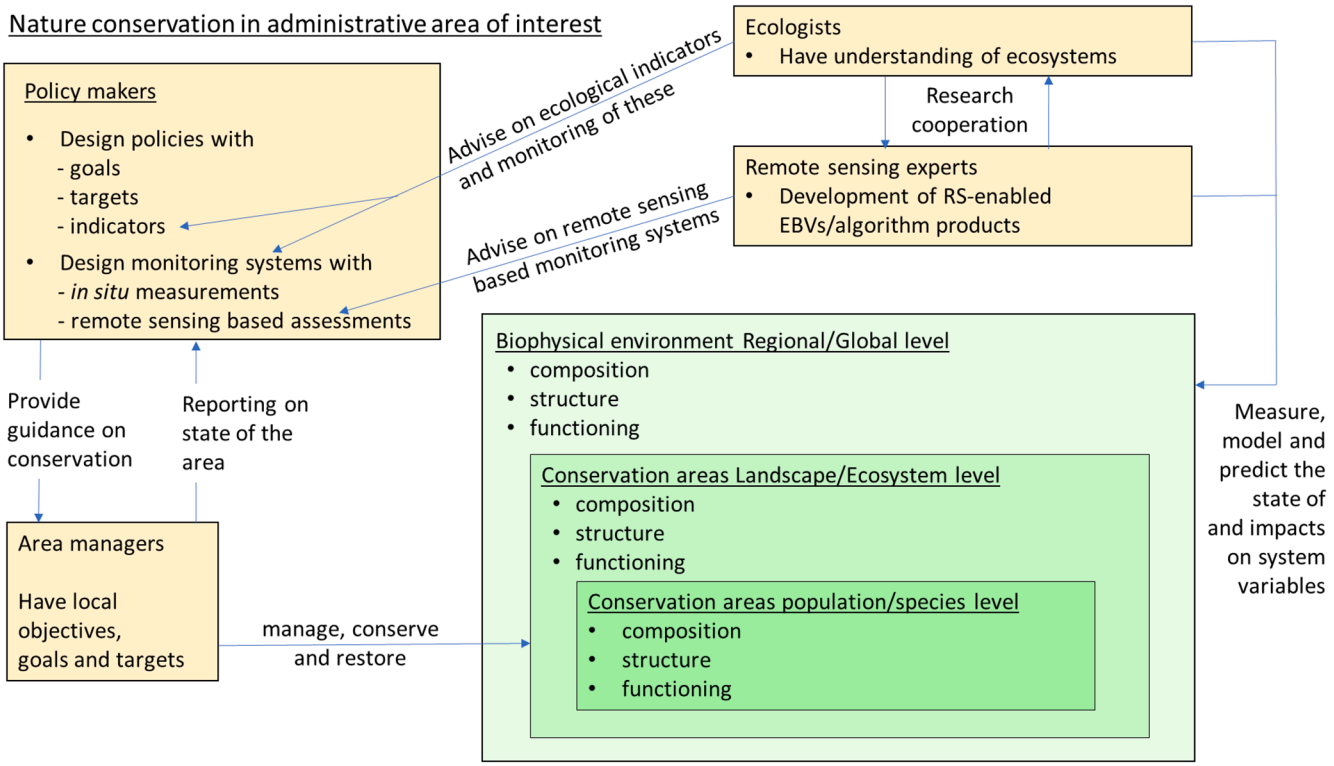

Fig. 1. Conceptual diagram showing the links between nature conservation, biodiversity attributes, policy, and remote sensing.

suggests that only by monitoring all four levels (genetic, species/population, ecosystem, and landscape), as well as the three attributes (composition, structure, and function), biodiversity to be comprehensively monitored and ultimately understood. As it is virtually impossible to track biodiversity attributes at all geographic scales in the natural environment, indicators are used (Bunce et al., 2013; Dale & Beyeler, 2001; Noss, 1990). The term indicator is often used as an interface between science and policy, but is generally used to track a certain (ecological) target (Heink & Kowarik, 2010). To track progress towards goals and targets, monitoring programs are initiated. These require evidence-based indicators that are meaningful for the set goal or target. The requirements regarding what should be monitored within national and international nature conservation policies should be very clear and transparent to aid effective decision-making on biodiversity and management (Tittensor et al., 2014; Walpole et al., 2009).

To be an effective tool both from a scientific point of view and for management, a suite of indicators covering the three biodiversity attributes (composition, structure, and function) at various geographic extents (species, ecosystem, and landscape level) is needed to monitor the state of the natural environment (Dale & Beyeler, 2001). Although attempts have been made to monitor genetic diversity and gene expression using remote sensing, this research is still in a too premature stage of development to be meaningful for policy (Larsen et al., 2015; Oberholster & Botha, 2010). Effective monitoring requires well-designed monitoring programs and policies. But current indicators do not cover all knowledge gaps (*e.g.,* taxonomic coverage, ecosystem resilience) (Tittensor et al., 2014).

This is where, we believe, RS-enabled EBVs could assist. However, it is not clear where scientific products from RS-EBVs meet and best serve policy requirements of various national and international policies and treaties.

Tracking the targets set in policy usually involves evaluating whether a policy has been successful, in a process much like the Plan-Do-Check-Act cycle (Althaus, 2007; Deming, 1950). This cycle is a way to quantify societal value and to put them forward in policy. A policy ideally is supported by data (Harrison & Sayogo, 2014; Sowa & Lu, 2017), allowing for evidence-based decision making. Science and politics have long been considered to be best kept apart, but Elliott and Resnik (2014) suggest that society is likely to be better served with scientists being involved in policy development. In doing so, their involvement should be transparent, *e.g.,* by stating their interests and bringing evidence-based information to a political discussion. Adams and Sandbrook (2013) have concluded that policymaking is complex and messy, and the role of evidence can never be neutral. Yet, strengthening the knowledge exchange across the science-policy interface aids in developing evidence-based nature conservation policies (Weatherdon et al., 2017). However, the problem with biodiversity policy is that it is generalized, vague and hard to operationalize as a single concept (Butchart et al., 2016; Habib, 2015). The term biodiversity is categorically difficult, as it has been used for different purposes such as describing the property of an area, composition of an area or other characteristics of nature (Wallace & Jago, 2017). It can also be seen as the 'state of nature', or as a synonym for (the whole of) nature itself (Habib, 2015). On top of that, the term biodiversity was originally conceived as a bridge between scientific measurements of the natural world and what we value in nature (Habib, 2015), which renders the term open to different interpretations. Some have argued it must be made more precise to be meaningfully measured (Butchart et al., 2016; Habib, 2015). This would mean that to fulfil the agreements made under national and international nature conservation treaties, policy requirements should be scientifically quantifiable. This leaves the challenge to match nature conservation policy requirements with scientific variables, to quantify biodiversity in a meaningful way. Remote sensing enabled EBVs can play a key role in this, as remote sensing imagery can inform policy.

