Theories and methods to disclose the underlying causes of biodiversity loss

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Lead authors: Zsolt Molnár (CER) and Roel During (WUR)

Co-authors: Audra Balundė (MRU), Karolina Gurjazkaitė (social partner), Dacinia Crina Petrescu (UBB), Oscar Jacobsson (UGOT), Julia Neidig (BC3), Unai Pascual (BC3), Rita Campos (CES), Esther Turnhout (UT), Tamalone van den Eijnden (UT), Ruxandra Malina Petrescu-Mag (UBB), Katarina Haugen (UGOT), Aistė Bakaitytė (MRU), Goda Kaniušonytė (MRU), Luciane Lucas (CES), Domenico Pappalardo (UNICT), Amy Wortel (WR)

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Summary

BIOTraCes, as a project funded by the European Union, aims to develop knowledge, tools and novel approaches towards a society in harmony with nature. To achieve this, the project should develop a deep understanding why and how biodiversity is lost and what the benefits would be of novel nature inclusive policies and would trigger nature positive behaviour among citizens. This report focuses on causes and especially on underlying causes of biodiversity loss. It reviews and synthesizes theories, describes tools to assess causation chains in a transdisciplinary way. The focus is not exclusively on academic knowledge, as lay people's understanding and relation to nature are deliberately considered. This sheds a light on how underlying causes in the biodiversity science policy interface may resonate or collide with how causes are understood in unfamiliar perspectives on human-nature relations.

The concept of nature itself and its values, is subject of pluralist views, even in Europe, even among scientists. The consequence is that defining nature is not a scientific exercise. Another consequence is that there is room for local understandings of nature. Local or unfamiliar understandings may be important because they may hint to new pathways to a nature positive society. The reason that they are worth listening to is that they may be more connected to nature, whereas disconnection between people and nature in general may be seen as one of the underlying causes of biodiversity loss. The loss of biodiversity is measured by means of indicators. The indicators in use reflect the interest of those who are measuring or who uses the monitoring results. An all-inclusive measurement of biodiversity loss is impossible. Biodiversity specialists and marginalized social groups may have hardly overlapping knowledge of biodiversity change, which is often a source of conflict and misunderstanding. Also, ecosystem responses to changes in causation chains are difficult to predict. For instance, when an ecosystem is species poor and stuck in a functionally simple phase of development, it can be vulnerable for colonizing invasive species. Recovery of ecosystem characteristics can run into lock-ins. Knowledge of the history of a system and its functions for humans is important to understand change and its manageability.

The drivers of changes in biodiversity may be human, natural or, often, a mixture of both. It is often not possible to disentangle natural variability from anthropogenic drivers. Direct drivers can be triggered by indirect drivers. The relations between direct drivers and its indirect drivers are complex. This necessitates the use of attribution methods by which drivers of biodiversity loss are put in a causation framework. There are qualitative methods, such as causal process tracing or path dependency analyses, next to quantitative methods, using causal network diagrams.

The loss of biodiversity always takes place in a governance context. Decision makers providing permits for economic activities are not used to apply cutting edge knowledge on biodiversity loss and its (underlying) causes. Transformative governance aiming for biodiversity recovery is still in its infancy. Nature or biodiversity often is seen as a mere interest, that needs to be outweighed against the interests of the economy in a political process. Knowledge on causes is adopted and created in a specific governance context and unfamiliar perspectives on human-nature relations and its ramifications for causes may be included or excluded based on policies or political preferences. For decisions which may have huge impacts, environmental impact assessments are to be made, but this is also no guarantee that either specialist or marginalized knowledges on causation will be used.

Bending the curve of biodiversity loss requires social psychological approaches, which address lifestyles, food consumption, shelter, transportation, work, recreational activities among others. One needs to understand individual, social and contextual factors of complex behavioural systems. It is concluded that there is a lack of biodiversity-related theoretical approaches in behavioural sciences. Indirect drivers encompass practices that may or may not have an immediate or apparent connection to biodiversity loss, but through intricate and multifaceted pathways, ultimately have influence. New theoretical

developments focus on the relationship between people and the environment and are operationalized in multiple ways.

To know and understand the underlying causes of biodiversity loss, one needs to understand how biological diversity is lost by direct drivers in the so-called high impact sectors. For BIOTraCes four of these sectors are important: water management, agriculture and food production, urbanisation, and forestry. Loss of biodiversity is specific for each sector, because of spatial scales, economic organisation, public policies and so on. There are cases of knowledge exclusion and ignorance, as well as best practices of knowledge inclusion and knowledge transfer, that lead to new biodiversity avenues within a sector, resulting in payment for ecosystem services.

BIOTraCes is interested in listening and amplifying marginalised voices coming from groups with distinctive human-nature relations. But knitting their knowledge about causes to the formal body of knowledge on biodiversity loss in the biodiversity science policy interface may be almost impossible in some cases. If cultures have developed a specific and outstanding view on the world, the discussion on causes may become impossible.

Based on the general information about nature and biodiversity, on governance, on technical issues and anthropological views on behaviour, some conclusions are drawn about what ecological work should be done in the case studies. This entails a profound discourse analysis on causes of biodiversity loss, a comparison between business as usual in a high impact sector and what a societal partner wants to achieve, and, lastly, an ecological assessment to substantiate the benefits of inclusion of the perspectives of the societal partner in the governance.

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1. Introduction

The original plan of the deliverable was to review, synthesize, and adapt theories and tools to assess causation chains and interacting networks associated with biodiversity change at local, national and European scales paying special attention to how transdisciplinary approaches can offer opportunities and limits to biodiversity mapping; to assess relevant political perspectives, practice theory and social psychology to support the joint deliberation of what policy, economic, institutional, cultural and psychological barriers and lock-ins prevent change; to review literature to assess the policy, institutional (including regulatory) and governance context, enablers and constrains of transformative change leading to a theory of transformative governance¸ and provide some guidance on participatory methods and co-learning.

In this deliverable (D1.7) first we introduce concepts of biodiversity and nature, meanings of biodiversity and nature for diverse groups of people, mentioning also the disagreements, disputes and misunderstandings. We collected the relevant methods for measuring biodiversity and biodiversity loss, emphasizing challenges, for example, the relevance of different spatial and temporal scales. We describe causes and underlying causes of biodiversity loss, theories and frameworks, qualitative and quantitative attribution of drivers, again focusing on challenges and limits of knowing. The deliverable has a section on governance and biodiversity loss, focusing on political perspectives, understanding economic arguments and social psychological approaches, and finally providing some inspiring governance examples. We also summarize what biodiversity loss means in the four high impact sectors (agriculture, forestry, water management and the urban world), how knowledge is used today in policy making at national and local scales, pointing on how lack of knowledge plays out. We discuss how non-mainstream perspectives on causes of biodiversity loss could help transformative change, and help generate new ideas, new solutions. For this we collected some puzzling inspirational, thought-provoking examples. We also discuss that some of the differences in the understandings of the causes of biodiversity loss are bridgeable using appropriate research approaches and methods while others are insurmountable. Finally, we conclude by contrasting business as usual with societal partners approaches and emphasize the benefits of inclusion of marginalized voices in the transformative process towards a nature-positive society.

In BIOTraCes we focus on biodiversity innovations to achieve a nature-positive society through transformative change. For this we must have a deep enough understanding how nature works and we have to be able to document and predict changes in biodiversity and understand their drivers.

How this deliverable was created ?

First a literature review was done and parallel the earlier and ongoing (project) experiences of project partners and their social partners and local ecology experts on theories and methods they use to disclose the underlying causes of biodiversity loss was collected. As a second step, online discussions were organized, different sections were written by BIOTraCes partners, and finally reviewed by the key authors of all partners.

2. Nature(s) and biodiversity: diverse understandings

In any attempt to "rethink" biodiversity governance, we need to consider that defining nature (and related concepts such as biodiversity, ecosystems, landscapes or green infrastructure) is not merely an objective scientific exercise. In reality, context-specific, subjective, normative and dynamic worldviews and values are at play in any definition of nature, whether explicitly or implicitly. Being aware of this pluralism is essential for avoiding "objective" definitional attitudes that risk disregarding and marginalizing the plurality of values and worldviews connected to different definitions of nature (Pascual et al 2021). In fact, paternalistic positions can create breeding grounds for fruitless dialogues between stakeholders, and thus pluralistic approaches help open up spaces for discussion (Keune et al. 2022). The plurality reflecting the different understandings and values of nature will play a fundamental role in transformative biodiversity governance (Pascual et al 2023).

In Europe, the image of nature as a nurturing mother was gradually transformed during the sixteenth and seventeenth centuries into an image of nature as being wild, chaotic and uncontrollable, a position directly related to the dominant view on women at the time and a view that justified the domination of nature and the exploitation of its resources (Merchant 1980).

Biodiversity is often used as a synonym of nature or living nature or the biosphere. The concept of biodiversity emerged from the scientific community in 1968 and, despite criticisms, represents one of the most common and recognized concepts for scientists and the general public. It was regarded as a useful catch-all representing the need for increased conservation for the underpinnings of life on Earth. One "formal" definition of biodiversity defines it as "variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems" (CBD, 1992). Aligned with this "formal" definition, Maclaurin and Sterelny (2008) acknowledge the multifaceted role of biodiversity, emphasizing its importance beyond a mere preservation standpoint. They highlight that biodiversity is often conceptualized not only as an indicator of elements worth preserving but also as a tool that measures the instrumentally important dimension of biological systems.

Defining nature is a value-laden task with theoretical and material repercussions. From the ancient Greeks to present, the concept of "nature" was approached from various perspectives and sciences, from the Philosophy to Biology, Political, or Economics (Fehnker et al., 2021) and received a variety of definitions (Arias-Maldonado, 2015; Stano, 2023), emerging from different worldviews and ways of thinking. For example, one century ago, Whitehead (1919) defined nature to be what "we observe in perception through the senses" and pointed to the fact that "thought about nature is different from the sense-perception of nature". More recently, this definition was challenged, as Davoudi et al. (2019) mentioned in relation to the "environment", a concept often seen as a synonym to "nature". Thus, Davoudi et al. (2019) explained that, ontologically, it was suggested to look at the environment from a historical perspective, considering the human influence, to consider it "a dynamic and evolving […] socio-natural hybrid" (rather than an object of analysis, an entity external to humans). Furthermore, the authors showed that, in time, epistemologically, diverse ways of understanding the environment were designed (e.g., citizen science), and methodologically, new rules and tools were added to the traditional ones used in environmental planning, and changes in scale or focus have emerged. However, despite this dynamism, the dominance of anthropocentric views of nature persists (Davoudi et al., 2019). More recently, ecomodernists viewed nature as transformed into a part of the human environment (Arias-Maldonado, 2012). Ecological economics opposes to this perspective and consider that the economy is a subsystem of earth's ecosystem and depends on it, the dependent is irreplaceable and, hence, it highly necessary to "restore/protect/preserve natural processes wherever and as much as possible" (Fremaux, 2019).

Choosing one definition and value of nature over another implies imagining and advocating for different worldviews, and visions of the past, present and the potentially unfolding futures. It means legitimizing one worldview over another. While this is inevitable, we must be aware of the implications for transformative biodiversity governance. Defining nature as wilderness and closely connected to the idea of pristineness (often applied by ecologists and conservationists) generates conservation strategies that are not only different but possibly at odds with conservation strategies deriving from other (e.g. local, Indigenous, deep ecological) conceptualizations of nature (Pascual et al 2021; Keune et al. 2022).

Ecosystems are dynamic interacting networks of animals, plants, fungi, and microorganisms, above and below ground and water-surfaces. These biodiverse networks of interacting organisms respond to a set of environmental factors such as climate, soil, or water conditions. But if we understand ecosystems from a social-ecological systems perspective, they also include humans and human activities (direct drivers) that modify almost all these ecosystem interactions and environmental factors, and the underlying societal (indirect) drivers of these activities. It is thus important to understand the status and trends of biodiversity, "biodiversity intactness," "biodiversity health," "species viability," and, ecological functions and services provided by biodiversity (Dinerstein et al., 2020; Mace et al., 2018; Schneiders and Müller, 2017) and that of the direct and indirect drivers that affect biodiversity, which thereby, affect nature's contributions to people (NCP) (Díaz et al 2018).

