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Indicators on the Impacts of Climate Change on Biodiversity in Germany—Data Driven or Meeting Political Needs?

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Abstract: When developing new indicators for policy advice, two different approaches exist and may be combined with each other. First, a data-driven, bottom-up approach determines indicators primarily by the availability of suitable data. Second, indicators can be developed by a top-down approach, on the basis of political fields of action and related normative goals. While the bottom-up approach might not meet the needs of an up-to-date policy advice, the top-down approach might lack the necessary data. To discuss these problems and possible solutions, we refer to the ongoing development of an indicator system on impacts of climate change on biodiversity in Germany, where a combination of both approaches has been successfully applied. We describe suitable indicators of this system and discuss the reasons for the remaining gaps. Both approaches, mentioned above, have advantages, constraints, and shortcomings. The scientific accuracy of the indicators, the availability of data and the purpose of policy advice have to be well-balanced while developing such indicator systems.

Keywords: indicators; climate change; biodiversity; data needs; monitoring; policy advice; Germany

1. Introduction

The task of the ongoing project, presented in this article, is to design and implement an indicator system that describes the direct and indirect impacts of climate change, on the state and development of biodiversity in Germany, in a summarized and easily-understandable way, so that conclusions for the shaping of nature conservation policy and related policy areas can be drawn. The article focuses on the crucial role of data availability and quality, for the development of such indicators.

The term "indicator" is ambiguous and linked to a number of different meanings, in many different contexts [1,2]. As a prerequisite for the conceptual design of indicator systems, an understanding of what is meant by the term is, therefore, necessary. We have based our work on the following definition:

Indicators in the context of nature conservation summarize empirical data from monitoring programs, in order to depict relevant pressures, states, impacts, or measures related to biodiversity, in an easily-understandable manner. They show successes and failures in achieving previously defined nature conservation objectives, provide policy advice, and inform the public [3]. This definition clearly differs from an older scientific concept of indicators, which is purely descriptive [2]. Our indicators are designed for policy advice and refer to normative standards that require political legitimacy, in advance. Their statements are based on a comparison of target and actual values. The necessary data and information for setting a target as the assessment standard must indeed be based on scientific knowledge. However, the decision on the actual target value or direction of development is beyond the scope of descriptive natural science and is part of a social or political process [2,3].

Data on state and changes of biodiversity provide fundamental information for planning and decision-making, in modern conservation policy [4]. In recent years, much effort has been spent to improve the communication of monitoring results, particularly towards politicians and the public. For this purpose, many different biodiversity indicators and indicator systems have been developed. The main objective of monitoring programs is to produce precise and reliable information on the state and trends of different biodiversity components. Reports based on comprehensive indicator systems are then used to make monitoring results known not only to experts but also to decision-makers and the public, cf. [3,5]. Such indicators need to reduce complex biological information to simple and easily-understandable messages of political concern.

Environmentally relevant phenomena can be classified in line with the Driving Forces-Pressures-States-Impacts-Responses (DPSIR) model (see Section 3) to systematically structure indicator systems representing an environmental issue, within its social and political context. The single indicators should measure distinct parts of the issue and represent phenomena of interest on various temporal and spatial scales. The realization of such an indicator system, however, is often confronted with, first, the need to select thematically and politically appropriate indicators and, second, an incomplete database that does not meet the needs of purposeful indicator systems [6]. Regarding biodiversity issues this is illustrated by current efforts to define the so-called "Essential Biodiversity Variables (EBVs)" as a set of key variables for detecting major dimensions of biodiversity change, bridging the gap between biodiversity data and policy reporting needs [7–9]. Schmeller and colleagues [10] (p. 2970) point out that the "development of indicators and the understanding of the causes of the documented change do not fall within the EBV framework, but are a logical next step in using the EBV data".

When developing new indicators for policy advice, two different approaches exist and must be combined with each other [3]. First, there is a data-driven bottom-up approach, primarily determining indicators by the availability of suitable data. By contrast, indicators can be developed by a top-down approach, on the basis of political fields of action and related normative goals, e.g., nature conservation or biodiversity goals, for which meaningful indicators and suitable data, for their calculation, are sought. Ideally, if a top-down approach is successfully applied, policy advice can use tailor-made indicators [2,3]. Each of the two approaches, taken individually, is insufficient. While the bottom-up-approach might not meet the needs of an up-to-date policy advice, the top-down approach might lack the necessary data.