Nature conservation policy indicators and remote sensing variables *both* describe certain geographical scales and biodiversity attributes of an area of interest (Noss, 1990, Pereira, et. al. 2013). Thus, geographic extent and biodiversity attributes can be used as a means of comparison (*i.e.*,'units of analysis', (Ragin, 1983). We compare differences in indicators in how they emphasise biodiversity attributes and geographical extent. This allows us to quantitavely understand how policy requirements and RS-enabled EBVs are similar, as well as differ, from an ecological perspective.

This leads to an understanding of how policies and RS-enabled EBVs align, based on the geographic extent and biodiversity attributes that are emphasised in their indicators and variables, respectively. Knowing how policy requirements align with the information that can be derived from remote sensing may provide a common departure point to inform and further improve in policy indicator design and development of RS-enabled EBVs.

2. Methods

Our selection of policy indicators was taken from ten current policies and monitoring methods (from here onwards 'all policies') (Table 1). Openly accessible and current policy documents were searched for goals, targets, and indicators on biodiversity monitoring. We chose three policies that were designed on a global scale, as well as one European policy and one European monitoring program (designed on a supranational scale) and national policies of two countries with similar governmental structures.

At a global governance level, three well-known conservation policies were selected as key examples as they overarch many other policies and monitoring programs: the Convention on Biological Diversity (Aichi

Table 1
Overview of the 10 examined policies and scientific variables and their governance level. For the purpose of this study, policies concerned with biodiversity at a provincial level for the Netherlands and state level for Australia are set to 'regional'. Local policies, such as in specific area management, are not considered in this study.

Indicators / variables from:	Governance level	Policy documents
Convention on Biological Diversity (Aichi Targets)	Global	CBD/COP/DEC/XIII/28 , Biodiversity Indicator Partnership (Partnership, 2011)
Sustainable Development Goals (SDGs)	Global	Tier Classification for Global Indicators (UN, 2017), Biodiversity Indicator Partnership (Partnership, 2011)
Convention on Wetlands (Ramsar)	Global	The Fourth Ramsar Strategic Plan (Ramsar Convention, 2016)
European Habitat Directive (EU HD)	Supra-national	Council Directive 92/43/EEC (EC, 1992)
Streamlining European Biodiversity Indicators (SEBI)	Supra-national	Streamlining European biodiversity indicators 2020 (BISE, 2019)
Netherlands Natura2000 (N2000)	National	Werkwijze Natuurmonitoring en –Beoordeling Natuurnetwerk en Natura 2000/PAS (Van Beek, R.F., et. al, 2014)
Netherlands National Ecological Network (NEN)	Regional (provincial)	Werkwijze Natuurmonitoring en –Beoordeling Natuurnetwerk en Natura 2000/PAS (Van Beek et al., 2014)
Australia's Biodiversity Conservation Strategy 2010 – 2030 (ABC)	National	Australia's Biodiversity Conservation Strategy 2010 – 2030 (Commonwealth, 2010))
Draft New South Wales Biodiversity Strategy 2010 – 2015 (NSW)	Regional (state)	Draft New South Wales Biodiversity Strategy 2010 – 2015 (NSW, 2010)
Queensland Biodiversity Assessment and Mapping Methodology (QLD)	Regional (state)	Queensland Biodiversity Assessment and Mapping Methodology (EHP, 2014)
Remote Sensing enabled Essential Biodiversity Variables	Scientific (GEO-BON)	Remote Sensing enabled Essential Biodiversity Variables (GEO-BON, 2018; Pereira et al., 2013)

Targets) (CBD, 2010; UN, 1992; UNEP, 2016), the Sustainable Development Goals (SDGs (UN, 2015, 2017)) and the Convention on Wetlands (Ramsar (UNESCO, 1994; Wetlands, 2016)). During the examination of the indicators of the Aichi Targets and SDG, we found that the Biodiversity Indicator Partnership (BIP, Partnership, 2011) had a list of indicators that differs from the examined policy documents (see also supplementary material Table S1 Indicator List). Analyses were run for both the official decision documents and BIP unless stated otherwise. At a supranational level, indicators were selected from two documents. These were the European Habitat Directive (EU HD (EC, 1992) and the indicator program Streamlining European Biodiversity Indicators (SEBI). The latter is part of the Biodiversity Information System for Europe (BISE). The member states of the European Union have to implement the European Habitat Directive in their national nature conservation policy. National policies from two developed countries we compared: The Netherlands (part of the European Union) and Australia.

The remote sensing variables consisted of 50 RS-enabled EBVs defined by GEO-BON (GEO-BON, 2018; Kissling et al., 2018; Kissling et al., 2015; Pereira et al., 2013; Pettorelli et al., 2016). For an overview see supplementary material Table S1 Indicator List.

We used the descriptions of indicators in policies and RS-enabled EBVs, the definitions of Noss (1990) and the scheme from Dale and Beyeler (2001) to determine what attribute (composition, structure or function) is being tracked at what extent (species habitat, ecosystem or landscape/region). Indicators usually describe what is being monitored in a certain area (*e.g.*, bird species in a particular ecosystem). Thus, an indicator usually consists of a biodiversity attribute (*e.g.,* species composition) in a set geographical extent (*e.g.*, ecosystem) (see example Fig. 2). The definitions we used to 'label' an indicator with a geographic extent and biodiversity attribute are as follows:Fig. 3.