In this deliverable we will mostly use the European and scientific understanding of (living) nature and biodiversity, though we also aim to remain open to other, especially to marginalized understandings and conceptualizations. Compared to other regions, local people's and scientists' understanding of nature is much closer to each other in Europe (cf. the strong nature-culture divide). Considerable differences may exist how various stakeholders perceive nature and its values (Molnár et al. 2008).

3. Biodiversity loss

Biodiversity, as a western scientific concept, is a term that is useful to describe the deterioration of our living nature, the biosphere. In this section we introduce what biodiversity loss means and how we can measure and monitor it.

3.1 Biodiversity loss and its consequences

Biodiversity loss is a decrease in biodiversity within a species, an ecosystem, a given geographic area, or Earth as a whole. Biodiversity, or biological diversity, is a term that refers to the number of genes, species, individual organisms within a given species, and biological communities within a defined geographic area, ranging from the smallest ecosystem to the global biosphere. Likewise, biodiversity loss describes the decline in the number, genetic variability, and variety of species, and the biological communities in a given area. This loss in the variety of life can lead to a breakdown in the functioning of the ecosystem where decline has happened[1].

Biodiversity loss has consequences not only on how nature functions but also on human health and other constituents of wellbeing. Biodiversity loss often leads to decreased provision of including material, non-material and regulatory nature's contributions to people (NCP) (Diaz et al 2018). Biodiversity loss, accompanied with anthropogenic changes such as urbanisation, industrial pressures on extraction of natural resources and changing lifestyles, often results is loosened and/or re-formed human-nature relationships. All over the world, but especially in urbanized regions, less and less people interact (cooperate, co-create) with nature directly for subsistence (e.g. farm, herd, fish, or hunt for food), while the number of people 'using' nature for recreation is sharply increasing. Disconnection between people and nature is also changing and this influences nature-positive behaviours (Gaston and Soga 2020, Chawla 2020). These changes play an important role how people see and value nature, and what they know about nature, its change, functioning and the impacts of drivers on biodiversity. The "extinction of experience" hypothesis refers to a lack of direct and meaningful experiences with nature, especially in urban environments, that may lead to an emotional, physical, spiritual or intellectual alienation from nature (Soga & Gaston, 2016).

It is key to understand how nature works/functions form the foundation of ecological literacy as it provides a critical foundation for making informed and sustainable decisions about how we live, how we grow and develop our communities and settlements, and how we address the environmental and socio-economic issues with which we are confronted. Ecological literacy involves the capacity to know and understand places as ecological systems, including how they function and connect with other systems (Pitman & Daniels 2020). To achieve a nature-positive society, it is imperative to substantially increase the ecological literacy of our societies, including that of the lay citizens, decision makers and scientists.

A Kyrgyz sacred site guardian distinguished three ways how we can 'learn nature' (pers. comm, 2016, Paris). The most common way today is learning about nature outside of nature, indoor, in school, from books, films and the internet. The second way is learning in nature, e.g. during excursions, field trips and environmental school exercises. However, he emphasized a third way of learning: learning from nature, which he understood as learning from the direct interaction with nature during e.g. farming, herding and other activities where food or other contributions are co-created by nature and humans. Direct teaching of humans by nature (cf. nature has agency in many cultures), is a fundamental aspect of the third way of learning. Recently more and more

[1] https://www.britannica.com/science/biodiversity-loss

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children have limited opportunity to learn in and even less from nature, as in-door learning practices dominate in their life (Chawla 2020).

3.2 Documenting ongoing and historical biodiversity loss (gain and stability) and the changing functioning of nature

Documenting change in biodiversity is a complex and challenging task. Visibility, detectability and measurability of biodiversity change is diverse, from easily observable farmland birds to, for example, the spread and impact of invasive alien earthworm species, slugs and micro-fungi living in the soil or on the soil surface. Documentation of biodiversity change is strongly determined by the objectives of the documenting person and institution, whether the objective is to exploit, manage or conserve biodiversity, to catalogue it, or to use the documentation to improve our understanding of how nature works.

Ecologists and some other experts managing biodiversity, e.g. some farmers, foresters, fishers may seem to be the key experts in understanding and documenting biodiversity change. However, almost every person has the ability and often the intention to 'monitor' changes in his/her environment, including changes in species populations, ecosystem structure and function and landscapes or higher-level changes in our biosphere. The indicators we use are, of course, often determined by our interests, so we usually only perceive a small portion of biodiversity change, sometimes key aspects (cf. cultural keystone species), in other cases only the ones may be relevant to a given stakeholder (e.g. scientist) without broader implications for others. That is, biodiversity specialists and marginalized social groups may have hardly overlapping knowledge of biodiversity change or/and values about nature, which is often a major source of conflict and misunderstanding (see below). Just to mention some highly different groups: hobby naturalists, traditional herders, children, people living with autism, or space-based multi-generational forest engineers.

To cover the key features of biodiversity efficiently, a diverse group of scientists recently developed the concept of Essential Biodiversity Variables (EBVs) (Pereira et al. 2013). EBVs form a putative set of parameters intended to be the minimum set of broadly agreed upon necessary and sufficient biodiversity variables for monitoring, researching, and forecasting biodiversity change. The six classes are: genetic composition, species populations, species traits, community composition, ecosystem structure, and ecosystem function. Developing such practical approaches to identifying key features that can then be turned to indicators is critical and there is a demand from policymakers at different jurisdictional levels, including national and sub-national levels, for more pluralistic perspectives on biodiversity and to synthesize different types of actionable biodiversity knowledge, despite the challenges to bridge across conflicting goals of and values associated with (Soto-Navarro et al 2021). All of these will be relevant in one or more of our BIOTraCes case examples, though local conceptualizations of these variables may deviate from the ones above. However, we must keep in mind, that there are cultures and worldviews that also take other 'nature' variables as crucial, for example, spirituality and sacredness of species, forests and mountains.

Understanding the status and dynamics of an ecological (or social-ecological) system is impossible without the detailed knowledge of its past. Better understanding of the past also improves our predictions, for example, about the regenerative capacity of the local system, which are essential for meaningful biodiversity innovations and improved biodiversity governance. For a detailed reconstruction of the ecological history of a site we need to reconstruct 1) the particular ecological events over time, since these can influence the subsequent trajectory of the system (priority effects, natural and anthropogenic legacies and disturbances, path dependence); and 2) past constraining or enabling conditions, external to the system, since these can affect its performance (boundary conditions) (Pickett 1989, Biró et al. 2024). Human land use has modified our ecosystems since prehistoric times, and its impacts, as historical legacies, can often be recognised even after a long period of time, centuries or millennia. Identifying these legacies can help us understand the origins of many ecological features and processes and the drivers of recent changes. Legacies are ecosystem characteristics, elements, features, ecological patterns and processes detectable in the landscape as impacts of a former, but generally discontinued habitat management practice or disturbance (Perring et al., 2016; Saatkamp et al., 2021). Unexpectedly, these legacies are often underestimated and not taken into consideration during the planning process of future actions (e.g. biodiversity management). However, studying legacies can help understand the manageability of local nature, the causes of low or high species richness, and also the dynamics of power imbalance between species or species groups (e.g. native and invasive species).

Time lags are common in ecological systems. Ecological time-lags relate to the rebalancing of a system following a perturbation. For species, populations and communities this may take the form of an 'extinction debt' following a negative change (e.g. habitat loss, habitat degradation, invasive species, fire and climate change) in which species do not disappear immediately but respond after a considerable delay (Watts et al. 2020). In contrast, a 'colonisation credit' (also referred to as an 'immigration' or 'species' credit) is a delayed species response to conservation interventions (e.g. restoration of degraded habitat, habitat creation or actions to improve connectivity between isolated fragments). Lack of certain functional groups (e.g. large grazers and top predators) from the local species pool may pose serious barriers to or slow down change, while species poorness can lead to lock-ins where even decreasing anthropogenic pressure will not initiate regenerative processes, the system is stuck in a species poor, structurally and functionally simple phase. In this later case colonizing invasive species may spread quickly and become 'overdominant' on the site. Rare events may substantially impact ecological trajectories, however, because they are rare, they can easily be overlooked. It may be worth to listen carefully to elders of both the expert and lay society, because they may have deeper understanding of rare events. Slow changes may also be difficult to perceive, both for experts and the public.

Below we summarize some of the key approaches and methods that can be used to document biodiversity change and their direct drivers of change. The list and the descriptions are far from being comprehensive but can serve as an introduction to help the selection of methods that are most suitable for certain situations (e.g. case examples in BIOTraCes). The approaches and methods can be grouped in many ways, we focussed on the main information sources and also discussed the advantages and limitations of the approaches and methods, including their potential usefulness for BIOTraCes case examples.

3.1.1 Methods to document biodiversity and their direct drivers

<u>Field-based, on-the-ground methods</u>

The basic ecological information sources for understanding biodiversity change, and in general the ecological subsystem of a social-ecological system are the populations and ecosystems of the study area themself. We need to have an overview of what species and what ecosystems are present (or missing), we need to 'read' the landscape, understand the history of natural and anthropogenic disturbances, identify historical legacies and time lags that still impact ecological change, estimate the regenerative potential of local nature, and develop hypotheses (or a model) about the functioning of the local ecological system.

Classical botanical and zoological survey methods used for documenting biodiversity change are usually based on estimating the quantity and spatial-temporal distribution of individuals belonging to a species (or species group), or on mapping the extent, spatial distribution and quality (e.g. conservation or 'health' status) of ecosystem, habitat or landscape patches and types. Changes can be quantified and analysed if surveys from two or more time periods are available.

The main limit of these field survey-based methods is that they require a deep knowledge of hundreds of species and tens of ecosystem and habitat types. Many of these methods are also time consuming and consequently expensive. These limitations led to a biased understanding of biodiversity change across taxa and regions, where changes of less salient species groups and more distant, difficult to access places are less documented. Citizen science can be used effectively mostly only for widely known taxa (e.g. birds, plants, some pollinator groups, mushrooms) or to collect specimens from diverse places to be identified subsequently by specialists (e.g. mosquitos, ticks).

Field experiments are vital tools to increase our understanding of biodiversity change and change in function, as controls and different treatments can be compared. However, experiments also have limitations, they can under- or overestimate changes and impacts (Kröel-Dulay et al. 2022). A special type of experiment is the 'experiment-by-chance' where information from different sites is compared where the difference of site conditions and site histories can be deeply documented (e.g. arable lands abandoned in different periods of the past). 'Experiment-by-chance' is especially useful to understand longer term changes (usually across decades) for which controlled experiments are missing or only cover shorter time periods.

Novel technical developments can substantially contribute to a better monitoring of biodiversity change. For example, camera traps open up a new horizon of information gathering, making the observation of nocturnal and shy species (e.g. wolves, beavers) or the behaviour of wild animals (e.g. chick feeding in nests) easier (Steenweg et al. 2017). Citizen science can be used, for example, to scan 'millions' of hours of recordings for rare events (e.g. when chicks are killed by their own parents). Another new promising technique is soundscape analysis, where sounds are recorded, and the presence of certain species is identified based on their sound (Alcocer et al. 2022). Environmental DNA (eDNA) techniques are developing unbelievably rapidly, for example, it is now possible, to list nematode species that live in a fly individual. However, using eDNA for biodiversity monitoring needs further development as abundance estimations are (and the monitoring of other key biodiversity attributes) still limited (Deiner et al. 2021).

Remote sensing analysis

Remote sensing technologies (e.g. aerial photography and satellite images) contributed to a revolutionary step in documenting our biosphere and its changes. These techniques are mostly used to map land-cover categories, ecosystem types (e.g. little disturbed forests), landscape-scale habitat mosaics and its changes; land-use changes (incl. intensity change); biomass production and its change; and even the change of individual trees, populations of some salient species, small water bodies etc. (depending on resolution).