In the following sections, we outline the requirements for biodiversity monitoring programs and data (Section 2), as well as for indicators and indicator systems (Section 3). Based on these findings, we introduce an indicator system on direct and indirect impacts of climate change, on biodiversity in Germany, as a practical example for the feasibility and constraints of developing an indicator system. Successfully developed indicators, based on the requirements outlined before, will be presented as well (Section 4). Finally, we discuss the data-related factors which hampered the development of the indicator system (Section 5) and summarize the experiences gained (Section 6).

2. Monitoring Data as a Basis for Developing Indicators

In the context of nature conservation, monitoring comprises empirical records (observations, counts, and measurements) of selected elements of species, communities, habitats, and landscapes in regular long-term spatiotemporal sequences gained by standardized scientific methods. These records are designed to achieve reliable data on the state and changes of these elements and are directed to nature conservation objectives [3,11–13]. In order to enable a regular reporting system, consistent, trustworthy, and accessible data are a prerequisite [14]. More precisely, the requirements for monitoring programs, as a sound database for indicators are [15]:

- permanent surveys in order to enable continuous availability of data from monitoring programs;
- ensured financing of the monitoring programs;
- functional organization of the monitoring (consolidation and analysis of data and transfer of results);
- sufficient update interval, depending on the variable;
- data series over long periods of time;
- full area coverage or representative sample;
- sufficient resolution which allows for spatially different findings (administrative units like counties, federal states, etc.);
- differentiation between different sub-issues, e.g., different habitat types, species, etc.;
- standardized reliable survey methods; and
- accurate data.

Regarding the impacts of climate change on biodiversity, there are hardly any specific monitoring activities. Consequently, a corresponding indicator system has to be based predominantly on data that were originally collected for other purposes–in our case for biodiversity and climate change issues separately. Several examples for ongoing monitoring activities or the development of such monitoring programs concerning different components of biodiversity do already exist, e.g., for bees, locusts, butterflies, dragonflies, birds, fish, and plankton at the species level, as well as high nature value farmland and inland and coastal waters at the habitat level. Monitoring of the natural environment in Germany is carried out by governmental agencies, administrations, or non-governmental organizations (often in combination with citizen science). These efforts, however, cover, only selected groups of species and habitats, so far, and the resulting data sets are often incomplete and heterogeneous, e.g., in data quality and sampling intensity. Climate data and phenological phases (annually recurring growth and development phenomena) of plants are gathered within the monitoring programs of the German Weather Service (Deutscher Wetterdienst—DWD) and provided, e.g., through its Climate Data Center (CDC) and the German Climate Service (Deutscher Klimadienst—DKD).

3. Indicators and Indicator Systems for Biodiversity—Balancing Information and Communication Needs

An indicator system for assessing the state of biodiversity and the trends in the development of its components, caused, inter alia, by climate change, should reflect the impacts of all relevant drivers on the biological diversity and the associated cause-effect chains, as well as the success of nature conservation strategies and measures for adaptation to climate change. It is also intended to provide political advice [2]. To this end, the single indicators as well as the entire indicator system must meet certain requirements [1,2,14–21], like that of relevance, data sufficiency, and suitability for policy advice.

1. **Relevance:** The indicator system must address a representative sample of relevant key topics in the context of biodiversity changes caused by climate change, which includes direct and indirect impacts of climate change on biodiversity. The relation between climate and biodiversity change, as described by every single indicator, has to be evident or of high probability. Consequently, it is not sufficient to merely represent changes in either biodiversity or climatic parameters, but the connection between both should also be illustrated. Species and habitats with distinct sensitivity for climatic changes, such as alpine, marine, and coastal species and habitats, are particularly suitable for indication, in order to fulfill this requirement. Selecting species and habitats predominantly sensitive to climate change is crucial for the conception of purposeful indicators. In our project, scientific literature surveys have validated such choices.

2. **Data sufficiency:** This includes different basic requirements of the data used for forming the single indicators: Availability, stability, and regular collection, based upon scientifically reliable and standardized methods. To allow for area-covering findings of single indicators and the indicator system, data should cover Germany's entire terrestrial and marine territory.
3. **Suitability for policy advice:** This comprises the following criteria.