- Geographical extent – the spatial extent relevant for the indicator
  - o Species – population habitat
  - o Ecosystem – a community of interacting organisms and their physical environment
  - o Landscape – multiple ecosystems
- Biodiversity attribute
  - o Composition – abundance and distribution of species
  - o Structure – horizontal and vertical structure, *e.g.,* mosaics of shrub height
  - o Function – processes and dynamics

2.1. Frequency and emphasis on biodiversity attributes and geographic extent

We counted how many times a particular biodiversity attribute and geographic extent was tracked by an indicator within a policy or RS-enabled EBV, *e.g.*, how many indicators of a policy are tracking a structural attribute. For an example see Box 1. This procedure was followed for all listed policies and RS-enabled EBVs (see also supplementary material Table S1). We did not include administrative or management indicators in this study. We only focused on ecological indicators, describing a biodiversity attribute and geographical extent. In some cases, it was unclear to what extent a biodiversity attribute was measured (or what attribute). Then it was labelled with 'undefined'. In other cases, multiple attributes were monitored, or could be monitored at different scales. Then it was labelled with 'multiple'. We used a chi-square test to compare these counts from policies and RS-enabled EBVs to a hypothetical policy. This hypothetical policy has an equal distribution across biodiversity attributes and geographic extent. This means that an equal count of indicators addressing is a particular attribute/extent. This comparison was used to determine whether counts were evenly distributed or not over the three biodiversity attributes and three geographical extents. In other words, if a particular attribute or extent was emphasised by a policy or RS-enabled EBVs (see also Box 1). We did not expect policies and RS-enabled EBVs to have an even distribution. Neither did we expect a normal distribution of indicators.

2.2. Differences in count numbers between policies and RS-enabled EBVs

As a policy can be carried out on different levels, such as local (*e.g.* Dutch policy) or global (international treaties), we also grouped policies

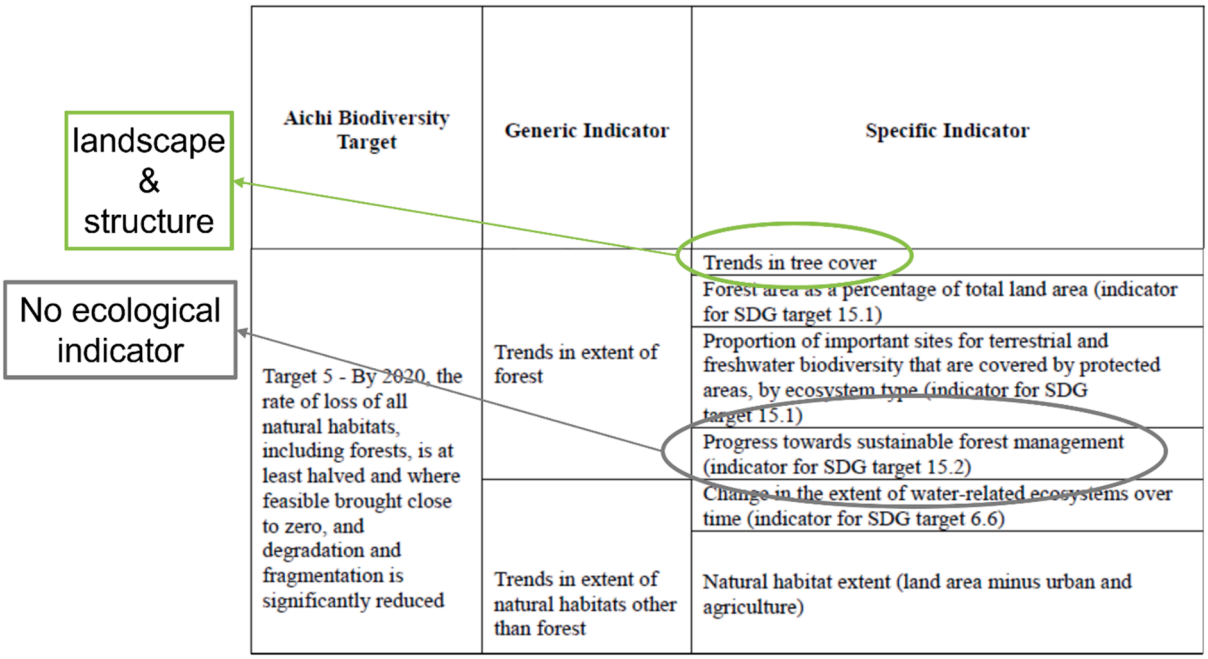

Fig. 2. An excerpt of the Aichi Biodiversity Targets 2020 (UNEP, 2016). The specific indicators were used in our analysis. The green outlined example is the indicator 'trends in tree cover'. This indicator covers a large area (geographic extent 'landscape') and describes a structural biodiversity attribute. The grey outlined example is not an ecological but an administrative indicator, and therefore not part of this study.

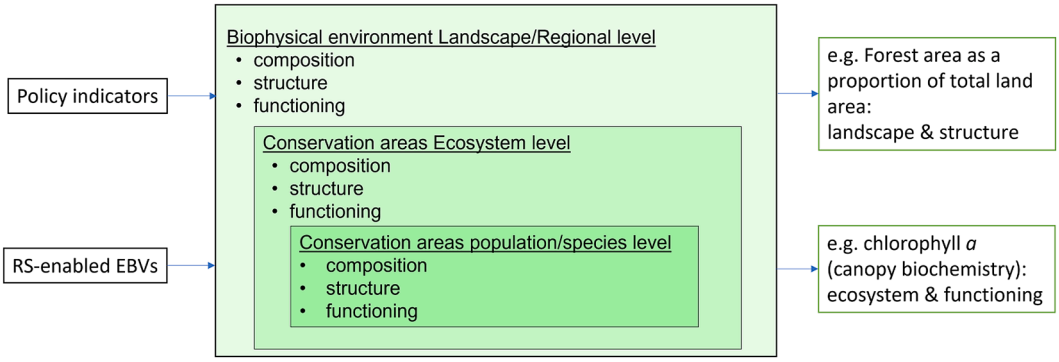

Fig. 3. Examples of how both policy indicators and remote sensing enabled variables were labelled with an geographic extent and biodiversity attribute.