Aerial photos are available since the pre-II World War period for most European regions and make time series analysis of landscape change possible. The key limitation is that most photos are black-and-white, and available irregularly, often only at the decade time scale up until recently. Drone technology provides a new tool for aerial photography. The main advantage of drones is that they can be easily and cheaply used to make local aerial photos at different heights, and monitor changes at fine temporal and spatial scales (especially when videos/photos are georeferenced).

The first satellite images were American and Russian spy images in the 1960s, some of which recently became openly available (e.g. USGS Corona). LANDSAT, SPOT and the recently launched European Sentinel satellites provide unimaginable amount of information about recent changes of the Earth surface. Satellite images are useful for a large variety of objectives. However, their analysis may need special expertise (e.g. special analyses with specific software, e.g. automatic segmentation). A diverse set of proxies (e.g. NDVI) help estimate vegetation/landscape features that would not be possible without satellite images. However, advocates tend to overvalue the usefulness of remote-sensed materials for the monitoring of biodiversity change, but expectations may fail if the wished indicator is not deductible from these materials (e.g. umbrella and keystone species, species composition, species richness, naturalness, habitat suitability for certain species). Ground-truthing is still vital in most cases. GoogleEarth and BingMap made real-colour images easily accessible for the wide public and this has generated an unprecedented increase of knowledge on landscape changes among the public. We do not, however, know yet any citizen science project that explicitly utilizes this opportunity to monitor biodiversity change.

The LIDAR technique (Light Detection and Ranging that uses light in the form of a pulsed laser) can provide gap filling information on the surface of the ground (often hidden for aerial photos and satellite images under dense vegetation cover), and reveal historical changes of a site (e.g. earlier settlements, channel networks in present-day high nature-value forested landscapes and cultivated lands).

<u>Map analysis using recent and historical maps</u>

Maps are spatial models of the geographical reality. All maps have a thematic focus, and reflect the interest, expertise and knowledge of the people who prepared them, and their usefulness for monitoring change can vary substantially.

Species distribution maps can be used to monitor range reductions and extensions (e.g. caused by changing environmental conditions), however, maps that provide quantitative information on local abundance of species are still fairly rare, mostly only available for the most salient species groups (e.g. birds), some specifically studied taxa (e.g. rare and threatened species), and densely populated regions (e.g. large parts of Western Europe). Nature 2000 species have a rapidly improving documentation, but the reliability of these maps changes considerably across countries.

Ecosystem and vegetation maps are useful tools to monitor spatial changes of landscape pattern. Their thematic resolution is diverse, from coarse land-cover types to phytosociological subassotiations. The key challenge of these maps is the subjectivity of the delineation of 'homogenous' patches and their attribution to one or more categories of the classification system. Subjectivity can be so high (>50%), that it prevents the proper monitoring of change (Takács and Molnár 2009).

There are many other thematic maps that document our environment, many of which has direct or indirect information on biodiversity and its change (e.g. soil maps, hydrological maps). Some of these maps provide relevant information on drivers of biodiversity change (e.g., on soil acidification, drainage)

Historical maps are vital sources to understand longer-term changes of ecosystems and landscapes, in Europe back to the 17-18th centuries. Their spatial precision and thematic resolution is diverse, but 'all historical maps are useful for something'. The iterative information transfer and enrichment of maps is a promising novel technique (Biró et al. 2018), that can substantially increase the usefulness of historical maps. During the iterative process, information from a map source (e.g. soil map, aerial photo) is used to improve the information content or the spatial resolution of another map source (e.g. an 18th century military survey). The higher knowledge the interpreter possesses on the area's biodiversity and its potential changes and drivers, the more information can be gained from the analysis of historical maps (Biró et al. 2018). Furthermore, combining map analysis with direct field surveys can considerably improve the reliability of the documentation of biodiversity change (Wulf et al. 2010).

<u>Use of modelling</u>

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Modelling is another useful tool to understand biodiversity change and to assess and predict the impacts of drivers. Modelling can address different biological levels, such as, individual-level models and evolutionary adaptation models, species- and population-level models, community-level models, ecological interaction networks and ecosystem-level models and integrated assessment models (IPBES 2019). However, the use of models for the above objectives is still challenging, because biodiversity and ecosystem dynamics are inherently complex, and the cause-effect relationships are often not sufficiently known, while in models the complexity has to be reduced to a few, hopefully, meaningful dimensions. Non-linear system changes and tipping points are also challenging to be modelled.

A special types of models are the potential vegetation models (Somodi et al. 2017). These models predict the potential vegetation of a site that fits the present abiotic conditions. That is why these models provide useful reference for any further biodiversity enhancement activity.

Use of government and other reports, inventories, statistics

Grey literature produced by different agencies, companies and ministries can be important sources of information on biodiversity change and its drivers, especially documents directly documenting elements of biodiversity (e.g. Natura 2000 reports, environmental impact assessments, forestry maps and databases). Other documents on the changes in our environment (e.g. Water Framework Directive management plans and reports) may also contain relevant information on biodiversity change and its drivers. National statistics are usually poor in biodiversity data.

3.1.2 Sharing perceptions and understandings of biodiversity change and its drivers among stakeholders (incl. experts and the public)

Almost everyone has some level and type of knowledge on biodiversity change, and sharing these knowledges can substantially increase our common understanding of changes in nature and biodiversity. These knowledges are often person or place specific, because they depend on the person's everyday life, interest, skills, memory associated with specific places. The lifespan of humans as 'data gatherers' and 'analysts' (<100 years) and the size of humans as 'observers' (<2 metres) may heavily influence the spatial and temporal scales at which we perceive changes and their drivers.

Some people have deeper understanding, others who are not so much interested in (even neglect) nature, may have shallow knowledge and an unreliable understanding of biodiversity change, its drivers and how local nature works. Disconnection of people (incl. researchers) from the year-round cycle of nature may also limit the understanding of nature. On the other side, repeated visits to a given site, even without conscious observation, can lead to a rich and complex perception of local biodiversity change and to a considerable understanding how local nature works. The more observant a person is and the better memory he/she has, the more precise and reliable information may be available for sharing. Citizen science and Participatory Action Research methods can be able to collect much of this information. Whose voice and knowledge should be heard in a specific case, and how we can deal with unreliable or distorted information is a key challenge during sharing.

Indigenous Peoples and traditional local communities (IP&LC) still often rely directly on nature and their worldviews are typically pluri-centric, implying that people and nature are often seen as a whole or unity (Pascual et al 2023). This implies deep interconnectedness and requires the continuous monitoring of the state and interconnectedness between culture and the environment (Berkes 2017). Informal monitoring of natural resources is based on locally developed indicators (similar or not to scientific indicators) filtered by the main characteristics of the environment, livelihood, and cultural background. IP&LCs often possess a deep understanding of local nature. Knowledge of IP&LC belongs to another knowledge system (different from the so-called Western Science). However, and despite being firmly recognized in international instruments for biodiversity conservation, this knowledge is often invisible to scientists seeking to understand how managed ecosystems and organisms function, and how to ensure biodiversity conservation and sustainable use in such ecosystems. The lack of recognition and understanding of this knowledge, due to epistemological issues deeply rooted in the history of scientific disciplines as well as social stigma as irrelevant, has often made it difficult for scientists to create fruitful partnerships with IP&LC knowledge holders (Molnár et al. 2023).

Understanding each other's knowledge about nature may efficiently help collective actions towards a nature-positive society. There are, however, many challenges of sharing information on biodiversity change and its drivers between people. This implies the need to mobilise, translate, negotiate, synthetise and apply (often very) diverse knowledges (Tengö et al. 2017). Mobilise means to bring out and articulate knowledge into a form that can be shared with others; translate implies interactions between knowledge systems to enable mutual comprehension of the shared knowledge; negotiate means joint assessment of convergence, divergence and conflicts across knowledge contributions, whereas other may remain contradictory; synthesise concerns shaping a broadly accepted common knowledge that maintains the integrity of each knowledges, rather than 'integrating' them into one common understanding; apply emphasizes knowledge usable for decision making for all actors involved, at different scales, that can feed back into respective knowledge system.

For sharing data, information and knowledge on biodiversity change and its drivers, we can use, among many other approaches and methods, face-to-face interviews (incl. oral histories and specialist expert interviews), online or paper-based questionnaires, and especially participatory action research (PAR) methods, including various indoor and outdoor exercises.

The expertise of the persons who are leading the interviewing or the participatory action research or designs questionnaires may have a substantial impact on the outcomes of the knowledge generation, knowledge co-production process. Natural scientists with limited understanding of the behaviour of the social subsystem and social scientists with limited understanding of the behaviour of the ecological subsystem, may limit the complex holistic understanding of the local social-ecological system. Both ecologists and social scientists need to familiarize themselves more deeply with the methodologies of the other sciences, further develop their links with each other, and adopt new approaches in their research to avoid narrow focusses and paradigm blindness. Reciprocal learning, co-learning, reflexive monitoring, and knowledge co-production are further efficient methods to increase common understanding and the knowledge base for action for a transformative change.

The reliability of knowledge shared among the participants of a discussion is far from trivial. Established trust can efficiently increase honesty and decrease information distortion and unnecessary conflicts around the table, while political correctness may decrease honesty. The constitution of the group of participants, identification of the people who will provide information need to include a prior reflection on the mechanisms of inclusion and exclusion to guarantee the participation of people who are often excluded or invisible. Power imbalances can affect what information is shared, when and with what level of detail and honesty. The shifting baseline syndrome may impact the perception of change, its speed and drivers, by changing the past reference to which changes are compared to by the younger generations. Shifting baselines can also impact researchers' perceptions. Secrets, classified and other undisclosed decisions (e.g. around conflicts) at multiple levels, from local and national to EU-level and global, on knowledge sharing is often not known, though may substantially affect conclusions and the efficiency of planned action. The impact of the mainstream media may also have a difficult-to-entangle impact not only on shared information but also on scientific research and conclusions (c.f. the ‘overdominant’ attribution of changes to climate change).

3.1.3 Combination of approaches and methods in BIOTraCes

As all above described approaches and methods have their own limitations, a combination of methods specific to the needs of our case examples in BIOTraCes is suggested. Because we are working with the framing of social-ecological system, a close collaboration between locals (representing different sectors of society, such as the political, economic, cultural and educational sectors, or population groups such as the Roma, the elderly, children and young people, farmers, etc.) and researchers, specialist experts and decision makers, social and natural scientists is crucial. This also includes the involvement of people who are able to efficiently bridge these different stakeholders and rightholders as participating groups during the in-door and out-door discussions.

Last but not least, acknowledging the diversity of perspectives, values and interests within BioTraCes is the way for fair and effective decision making within the project. Through this collaborative approach, we aim to bridge the gap between various forms of knowledge, from traditional wisdom to scientific expertise, creating the foundation for informed decision-making. This inclusive process is expected to not only enhance our capacity to address environmental challenges but also to strengthen the shared responsibility of caring about nature, as a common good (local-to-global). It is a common good that is formed through the collaborative efforts of community members, as they strive towards the promotion of human flourishing and human dignity (Fremeaux & Michelson, 2017), as well as the care for other living forms even at a planetary level (Rockstrom et al 2024).

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4. Causes and underlying causes of biodiversity loss

4.1 Causes, drivers (based on IPBES 2018, 2019)

Direct and indirect drivers (based on IPBES 2018, 2019)

Biodiversity change is driven by direct drivers, like land-use change, climate change, the spread of invasive alien species, overexploitation of species and ecosystems, and pollution (IPBES 2018, 2019). Indirect drivers (Table 4.1, 4.2), such as institutional, demographic, economic, cultural & religious, and scientific & technological drivers, underpin the direct drivers of changes in biodiversity and nature's contributions to people (ecosystem services). Direct drivers (Table 4.3) are the result of human interactions with natural processes that directly act upon biodiversity, including ecosystems, by altering natural processes, while indirect drivers are structures and processes governing the human interactions, thereby influencing direct drivers. So, while we would consider climate and weather, habitats, and species' dispersal and range dynamics to be natural processes, anthropogenic climate change, land-use change and invasion by alien species reflect the human influence on climate, land use and biodiversity dynamics, respectively.