   - Relation to politically defined targets: The indicators should relate to targets politically agreed upon, e.g., as laid out in strategies and legal norms, in order to inform about the degree of target achievement.
   - Relation to politically controllable issues: In general, the indicator subject should be influenceable by policy measures. However, there are indicator subjects which can only be influenced on a global scale or very indirectly, over long periods of time, such as phenological changes.
   - Comprehensibility and clarity: As soon as an indicator system is designed for policy advice, the single indicators, as well as the entire indicator system have to be as understandable, transparent and simple as possible, without simplifying facts in a way that may lead to misinterpretation or scientific incorrectness.
   - The indicators should have a high spatial resolution to allow for the implementation of specific and appropriate measures in different parts of Germany, at least, at the federal states level.

4. Developing an Indicator System for the Impacts of Climate Change on Biodiversity in Germany

Man-made climate change is leading to significant changes in global biodiversity altering the biosphere in marine, limnic, and terrestrial environments, on large and small scales. Species ranges are shifting in response to climate change, and species interactions are changing due to climate driven shifts, in abundance or distribution of species, for example. Consequently, entire ecosystems are rearranged. Trends that are expected to intensify in the coming decades, for Germany, include poleward and upslope range shifts, formation of novel ecosystems, decline and extinction of species and habitats, and expansion of new species [22]. Major losses are expected with respect to freshwater and marine habitats [23–26]. Climate change is considered to be a critical threat to many components of biodiversity and is generally expected to have an increased impact on biodiversity, in the future. Numerous examples from scientific studies have shown complex relationships between climate change and biodiversity. Campbell and colleagues, as well as Bellard and colleagues, provided a comprehensive overview on this matter [24,27].

However, there is still a vast need for research in order to obtain a more detailed picture of the changes and to develop a full understanding of the underlying processes. Since climate change occurs over relatively long time-scales of several decades and resulting changes in biodiversity also show time lags, long-term, systematic observation programs of the environment are of outstanding importance. This has been demonstrated by McMahon and colleagues, for the global scope, and by Dröschmeister and Sukopp, for Germany [4,28]. For Germany, however, monitoring programs with a long-term perspective, which aim to provide data on the impacts of climate change on biodiversity, are largely lacking or cover only selected aspects of biodiversity, at federal or federal state level. Heiland and colleagues point out this problem and emphasize the necessity of long-term surveys [29].

Among other policy measures, the German government is taking into account the ongoing biodiversity loss and climate change by the ambitious goals of the National Strategy on Biological Diversity ("Nationale Strategie zur biologischen Vielfalt"—NBS) [30] and the German Strategy for Adaptation to Climate Change ("Deutsche Anpassungsstrategie an den Klimawandel"—DAS) [31]. To achieve the goals of these strategies, monitoring programs and indicator systems are required which are suitable for comprehensively assessing the broad spectrum of climate-change-related impacts on biodiversity, as well as the effectiveness of adaptation measures. Indicator systems delivering a broad picture of climate-change impacts on biodiversity, however, are, so far, largely missing at national levels, which is also true for Germany.

In 2011, the German Agency for Nature Conservation (BfN) initiated the development of a comprehensive indicator system on the impacts of climate change, on biological diversity. Hereby, the BfN aimed at gaining new knowledge on the relation between climate change and biodiversity, but mainly at an improved editing of already existing knowledge on the issue for policy advice and decision making. Two consecutive research and development projects have been funded to this end. The first project ("Indicator system for depicting direct and indirect impacts of climate change on biodiversity", FKZ 3511 82 0400, 2011–2015) aimed at developing an expert information system for the federal level, but also included the calculation and implementation of five indicators for policy advice (see below). An extensive report explains the reasons why and how indicators could be implemented or not [21,32]. In the second project ("Further development of indicators on the impact of climate change on biodiversity", FKZ 3517 81 1000, 2017–2019), seven indicators from the first project, which could not be realized then, are currently being further developed, calculated, and implemented, if possible.

During the first project, a systematic structure of the indicator system was developed. It is based on the DPSIR model (see Section 1) [33] and comprises three indicator domains (Figure 1) with nine indicator fields (Table 1). The DPSIR model is useful for describing the origins and consequences of environmental problems and allows for exploring the links between the different elements of the model. According to the model [33], (p. 6), "social and economic developments exert Pressure on the environment and, as a consequence, the State of the environment changes, such as the provision of adequate conditions for health, resources availability and biodiversity. Finally, this leads to Impacts on human health, ecosystems and materials that may elicit a societal Response that feeds back on the Driving forces, or on the state or impacts directly, through adaptation or curative action."

