Mapping linkages between biodiversity and nature's contributions to people: a ValPar.CH perspective

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Working Paper

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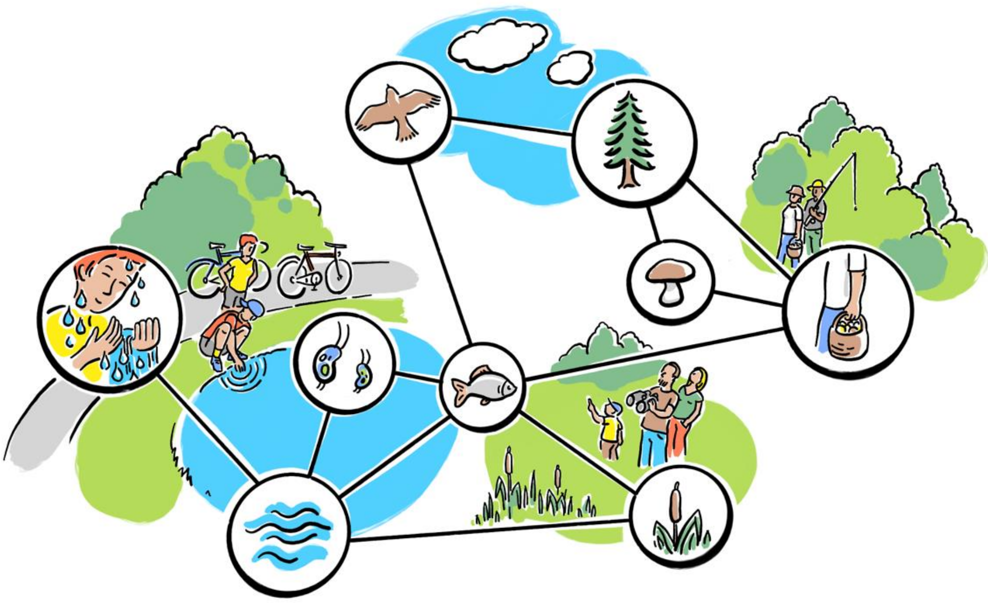

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Participation

The following people contributed to the working paper:

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Abstract

The approach of Nature's Contributions to People (NCP) has been developed to emphasize human dependence on nature and to better target environmental conservation efforts. While the methods used for NCP assessments have evolved greatly over the last 20 years, the challenge of how to best link and predict NCP to and from individual species or biotic communities still remains largely unmet. Current NCP-based conservation prioritization methods tend to fail to account for individual species and many other dimensions of biodiversity (BD). Therefore, land-management policies based on simple NCP mapping are unlikely to properly account for the full complexity of ecosystems and can ultimately lead to biodiversity loss. Furthermore, as landscapes are increasingly modified by anthropogenic forces, the remaining (semi-)natural ecosystems represent a potential ecological 'infrastructure' to be maintained and kept functional. In this working paper, we provide i) a review on the BD-NCP spatial relationships, ii) the main methods used for their study, iii) the main research gaps, and iv) recommendations on how the study of their relationships can be improved, especially when considering a national ecological infrastructure (EI), and a roadmap about how we will approach this subject within the ValPar.CH project. The roadmap focuses on the EI mapping objectives of ValPar.CH, and its main stakeholders.

Content

Abbreviations

BD: Biodiversity
CBD: Convention on Biological Diversity
EF: Ecosystem Functions
EI: Ecological infrastructure
NCP: Nature's contributions to people
IPBES: The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
MAES: Mapping and Assessment of Ecosystems and their Services

1. Defining a common understanding of the theoretical linkages between BD and NCP

Since the 2000s, many conservationists adopted the concept of Ecosystem Services in the hope to convince a wider audience about the importance of "Nature for people" (Costanza, 1997), using monetary or other values. With the launch of IPBES in 2012, the focus has evolved toward a less utilitarian vision where both "People and Nature" must live in harmony in sustainable and resilient socio-ecological systems (Mace, 2014). In accordance with recent publications and current terminology used by IPBES, this working paper will use the term "Nature's contribution to people" (NCP) instead of "Ecosystem Service" (Díaz et al., 2018), even though the latter is still widely used in the scientific literature and in the communication to the public.

ValPar.CH explores the benefits and values of the ecological infrastructure (EI) in Switzerland and its regional parks (Reynard et al. 2021). EI is defined as a network of natural and semi-natural habitats with high quality and functionality (BAFU, 2021). By identifying and preserving these habitats, the EI is assumed to be essential to promote and protect biodiversity and ensure the supply of NCP (Grêt-Regamey et al., 2021). Within ValPar.CH, the valuation of EI is carried out through multiple inter- and transdisciplinary processes, including a mapping of biodiversity (BD) and NCP. This working paper focuses on the different mapping methods relating BD and NCP.