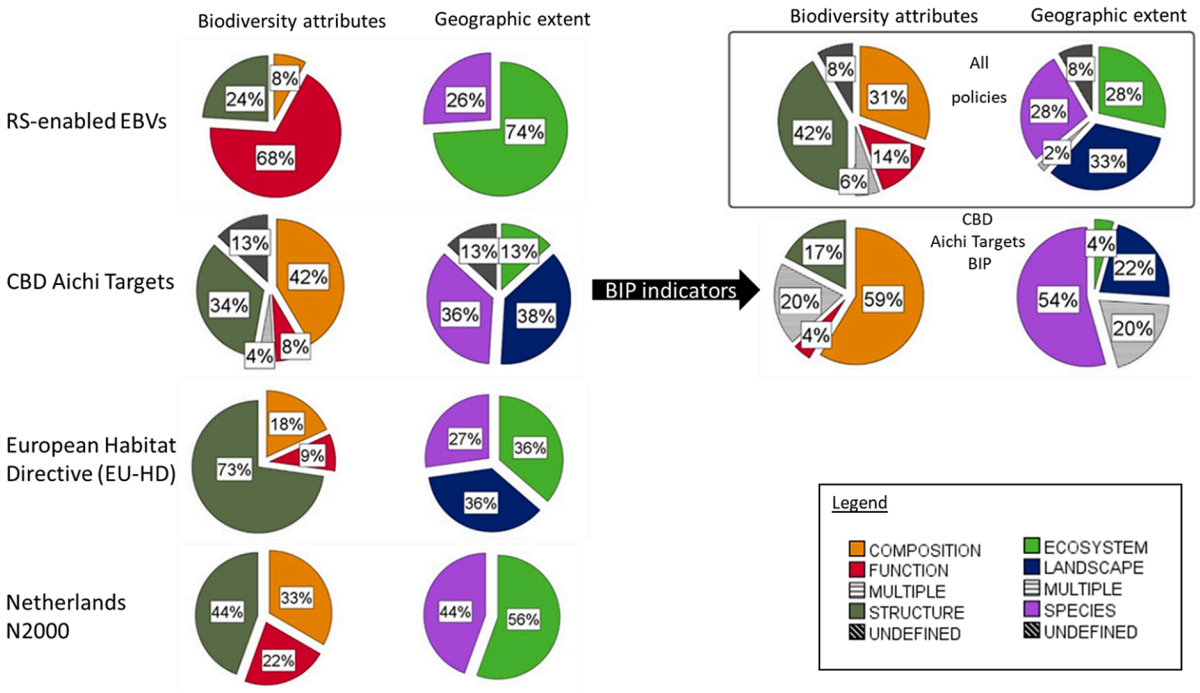

Fig. 4. The pie charts show the percentage of indicators describing geographic extent on species, ecosystem or landscape level and biodiversity attributes on composition, structure or function. The pie chart in the right upper corner shows these percentages for all policies combined.

Hypothetical policy	Actual policy (fictional example)
Geographic extent	Geographic extent
• Species – 7	• Species - 9
• Ecosystem - 7	• Ecosystem - 7
• Landscape - 7	• Landscape - 5
Biodiversity attributes	Biodiversity attributes
• Composition - 9	• Composition - 15
• Structure - 9	• Structure - 10
• Landscape - 9	• Functioning - 4

Box 1. This is an example of the counts of indicators divided among geographic extent and biodiversity attributes, compared to a hypothetical policy. The hypothetical policy has the same amount of indicators, with an equal distribution within geographic extent and biodiversity attributes.

at 'governmental levels' and put RS-enabled EBVs in the group 'scientific' (see Table 1). We analyzed if policies and RS-enabled EBVs were comparable in their emphasis on geographical extent and biodiversity attributes. In other words, if the distribution of indicators and variables across the different geographic extents and biodiversity attributes was similar for all policies, RS-enabled EBVs and government levels. Using a Mann-Whitney *U* test, we determined if there was a difference between policies and RS-enabled in their emphasis on geographic extent and biodiversity attributes. This test was also used to determine if there was a difference between groups of policies and RS-enabled EBVs on the same governance level *or* between policies of governance levels.

3. Results

3.1. The emphasis of indicators on geographic extent and biodiversity attributes

Of the ten policies and monitoring methodologies (all referred to as policies) and RS-enabled EBVs, six policies had indicators that were undefined or could be assigned to more than one geographic extent or

biodiversity attributes. Fig. 4 shows the percentage of indicators that were labelled in geographic extents and biodiversity attributes categories or as having potentially multiple or undefined extents and attributes for a few policies and RS-enabled EBVs (the pie charts of all policies are shown in Supplementary material Figure S2).

The biodiversity attribute structure is emphasized by seven policies (SDGs, SDGs BIP, Ramsar, EU HD, N2000, NEN and ABC) (see Table 1 for the meaning of abbreviations), making it the most emphasized biodiversity attribute. Three policies (The Aichi Targets, Aichi Targets BIP, and NSW) emphasized composition. The biodiversity attribute 'function' is emphasized most by RS-enabled EBVs (see also Fig. 4). National policies and RS-enabled EBVs emphasize the geographic extent 'ecosystem' the most (N2000, NEN, ABC), whereas global treaties emphasize 'landscape' the most (Aichi Targets, SDGs, SDGs BIP, Ramsar, EU SEBI). The Aichi Targets BIP however, emphasized species level. For the European Habitat Directive and Draft New South Wales Biodiversity Strategy 2010 – 2015 (NSW), more than one emphasis was found for geographic extent. This was also the case for the indicator program Streamlining European Biodiversity Indicators (SEBI) for biodiversity attributes. One Australian policy had many of undefined indicators (QLD). The results are summarized in Table 2.