The indicator system to be developed should focus on mapping direct and indirect impacts of climate change on species and habitats, but also include some pressure, state, and response indicators. Accordingly, Column 1 in Figure 1 (direct impacts) comprises impact indicators only, Column 2 comprises predominantly pressure indicators, while Column 3 (adaptation of nature conservation strategies and measures) represents response indicators only. Depending on the context, some of the proposed indicators may also be interpreted as state indicators.

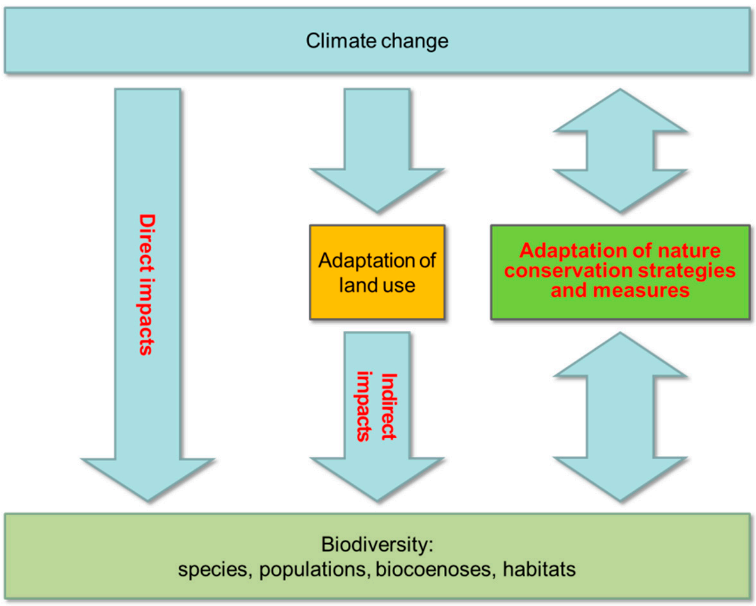

Figure 1. Structure of the indicator system with three indication domains (**red color**).

The first indication domain deals with changes of biodiversity, directly resulting from climate change, and addresses three thematically distinct indication fields: (i) Phenological changes of plant and animal species, (ii) changes in species distribution areas, populations and biocoenoses, and (iii) changes of habitats. It is intended to reflect as many changes in biodiversity caused by climate change as possible and to cover terrestrial, limnic, and marine ecosystems, as well as different groups of species (plants, birds, mammals, amphibians, reptiles, insects, and possibly microorganisms).

The second indication domain discusses indirect changes in biodiversity due to climate change and includes indicators addressing pressures on biodiversity caused by sectoral adaptation measures of different land uses, such as forestry, agriculture, and water management. Indirect climate-change impacts, including changes in land use, have a major effect on biological diversity. An exact quantification of these indirect impacts on species and habitats is, however, hardly possible at present, as the interaction of the various influencing factors is too complex and consequently does not allow for a clear analytical isolation of each factor.

The third indication domain contains indicators which relate to the adaptation of nature conservation strategies, measures to climate change, its direct and indirect impacts on biodiversity, and reflect the success of such adaptations. This indication domain also addresses three thematically distinct indication fields: (i) The adaptation of nature conservation policies and landscape planning to climate change, (ii) the implementation of adaptation measures, and (iii) the physical effectiveness of such measures.

Potentially suitable indicators were either selected from existing indicator systems (e.g., the SEBI—Streamlining European Biodiversity Indicators initiative and the Climate Change Indicators of the European Environment Agency), or were newly developed [21], resulting in a set of forty-four indicators which have been examined, in depth, for their feasibility at the German national level. Out of these, five indicators could be fully calculated ("realized" in Table 1) and nine indicators could be developed as "prototypes"; meaning that they could be fully developed on a conceptual level, but the necessary data for their calculation have not been available due to different reasons. Six out of these nine indicator prototypes are currently to be calculated and realized ("prototype in development" in Table 1). Thirty indicators, due to different reasons (see Section 4.2 and 5 and Reference [21]), could not be feasibly developed further. Indicator factsheets for all realized indicators and indicator prototypes describe the indicator and include all relevant information, such as suitability of the indicator, legal references and existing political targets, calculation algorithms, data sources, spatial and temporal resolution, as well as graphical and textual representations of the determined indicator values. All newly developed indicators have been included in the indicator set of the DAS [34] and one of them (phenological changes in wild plant species) has been added to the indicator set of the NBS [35].