The relationships between BD and NCP are numerous and complex, operating at multiple levels from genes to ecosystems, through species and communities (Harrison et al., 2014). The study of these relationships is important for promoting the role of nature conservation in NCP supply (Bastian, 2013). As a result, the amount of research focusing on the relationships between BD and NCP has increased in recent years. In particular, the direct links between BD and NCP that arise from ecosystem functions (EF, e.g. resource capture, biomass production, decomposition, nutrient recycling) were extensively studied and reviewed by Cardinale et al. (2012). EF are precursors of NCP supply and sometimes are an NCP themselves (Costanza et al., 2017). However, the relationship between BD and NCP supply is more difficult to determine than that of BD and EF because the complexity of processes and interactions present in ecosystems cannot be completely encompassed, and has accordingly remained understudied (Harrison et al. 2014, Ricketts et al. 2016, Smith et al. 2017).

In addition to the complexity of the relationships between BD and NCP, the spatial and temporal scales in which studies are conducted can vary greatly (Isbell et al., 2017). Given that assessments of NCP are often prompted by the need for immediate or near future decision-making, they typically adopt short temporal scales, often focused on a small geographical extent. By contrast, the time scale of biological extinctions or the estimated regeneration time (Delarze et al., 2016) of ecosystems and habitats necessitate studies considering a similar scale (decades or centuries; Isbell et al., 2017, Birkhofer et al., 2018). These reasons could help explain the poor accounting for direct links between BD and NCP in many studies (Bateman et al., 2013; De Groot et al., 2016). Using tiered (i.e. 'multi-levels hierarchical') approaches for representing BD, NCP, and their relationships over multiple relevant spatio-temporal scales can be of major interest for overcoming these challenges (Grêt-Regamey et al., 2015). The direct relationships between BD, EF and NCP can be difficult to demonstrate, especially through maps. Additionally, strong and intricate links exist between ecosystems, biodiversity, and functions and processes to supply services that meet societal demands (e.g. Maes et al., 2012; Lefcheck et al., 2015; Isbell et al., 2017; Ceaușu et al., 2021).

The terminology used around NCP can be confusing and therefore is best clarified at the start of a project (see Appendix 1, Definition box). These definitions allow us to propose an integrated representation of these important concepts and their relationships (Figure 1).

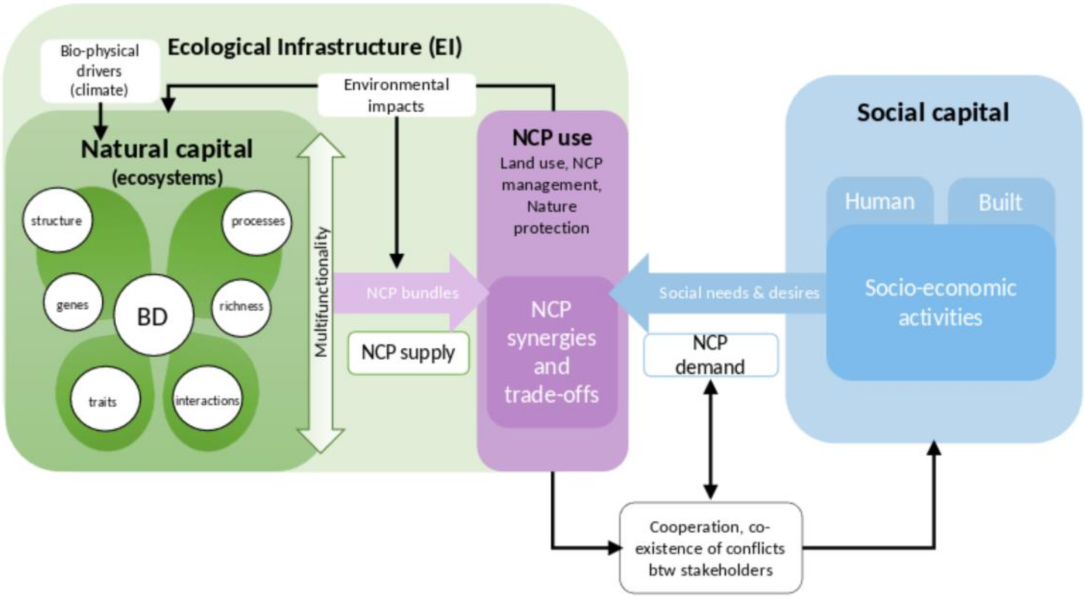

Figure 1: From Biodiversity (BD) to Nature's contributions to people (NCP) synergies and trade-offs, where bundles of NCP supply meet NCP demand, and where ecosystems and their biodiversity components are multifunctional. Adapted from: European Commission, 2013; Turkelboom et al., 2016.