Table 4.1 Different categorizations of indirect drivers (from IPBES 2018)

UNESCO1	IGBP-IHDP2	EU3	MA 2005a	IPBES
Socioeconomic	Economic	Economic	Economic	Economic
Policy	Policy/Institutional	Institutional	Socio-political	Institutional
Cultural	Cultural	Sociocultural	Cultural & religious	Cultural & religious
–	Demographic	Demographic	Demographic	Demographic

Table 4.2 Categories and subcategories of indirect drivers that underpin direct drivers of change in biodiversity and nature's contributions to people (ecosystem services) (IPBES 2018)

Institutional	**Economic**	**Demographic**	**Scientific & technological**	**Cultural & religious**
• Regulations • Institutional capacity • Environmental policy integration • Political/armed conflicts	• Material intensity of GDP • Globalization • Taxes and subsidies • Environmental fiscal reform	• Population growth & density • Urbanization • Migration	• New technologies • Innovation	• Public awareness, knowledge • Values, beliefs, social norms • Lifestyle, consumption • Social capital • Cultural capital

Table 4.3 Categories and subcategories of direct drivers of change in biodiversity and nature's contributions to people

Natural resources extraction (overexploitation)	**Land-use change (intensity change and use-type change)**	**Pollution**	**Climate change**	**Invasive alien species**
• Fishing • Hunting • Gathering of wild plants, animals and fungi • Water use & desalination • Mineral & fossil fuel extraction	• Changes in agriculture • Changes in forestry • Changes in protected areas • Changes in traditional land use • Changes in urban development	• Nutrient pollution • Organic pollution • Acidification • Xenochemical & heavy metal pollution	• Temperature change • Precipitation change • Sea-Level change • Glaciers & permafrost • Extreme events • Marine circulation and deoxygenation • Atmospheric CO_2 concentration	• Terrestrial • Freshwater & Brackish • Marine

The distinction between "indirect" and "direct" drivers was popularized by the Millennium Ecosystem Assessment (MEA, 2005) and this classification still dominates the discussion on ecosystem change (e.g. Pereira *et al.*, 2010). The older DPSIR terminology (drivers, pressures, states, impacts, responses), popular in Western Europe (Stanners & Bourdeau, 1995), divided drivers into "driving forces" and "pressures", with the former corresponding to indirect drivers and the latter corresponding to direct drivers of the Millennium Ecosystem Assessment (Tzanopoulos *et al.*, 2013).

Authors often distinguish natural and anthropogenic direct drivers, and study them separately. However, analytically it is sometimes difficult to distinguish whether an element (process, factor, driver) belongs to the natural or the human system. Biogeophysical processes and factors such as volcanic eruptions, tsunamis, El Niño, solar radiation, or storms, are natural and they influence all elements of life on Earth. To unequivocally disentangle natural variability from anthropogenic drivers is often difficult. Human impacts now affect more than half of the Earth's ice-free terrestrial surface (Ellis *et al.*, 2010) and humans now exert a dominant influence on key Earth system processes and on ecosystem change and biodiversity loss (Newbold *et al.*, 2015). Most drivers impacting biodiversity loss are anthropogenic or at least anthropogenically influenced drivers.

Some scholars call indirect drivers "underlying drivers" (van Vliet *et al.*, 2015), "underlying causes," "fundamental social processes" (Geist & Lambin, 2002). Hence, there are different attempts to conceptualize indirect drivers (Table 4.1). If indirect drivers are the underlying causes of, for example, land-use change or pollution, then the tangible results of human activities can be seen as direct drivers, or "proximate causes". For example, for deforestation, proximate causes can include agricultural expansion, wood extraction or the extension of road infrastructure (Geist & Lambin, 2002).

So-called triggers emerge from indirect drivers and may have dramatic effects on direct drivers. Biophysical triggers include fires, droughts, floods and storms, and social triggers

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including revolution, social disorder, abrupt displacements, economic shocks, and abrupt policy shifts (Geist and Lambin 2002). From a policy perspective, it is important to understand both drivers and triggers, to "accept uncertainty, be prepared for change and surprise, and enhance the adaptive capacity to deal with disturbance" (Folke *et al.*, 2005).

The interaction among indirect drivers is highly complex, i.e. they are hard to trace back to a single point of origin, and their impacts are often reciprocal and not unidirectional. Jointly, indirect drivers impact on direct drivers, which in turn also interact in the way they drive ecosystem change (Fig. 4.1).

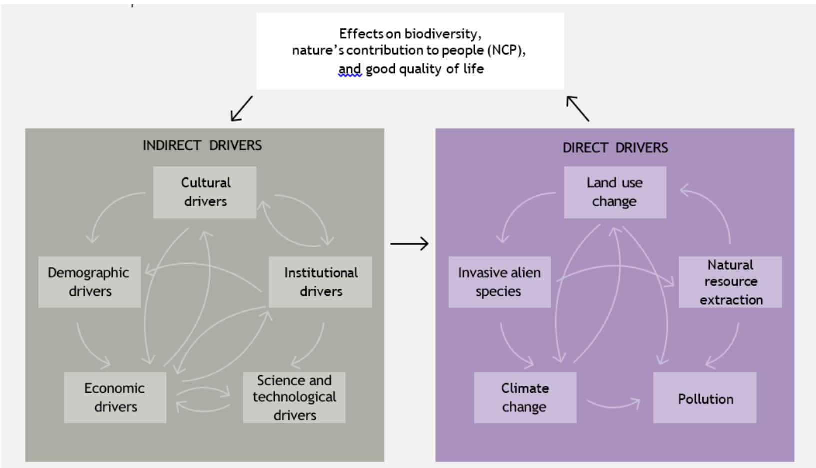

Figure 4.1 Illustration of multiple interactions among indirect and direct drivers within a specific context that have impact on biodiversity and nature's contributions to people. The graph illustrates important links; more are possible. Knowledge and awareness *of changes in biodiversity and nature's contributions to people influence indirect drivers and make adaptations possible (IPBES 2018). Note the single arrow in the middle of the figure symbolizing the 'complex interaction' between indirect and direct drivers.*

4.2 Dominance and scales

<u>Dominance of drivers</u>

As a recent joint review jointly carried out by IPCC and IPBES experts attest, global warming and the increasing frequency and severity of extreme events disturb ecosystem functioning and exacerbate biodiversity loss, on top of (or acting as a multiplier three already caused by human-induced habitat degradation, overexploitation of natural resources, and pollution (Portner et al 2023)). However, this does not imply that climate change ought to be understood and reported as 'the most important' driver of biodiversity change. Based on a global review of literature Jaureguiberry et al. (2022) found, that overall, land/sea use change is the dominant direct driver of biodiversity loss, although it is not significantly ahead of the second-ranked driver, direct exploitation. Both land/sea use change and direct exploitation are significantly dominant over climate change and invasive alien species. The dominance hierarchy of drivers differs significantly between terrestrial, freshwater, and marine realms. Land/sea use change is ranked first in terrestrial systems. While land/sea use change is ranked first and direct exploitation second as a driver of change in species populations, they are, respectively, ranked second and fourth in community composition. Climate change ranks first among the drivers of community composition changes, but last among the drivers of species population changes. Land/sea use change is also ranked as the top driver of changes in ecosystem structure and ecosystem function.

In any case, climate change is probably the most rapidly intensifying threat to biodiversity, and its impacts are increasingly well quantified, but it should not be forgotten that other threats are still doing more direct damage to biodiversity as mentioned above. Hence, combating climate change alone will not be enough to prevent—or possibly even slow—the further loss of biodiversity, unless damaging land/sea use change and direct exploitation are also tackled with similar ambition and determination (Tingley et al. 2013). While quantitative estimates of the impacts of climate change—the driver that is studied most often—show increases over time (Antão et al. 2020) that are projected to continue, similarly robust information is not yet readily available for the less studied drivers. It may even be the case that the impact of land/sea-use change will increase in the future more than that of climate change.

Spatial and temporal scales

Even though the major direct drivers are known, their specific effects and overall trends over time are not always easy to identify, quantify and assess (IPBES 2018). This is primarily due to their high spatial and temporal variability. Some drivers are local in nature (e.g., land-use change and point-source pollution of heavy metals or nutrients), while others are regional (e.g., ozone or atmospheric nitrogen pollution from combustion engines) or global (e.g., atmospheric CO_2 or sea-level rise). Some of these drivers affect all species and ecosystems more-or-less equally (e.g., radioactive pollution), while other drivers affect species and ecosystems very selectively (e.g., nitrogen deposition), and therefore often exert complex effects on biodiversity and nature's contributions to people.

While the effect of some drivers is immediate (e.g. mining), others exhibit significant time lags in their effect on biodiversity and nature's contributions to people. While climate and land-use change and invasions by alien species are steadily increasing, their full effect is often visible only much later, since the biodiversity and ecosystem response is slow. This has given rise to the term invasion debt (Essl *et al.*, 2011) or extinction debt (Dullinger *et al.*, 2012), to express the expected time lags until the full effects of drivers are realized. The many facets of climate change rarely affect species and ecosystems without delay, and the climate itself also lags behind the increase in greenhouse gas concentrations (IPCC, 2014). The same holds true for regenerative changes, including restoration (time lags, unexpected changes, incl. harmful longer-term impacts of well-intentioned actions on biodiversity).

While some effects are steadily shifting (e.g., sea-level rise), others are unstable and show high temporal variability. This is especially the case with climate, which includes changes in mean conditions, time course and extremes (such as heatwaves, drought, fire, floods or winds). The biological response can be linked to the changes in means, time courses and in extremes, and the responses can be gradual, or they can be in the form of tipping points between alternative stable states (Barnosky *et al.*, 2012), which can be irreversible.

Some messages for BIOTraCes regarding drivers

In our BIOTraCes case examples we need to have a deep enough understanding of the impact, the dominance, the spatial and temporal variability of drivers because these may substantially impact which management and governance changes are needed to reach the objectives of the case. All actions have short and long-term impacts, with often unknown time lags, both in the social and the ecological subsystems of the local SES. It is impossible to fully reconstruct the interactions among and between direct and indirect drivers, but we can aim to go as deep as possible. Working with diverse knowledges of different partners, including marginalized voices can help build a more holistic picture of the local SES than usually used in business-as-usual decision making.

4.3 Attribution of drivers of biodiversity change

Cheek et al. (2023) have recently reviewed qualitative attribution methods, especially those that are highly relevant in the biodiversity conservation literature. They have emphasized that the critical first step in using qualitative attribution methods is to develop an explicit causal model. Causal models (also referred to as theories of change, logic chains, causal chains, or mental models) delineate the causal linkages between the inputs, outputs, and outcomes of an intervention and state the assumptions that support the causal pathway (Biggs et al., 2017; Kimmel et al., 2021). Causal models have generally been used as a planning tool, and government organizations and funders are increasingly requiring practitioners to develop causal models.

4.3.1 Casual Process Tracing

Causal Process Tracing is the systematic examination of the mechanisms linking causes to effects within single case studies (Collier, 2011). This method is almost identical to General Elimination Methodology (Salazar et al., 2019), which was developed independently. General Elimination Methodology has been specifically used in conservation research (Salazar et al., 2019). The process tracing approach enables understanding of the causal processes through which interventions generate impacts by validating theorized causal connections based on evidence. This approach requires sufficient understanding of the history and key elements of the system to identify potential causal pathways as well as significant time and resources to collect and analyze primary and secondary data.

Process tracing (Corrier 2011) is an analytic tool for drawing descriptive and causal inferences from diagnostic pieces of evidence— often understood as part of a temporal sequence of events or phenomena. Causal process tracing is particularly well suited to answer 'why' and 'how' questions because it focuses on the causal conditions, configurations and mechanisms which make a specific outcome possible. Given the close engagement with cases and the centrality of fine-grained case knowledge, process tracing can make decisive contributions to diverse research objectives, including: (a) identifying novel political and social phenomena and systematically describing them; (b) evaluating prior explanatory hypotheses, discovering new hypotheses, and assessing these new causal claims; (c) gaining insight into causal mechanisms; and (d) providing an alternative means—compared with conventional regression analysis and inference based on statistical models—of addressing challenging problems such as reciprocal causation, spuriousness, and selection bias. Thus, qualitative tools can add leverage in quantitative analysis. They can also strengthen causal inference in small-N designs based on the matching and contrasting of cases—designs which have great value, but whose contribution to causal inference urgently needs to be supplemented by within-case analysis.