Table 1. Indicators and indicator prototypes for an indicator system on climate-change impacts on biodiversity in Germany (status: May 2018).

Indicator Name	Status
Indication domain I: Direct climate-change-induced changes in biological diversity	
Indication field I.1 Phenological changes in species and communities	
Phenological changes in wild plant species	Realized
Phenological changes in animal species	Prototype in development
Indication field I.2 Changes in populations, areas and biocenoses	
Temperature index of the bird species community	Realized
Changes in the species inventory of high nature value farmland	Prototype
Distribution of marine fish species	Prototype
Climate-change-induced shifts in plant distribution	Prototype in development
Temperature index of the butterfly species community	Prototype in development
Changes in the flora on Alpine summits	Prototype in development
Climate-change-induced changes in dragonflies	Prototype
Indication field I.3 Changes in habitats	
No realizable indicators	

Table 1. *Cont.*

Indicator Name	Status
Indication domain II: Indirect climate-change-induced changes in biological diversity	
Indication field II.1 Changes in biodiversity due to climate-change adaptations in the agricultural sector	
No realizable indicators	
Indication field II.2 Changes in biodiversity due to climate-change adaptations in the forestry sector	
No realizable indicators	
Indication field II.3 Changes in biodiversity due to climate-change adaptations in water management	
Restoration of natural flood plains	Realized
Indication domain III: Adaptation of nature conservation strategies and measures to climate change	
Indication field III.1 Adaptation of nature conservation strategies to climate change	
Consideration of climate change in landscape planning (state / district level)	Realized
Indication field III.2 Adaptation of nature conservation measures to climate change	
Nationwide biotope network	Prototype in development
Habitat diversity and landscape quality	Prototype in development
Protected areas	Realized
Indication field III.3 Successes of climate-change-induced adaptations of nature conservation strategies and measures	
No realizable indicators	

The assignment of the proposed indicators to the indication domains and fields (see Table 1), the indicator data sheets with all the necessary information for a transparent documentation of calculation, the employed data, and the spatial and temporal resolution make it easy to understand the structure of the system. The graphical and textual representations of the computed indicator values included in the indicator factsheets are easy to understand and the indicators mainly comply with all requirements presented in Section 3.

4.1. Successfully Developed Indicators

The five realized indicators listed in the table above have been briefly explained below (see [21,29,34] for additional information).

4.1.1. Phenological Changes in Wild Plant Species

The newly developed indicator shows climate-change-related changes in the annual entry date of the phenological seasons, since 1951. The beginning of these seasons is marked by the occurrence of certain phases in the development of selected native wild plant species. For example, the beginning of the early spring as a phenological season, is indicated by the beginning of the flowering of the coltsfoot (*Tussilago farfara*). The shifts of entry of all ten recognized phenological seasons can be graphically illustrated by a phenological clock. The nationwide mean values of the entry data and the resulting duration of each of the ten phenological seasons from a thirty-year reference period (1951–1980) have been compared with the corresponding current values, which are available for the last thirty years. In 2017, the comparison shows an earlier entry of the phenological seasons of spring (early spring, first spring, full spring), summer (early summer, midsummer, late summer) and early autumn [36].

4.1.2. Temperature Index of the Bird Species Community

This index is based on the Community Temperature Index developed by Devictor and colleagues [37] and has been modified for the purposes mentioned above. The index adds up temperature indices of eighty-eight common breeding bird species, occurring in Germany, based on the average temperature in the European breeding range of these species, from March to August. The index shows the changes in the relative abundances of these species in relation to a reference year, linking it to the adaptation of the species to a colder or warmer climate. In the years 1990 to 2016, the relative frequencies of bird species have shifted in a statistically significant way in favor of species adapted to warmer conditions, consequently, to the disadvantage of species adapted to colder conditions [38].