2. Identifying the main methods to link BD and NCP

Despite the recognised evidence that BD is the basis for NCP provision and for the maintenance of ecosystem processes (MEA, 2005; Díaz et al., 2006), the way ecosystems are used can also influence their species composition, so that the relationships between BD and NCP remain difficult to quantify (Harrison et al., 2014). To grasp the complexity of these relationships, we propose a modified version of a two-way table published by Smith et al. (2017) to display which nature (here biodiversity) characteristics are hypothetically related to NCP supply (here restricted to NCP that will be mapped in ValPar.CH – Module A; Figure 2).

N1: Effect of individual species: presence, abundance, traits, biomass... **N2:** Effect of populations, communities, ecosystems, biomes, ... **N3:** Effect of ecosystem functions and processes, ecological resilience, connectivity, ... **N4:** Effect of genetic, functional, taxonomic and phylogenetic diversity	**C** Nature's contibution to people (NCP)																
	C2 Regulating									**C3** Material				**C4** Non-material			**C1** Option
	Habitat creation and maintenance	Pollination	Air quality	Climate	Water supply	Water quality	Soil	Natural Hazards	Pest and disease	Energy	Food and feed	Material and assistance	Medicinal, biochemical and genetic resources	Learning and inspiration	Physical and psycho-logical experiences	Supporting identities	Maintenance of options
N Biodiversity characteristics – **N1** Species	●	●							●	●	●	●	●	●	●	●	●
N2 Biophysical assemblages	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
N3 Biophysical processes	●		●	●	●	●	●	●		●				●	●	●	●
N4 Biodiversity	●	●					●	●	●		●		●	●	●	●	●

Figure 2: Hypothetical relationships between biodiversity (BD) characteristics (i.e. IPBES' biotic characteristics N1 to N4) and nature contributions to people (NCP). Modified from Smith et al. (2017) to account for IPBES new NCP definitions (IPBES 2018) and restricted to those BD components and NCP considered within the ValPar.CH project – Module A.

We identified four main linkage methods in the literature to connect BD and NCP (Figure 3). Each of these four methods can be applied at different BD and NCP levels (Figure 2), such as individual species or groups vs communities for BD, or single vs bundles (i.e. groups) for NCP (Raudsepp-Hearne et al. 2010), and through either direct or indirect analyses. The direct analysis aims at demonstrating a causal relationship between biodiversity (e.g. species, community, functional group, etc.) and the provision of NCP, whereas the indirect analysis aims at linking BD and NCP either through a relevant indicator or proxy, or through the comparative response of BD and NCP to the same variable. Indirect analyses are expected to remain more speculative (i.e. less causal) links between BD category and NCP provision.

Although we introduce them independently here, these distinct linkage methods have strong interdependencies. Despite only one linkage method having an explicit mapping purpose (i.e. the "spatial" linkage), all of them can be used for mapping the BD-NCP relationship. Within ValPar.CH, the spatially explicit assessment is mainly done within Modules A and C, and is our main focus here.

The four methods (detailed below) are: I "spatial"; II "functional"; III "valuation (economic/social)"; and IV "management". Linkage methods of type I, II and IV directly echo the spatial, functional and management linkages of Ricketts et al. (2016), whereas we added III to account for the socio-economic valuation of this linkage (e.g. Schirpke et al., 2018; Nahuelhual et al., 2013; Jaligot et al., 2019; Alemu et al., 2021).