The method of process tracing is especially suited when it is impossible to control for intervening variables, i.e. when causality is complex (Goldstone 1991). Complex causality is characterised by low proximity (many intervening variables between cause and effect), high multicausality (many variables operating together to produce the outcome), interactivity (none of the causes alone is sufficient to produce the outcome), non-linearity (a process exhibiting threshold effects) and equifinality (the same cause is linked to the same outcome through different causal mechanisms depending on the contextual conditions present) (Boonstra et al. 2023).

Process tracing requires finding diagnostic evidence that provides the basis for descriptive and causal inference. How does the researcher establish that a given piece of evidence is diagnostic? Identifying evidence that can be interpreted as diagnostic depends centrally on prior knowledge. Four interrelated types of knowledge are distinguished (based on Waltz 1979).

Conceptual Frameworks. A first type of prior knowledge involves sets of interrelated concepts, often accompanied by general ideas of how the concepts can be operationalized. These frameworks thereby identify and link the topics seen as meriting analytic attention. The framework often points to the counterfactuals that conceptually establish what it means for a given phenomenon to be absent.

Recurring Empirical Regularities. These are established patterns in the relationships among two or more phenomena (a relationship that has been found repeatedly).

- Theory-I. This builds on these recurring regularities by more tightly connecting them as a set of insights into "a particular behaviour or phenomenon". Here researchers seek to build theory "by collecting carefully verified, interconnected hypotheses."
- Theory-II. A final type of prior knowledge entails not only interconnected empirical regularities (Theory-I), but also a set of statements that explain them, that is, offering explanations of why these regularities occur. Theory-II may also be called an explanatory model.

Blatter and Haverland (2012) distinguish three types of causal-process observations.

i. A small-N study based on Casual Process Tracing should provide a 'comprehensive storyline' in which the development of potentially relevant causal conditions is presented in a narrative style. A major goal of these comprehensive storylines is to differentiate the major sequences of the overall process and identify the critical moments that further shape the process.
ii. The study should also provide more detailed insight into the causal processes that occur at critical moments. The most important goal is to find empirical evidence that provides a high level of certainty that a causal factor or a combination of causal factors actually led to the next step in the causal pathway or to the final outcome of interest. In other words, we attempt to find smoking-gun observations embedded in a dense net of observations that show the temporal and spatial proximity of causes and effects.
iii. In order to gain 'deeper' insights into the perceptions, motivations and anticipations of major actors, we need further observations that we call 'confessions'. We should carefully examine the contexts in which actors provide information about their perceptions, motivations, and anticipations. We should be aware of typical biases with respect to motivations when we interpret the statements of actors in specific contexts. Empirical observations alone are never sufficient for drawing inferences. They have to be complemented by and interpreted with the help of further logical and theoretical tools. Crucially important is the insight that counterfactual reasoning requires a solid and comprehensive knowledge of the historical process that we want to 'rewrite' in our thought experiment.

As a tool of causal inference, causal process tracing focuses on the unfolding of events or situations over time. Yet grasping this unfolding is impossible if one cannot adequately describe an event or situation at one point in time. Hence, the descriptive component of process tracing begins not with observing change or sequence, but rather with taking good snapshots at a series of specific moments. To characterize a process, we must be able to characterize key steps in the process, which in turn permits good analysis of change and sequence.

Qualitative tools such as process tracing can address some challenges faced in quantitative analysis, but process tracing faces serious issues in its own right. Doubts may arise as to which causal-inference test is appropriate. The analysis may face standard problems of missing variables. Measurement error can also be an issue, and probabilistic relationships are harder to address than in quantitative research.

4.3.2 Analysis of Path Dependence

Path dependence and lock-in effects are important factors that affect the long-term consequences of present decisions and may lead to inefficiencies (North, 1991). The concept of path dependence typically is used to describe situations where history, i.e. previous conditions, strongly influences present decisions (Liebowitz and Margolis, 1995). The term lock-in has been used to explain that an earlier decision provides strong incentives to follow a particular path –to be locked-in in that path - even if more efficient alternatives are available later (David, 1985).

Institutions or technologies tend to become committed to develop in certain ways as a result of their structural properties or their beliefs and values (Britannica by I. Greener). As a theory, path dependence is based on the straightforward assumption that "history matters." It attempts to explain exactly how history matters through studies of how constraints on normal behaviour appear and of the form that those constraints take. Path dependence is often used in studies based on the historical-institutionalist approach to political science, which focuses on how institutions come to constrain organizational life. It has become a key concept in explanations of why institutions in political life do not change as much as might be expected. Path dependence tends to suggest that policy makers work within a series of limited assumptions about their world, that they frequently fail to learn from past experience, and that they emphasize caution in their decision-making processes.

A system (e.g., an institution or a technology) can be shown to be path-dependent by identifying three essential elements.

i. It must be demonstrated that, at the creation of the institution or technology under study, a contingency or series of contingencies occurred that led to the selection of one outcome over another, which, given another set of initial conditions, might have led to another outcome having been selected instead. In other words, there must be a strong element of contingency in the model; chance can end up as a deciding factor.
ii. It must be demonstrated how a new technology or organizational form becomes insulated to some extent from change. The factors involved in that insulation, or feedback mechanisms, may be positive (supporting advocates of the path-dependent institution or technology) or negative (interfering with attempts at change from advocates of alternative institutions or technologies). The feedback mechanisms that lock in the system under investigation along a particular path might be either cognitive or institutional. In the former case, policy makers come to see the world only through the perspective of a particular idea, ignoring elements that do not conform to it. In the latter case, properties of institutions constrain actors within them so that they are unable to act in particular ways, even if they are not subject to cognitive limitations. The foregoing is not to suggest that path-dependent institutions are "stupid"—i.e., unable to react to changes in their environments in rational ways. Rather, their behaviour may be extremely sophisticated, in certain ways, but only within defined behavioural limits. Path dependence suggests that human behaviour has limits, both cognitive and institutional, which have profound implications for politics and decision making in general.

iii. It must be demonstrated how change within a path-dependent system is possible, given the feedback mechanisms identified in the second stage of the analysis. For example, the analyst might examine the system under investigation for contradictions or problems that might eventually lead to the establishment of a new policy or technology pathway.

4.3.3 Some other qualitative attribution methods (based on Cheek et al. 2023)

Contribution analysis: Contribution analysis explores the potential contribution of an intervention to an outcome while accounting for other causal factors (Mayne, 2001). It centers on the development and verification of a theory of change and focuses on the question of what contribution an intervention has made to an observed outcome. This method is similar to Causal Process Tracing and has similar limitations. In addition to identifying causal mechanisms like Casual Process Tracing, Contribution analysis also includes analysis on how important the mechanisms are relative to one another or other contextual factors.

Realist evaluation: Realist evaluation is based on a philosophy of "scientific realism," and it is used to identify the process(es) through which an intervention leads to an outcome by developing and testing theory (Blamey & Mackenzie, 2007). It differs from the methods above by emphasizing that interventions necessarily interact with contextual factors to generate outcomes. Using Realist evaluation, impact assessment must consider such interactions to draw conclusions about "what works, where, how, and for whom." Did a given intervention cause an observed outcome in a particular circumstance? Why or why not? Where else and for whom might the intervention work and why? Understanding contextual factors that influence an intervention requires deep knowledge of the study site, which requires time and different types of information and data.

Qualitative comparative analysis: Qualitative comparative analysis is a comparative method that bridges qualitative and quantitative research by exploring causality across a "medium" number of cases (i.e., more than a few cases but less than the large number required for statistical analysis) (Ragin, 1999). Drawing largely (though not exclusively) from qualitative methods, Qualitative comparative analysis is a systematic cross-case analysis that aims to answer: What combination of causes and underlying conditions led to the observed outcome(s) across cases? A limitation is that this method requires enough relevant cases to capture the variation of underlying conditions.

Most significant change: Most significant change is a participatory monitoring and evaluation method in which stakeholders report on significant changes they perceive during and after an intervention (Sawrey et al., 2019). This method is unique in emphasizing participant perspectives on key changes in their lives and why they occurred. Most significant change starts by asking what significant changes occurred in the lives of residents and participants since an intervention was implemented and then draws on narratives provided by these individuals to answer why and how those changes occurred. This method requires significant time in the community to build trust and solicit stories from different stakeholders. Because most significant change builds on collecting diverse perceptions, this method has the weakest potential in establishing causality.

4.3.4 Quantitative attribution of direct drivers of biodiversity change

Attribution of direct drivers to biodiversity change is also a huge challenge. Gonzales et al. (2023) in their recent review advocate applying the principles of causal analysis and causal networks as the basis for the analyses in the next steps of the framework (Grace & Irvine 2020, Kimmel et al. 2021, Arif et al. 2016).

A causal network diagram describes the relationship between the putative causal factors hypothesized to drive biodiversity change. It can be seen as a non-parametric structural equation model that explicitly lays out directed paths between variables, but the form of the relationship between two variables does not matter, only its direction. A causal analysis is the logical approach to assessing the influence of different direct and indirect relationships among the multiple potential interacting factors, typically a suite of natural and human direct drivers. Potential causal links in a model can be derived from expert knowledge and findings from controlled experiments and theory (step 1).

The collection of observations in step 2 should be guided by the hypothesized causal dependence between the drivers and biodiversity variables formalized by the graphical models used for attribution. Historical baselines are needed to estimate the full extent of change in biodiversity over time, but limited data availability at appropriate time scales is a barrier. Temporal baselines set long after the inception of biodiversity change will therefore underestimate the full range of impacts of anthropogenic drivers (Gonzales et al. 2016) (see more in the section on documenting biodiversity loss above).

Attribution is the process of evaluating the relative contributions of causal factors explaining detected biodiversity change with an assignment of statistical confidence. Alternatively, the observed trend is consistent with a process-based model including the hypothesized driver and is inconsistent with a counterfactual case that is otherwise identical but excludes the factor (Hannart et al. 2016, Rasolofoson 2020). When a system model is absent, the attribution step can begin by assessing the relative explanatory power of informal models put down in step 1.

In most cases, the strength and influence of these drivers will vary through time and over space, potentially involving feedback (O'Connor et al. 2021) and causal drivers may be geographically distant from the site where biodiversity change is observed (i.e. tele coupled effects). Three key ingredients of attribution are required: evidence of consistency, evidence of inconsistency, and a statement of confidence. The strength of our evidence of consistency is based on our ability to demonstrate the sign and magnitude of the relationship between cause and effect. Evidence of inconsistency is necessary to avoid confirmation bias (i.e. the tendency to favour information that confirms existing preconceptions or hypotheses, see above the example on overemphasizing the impacts of climate change). Attribution can be done in a single step or involve multiple steps of modelling and hypothesis testing.