4.1.3. Restoration of Natural Flood Plains

This newly developed indicator shows the annual cumulative increase in natural flood plains due to dike relocations in the main catchment areas of the Meuse, Rhine, Ems, Weser, Elbe, Oder, Danube, and their direct tributaries, to the North and the Baltic Seas. Land use changes that can be linked to climate change, include adaptation measures in water management. In addition to technically-oriented measures, the permanent restoration of natural flood plains is regarded as an effective flood protection strategy. The re-connection to the water bodies and the restoration of the natural flood dynamics have created new habitats of high conservation value for a large number of rare and endangered animal and plant species. Through different restoration measures on seventy-nine rivers, from 1983 to 2018, 4951 hectares of former floodplain area have been reconnected to the natural flooding dynamics of watercourses, and these areas are now flooded in an uncontrolled way during flood events. However, these measures were generally not planned, primarily, to adapt to climate change [39].

4.1.4. Consideration of Climate Change in Landscape Planning

This newly developed indicator describes if, how, and to what extent, the impacts of climate change on biodiversity are taken into account in landscape programs and landscape framework plans, which landscape plans are at the federal state or at the regional level. The indicator presents the percentage share of plans addressing climate change in the total number of evaluated plans. The evaluation of a hundred and seventy-nine plans that were in force, in 2018, showed that that the impacts of climate change and the resulting planning requirements have not yet been widely taken into account, as the mainstreaming of climate change issues, in landscape planning, takes its time, due to the fact that landscape plans are usually updated only every 15–20 years. However, climate-change-related statements have increased significantly, between 2000 and 2018 [40].

4.1.5. Protected Areas

This indicator assesses the total size of strictly protected areas in Germany. The area of land designated as nature conservation areas (NCAs) and national parks (NLPs) is expressed as a percentage of the German land surface. Natura 2000 sites and core areas and buffer zones of biosphere reserves are included, if designated as NCAs or NLPs.

The area of these strictly protected areas has increased significantly from 1.1 million hectares, in 2000, to 1.6 million hectares in 2016, which is an increase from 3.2% to 4.4% of Germany's land area. Even though the designation of new strictly protected areas was not mainly driven by it, it also has to be assessed positively in terms of adaptation of species to climate change. However, the formal designation of a protected area is only a first, albeit important, step towards adapting the system of protected areas to the requirements associated with climate change. In addition to the protection of suitable areas on a sufficiently large scale, effective management of these areas is an additional important requirement [41].

4.2. Gaps in the Indicator System

Despite these successes, certain indication fields could not be supported by indicator proposals. This concerns all indication domains and in particular indication fields, such as "changes in habitats" and "successes of climate-change-related adaptations to nature conservation strategies and measures", which were classified as central to the structure of the indicator system, within the framework of the projects, and are, therefore, listed as indication fields to be further developed in the future. Tracing impacts of climate change via indirect pathways in Indication Domain II, turned out to be particularly difficult and yielded only one appropriate indicator (Restoration of natural flood plains). Against the background of the ongoing expansion of wind power, changes in biological diversity, as a result of energy generation from wind power, and the associated, nationwide-expected considerable impacts on species groups, such as birds and bats, as well as on marine ecosystems, would have been of particular interest to the indicator system. However, the lack of data recorded in sufficient update intervals and gained on a uniform methodological basis, over long periods of time, does not allow for developing an appropriate indicator on this important issue.

In summary, the gaps in the indication fields are mainly caused by three factors:

- **Knowledge deficits on the direct impacts of climate change on biological diversity, at the habitat level:** In this area, scientific knowledge and data from monitoring programs are still unsatisfactory in many cases [4]. The links between climate change, on the one hand, and climate-change-induced changes in habitats, on the other, have not yet been sufficiently researched. The extent to which the natural adaptability of species influences the observable effects of climate change remains unclear in many areas. Furthermore, it is to be expected that, in certain cases, effects on habitats will only become apparent after a long time-lag. Therefore, no approach could be found to translate the effects of climate change on habitats, into a suitable indicator proposal.
- **Interaction of climatic effects with other influencing factors:** Overall, it has to be considered that climate-change-induced impacts on biological diversity interact with effects of other factors, such as land-use changes or the spread of alien species [42]. It should be noted, however, that these factors are also partly dependent on climate change, but have so far also essentially changed independently of it. For example, the general changes in land use that have prevailed for a long time, such as urbanization or agricultural intensification, result in massive changes in biological diversity, from which direct and indirect impacts of climate change can hardly be isolated. This is partly due to the fact that, in many cases, the indirect effects of climate change on biological diversity (e.g., through adaptation of land use to climate change), have so far been little pronounced and can, therefore, hardly be detected [43]. For these reasons, none of the indicator approaches discussed, fully meets the requirement to reflect changes in biological diversity that are predominantly and, above all, clearly attributable to land use adaptation measures to climate change or climate protection measures.
- **Difficulties in monitoring success:** At present, it is not possible to assess the success of adaptations to nature conservation strategies and measures to climate change, as such measures have hardly been implemented to date and it is very difficult to conduct a corresponding survey in terms of effectiveness monitoring. For this reason, no indicators have been implemented for this indication field, to date. However, considerations, such as balancing the decline in the vulnerability of climate-change-sensitive species or improving the conservation status of climate-change-sensitive habitats, are worthwhile approaches for developing indicators which, however, still require further elaboration and cannot be implemented directly. In particular, it should be clarified whether improvements in conservation statuses or the threat to climate-change-sensitive protected goods can actually be achieved through targeted adjustments and the implementation of appropriate nature conservation strategies and measures. Attention must be paid to the close relationship to other influencing factors, such as changes in land use.