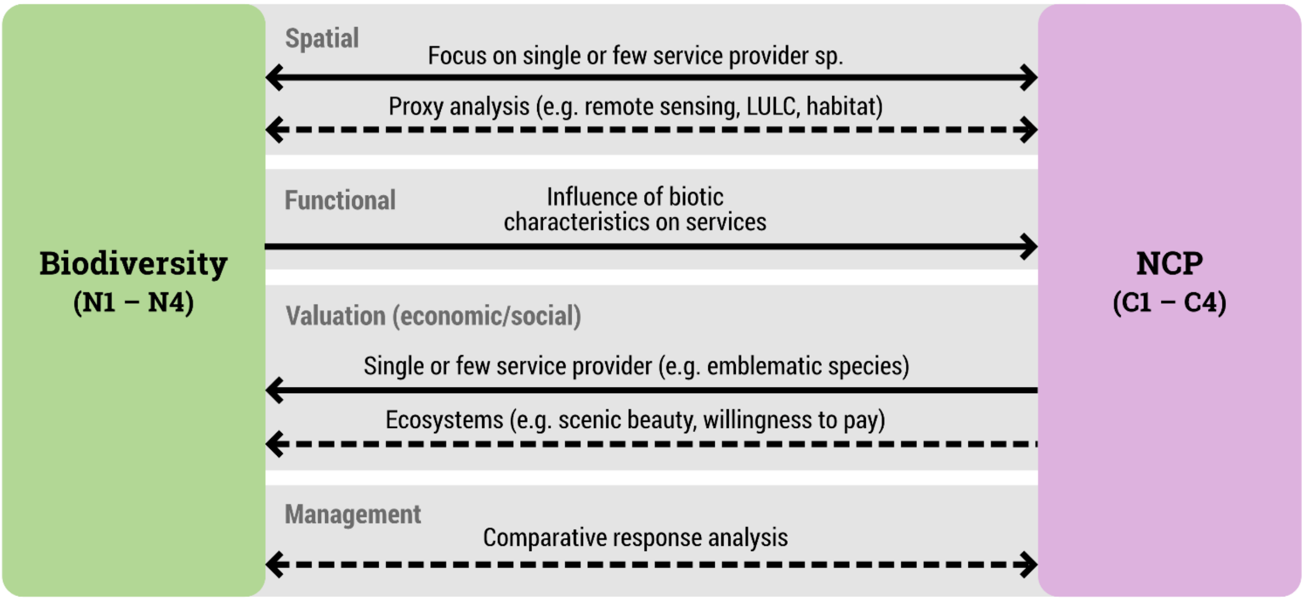

Figure 3: Possible expression of the relationships between biodiversity (BD) and Nature Contributions to People (NCP). Linkage methods adapted from Ricketts et al. (2016) to account for social/economic valuation (e.g. Schirpke et al., 2018). Directional arrows represent the direction in which the relationship is established (e.g. for functional linkage, the relationship is established from the species to the service provided).

I. The **"Spatial"** linkage method focuses on searching for common spatial patterns between BD and NCP levels. This linkage method assesses the spatial correlation between BD and NCP. BD and NCP may be linked by mechanistic or functional processes, or they may respond in a similar way to spatial variables like environmental conditions.

This method relies mainly on "indirect analysis" as it makes use of empirical correlations and proxy metrics for BD and NCP derived from spatial layers such as land use/land cover classifications, vegetation maps or remote sensing indices assumed to be informative about the quality of the habitat/ecosystem, its contributions to people, and its ability to support the species.

Within the ValPar.CH project, an important use is made of spatial analysis software and methods, such as Zonation (Lehtomäki & Moilanen, 2013) or machine learning clustering techniques, respectively. Zonation is a powerful tool for systematic conservation planning based on an optimization algorithm. As such, it can facilitate spatial targeting of conservation actions and resource allocation for ecosystem preservation, and accordingly contribute to consider BD and NCP in a common conservation prioritization scheme. However, it does not really assess the intrinsic nature of the linkage between species and NCP, which requires backing up spatial correlations with more in-depth investigations (e.g. literature, expert knowledge, etc.). While species-level metrics should provide us with a more precise picture of the BD-NCP relationships, upper-level metrics' (e.g. community, habitat area, structure, production, etc.) estimation can provide a simpler and potentially valuable alternative (Harrison et al., 2014). This explains why the indirect analysis approach is currently popular among researchers seeking to establish a link between BD and NCP (Smith et al., 2017). Although species and community-level characteristics allow to assess positive or negative impacts on NCP, Kleijn et al. (2015) demonstrated that species occurrence, abundance or richness were not necessarily sufficient to infer meaningful conservation strategies for both BD and NCP. A better understanding of the processes underlying these empirical observations would require working with "functional linkage" methods.

Kong et al. (2018) use the spatial linkage approach to analyse trade-offs and synergies between a set of NCP and biodiversity in the Yangtze river basin, China. They found significant synergies between regulation services and biodiversity, as well as synergies among regulation services (NCP bundles).

II. The **"Functional"** linkage method assumes that NCP are a direct or mechanistic function of BD. This link can be identified by conducting in-situ experiments aimed at evaluating NCP response to controlled changes in BD (Ricketts et al., 2016), or through expert knowledge (e.g. based on species functional traits or ecological roles). A direct link between BD and NCP can be easily identified when a specific species or group corresponds directly to a material service, as in the case of species identified through ethnobotany (e.g. Abbet et al. 2014; Dal Cero 2016, Oka et al., 2019). For example, Schulp et al. (2014) identified wild garlic (A. ursinum) as one of the most consumed wild plants in Europe, and mapped its distribution and abundance along with other common wild plants to obtain a spatially explicit representation of this material NCP. The study of Civantos et al. (2012) is one of the few examples using a functional relationship between species (vertebrates) and NCP in the context of climate change. Results from this study are anticipating a significant drop in the richness of species contributing to pest control across Europe. The paper by de Bello et al. (2010) is another example where the relationship between BD and NCP is approached through the analysis of species traits that provide specific ecosystem functions. However, this study is an exception as this type of linkage tends to be mostly reported at fine scales (e.g. in experimental plots, Balvanera et al., 2006). Metrics and knowledge derived from the functional linkage method are key inputs for direct spatial linkage analyses and economic/social valuation analyses, such as Benefit Transfer calculation (BT; Costanza et al., 1997, Grêt-Regamey et al., 2014). The functional linkage method is an excellent basis for the economic/social valuation in ValPar.CH, especially to transpose these results into a spatially explicit representation.

Oka et al. (2019) is to date one of the most comprehensive studies to highlight the functional services of trees (171 tree species for 15 NCP). It offers a new functional group approach based on the relationships between species and NCP.