3.2. Indicator distribution across geographic extent and biodiversity attributes

Table 3 shows the results of the Chi-square analyses, which we used to test the distribution of indicators across geographic extent and biodiversity attributes. Here, a significant result means that the indicators of a policy (or RS-enabled EBVs) are not evenly distributed across geographic extent or biodiversity attributes. That is to say, a particular extent or attribute is emphasized more than the other. Indicators were unequally distributed across geographic extent for the Aichi Targets ($p = 0.05$), Netherlands National Ecological Network ($p = 0.05$), and RS-enabled EBVs ($p = 0.0$). When the BIP indicators were considered, the SDGs also showed an unequal distribution ($p = 0.01$) (the number of the BIP indicators and p-values are shown in brackets in Table 3). Statistically, the Dutch implementation of the Habitat Directive (N2000) and Australia's Biodiversity Conservation Strategy 2010 – 2030 did show an equal distribution. However, both had altogether omitted to design indicators at landscape and species level respectively and should thus be considered as failing to have indicators evenly distributed over geographic extent. An even distribution of indicators over geographic extent was found for all governance level except for the scientific level (RS-EBVs, $p = 0.00$)). When BIP indicators were used for the analyses, an unequal distribution was found at global governance level ($p = 0.00$).

For biodiversity attributes, the Aichi Targets ($p = 0.00$), European Habitat Directive ($p = 0.02$), the Dutch NEN ($p = 0.05$) and RS-EBVs ($p = 0.00$) showed an unequal distribution. Australia's Biodiversity Conservation Strategy 2010 – 2030 omitted compositional attributes and is therefore considered as failing to have an equal distribution. The SDGs also showed an unequal distribution when BIP indicators were considered ($p = 0.01$). The RS-enabled EBVs, on the other hand, displayed a strong emphasis on functional attributes ($p = 0.00$). For governance levels, an unequal distribution of indicators over biodiversity attributes was found for policies on global ($p = 0.00$) and supranational level ($p = 0.02$) and the scientific RS-enabled EBVs ($p = 0.00$).

3.3. Differences in emphasis between policies and RS-enabled EBVs

We compared two policies that were on the same governance level or two policies at a different governance level (*e.g.*, European and Dutch policies), to test how similar policies and RS-enabled EBVs were in the number of indicators addressing geographic extent and biodiversity attributes. (Table 4). In the following results, a significant difference means that one policy significantly emphasis another extent or attribute than the other policy or group of policies.

Overall, policies are very similar in the geographic extent they emphasize. Significant differences in emphasis were found between RS-enabled EBVs and the Aichi Targets ($p = 0.00$) as well as RS-enabled EBVs and SEBI ($p = 0.00$). When comparing grouped policies from the same governance level to another group on a different government level, significant differences were found between global and local governance level ($p = 0.02$), global and scientific level (RS-enabled EBVs) ($p = 0.00$) and supranational and scientific level ($p = 0.01$). When the BIP indicators were used for the analyses instead of the official policy documents (Aichi Targets and SDGs), significant differences were found between the Aichi Targets and RS-enabled EBVs ($p = 0.00$) and global governance level and all other levels (supranational $p = 0.03$, national $p = 0.01$, local $p = 0.00$, scientific $p = 0.00$).

Table 2
Policies and RS-enabled EBVs listed according to the geographic extent and biodiversity attribute they emphasize. Most policies and variables are centred around the structural biodiversity attribute and either on ecosystem or landscape level.

		Geographic extent					
		Species	*Ecosystem*	*Landscape*	*Multiple*	*Undefined*	*Extent > 1*
Biodiversity attributes	*Composition*	Convention on Biological Diversity (Aichi Targets) & BIP		Convention on Biological Diversity (Aichi Targets)			Draft New South Wales Biodiversity Strategy 2010 – 2015
	Structure		*Netherlands Natura2000*	*Sustainable Development Goals & BIP*			European Habitat Directive
			Netherlands National Ecological Network*	Convention on Wetlands			
			Australia's Biodiversity Conservation Strategy 2010 – 2030				
	Function		Remote Sensing enabled Essential Biodiversity Variables				
	Multiple						
	Undefined					Queensland Biodiversity Assessment and Mapping Methodology	
	Attributes > 1			Streamlining European Biodiversity Indicators			

Table 3
Chi-square analysis showing if indicators were evenly distributed over geographic extent and biodiversity attributes within a policy or RS-EBVs and within a governance level. For the Aichi Targets and SDGs, the numbers between brackets are from analysis based on the indicators listed on the Biodiversity Indicator Partnership, instead of the official decision document of the policy.

Indicators / variables from:	*n*	p-value Chi-square		Governance level	*n*	p-value Chi-square	
		Geographic Extent	Biodiversity attributes			Geographic Extent	Biodiversity attributes
Convention on Biological Diversity (Aichi Targets)	44 (37)	0.05 (0.00)	0.00 (0.00)	Global	62 (83)	0.12 (0.00)	0.00 (0.00)
Sustainable Development Goals (SDGs)	6 (34)	0.61 (0.01)	0.22 (0.01)	Supranational	27	1.00	0.02
Convention on Wetlands (Ramsar)	12	0.78	0.17	National	15	0.25	0.25
European Habitat Directive (EU HD)	11	0.91	0.02	Local	18	0.14	0.31
Streamlining European Biodiversity Indicators (SEBI)	16	0.94	0.21	Scientific	50	0.00	0.00
Netherlands Natura2000 (N2000)	9	0.74	0.72	Total	172 (194)		
Netherlands National Ecological Network (NEN)	10	0.05	0.05				
Australia's Biodiversity Conservation Strategy 2010–2030	6	1.00	0.41				
Draft New South Wales Biodiversity Strategy 2010 – 2015 (NSW)	4	1.00	0.78				
Queensland Biodiversity Assessment and Mapping Methodology (QLD)	4	0.78	0.78				
Remote Sensing enabled Essential Biodiversity Variables	50	0.00	0.00				
Total	172 (194)						