5. Availability and Limits of Data Feeding Indicators

In order to report indicators, permanently, and provide policy advice, the requirements on monitoring programs and data mentioned in Section 2 have to be fulfilled, as far as possible. This is often not the case, especially in newly emerging policy and conservation fields—such as, climate change and biodiversity—in which no regular and systematic monitoring and data gathering could have been developed so far.

Even if suitable data exist, many other restrictions can appear. Heiland and Schliep discussed these data-related obstacles in indicator development [44]. Along with content-driven problems, the lack of appropriate data is a well-known problem in the development of indicators. This is also the case within the realm of climate-change impacts on biodiversity, for example, in connection with indicators relating to animal species [45]. Other problems include:

1. **Accessibility:** In some cases, appropriate data exist, but are not or are only partially provided by the data-holding institution.
2. **Quality:** Existing data are not sufficiently accurate (either in thematic or spatial accuracy) and, therefore, do not allow reliable statements.
3. **Scope:** Existing data are not comprehensive or representative, e.g., habitat maps are available only for some federal states.
4. **Heterogeneity:** Data of very different quality are collected regionally or with different methods and different classifications in the federal states and, therefore, cannot be compared nationwide. This is partly due to the federal structure of Germany, which refers not only to governmental structures, but also to NGOs and voluntary associations collecting data, e.g., on dragonflies, in our particular case. It was not possible to use those data as they were based on different, non-comparable data collection methods, at the federal state level, and as the continuity of data collection could not be ensured, due to lack of personnel.
5. **Frequency:** Data are collected, but at intervals that are too long, as is the case, e.g., with nation-wide floristic mapping.
6. **Time span:** Data are only available for a short period, which actually does not allow for showing trends. It would be ideal if the data were also available for past periods of time. This is often the case, e.g., with digital habitat or land use maps.
7. **Frame of reference:** Some indicators require the geometric and statistical intersection of different data sets. This causes further problems:
    - Several thematically-related data sets may have different spatial reference units (data set A e.g., habitat, data set B e.g., district). This means that they can no longer be sensibly blended together. Examples are official statistical data, which mostly refers to administrative units, and floristic data, which is captured in regular grids.
    - The datasets have different scales, e.g., nationwide data on climate and local floristic data.
    - The datasets have different time points of acquisition, e.g., datasets gathered by the federal states on the same thematic issues, but at different time points.

The mentioned problems can be illustrated by the example of habitat mapping. Habitats are of crucial importance in the field of climate change, e.g., in the case of shifting distribution areas of animal and plant species and in the need for networked corridors. For this reason, the data problem will be described in more detail, using this example. The main requirements of data are, a sufficiently high-resolution and a full area-coverage. If data are available, they are often not repeatedly updated or not comparable across the federal states of Germany. Only in some federal states, habitat maps, that are derived from aerial color-infrared photographs, cover the entire area [46]. These were collected in the 1990s, for all eastern German states and the federal state of Schleswig-Holstein. However, only a few states repeated the survey (e.g., Saxony [47] and Brandenburg [48]) after the year 2000. Another problem is that the mapping units differ from state to state, so that no uniform map can be produced. Almost all federal states record legally-protected biotopes in a separate mapping ("selective biotope mapping" [49]). Here, too, the problems are the comparability of the data between the different federal states and the regularity of the survey.