III. The **"Valuation (social/economic)"** linkage is done through the extrapolation of qualitative (e.g., description of perceptions and experiences) and quantitative (e.g. price, frequency, absence/presence, etc.) values which link BD to NCP.

"Social" valuation is a way to understand the values of stakeholders in conservation processes (Omoding et al., 2020). Methods such as interviews and surveys are used to establish the link between BD and NCP, or to address social and ethical issues related to BD (Jetzkowitz et al., 2018). Social valuation can be used to assess non-material NCP (Jaligot et al., 2019) and can also be translated into maps (Richards and Friess, 2015). In ValPar.CH, qualitative methods (micro-narrative analysis, go-along interviews, focus groups and participatory mapping, geosemantic analysis, etc.) are used to assess these social valuation links between BD and NCP.

"Economic" valuation methods can link BD to NCP by estimating a market value for NCP that are provided by biodiversity characteristics (Figure 2). Although economic valuation methods are useful to highlight the multifunctional role of ecosystems, and thus defining NCP bundles (Ojea et al., 2016), their final aim remains to obtain the stocks and flow of Natural Capital (Banerjee et al. 2016; Sharp et al. 2018). Natural Capital Accounting can be assessed using different economic valuation approaches, such as: i) direct market evaluation (market price, cost-based, production function, meta-analysis methods); ii) indirect market valuation (hedonic pricing, travel cost, meta-analysis methods); or iii) non-market valuation (contingent valuation, choice experiment, meta-analysis methods) (Koetse et al., 2015). The indirect market valuations are mainly oriented towards non-material NCP (e.g. scenic beauty) and generally rely on social valuation methods (e.g. surveys, geolocalised activities, etc.). In ValPar.CH, the economic benefits of NCP are calculated through the "exchange value approach", which is used for the valuation of ecosystem services in the United Nations System of Environmental Economic Accounting (SEEA) (UN DESA 2019) and can also be translated into maps (as in Ramel et al. 2020).

Based on the opinions of their study participants, Schirpke et al. (2018) have listed symbolic plant and animal species in the Alpine region. They validated the resulting list by screening for websites referring to the target species. Based on these results, they produced a cartography of cultural NCP associated with these symbolic plants and animals.

IV. The **"Management"** linkage method establishes the link between BD and NCP through the comparative analysis of their individual responses to the same management intervention. As for "spatial linkage", this type of linkage is most often expressed at larger scales than functional linkages and there is no specific hypothesis as to its nature (Ricketts et al., 2016). Land management policies have a straightforward link to certain NCP (e.g. forests or agriculture in Switzerland) and to BD (e.g. protected areas). However, the effect of certain policies, for example intended to protect target species or to maximize specific types of services, can generate unexpected trade-offs and/or synergies (Turkelboom et al., 2018). For instance, biological farming has been shown to host greater amounts of NCP and BD relative to conventional farming, and to increase the resilience of the ecosystem to climate change (Kremen & Miles, 2012). In ValPar.CH, this linkage method is used in particular by comparative analysis of the effect of changes in land use on BD and NCP from the past to the present (module A) and between the present and future scenarios (module C).

Häger (2012) observed the effect of management of agroforestry systems in terms of ecosystem service supply and plant diversity. He compared the estimated carbon content as well as the number of tree species and their density in organic farms and in conventional farms to observe the response of ES (carbon storage) and BD to these two kinds of management.

3. Main gaps in the identified linkage approaches and proposed solutions

Substantial progress has been made on linking BD and NCP since the Millennium Ecosystem Assessment (MEA, 2005), and the recent assessments by the IPBES (Jetzkowitz et al., 2018). Nevertheless, large gaps remain in the data, models/analyses, and temporal/spatial scales used to assess these linkages, but also in their complexity, uncertainty and interpretation by scientists, and ultimately use by stakeholders (Table 1). This section elaborates on the gaps, as identified by IPBES (2018) and other references (see Table 1), and offers potential solutions developed in ValPar.CH.

Table 1: Synthesis of the main gaps in the identified BD-NCP linkage approaches. Green text in bold corresponds to the potential solutions that will be used in the ValPar.CH project. Dark red text highlights recommendations on appropriate linkage methods for the identified gaps (method I = "spatial"; II= "functional"; III= "valuation (economic/social)"; and IV= "management"). References highlight key literature.