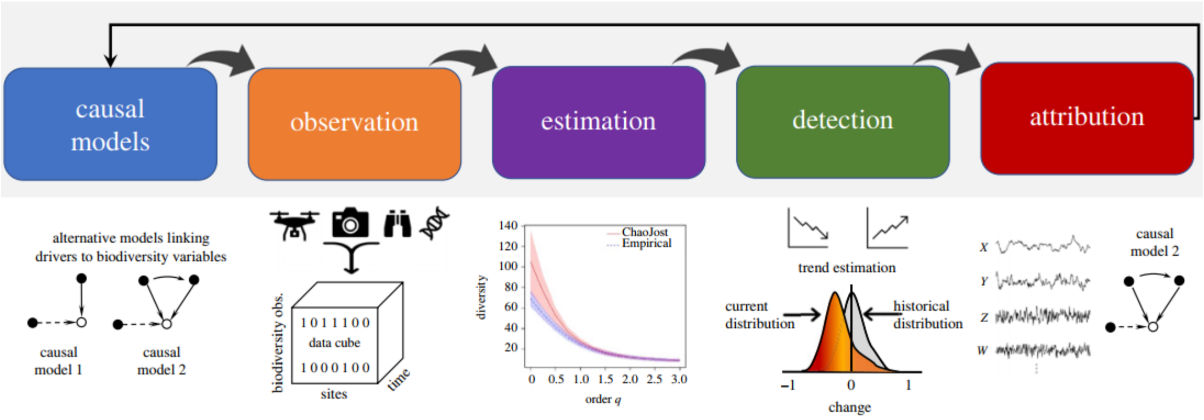

Figure 4.2 The five steps in the detection and attribution workflow (Gonzalez et al. 2023)

Identifying causal networks is important for effective policy and management recommendations. However, it is difficult to distinguish causality from correlation, especially in complex systems (Sugihara et al. 2012). Contradictions arise in many scientific contexts where variables are positively coupled at some times but at other times appear unrelated or even negatively coupled depending on system state. Such state-dependent behaviour is a defining hallmark of complex nonlinear systems. Ephemeral or "mirage" correlations are common in even the simplest nonlinear systems. When this happens, variables that may be positively coupled for long periods can spontaneously become anticorrelated or decoupled; this can create problems when fitting models to observational data.

Despite the fundamental problems raised already in Berkeley's 1710 A Treatise on Principles of Human Knowledge, correlation remains the analytical standard of modern science, although correlation is neither necessary nor sufficient to establish causation. One might conclude, for example, that some variables have no causal relation because they are uncorrelated. Obviously, lack of correlation does not imply lack of causation. Because of this and other reasons, the use of correlation to infer causation is risky, especially as we come to recognize that nonlinear dynamics are ubiquitous.

5. Governance and biodiversity loss

5.1 Political perspectives

Below, we will briefly discuss governance of biodiversity loss because each case within BIOTraces will be embedded in a specific governance context. Any analysis of a case needs to pay sufficient attention to the governance context. Governance of biodiversity loss should be transformative in addressing underlying causes but is still in its infancy (Visseren-Hamakers et al., 2021; Pascual et al 2022). Governance models that use deep leverage points by for instance addressing the plurality of values is increasingly called (Leventon et al., 2021; Pascual et al 2023). The focus here may lie on how in governance knowledge is created and used, how it conceives constraints and enablers, and how governance deals with unfamiliar ideas and initiatives. Inspiring examples may be found outside Europe or on a local scale in (historic) Europe. They will show that other avenues for governance, not necessarily following the path the European SPI has taken, are worth considering. With this, the report pluralizes governance of nature, in which arguments can be found to deviate from path dependent solutions.

Governance includes the political perspectives on the functioning of economy (economic growth paradigm, free market ideal, conceptions of property, etc.) and the protection of nature and its social psychological ramifications for cultural and individual behaviour (consumerism) in general. The fact that there is extensive knowledge about underlying causes of biodiversity loss in the science policy interface does not necessarily imply that it will be accepted and used in a certain governance context. Governance contexts are creating their own understandings if and how nature needs to set limits to economic activities (Beunen & Van Assche, 2013). Often, nature is seen as a constraint or as an interest that needs to be balanced with other interests. Seen in this way, knowledge should be dynamically understood in the process of making, accepting, and rejecting.

Knowledge about natural processes is essential and foundational to political processes regarding the protection of nature, in which institutions play a key role. Knowledge (about nature) is constructed, reviewed, validated, and made relevant or irrelevant in political deliberations. In deliberations in the public sphere one can discern characteristic styles of reasoning, modes of argumentation, standards of evidence and norms of expertise (Miller, 2008). The public sphere comprises a rich and complex array of dynamic interacting spaces within which knowledge is made and deliberated by means of administrative and regulatory hearings and scientific advisory processes, legislative research, and legal proceedings, next to citizens science and activist knowledge (Miller, 2008). The dynamics of knowledge creation can involve intertextuality: texts that lack fixed authorship and meaning, which are nevertheless part of ongoing political transformations (Vargova, 2007). This contrasts the idea of normatively superior and historically privileged authoritative texts, and therefor as such intertextuality may be seen as transformative potential. According to Derrida, intertextuality contributes to an ongoing revolutionary change, that constantly challenges the social status quo and authority in society (cited in Vargova, 2017, p 416). In research on underlying causes of biodiversity loss, adequate attention must be paid to governance texts, discriminating between intertextual and fostering pluralism or authoritative and thus narrowing down the scope of knowledge.

Knowledge on underlying causes of biodiversity loss can be considered irrelevant in political discourses, especially when its foundations are disputed. One striking example of this lies in the effects of nitrogen deposition in nature reserves, caused by industrial farming in the Netherlands. Despite overwhelming scientific evidence and compelling European policies, politicians still try to shovel the matter from the table (Dise, 2011). For many institutions this view on causality lies way beyond their horizon of relevance: the boundaries of the visions at stake. It is important to note here that scientific knowledge doesn’t have the credibility in broader society that it used to have (Sarewitz, 2016; Jasanoff & Simmet, 2017). The idea of science as a domain of autonomous work of researchers with adequate mechanisms of self-regulation becomes more and more disputed (Turnhout, 2016). Despite governance becoming less based on modernist, long-range planning principles, and despite more forms of local knowledge become formally accepted, the dominance of a narrow set of methods stays in place (Van Assche et al., 2022). Quantitative methods dominate, and trust in numbers remains high (Latour, 2004). The current popularity of numbers, modelling and simulation can be understood not only as a response to current overriding concerns such as climate change and biodiversity conservation, but also as an attempt to accommodate the growing internal complexity of governance[2] , where numbers seem to enable synthesis and integration (Van Assche et al., 2022). Pluralism in perspectives on the underlying causes of biodiversity loss runs at odds with this narrow methodological preference. Relying on quantitative factual knowledge blocks the integration of diverse knowledges, necessary for the understanding of a poorly understood phenomenon such as the chains of causes of biodiversity loss. Methodological pluralism can be achieved by embracing coproduction of knowledge (Bell & Pahl, 2018). Coproduction builds on the work of Ostrom and involves various methods of action research and participatory action research as outlined in D 1.3 and 1.4. In a case study analysis one can address the matter of horizon of relevance in terms of causation chains: are they simple straightforward or complex and intuitive? And the subsequent question would be if causes are layered and complex, or restricted to what is considered relevant or legally convincing under the specific political conditions.

When reviewing the governance context of a specific case, one should pay attention to the policy theory at various levels of the high impact sector. The policy theory often remains implicit, is seldomly outspoken, but involves the mechanisms with which economic activities are connected to nature and the basic assumptions about change for the better, a policy is built upon. A widespread opposition nowadays deals with profit or degrowth as a condition for sustainability. This is a clear example of such a basis assumption. Another part of the policy theory deals with the coupling of human and natural systems. Basically, this deals with understanding the environment, culture, and human cognition. The more complexity is accepted in the policy theory, the more open it will be for other perspectives and for bricolage of formal and informal knowledges (Orr et al., 2015; Kimmerer, 2013).

Biodiversity Footprint Assessment Tools

It will be beneficial when focusing on underlying causes of biodiversity loss, not to lose sight at neither get lost in the primary causes. Primary and underlying causes should be related in a causation framework. Without going in the direction of performing an assessment of biodiversity loss due to primary causes, one can easily incorporate or become inspired by existing footprint assessments. Widely used global tools for biodiversity footprint assessments in use are:

- Biodiversity Footprint Financial Institutions (BFFI)
- Biodiversity Impact Analytics powered by the Global Biodiversity Score (BIA-GBS)
- Corporate Biodiversity Footprint (CBF)
- Global Biodiversity Score for Financial Institutions (GBSFI)

Worldwide data can be found in ENCORE: Exploring Natural Capital Opportunities, Risks and Exposure.

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[2] Internal complexity in practice can lead to lengthy negotiations between policy domains (such as water management, agriculture, shipping routes etc), in which it takes so much effort for policy officers and stakeholders to understand one another, that ideas from outside the negotiation arena are automatically set aside.

Environmental impact assessments

An important tool to make well informed decisions that affect nature is the environmental impact assessment. Its regulation is under European law. When reviewing a high impact sector, it will be enlightening to include environmental impact assessments, on various scales. The first question here is if any attention paid to underlying causes of biodiversity loss. The second question is about the concreteness of a policy and on what scale and level of implementation potential effects on nature emerge or are discussed.

5.2 Understanding economic arguments

Each high impact sector is embedded within a web of discourses that aim at gaining advantage over others, often with a set of assumptions and ambivalences about how the economy effects nature and how both depend on each other. In the one hand there is a strong believe in a free market economy with a level playing field (also international), in a need for economic growth and in efficient technical solutions for any sort of problem. On the other hand, in economy the need to become more sustainable is deeply felt. Innovations are seen as a panacea for environmental issues, and transition pathways towards sustainable growth are believed in. Transitioning goes well with control (Stirling, 2015) and with an evolutionary view on economy (Cecere et al., 2014).

In doing case study work one may study the economic arguments why things go as they go, as a discourse within the governance discourse. Economic and governance discourses can be seen as two social systems of communication that are intensely coupled. Ideas, concepts, and reasoning migrate from one to the other. It will be interesting why innovations coming from outside the social system are embraced or rejected, based on how causality is framed within the discourse and how causality outweighs costs, efficiency, trust and so forth.

Understanding economic arguments often means understanding the role of data and legal advocacy. Preferred proof of an economic activity causing biodiversity loss consists of a large database, a simple and not compounded relation between economic activities and species based on science. And when this evidence is delivered, economic actors will typically plea for compensation of their effects by investing in nature elsewhere. This all stands far away from the idea of economic actors influencing the underlying causes of biodiversity loss.

Critical discourse analysis, system analysis and framing will be important to understand processes of marginalization or negotiation. This analysis goes hand in hand with the power analysis, as described in D1.8.

5.3 Social psychological approaches to biodiversity loss

Biodiversity loss induced by human activities is an outcome that arises from people's necessities and lifestyles, including food, shelter, transportation, work, procreation, and recreational activities, often involving the extensive use of natural resources. To understand why societies continue going the way towards biodiversity destruction even knowing about the severe consequences for nature and for themselves (and more often than not, do not hold intentions to destroy nature) calls for analysis of complex socio-psychological systems (Nielsen et al., 2021). As indicated in systems theory **people operate in complex systems** where all elements in these systems depend on each other and are related in intricate causal pathways (Phelan, 1999; Von Bertalanffy, 1972). Likewise, people, due to their psychological, biological, and social idiosyncrasies, participate in and react to these systems and elements thereof in complex ways. **Individual, social**, and **contextual factors** might help to understand these systems and motives why people behave in certain ways towards biodiversity. Depending on their valence these factors can serve as both hindering and inducing forces of behaviours leading to biodiversity loss. The list of factors and their examples provided below is not exhaustive, but they nevertheless pretty well reflect those most commonly mentioned in the literature on antecedents of environmental behaviour (defined as aim to conserving the environment or at least not harming it; Steg & Vlek, 2009).

Individual factors refer to person's features that might be biologically determined or formed over interactions with the environment (e.g., close others, peers, society, culture). The following are the examples of individual factors: personality traits - openness to experience, conscientiousness, extraversion, agreeableness, and neuroticism (emotional (in)stability) (John, 2021); normative f. – environmental values, personal norms to conserve the environment, perceived social norms on how on should act according to important others (Cialdini, 2003; Cialdini & Goldstein, 2004; Steg & de Groot, 2012; van der Werff et al., 2013); identity - environmental (self)identity, connectedness with nature, place identity and place attachment (Altman & Low, 1992; Clayton, 2003; Proshansky et al., 1983; Schultz, 2002; van der Werff et al., 2014; Whitmarsh & O'Neill, 2010); attitudinal f. - attitudes towards wildlife (Kellert 1983, 1996); habitual f. - learned automatic actions in favour (or not) of the environment and nature (Verplanken et., 1997); emotions - feeling good when conserving the environment (Venhoeven et al., 2020), also various perceptions of self (e.g., self-discrepancy from the desired self; Higgins, 1989), learned helplessness (which can hinder environment conservation actions; Landry et al., 2018) and many others.