When the emphasis on biodiversity attributes by policies was tested, evidence of significant differences was found between RS-enabled EBVs and the European Habitat Directive ($p = 0.03$) and RS-enabled EBVs and NEN ($p = 0.02$). When the BIP indicators were used for the analyses, significant differences were found between global governance level and all other levels (supranational $p = 0.03$, national $p = 0.01$, local $p = 0.00$, scientific $p = 0.00$). The major difference between the BIP indicators of international treaties (Aichi Targets BIP and SDGs BIP) and RS-enabled EBVs was the emphasis on functional biodiversity attributes see also Fig. 4 and supplementary material S2. International treaties tended to focus on composition and structure (*e.g.,* Wild Bird Index' and 'Area size'), whereas RS-enabled EBVs emphasized functional variables (*e.g.,* 'Net Primary Productivity').

Some indicators of policies and methods are linked, such as the European Habitat Directive, SEBI (Streamlining European Biodiversity Indicators) and the Dutch implementation of the Habitat Directive. No significant differences in emphasis were found between the policies for geographic extent and biodiversity attributes ($p > 0.05$, not shown in table).

Australia and The Netherlands may have a similar governmental organization, but the size of the countries and the type of ecosystems are quite different. In this analysis, federal policies were compared with each other, as well as regional (state or regional) policies of both countries. There was no significant difference in the emphasis on geographic extent and biodiversity attributes when comparing the federal and regional policies of the two countries with each other ($p > 0.05$).

3.4. Additional results: Textual differences

What does not emerge from the analysis but is clear from the text of the policy documents, is that policies differ in how they view biodiversity and drivers of change. For example, Australian nature conservation policy takes climate change into account as a factor that affects biodiversity. There is little or no mention of the effects of climate change on biodiversity in Dutch policies. Another striking difference is that where The Netherlands have devoted an entire national monitoring program to all protected species and habitats. In fact,- there ar two very similar policies that both need reporting. However, the Australian national monitoring program is non-existent. There, monitoring consists of various separate projects per state.

We also found that descriptions of ecosystem function and ecosystem structure are sometimes mixed up, *e.g.,* 'the connectivity of fragmented landscapes and seascapes' is listed under Australia's policy goal 'maintaining and re-establishing ecosystem functions' (pointing to a functional attribute). However, connectivity and fragmentation are typically placed under 'structural elements', both in RS-enabled EBVs and scientific literature (Noss, 1990). On a global level, the BIP indicators for the Aichi Targets and the SDGs make use of 'primary' or 'official' indicators, and 'secondary' or 'relevant' indicators respectively. It is not clear from these policies how primary/official indicators were used or weighted in comparison to secondary/relevant indicators. In most cases, the primary indicators did not cover the complete target description. For example, a primary indicator could be 'Forest area size' for a target with a broad description, such a 'rate of loss, degradation and fragmentation'. However, a clear and concise description of the parameters to be monitored to reach the target was often lacking (see also (Butchart et al., 2016). Also, regularly the same indicators were used for different targets and quite an overlap existed between the Aichi Targets and the SDGs.

4. Discussion

The main finding of this study is that nature conservation policies emphasize the biodiversity attributes 'composition' and 'structure' and RS-enabled EBVs emphasize the biodiversity attribute 'function', followed by 'structure'. In other words, policy indicators are mostly related to species composition and vegetation structure, whereas scientific variables obtained through remote sensing are mostly related to functional attributes. This means that policy is unbalanced and seems to favour attributes that can be easily observed. Functional attributes often describe features or processes that are easily overlooked. For example, functional attributes such as productivity and small-scale disturbances provide information on an ecosystem that might be missed when only focusing on species level and compositional attributes (Dale & Beyeler, 2001).

This may result in an incomplete understanding of the state of biodiversity. This failure to recognize the underlying processes could be a threat to biodiversity. It also means that, because RS-enabled EBVs

Table 4
Comparison of policies and RS-enabled EBVs on governance level and between governance levels, for the similarity in emphasis on geographic extent and biodiversity attributes. The number in brackets are the results based on the BIP indicators for the Aichi Targets and SDGs. Overall, policies are similar in the emphasis on geographic extent and biodiversity attributes. Differences between global and other governance levels became significantly larger when BIP indicators were used.

Policies		p-value Mann-Whitney-U		Governance level		p-value Mann-Whitney-U	
		Geographic Extent	Biodiversity attributes			Geographic Extent	Biodiversity attributes
Convention on Biological Diversity (Aichi Targets)	Sustainable Development Goals (SDGs)	0.21 (0.03)	0.21 (0.01)	Global	Supranational	0.39 (0.03)	0.31 (0.04)
Convention on Biological Diversity (Aichi Targets)	Convention on Wetlands (Ramsar)	0.15 (0.00)	0.58 (0.05)	Global	National	0.07 (0.01)	0.23 (0.04)
Convention on Wetlands (Ramsar)	Sustainable Development Goals (SDGs)	0.10	0.87	Global	Local	0.02 (0.00)	0.28 (0.04)
European Habitat Directive (EU HD)	Streamlining European Biodiversity Indicators (SEBI)	0.68	0.20	Global	Scientific	0.00 (0.00)	0.40 (0.01)
Netherlands Natura2000 (N2000)	Australia's Biodiversity Conservation Strategy 2010–2030	0.61	0.33	Supranational	National	0.31	0.80
Netherlands National Ecological Network (NEN)	Draft New South Wales Biodiversity Strategy 2010 – 2015 (NSW)	0.45	0.14	Supranational	Local	0.18	0.94
Netherlands National Ecological Network (NEN)	Queensland Biodiversity Assessment and Mapping Methodology (QLD)	0.24	0.24	Supranational	Scientific	0.01	0.44
Draft New South Wales Biodiversity Strategy 2010 – 2015 (NSW)	Queensland Biodiversity Assessment and Mapping Methodology (QLD)	1.00	0.69	National	Local	0.87	0.87
Remote Sensing enabled Essential Biodiversity Variables	Convention on Biological Diversity (Aichi Targets)	0.00 (0.00)	0.15 (0.00)	National	Scientific	0.26	0.25
Remote Sensing enabled Essential Biodiversity Variables	Sustainable Development Goals (SDGs)	0.28 (0.00)	0.20 (0.60)	Local	Scientific	0.33	0.35
Remote Sensing enabled Essential Biodiversity Variables	Convention on Wetlands (Ramsar)	0.05	0.92				
Remote Sensing enabled Essential Biodiversity Variables	European Habitat Directive (EU HD)	0.08	0.03				
Remote Sensing enabled Essential Biodiversity Variables	Streamlining European Biodiversity Indicators (SEBI)	0.01	0.55				
Remote Sensing enabled Essential Biodiversity Variables	Netherlands Natura2000 (N2000)	0.27	0.98				
Remote Sensing enabled Essential Biodiversity Variables	Netherlands National Ecological Network (NEN)	0.94	0.02				
Remote Sensing enabled Essential Biodiversity Variables	Australia's Biodiversity Conservation Strategy 2010–2030	0.67	0.07				
Remote Sensing enabled Essential Biodiversity Variables	Draft New South Wales Biodiversity Strategy 2010 – 2015 (NSW)	0.45	0.33				
Remote Sensing enabled Essential Biodiversity Variables	Queensland Biodiversity Assessment and Mapping Methodology (QLD)	0.25	0.71				