Gaps	Identified issues	Potential solutions	References
Data	. spatial & temporal data gaps for (a)biotic sources	**. remote sensing** . citizen science . collect data on species (**functional capacity**, genetic resource, …) Method **II, III**	. Ferrier et al., 2016 . Randin et al., 2020 . Burkhard & Maes, 2017 . Jaligot et al., 2019
Models	. plurality of methods of BD and NCP assessment, making it difficult to compare / extrapolate the results . ecological processes at temporal and spatial scales relevant for decision making . inability to identify tipping points	. incorporate species interactions and community dynamics **. use of clearly defined metrics and methods for BD/NCP assessment** **. develop integrated socio-ecological models (with prioritizations' scenarios,** direct and indirect drivers of species, **BD, NCP**) Method **I, III**	. Ferrier et al., 2016 . Rubicode, 2009 . Rounsevell, 2018 . D'Amen et al., 2017
Scales	. scale conflict between management (large scale) and functional (small scale) studies . BD-NCP relationships are spatial-scale dependant	**. work with various scales and build complex models (both - BD and NCP)** Methods **I, IV**	. Ricketts et al., 2016 . Hauck et al., 2013 ; Turner et al., 2013 ; Martinez-Harms et al., 2015 . Birkhofer et al., 2018 . Mateo et al., 2019 . Grêt-Regamey et al., 2015
Complexity of the linkages	. difficulty of identification of interdependencies between BD & NCP . studies focus on small subset of interactions between BD & NCP . difficulty of identifying equilibrium between BD & NCP	**. develop integrated socio-ecological approaches (with prioritizations' scenarios, direct and indirect drivers of species, BD, NCP)** **. identify (in)direct links between BD & NCP** . identify multifunctionalities of species, community & bundles of NCP Methods **I, II, III, IV**	. Maes et al., 2012 . Ramel et al., 2020 . Turkelboom et al., 2018
Interpretations of the BD-NCP relationships	. NCP do not solely depend on BD, but also on abiotic factors . most relationships studied between BD & NCP focus on positives links . complexity of relationship for decision-making (when trade-offs exist between NCP/BD)	. identify (in)direct links between BD & NCP **. consider abiotic factors as non-dependant of the BD to assess NCP** **. interpretation of potential results with the support of stakeholders to support national conservation objectives** Methods **III, IV**	. Harrison et al., 2014 . Smith et al., 2017 . Kleijn et al., 2015 . Gray, 2011
Stakeholder's involvement	. Practical Insights on BD - NCP linkages could be contributed by stakeholders, but they are often involved too late in the process	**. integrate stakeholders throughout the BD-NCP linkage assessments (as advocated in related fields, e.g. biodiversity modelling)** Method **III**	. Guisan et al., 2013 . Mouquet et al., 2015 . Ferrier et al., 2016

Data

The IPBES report on scenarios and models (Ferrier et al., 2016) highlighted important spatial and temporal data gaps to properly assess BD and NCP and their linkages from biotic and abiotic data sources. While Switzerland is rightly considered as a data rich country, our capacity to model BD and assess NCP is still largely dependent on the availability and access to all existing data (e.g. soil data not nationally available at fine scale). In some instances, remote sensing can be used to fill specific data gaps, even though there are limitations on what can be captured from the sky (Vihervaara et al., 2017; Randin et al., 2020; Wuest et al., 2020; Skidmore et al., 2021).

Although some material services can be directly quantified to some extent (e.g. crop, wood, drinking water) without being directly related to specific species, there are others that need such direct link with BD, and are often less documented (e.g. medicinal plants, traditional goods, decoration, energy, wild food; Smith et al., 2017). The underlying reason is that the functional characteristics of these species are often not described. Similarly, regulating services would benefit from more advanced analyses of life cycle maintenance and gene pool protection, however these services need additional data on life history and ecological traits that are not readily available (Burkhard & Maes, 2017). In recent years, the collection of data (e.g. Jaligot et al., 2019) has been greatly increased by the rise of citizen science, an efficient process but one that can be biased and requires time before gathering a significant amount of data.

In ValPar.CH, we provide an extensive set of 25-m resolution abiotic variable layers at different temporal scales, including downscaled land-use map (from 100m to 25m) for three periods between 1992 and 2018. Species' data provided by Infospecies are also included in this work and related to the abiotic variables to parametrize species distribution models. In addition, a hyperspectral remote sensing campaign conducted in two of the four pilot parks (Jurapark Aargau and Parc naturel Gruyère Pays d'Enhaut) will allow deriving the potential benefit of using high-resolution spectral images to map BD and NCP. For the functional approach, a direct linkage between 2,000 species (vascular plants and vertebrates) and 17 NCP has been established (Rey et al., in prep). We are also exploring the potential of using species' genetic data; yet we expect the latter data to cover only a limited geographical extent for a small number of species.

Models

Modelling can help us exploring and understanding the complex multi-scale linkages that exist between BD and NCP. The IPBES report on models and scenarios (Ferrier et al., 2016) highlights three main modelling approaches that are currently under-utilized for studying the BD-NCP relationships: (i) models that explicitly link BD to NCP, especially models to predict NCP from BD; (ii) models that address ecological processes (i.e. underlying ecosystem functions and NCP, based on BD) at temporal and spatial scales relevant for decision making; and (iii) models that are able to identify tipping points (e.g. extinction of key species) in the BD-NCP relationship (Rubicode, 2009). Although these three modelling approaches would individually benefit from improvements, a necessary next step will be to develop integrated socio-ecological models that explicitly integrate prioritizations' scenarios, direct and indirect drivers of species, BD, NCP, and good quality of life to better account for important relationships and feedback between those components (Rounsevell, 2018). Importantly, these models should incorporate species interaction and community dynamics (Ferrier et al., 2016, D'Amen et al., 2017).