Social factors refer to the cultural and societal elements such as community, family, peers, romantic partner, cultural norms, social movements, among many others that plays a role in one's behaviours and choices regarding biodiversity conservation. For example, it has been established that children can affect their parents' environmental attitudes and behaviours. Studies have shown that when children are educated about the environment, it not only increases their awareness and motivation but also positively influences their parents. For instance, children's environmental knowledge has been linked to increased parental concern about local environmental conditions (Legault & Pelletier, 2000), improved energy-saving behaviours at home (Boudet et al., 2016), better water-management practices (Damerell et al., 2013), and greater awareness of endangered species (Vaughan et al., 2003). Next, engaging in discussions about environmental topics with others at home, irrespective of their levels of pro-environmental behaviour or concern about the environmental crisis, can motivate people to adopt pro-environmental actions (Lawson et al., 2019; Meeusen, 2014; Longman et al., 2023). Likewise, young people can be inspired by their peers for environmental actions (Wallis & Loy, 2021). Millions of school-aged people took to the streets across the world in 2019 to demand fairer environmental policies. Studies show that those who participated in protests were motivated by their friends, schoolmates and acquaintances (Wahlström et al., 2019). To add, climate marches of 2019 sharply increased societies attention towards climate change across 46 countries (Sisco et al., 2021).

Contextual factors refer to external agents emerging in the environment that do not necessarily directly depend on person affected by these agents. Absence or existence of the relevant infrastructure and access to certain resources/skills, education system, political system or policies that facilitate biodiversity conservation behaviour could be just a few examples of contextual factors. For example, studies show that people are more willing to engage in environmental activism in countries were people trust governments less, density of environmental NGOs is higher as well as levels of democracy (Tam, 2020). Next, systemic environmental education could be one of the key factors leading to consistent engagement in environment conservation (Ardoin et al., 2020; Castiglione et al., 2022; McGimpsey et al., 2023). And conversely, underdeveloped recycling or public transportation infrastructure could lead people to opting for less environmentally friendly behaviours (i.e., less recycling, more frequent use of a car; Chowdhury et al., 2018; Zhang et al., 2016; Rasca & Saeed, 2022).

The role of the above mentioned factors on environmental behaviour is often studied within the certain limited **theoretical frameworks** such as Theory of Reasoned Action (Fishbein & Ajzen 1975), Theory of Planned Behaviour (Bamberg et al., 2023; Ajzen, 1991), Norm Activation Theory (Schwartz, 1977; Schwartz & Howard, 1981), Value-Belief-Norm Theory (Stern, 2000), Comprehensive Action Determination Model (Klöckner, 2013; Klöckner & Blöbaum, 2010; Klöckner & Friedrichsmeier, 2011), Values-Identity-Personal norms model (Balunde et al., 2019, 2020a,b, 2023; Ruepert et al., 2016; van der Werff & Steg, 2016), among many others. Drawing from these theoretical perspectives, it can be proposed that people are more inclined to engage in nature conservation when they possess strong personal beliefs, towards the environment, a sense of moral responsibility towards its protection, or well-established eco-friendly practices. Furthermore, the presence of peer encouragement for conservation, coupled with favourable policies supporting biodiversity preservation and their robust enforcement, enhances people's motivation to actively contribute to conservation efforts.

Based on the above one could suggest that behavioural science methodologies, due to their quantitative nature, often focus on specific components or narrow models of behaviour change. This isn't due to intentional oversight but because it's challenging to encompass a broad range of factors within these empirical tests. As a result, each theoretical approach examines only a segment of the larger system. However, when we consider these studies together (as a components of a larger system), we can discern a more comprehensive picture. Nevertheless, there's a growing recognition among behavioural researchers that theoretical and empirical approaches need to evolve because narrow focus might fail to facilitate the points at which transformation occurs as well as may unwillingly overlook and marginalize certain groups (Wallis et al., 2021).

Moreover, there is another compelling reason why concentrating on specific factors or theoretical frameworks might be problematic when attempting to **elucidate complex environmental behaviours like biodiversity conservation**. This is primarily due to the multifaceted nature of biodiversity conservation, making it nearly impossible to simplify it into a singular unit for analysis. Biodiversity conservation encompasses a myriad of behaviours, some of which may not have a direct impact on biodiversity conservation. Furthermore, and perhaps more crucially, even when these behaviours do contribute to biodiversity conservation directly, individuals may not recognize them as such. For example, people might not associate river dam removal (or any other biodiversity conservation actions) with safeguarding biodiversity. It becomes much more complicated if people do recognize that dam removal might indeed aid biodiversity conservation efforts, but other stronger motives for opposition exists. These motives could include strong emotional ties with the dam developed during decades and even generations. Or river dam provides certain services that are tightly intertwined with economic activities (e.g., irrigation for farming reasons). In addition to this, biodiversity conservation requires collective decision-making involving various stakeholders, institutions, and organizations at both local and international levels, including local communities, policymakers, businesses, and the media (Wallis et al., 2021). Moreover, biodiversity loss frequently intersects with other societal issues, such as the marginalization of communities advocating for change (Batel & Küpers, 2022; La Sandia Digital, n.a.; Tupala et al., 2022).

Consequently, alongside traditional behavioural science tools, there is an increasing emphasis on employing critical and community psychology approaches (Kivell et al., 2023; Teo, 2015). Researchers utilizing these approaches aim to uncover how citizens, communities, and the broader public can be empowered to act as environmental change agents, influencing established practices and knowledge systems (Cattaneo et al., 2014; Nelson, 2013; Riemer & Harré, 2017). This recognition has prompted behavioural researchers to advocate for a more diverse range of research approaches (Bruhn, 2021; Hanss, 2021; Wullenkord & Hamann, 2021) and shift of the focus. Interestingly these changes have been particularly advocated in behavioural research concerning biodiversity loss. Specifically, it is argued that behavioural studies dedicated very little attention if at all to address biodiversity loss and its complex antecedents (Nielsen et al., 2021).

Next to being complex, biodiversity conservation could be considered as **high-impact environmental actions** that can bring about substantial and fare-reaching benefits for the environment and the society. Focusing on high-impact environmental behaviours arrives from very recent discussion within environmental psychologists' community suggesting that current approaches in behavioural sciences might not adequately address the grandiosity of environmental issues and fail to deliver results inducing transformative changes (Nielsen et al., 2021; Wallis et al., 2021). Likewise, some voices in behavioural sciences suggest that deductive approaches discussed earlier in this section might fail to explain these high-impact behaviours because of their complexity, hence inductive approaches might be needed to reveal the complexity of such behaviours, proposing in-depth exploration of the behaviour in question and the context behaviour emerges in; and only then based on these explorations build theory (Nielsen et al., 2021).

Despite the lack of theoretical approaches within behavioural sciences that would specifically address issue of biodiversity loss, there is one line of theoretical developments that could indeed aid in understanding biodiversity loss. These theoretical developments focus on **the relationship between people and the environment** and are operationalized in multiple ways the most prominent being connectedness with nature – the extent to which people perceive themselves as being part of the natural environment (e.g., Schultz, 2002) and environmental identity – the extent to which nature or its elements are incorporated into people's sense of self (an important part of who they are) based on people's past experiences, the degree of emotional attachment to nature and (dis)similarity to nature or its elements (Clayton, 2003). Multiple studies - across wide geographical locations, regardless age or gender - suggest that the more people feel connected to the natural environment the more likely is that they will engage in multiple nature conservation actions (see Vesely et al., 2021; Whitburn et al., 2019 meta-analyses). Although it might be that people value nature for various reasons (e.g., altruistic vs egoistic), but some initial studies suggest that relationship between connectedness with nature and environmental behaviours can be explained by environmental values (i.e., one's goal in life to conserve nature and the environment) (Martin & Czellar, 2017). These findings might serve as an inspiration for explorations what drives people to conserve biodiversity. Following the indigenous practices, re-establishing reciprocal connection with the natural environment might be one of the ways to encourage people appreciate biodiversity (Ojeda et al., 2022).

To summarize, drawing insights from the behavioural sciences, one can discern direct and indirect drivers of biodiversity loss at the individual level. Direct drivers are identifiable actions and behaviours that immediately contribute to the loss of biodiversity. Examples include, encompassing the mismanagement of resources such as overfishing, overharvesting, and the indiscriminate use of pesticides and other agricultural chemicals. These practices have immediate and discernible impacts, leading to the decline of specific species and the degradation of ecosystems. In contrast, indirect drivers encompass practices that may not have an immediate or apparent connection to biodiversity loss but, through intricate and multifaceted pathways, ultimately contribute to it. These could involve complex societal and economic factors, such as land-use changes, urbanization, and consumption patterns. While these actions may not directly cause biodiversity loss, their cumulative effects, when considered within a broader context, can significantly contribute to the overall decline of biological diversity. It's important to note that biodiversity loss is seldom solely attributable to individual actions. Rather, it emerges because of the intricate interplay of various direct and indirect drivers on different scales, from individual behaviours to larger societal and global trends. Understanding these drivers and their interconnectedness is crucial for developing effective conservation strategies that address the complex and multifaceted nature of biodiversity loss. To add, current theoretical and empirical approaches of behavioural sciences might be too limited to analyse and disentangle this complexity, thus inductive approaches that are able to capture the complexity could be considered.

6. Biodiversity loss in the four high impact sectors

Having discussed several general issues, the report now focuses more on the relevance and needs for BIOTraCes. It will be argued that knowing a high impact sector is vital for a deeper understanding of the relationship between bio-innovations and underlying causes of biodiversity loss. Each cause of biodiversity loss, acknowledged as a driver of change, relates to underlying causes in a system of multilateral and multifaceted relations. The idea to find unequivocal direct relations between decline of a specie and its causes is deemed to fail. One cause can have many different effects on biodiversity or in nature. The thinking on causalities of biodiversity loss is rapidly developing, but it is not yet sought out how changing underlying causes creates deep leverage and vice versa. It will be a challenge for the case studies in BIOTraCes to shed a light on the relations between underlying causes of biodiversity loss, bio-innovations, and deep leverage, in order to contribute to an inclusive whole of society approach.

In the case studies information will be helpful about how actors in governance think about the causes of biodiversity loss, how a lack of knowledge plays out for economic activities and for nature, and about opportunities for changes towards transformative governance. We will discuss these three fields of information below to give some instructions of what one needs to know and incorporate in the case study analysis.

6.1 Use of knowledge in policy making on national and local scales

On Global and European level, a huge body of knowledge is available to find clues about biodiversity loss in a high impact sector. IPBES, BISE (Biodiversity Information System for Europe) and Biodiversa+ invest in monitoring and research on biodiversity on global and European level. See the previous sections in this report.

Information on national level can be found in the National Summary Dashboards – Habitat Directive – Art.17[3]. On local level there is no single entry. One needs to check the provinces for information. More important, on local level, it is the question if and how the above-mentioned sources of information are acknowledged and used in governance. The research question to take on board in the case studies can be described as follows:

What is known about the causes and underlying causes of biodiversity loss in the context of your case study and how is this knowledge being used in governance?

Below we provide some examples showing the benefits of understand the high impact context of a case study. It is merely meant for inspiration for BIOTraCes' partners.