focus more on the biodiversity attribute 'function', they too could be incomplete in their understanding of biodiversity. This is perhaps due to what components can be practically measured in the field of remote sensing imagery. As RS-enabled EBVs are a subset of a larger group EBVs that can be measured with other techniques or traditional field monitoring, they could, however, add to the information that can be obtained with EBVs. Thirdly, as policy indicators emphasize different attributes as do RS-enabled EBVs, there is a mismatch between what policy requires and what RS-enabled EBVs can deliver.

Emphasis on (community) composition and (ecosystem) structure by existing policies may be due to an affinity of the public (or decision-makers) around these concepts. Functional attributes are harder to conceive and more difficult to communicate. Leaf Area Index, for example, is a measurable variable that monitors a functional attribute and is very useful from a scientific point of view. However, it does not evoke the same sentiment as a dune valley in bloom or a marine protected area (species and structure) and neither does it measure biodiversity as a whole. A few flagship species are being monitored very well and hold public interest, such as wild cats and elephants. Monitoring the habitats of these species is important but forms a harder concept to convey the public. RS-enabled EBVs could aid nature conservation policies with monitoring habitats and functional attributes. Nature conservation policies could use Leaf Area Index, for example, to measure canopy complexity and structure, vegetation stress due to drought, land cover change and the effect of climate change and disturbance on vegetation communities (Hanes, 2013; Liang et al., 2013). Policies would need to be adapted, so the information generated by RS-EBV products matches the monitoring requirements set out in the policy. But the question is whether to redesign conservation policy towards the use of RS-enabled EBVs (advocating a greater monitoring effort on

functional attributes), or to align RS-enabled EBVs along policy lines, or to employ best features of both to create a better match. Policies might become more evidence-based when the goals and indicators are designed for a clear purpose. As with all *in situ* data collecting and monitoring, RS-enabled EBVs will be of value in policy when it is clear from the policy to what geographic extent EBVs will be applied (*e.g.* designated national park, bioregion, etc.). Then, an approach can be prepared with the required variables collected at an appropriate spatial and temporal scale and equally divided over the biodiversity attributes. Based on our results, quantifying indicators on biodiversity attributes such as ecosystem function is where most can be gained if we use a scientific evidence-based approach to biodiversity monitoring. RS-enabled EBVs can provide extra information on ecosystem functioning in addition to the more conventional field-based observations on structure and composition. Adding units to indicators (such as vegetation height, frequency of monitoring and accuracy) to describe the geographic extent and biodiversity attribute that is being monitored could be beneficial to the transparency of a conservation policy.

Policies rarely emphasise the three biodiversity attributes 'composition', 'structure' and 'function' equally. Of the examined policies, almost half fail to evenly monitor the three geographic extents (*viz.* at habitat, ecosystem, and landscape level) and biodiversity attributes (*viz.* composition, structure, and function). The global policies (Aichi Targets, SDGs, and Ramsar) emphasized the 'landscape' level, whilst national policies (N2000, NEN and ABC) were focused on ecosystems (although a specific spatial description is hardly provided). The number of indicators used in policies varies. An 'ideal' number of indicators for a policy has not been determined, and this probably varies depending on the focus. Arguably, a clear target description of indicators is more important than the actual number. Each conservation policy and protected area is different, with different issues. However, being aware of what geographic extent and biodiversity attributes are emphasized by a policy, could help in designing clear goals, targets, and indicators. It also gives insight into what knowledge gaps exist or where decision making is not evidence-based when a comprehensive developed policy could not be achieved.

RS-enabled EBVs focus on the ecosystem level. This, however, could be due to the definition given by GEO-BON in the EBV classes 'ecosystem function' and 'ecosystem structure'. As described by authors working with and designing EBVs (Geijzendorffer et al., 2016; Kissling et al., 2018; Pereira et al., 2013; Pettorelli et al., 2016; Proença et al., 2017), they are meant to be scalable and not be restricted to a certain geographic extent. Peterson and Soberón (2018) argue, that for the classes ecosystem function and ecosystem structure, scalable datasets could indeed be achieved with the use of remote sensing. However, they state that this is not the case for the other classes (genetic composition, species populations, species traits, and community composition). Their finding that remote sensing could be useful in the EBV classes ecosystem function and structure fits well with our results. We have found that RS-enabled EBVs emphasize functional attributes on ecosystem level. This is an important notion, as in this study we set out to analyse where policies and RS-enabled EBVs align, based on both the geographic extent and biodiversity attributes they emphasize. As the functional biodiversity attribute was underrepresented in policies (and this is where knowledge gaps exist), alignment can be found when RS-enabled EBVs are to be used to aid in policy reporting on functional attributes. RS-enabled EBVs are optimal to support ecosystem structure, but less useful for analysis of species composition. Thus, when developing a policy, policymakers should be aware that when designing a policy there is an emphasis on compositional and structural attributes, while functional attributes are underexposed. The uneven distribution of indicators across biodiversity attributes observed at a global and supranational governance level and RS-enabled EBVs, might point towards a 'disconnect' in indicator design.. Adding RS-enabled EBVs to the mix of monitored variables, the data acquired by a monitoring program could be more evenly informative on all three attributes of biodiversity (composition, structure, and function).