In ValPar.CH we propose an innovative way to combine species distributions models (SDMs; Guisan et al. 2013) with the geographical distribution of NCP in Switzerland (as done regionally in Honeck et al. 2020, Ramel et al. 2020; Module A). The underlying goal is to obtain a better understanding of the BD-NCP relationships through the assessment of the ecological infrastructure under multiple scenarios (Module C). Integrating interactions between species and establishing community dynamics are perspectives that we would like to explore further in the future.

Scales

A literature review by Ricketts et al. (2016) shows that depending on the linkage method used to study BD-NCP relationships, the resulting outputs can vary greatly. In this regard, several studies have shown how the main factors driving the BD-NCP relationship are spatial-scale dependant (Hauck et al., 2013; Turner et al., 2013; Martinez-Harms et al., 2015). Although it was shown that the choice of the scale (e.g. landscape scale) can be crucial when analysing the relationships between BD and ecosystem functions (EF; Thompson et al., 2018; Isbell et al., 2018), these relationships can be underestimated at the time of decision-making because management trade-offs are not necessarily considered at the same scale (Vallet et al., 2018). Along the same lines, Cordingley et al. (2016) suggested that it is more appropriate to work at the landscape scale rather than at the individual patch scale for assessing BD-NCP relationships, as it allows to implement contrasting management strategies to enhance preservation of BD and human well-being in landscapes where trade-offs occur. This further emphasizes the importance of considering different linkage methods and relevant scales to assess this link.

In ValPar.CH, modules A and C will build models based on multi-scale approaches. For BD, spatially nested species distribution models (European and National scales) will allow accounting for niche truncation issues (Chevalier et al. 2021). For NCP, a tiered approach will be used to assess NCP at two scales (national and parks, which are finer), with varying scale-dependant objectives and levels of complexity (Grêt-Regamey et al., 2015). Further investigations on the scale effect on the BD-NCP relationships is needed (Birkhofer et al., 2018).

Complexity of the linkages

The BD-NCP relationships can be more complex than simple pairwise interactions (1:1). Maes et al. (2012) illustrated this point through the example of the geographical co-occurrence of BD and different bundles of NCP analysed in function of land protection status across Europe. Results showed that habitats benefiting from "favourable" conservation status (see Epstein et al., 2016) provide more BD and have a higher potential to supply regulating and non-material NCP (Maes et al. 2012). In addition, several studies showed the necessity of BD for the provision of NCP in the long term (e.g. Isbell et al., 2011; Soliveres et al., 2016). However, focusing on NCP for promoting BD conservation can be hazardous, as over-emphasising NCP can, in some instances, reduce BD conservation (Ramel et al., 2020). Indeed, some NCP were shown to rely mostly on a small subset of species (Kleijn et al., 2015), whereas many rare or endemic species of high conservation value might have no clear link with NCP (Balvanera et al., 2014). Moreover, an uninformed use of NCP (i.e. which does not account for BD) in operational frameworks (e.g. spatial planning, EI planning, water management or forestry) could result in counter-productive results both in terms of BD and NCP (Turkelboom et al., 2016).

In ValPar.CH, Module A makes use of all four linkage methods introduced above to account for the diversity of possible interactions between BD and NCP. In addition, other modules are enlarging the scope of analysis using other methods without a spatially explicit aim (social interpretations of nature; incl. linkage method III). This will provide Module C team with an integrated overview, useful for developing future scenarios of a functional ecological infrastructure.

Interpretation of the BD-NCP relationships

An update of the initial review by Harrison et al. (2014) on the links between BD attributes and NCP (conducted by Smith et al. (2017)) highlighted the multiple interpretations of the relationships between biotic characteristics (i.e. functional group, diversity, population dynamics, etc.; Figure 2) and NCP. These two reviews emphasized the importance of considering the landscape and all its characteristics (biotic and abiotic) as a whole system rather than focusing only on some specific species or functional groups. In addition, one of their main findings is that there are mostly reports of positive links between either species, functional groups or traits and NCP. This is probably related to the fact that most studies are designed with the objective of establishing positive BD-NCP relationships, at the expense of potentially hiding negative (e.g., from deleterious invasive species) or neutral (e.g. from non-structural species) relationships. We stress here the importance, when designing a framework aimed at establishing BD-NCP links, of being equally able to study the positive, neutral and negative aspects of these relationships. (e.g. using a synthetic contingency table to link species and NCP, with all above types of relationships explicitly identified; Rey et al., in prep. Module A).