The only current, regularly updated source on habitats is the High Nature Value Farmland Monitoring [50], which maps valuable habitats in the agricultural landscape in randomly stratified sample plots of 1 km^2 size. It is representative for the entire agricultural landscape of Germany. A regular repetition of this survey is secured. At present, a much more comprehensive monitoring program is being developed and tested in a pilot study. It is carried out on the same sample plots as the High Nature Value Farmland Monitoring, but covers the whole range of habitat types that are both quantitatively and qualitatively surveyed. Habitat types and land use types of the entire landscape are recorded and assessed as basic units for future ecosystem monitoring. If the test was successful it could be a possible solution to obtain statistically accurate information on the basis of randomly stratified sampling if a coverage of the whole area is not possible due to financial constraints.

At the moment, the only valid, full area-coverage data basis for habitats, including all kind of land uses, are digital land-use data from the official land surveying [51,52]. Advantages are a very high accuracy of the data, a high topicality and the regular repetition of the recording. However, these data are not specifically collected for monitoring biological diversity, but for other purposes, such as land information, spatial, and urban planning, etc. Therefore, the data and information provided on habitats are not particularly in-depth. Against this background, it becomes clear that compromises have to be made in the development of indicators between the accuracy of the indicator and the availability of data, as the latter often have originally been collected for other purposes.

While developing the indicator system on climate-change impacts on biodiversity, we strived for reaching a balance between the requirements presented in Section 3. Indeed, there were cases where we could not calculate indicators because the needed data did not exist. This especially applies to indicators dealing with new and emerging trends, e.g., the effects of renewable energies on biodiversity. The challenge results from the fact that these trends have not been dealt with before. Consequently, they have not been monitored before, leading to a lack of appropriate data which can only be collected, from now on. An indicator on the subject necessarily depends on data which have been collected for other purposes, before the problem concerned had occurred, and, therefore, are not appropriate, or are only partly appropriate. To date, however, Germany does not have an established comprehensive biodiversity monitoring system at the federal level, nor does it have an indicator system regarding climate-change impacts on biodiversity. In Switzerland, for example, it was possible to analyze climate-change impacts on biodiversity, ex post [53], as the current Swiss biodiversity monitoring programs and projects are surveying all important components of biodiversity, at two different spatial levels [54]. It remains a challenging future task for German authorities, at the national level, to initiate a nationwide monitoring system that can meet this task.

To sum up, the requirements on indicators and indicator systems sketched in Section 3, turned out to be a rule of thumb during the development of an indicator system on climate-change impacts on biodiversity. In the light of only a few, long-term, time-series data, data availability certainly becomes a key criterion. In one case (community temperature index of breeding bird species communities) the indicator was taken up because data are available, although the algorithm for the calculation of the indicator values is quite complex. Other indicator prototypes were put on hold (e.g., Lusitanian fish species) because it was not possible to find an agreement between data holders and possible users (BfN), about the use of data. Another indicator prototype (changes in the flora of alpine summits) was put on hold because it was not clear for a certain period of time if the Global Observation Research Initiative in Alpine Environments (GLORIA) monitoring program [55], on which the indicator is based upon, will be continued.

6. Conclusions

Anthropogenic climate change causes substantial changes in biodiversity on the global scale, as well as in Germany. Indicators can help to illustrate this impact and make it easily comprehensible, beyond science, for the public and politicians. Worldwide, indicators at the interface between climate change and biodiversity are still underrepresented in indicator systems.

Thus, first appropriate indicators have been and, are being, developed. For Germany, six indicators are currently under development, to complement the existing set of five indicators, on the impacts of climate change on biodiversity, at the national level. However, data availability for indicator development is still insufficient. Therefore, an improved database is a goal to strive for, in the future.

When developing new indicators for policy advice two different approaches are usually combined. First, a data-driven bottom-up approach is determined by the availability of suitable data. Second, a top-down approach is based on political fields of action and related normative goals, for which meaningful indicators and suitable data are sought. Both approaches have advantages, constraints, and shortcomings. The scientific accuracy of the indicators, the availability of data, and the purpose of policy advice have to be well-balanced while developing such indicator systems. As a matter of fact, in many cases, data have been collected for certain purposes and are ex post used for other purposes that have not been considered before.

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