The disconnect mentioned in the previous paragraph is important for future policy design, especially for the harmonization of policy. If a national policy heavily emphasizes structure, and global policy is more interested in composition, upscaling to international goals is difficult. Many policies are designed for information exchange or designed in a way that international goals and targets can be estimated by concatenating national indicators. An example is the European Habitat Directive, where member states implement the Directive through their national laws while committing to European goals. Aligning the geographic extent and biodiversity attributes addressed in different nature conservation policies will also allow more consistent and efficient data collection and analyses. We expected policies that are developed on a similar governance level (*e.g.,* national), to be more similar than policies developed on a different governance level, and this is largely true. We compared policies and whether they were similar in how they emphasize the geographic extent and biodiversity attributes (see Table 4). Overall, policies seem similar in their emphasis on geographic extent and biodiversity attributes they emphasis. However, when comparing policies on different governance levels, it is striking that a significant difference arises when the BIP indicators for both the Aichi Targets and SDGs are used for the analyses, instead of the official policy documents. The indicators from the Biodiversity Indicator Partnership (BIP) could be more up to date then indicators listed in policy documents years ago. This, however, seems to create a greater difference with the policies on other governance levels and RS-enabled EBVs (Table 4). Thus, it seems, that when policies or indicators are developed further, a disconnect with policies on other governance levels appears. Policy should be designed in such a way that data on biodiversity attributes can be aggregated and understood in a larger context. For example, despite the differences in environment and government, both The Netherlands and Australia report to international biodiversity forums. To make relevant policy decisions at a global level, then national data and policies should be comparable. Indicators of global treaties are fed by national data, and most of these policies refer to ecosystem structural attributes. Thus, alignment between global policies is most likely to occur on the structural aspects of biodiversity. This can also be seen when looking at three policies that are intricately linked, the Dutch Natura2000, National Ecological Network and European Habitat Directive. This highlights the broad scope of international policies and suggests that communication between internationally orientated policy experts, leads to the same emphasis on ecosystem structural attributes. Admittedly, here we have only examined the policies of one member of the European Union, though a report from the European Commission (EC, 2017) concluded that harmonization needs improvement as biological monitoring suffers from the lack of systematic monitoring and differences in data quality.

Our selection of policies involved global, supranational policies and policies from two developed countries with advanced technological possibilities for biodiversity monitoring. Investigating different perceptions or views on nature conservation was not part of this study, but are expected based on our analysis of the textual differences. Despite different viewpoints, nations that report under international treaties still need to deliver comparable data. The method of labelling indicators with a geographic extent and biodiversity could be subject to interpretation. This adds to the notion, that, for harmonization and understanding policies and their effect on nature conservation, clearly identified objects of monitoring are important. Further research on how RS-enabled EBVs might align use in countries with other federal systems or viewpoints on nature conservation might shed a light on the influence of different perceptions.

We suggest that awareness of how indicators are distributed and what geographic extent and biodiversity attributes they emphasize should be a part of future indicator design. A clear definition of biodiversity attributes (both for *in situ* monitoring and remote sensing) could provide a common ground for ecologists, policymakers, and remote

sensing specialists. Nature and biodiversity conservation targets should focus on quantifying indicators of all three biodiversity attributes so that conservation policy can be designed with a clear goal in mind, to allow evidence-based nature conservation policy and decision making. This will enable a tighter connection between strategic policy design and implementation of meaningful measures regarding biodiversity. A starting point would be to incorporate more functional attributes into policy, as this can provide insight into the processes underlying biodiversity, and RS-enabled EBVs provide a good opportunity for monitoring these variables. Also, incorporating RS-enabled EBVs that address ecosystem structure into policy, could be another step forward to use remote sensing for meeting policy requirements.

5. Conclusion

Policies tend to emphasize composition and structure (*e.g.,* Wild Bird Index and 'area coverage'), whereas RS-enabled EBVs tend to emphasize functional attributes (*e.g.,* 'phenology' and 'productivity'). At a particular governance level (*e.g.,* global), policies are very similar in emphasizing geographic extent and the biodiversity attributes. But there is a disconnect between the global governance, the other governance levels, and the scientific viewpoint. When policy is coordinated through political and legislative links, such as in the case of European and Dutch policies, there is a similarity between policies. Aligning and redesigning policy indicators with RS-enabled EBVs on ecosystem functional attributes could improve the comprehensiveness of conservation policy. Indicator development should strive to strike a balance between the biodiversity attributes used for biodiversity reporting. Functional biodiversity attributes developed by GEO-BON could become part of an evidence-based approach to this alignment, next to composition and structure. Tying the perspectives of technically-orientated-engineers, decision-makers and ecologists together to result in meaningful evidence-based remote sensing variables, that can be understood by the community and are beneficial for policy reporting is a multidisciplinary challenge. If we want to design nature policies in a more evidence-based and innovative way, it looks like a must that this design is done by multidisciplinary teams. Such teams should have members with ecological expertise, remote sensing expertise and detailed knowledge about what policies our society needs and wants and how this can be achieved.

CRediT authorship contribution statement

M.C. Lock: Conceptualization, Methodology, Formal analysis, Investigation, Data curation, Writing – original draft. **A.K. Skidmore:** Funding acquisition, Supervision, Writing – review & editing. **I. Duren:** Supervision, Writing – review & editing. **C.A. Mücher:** Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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