In ValPar.CH, Modules A and B assess BD-NCP relationships from an ecological, a social and an economic perspective. The interpretation and use of identified relationships will be discussed between different stakeholders (within and outside academia).

Stakeholders' involvement

Several authors recognize the need to improve the link between policy maker requirements (e.g. conservation objectives) and research outputs (e.g. Guisan et al., 2013; Mouquet et al., 2015; Ferrier et al., 2016), and this similarly applies to the linkages between BD and NCP. The challenge is to create fit-for-purpose BD-NCP linkage outputs (e.g. maps) that are scientifically robust and stakeholder-friendly by improving the communication between scientists and end users, and by making the underlying scientific process more transparent and reproducible (Burkhard & Maes, 2017). There is thus also a gap in the abilities of stakeholders to use and interpret scientific outputs.

In ValPar.CH, module C will mobilize stakeholders for the evaluation and proposal of an operational EI (i.e. providing: (i) an inventory of policy objectives and instruments, (ii) reports policy design and (iii) reports park financial costs; incl. linkages method IV). The weighting of the BD and NCP inputs in the EI prioritization will also be based on a large consultation of stakeholders (incl. the main data providers, Infospecies.ch).

4. Conclusions and ways forward for ValPar.CH

Summarizing, the ValPar.CH project aims to identify a functional ecological infrastructure at two scales (selected regional parks and country-wide) by linking BD and NCP through modelling, mapping and prioritization analyses, where both direct (e.g. species-related) and indirect (e.g. landuse-related) relationships are considered. As detailed in table 1, cutting-edge methods will be applied with the aim of overcoming the identified gaps in BD-NCP linkages, to yield five main and complementary outputs (from modules A.1, A.2, for the present, and C.3 for future scenarios):

i) Spatial predictions of aquatic and terrestrial species distribution associated with NCP;
ii) Identification of synergies and trade-offs between BD and NCP;
iii) Spatial planning of a functional EI using a weighted joint prioritisation of BD and NCP ;
iv) Archetypisation of NCP resulting from a landscape-based upscaling of BD and NCP indicators.

As a potential framework within which to embed these outputs, ValPar.CH will further consider Petchey et al. (2015) proposed roadmap for ecological predictability research, emphasizing the need for an integrated approach with resulting models meeting the predictive requirements of stakeholders and policy, additionally promoting the development of consistent and replicable BD/NCP linkage protocols, and their integration in EI mapping, that also better address model uncertainty (Ferrier et al., 2016; Burkhard & Maes, 2017).

To conclude, the proposed developments for spatially linking BD and NCP will open exciting new perspectives to improve the mapping of a functional infrastructure in Switzerland and help pave the way toward a better accounting of BD and NCP in spatial conservation planning.

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6. Appendix: Definition box

***Biodiversity** refers to the diversity of life on the level of ecosystems (habitats), species (flora, fauna, fungi, microorganisms) and genetic diversity, i.e. the variability and variety of individuals within a given species. (FOEN)*

***Ecosystem functions** (EF) correspond to the flow of energy and materials through the biotic and abiotic components of an ecosystem. It includes many processes such as biomass production, trophic transfer through plants and animals, nutrient cycling, water dynamics and heat transfer. (IPBES)*

***Ecosystem Services** (ES) are the benefits people obtain from ecosystems. In the Millennium Ecosystem Assessment, ecosystem services can be divided into supporting, regulating, provisioning and cultural. This classification, however, is superseded in IPBES assessments by the use of the concept "nature's contributions to people". This is because IPBES recognises that many services fit into more than one of the four categories. For example, food is both a provisioning service and also, emphatically, a cultural service, in many cultures. (IPBES)*

***Nature's contributions to people** (NCP) are all the contributions, both positive and negative, of living nature (i.e. diversity of organisms, ecosystems, and their associated ecological and evolutionary processes) to the quality of life for people. Beneficial contributions from nature include such things as food provision, water purification, flood control, and artistic inspiration, whereas detrimental contributions include disease transmission and predation that damages people or their assets. Many NCP may be perceived as benefits or detriments depending on the cultural, temporal or spatial context. (IPBES)*

***A trade-off** is a situation where an improvement in the status of one aspect of the environment or of human well-being is necessarily associated with a decline or loss in a different aspect. Trade-offs characterize most complex systems and are important to consider when making decisions that aim to improve environmental and/or socio-economic outcomes. Trade-offs are distinct from synergies (the latter are also referred to as "win-win" scenarios): synergies arise when the enhancement of one desirable outcome leads to enhancement of another. (IPBES)*

***Bundles** are sets of associated ecosystem services that are linked to a given ecosystem and that usually appear together repeatedly in time and/or space. (Openness).*

***Multifunctionality** is closely related to bundles but is not the same. Multifunctionality is defined in this SP as "the characteristic of ecosystems to simultaneous perform multiple functions, that might be able to provide a particular ES bundle or bundles. (Openness).*

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