6.1.1 Biodiversity (loss) and agriculture

Worldwide, the total area of agricultural land is around five billion hectares, accounting for approximately 38 percent of the Earth's total land surface (FAO, 2020). Biodiversity loss caused by agricultural activities is a global concern with implications for ecosystems, economies, and human well-being (see illustration 1). Dudley et al. (2017) identified key factors contributing to biodiversity decline, including the transformation of natural habitats into agricultural land, the increased intensity of cultivated landscapes, the emission of pollutants like greenhouse gases, and the ramifications of value chain activities such as energy production, transportation, and waste disposal. Addressing

[3] www.eea.europa.eu/themes/biodiversity/state-of-nature-in-the-eu/article-17-national-summary-dasboards-archived

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biodiversity loss resulting from agricultural activities requires a multifaceted approach that leverages knowledge at every decision-making level. Agriculture encompasses diverse forms of knowledge, and the primary obstacle lies in the complexity of disseminating this knowledge. In this context, knowledge transfer denotes the process of generating knowledge in one setting and applying it productively in different environments (Argote & Ingram, 2000). Explicit knowledge transfer involves direct communication from one entity to another, often through instructions; implicit knowledge transfer occurs when knowledge is assimilated by adhering to established routines (Cawley et al., 2023).

Knowledge is essential in shaping successful governance models, serving as the cornerstone for informed decision-making and implementing effective strategies that address complex challenges, such as the delicate balance between agricultural needs and biodiversity conservation. Therefore, we must recognize the significance of knowledge integration, learn from successful examples, and foster a collaborative approach to ensure a sustainable future where agriculture and biodiversity coexist.

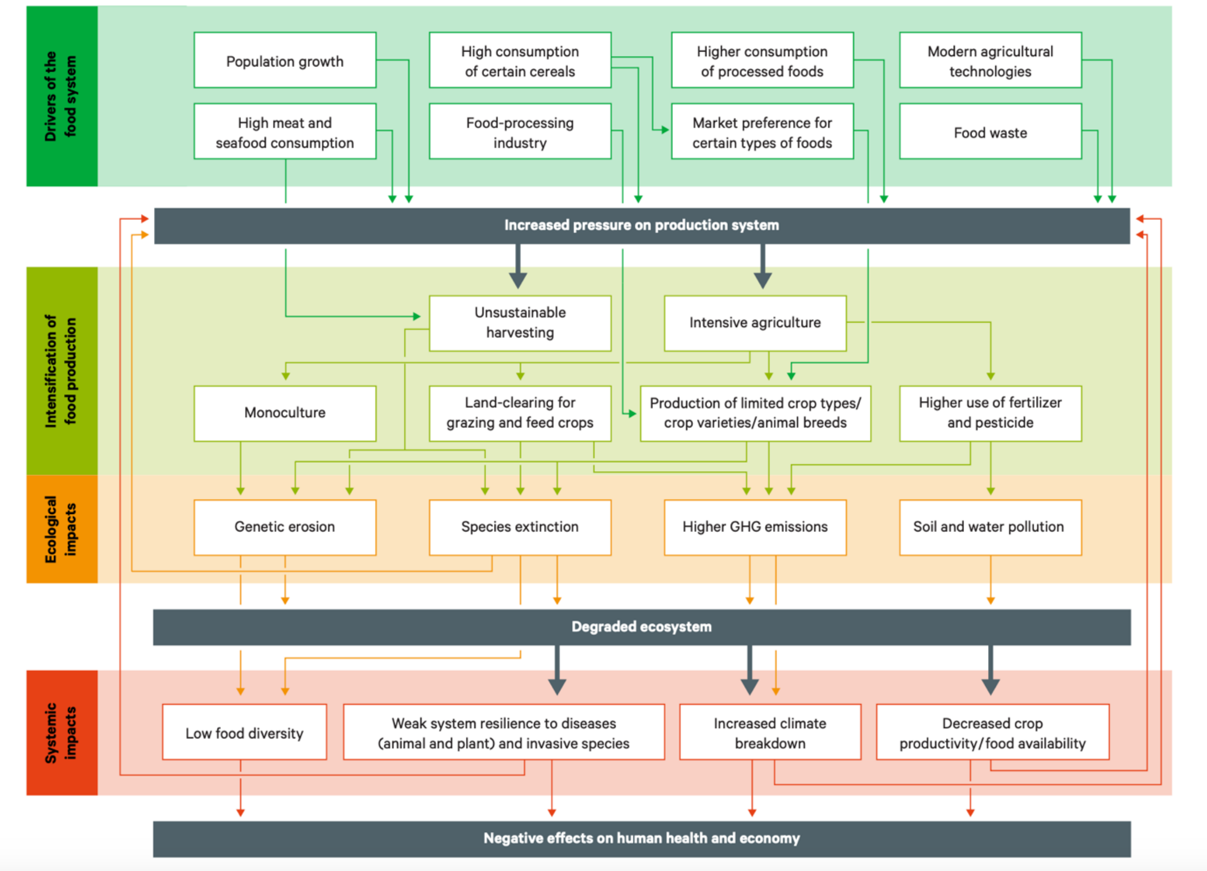

Figure 6.1 The food system and its impacts on biodiversity. Source Benton et al., 2021: https://www.chathamhouse.org/sites/default/files/2021-02/2021-02-03-food-system-biodiversity-loss-benton-et-al_0.pdf

Use of knowledge in policymaking

Government policies promote the adoption of conservation practices among farmers by offering incentives, enacting legislation, conducting research, engaging in consultations, and eliminating policy barriers detrimental to biodiversity conservation (Amato & Petit, 2023). However, the effectiveness of conservation initiatives driven by policies varies significantly across developed nations (Díaz et al., 2019).

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Insights from Local Action Groups (LAG) in Romania

Local Action Groups (LAG; GAL, in Romanian) bring people together to make their life better and improve their local area by joining forces, sharing knowledge, and using a common voice. Thus, LAG serve to transfer knowledge from the citizens to the policymakers. In Romania, LAGs are organized in the National Federation of LAG (FNGAL, n.d.). Romania ranks 5th in the EU, with 259 GALs (after Germany, France, Polang, and Spain) (European Network of Rural Development, 2023). LAGs are consulted on different topics by the Romanian Ministry of Agriculture and Rural Development (MADR). One consultation channel is through LAG membership in the National Network for Rural Development (RNDR) (RNDR, 2024). The RNDR (part of The European Network for Rural Development) is a link between central and local public administration and organizations involved in the National Plan of Rural Development (including LAG). RNDR promotes network collaboration and information exchange at regional, national, and EU levels, including events organization, creation and dissemination of communication materials, and promotion of good practices (e.g., a brochure about traditional foods; RNDR, 2015).

Case: Millet Revival in India - A Governance Perspective

A study by Kennedy et al. (2022) used several case studies to exemplify existing initiatives and programs designed to integrate greater food biodiversity into our food systems. The resurgence of millets as a staple food in India is one of these cases that presents a compelling case study in governance strategies for sustainable agriculture. Traditionally a vital grain in India, millets have witnessed a decline in both production and consumption over the past fifty years. This decline is attributed to factors such as production incentives favouring rice and wheat, low market demand, insufficient financial returns for millet farmers, societal stigma, and an underdeveloped food processing sector. Recognizing the potential benefits of millets, the government of India has initiated policy changes to promote their cultivation actively. National and state-level initiatives, such as those in Odisha and Karnataka, aim to boost millet production. The National Food Security Mission has incorporated millets into its policy framework, acknowledging their nutritional superiority, lower glycemic index, and adaptability to marginal soils and water-scarce regions. To combat the social stigma associated with millet consumption, the government coined the term "nutri-cereals" to emphasize their nutritional properties. Public awareness campaigns, such as those in Karnataka, promoted millets as beneficial for individuals, farmers, and the environment. Millets are gaining popularity in upscale restaurants, cooking shows, and modern recipes, reflecting a shift in perception. The government's inclusion of minor millets in the Public Distribution System, one of the world's largest social safety nets, further demonstrates its commitment to food security. The State Government of Karnataka's promotion of millets aligns with the slogan, "Good for you, good for the farmer and good for the earth." Looking ahead, the FAO's proposal for 2023 to be declared the International Year of Millets highlights global recognition of millets' role in nutrition, food security, and environmental sustainability. Drawing lessons from the rise and fall of quinoa, the governance model emphasizes the need for private sector involvement to ensure minimal sugar, salt, and processing in millet products. Nutrition education emphasizes the importance of a diversified diet, positioning millets as one healthy option. For millets to truly benefit farmers and the environment, inclusive decision-making involving farmers and the evolution of production systems in nature-positive ways are essential. This case study underscores the significance of governance in reshaping agricultural practices and promoting sustainable food choices.

Governmental focused programs: Promotion of sheep meet production and consumption in Romania

For most of Romanians' history, sheep breeding was a central economic activity and part of their historical and cultural identity (O'Brien & Creţan, 2019 citing Vuia, 1964), However, currently, sheep meet is not largely consumed by Romanians (except for lamb meat on Easter Holiday) and sheep breeding decreased. In an attempt to stimulate sheep production and consumption, attraction of labour force, and preservation of culinary traditions for sheep meat, in 2017, the Romanian Ministry of Agriculture and Rural Development launched a 6 million euros promotion campaign: "Choose the Sheep!". Between 1990 and 2019, the number of sheep in Romania decreased from 14 million heads to 10.3 million heads, with a slight increase during the end of this period that was possibly partially due to the mentioned campaign, as well as to non-refundable funds granted to shepherds (Chiurciu & Cofas, 2020). Other mentioned effects of the campaign were the increase of sheep meat consumption by 104% and the valorisation of wool from 30% before this campaign to 100% after it (also due to "The Wool" program) (Agerpress, 2018). Programs such as "Choose the Sheep!" and "The Wool" can contribute to the preservation of traditional knowledge about sheep breeding, foods, other customs, but their effect is temporary if the social-economic context is not favourable. Furthermore, attention should be paid to undesirable effects of the increase of sheep breeding, such as overgrazing and competition to the traditional practices.

6.1.2 Biodiversity loss in Maritime/aquatic living sources (freshwater ecosystems)

Despite peoples' admiration of nature due to its intrinsic value or practical use, natural ecosystems are still being degraded to rates unseen before (Díaz et al. 2015). The decline of biodiversity is particularly prominent in freshwater systems since it is exposed to a much higher decline rates compared to terrestrial and marine ecosystems (Acreman et al., 2020; Dudgeon et al., 2006; Maltby & Acreman, 2011). From 1970 freshwater wildlife index around the globe plummeted, suggesting 83% of bio-communities reduced (WWF, 2018).

The ecological status of a freshwater within European Union's ecosystems also continues to deteriorate (Haase et al., 2023), with anthropogenic factors such as climate change, spread of invasive species, soil/air/water pollution, unsustainable agricultural and forestry practices, and overconsumption of natural resources being the most prominent for this deterioration (Haase et al., 2023; Ortmann-Ajkai et al. 2018).

Beyond these mentioned, one of the most debilitating factors threatening freshwater aquatic systems' biodiversity are hydrological system alterations such as surface and ground water withdrawals, impervious surfaces, channelization and stormwater diversions, water storage reservoirs as well as interbasin transfers (Zolfagharpour et al., 2022). Yet the most easily recognizable examples include dams of various heights and purposes (e.g., for irrigation or hydropower purposes). Given that each of the above-mentioned factors is tightly attached to differing outcomes and that tailored actions (both practical and policy) are needed to address freshwater biodiversity loss, we further will focus on river dams as a case in point.

Rivers across Europe face over 1 million barriers varying in magnitude and impact on biodiversity loss, with 150 000 of them being completely obsolete and do not serve their purpose any longer (AMBER Consortium, 2020), suggesting that removing them could be a low hanging fruit for the enrichment of Europe's rivers and a first step moving towards removal of more complex dams. Even during this first stage, with a relatively small target over 25 000 km of rivers could be made free.

Freeing rivers from the various sorts of barriers is a crucial step, since they cause a staggering amount of decline of various forms of river-related biodiversity and plummeting migratory fish population up to 93% (Deinet et al., 2020)! Given that these numbers only account for migratory fish population, one can comprehend that this is also affecting other complex bio-communities of flora, fauna, and microorganisms that makes these systems distinctive and welcoming for rare species (not to mention services that they provide for people – e.g., overall resilience of ecosystems).

It is important to mention that there is no other true alternative to river dam removal that would benefit biodiversity. For example, it has been observed that even reducing other stressors from the rivers (such as pollution), but keeping the dams, bio-communities downstream of dams were still less likely to recover (Haase et al., 2023). Not mentioning the fact that when dam remains and other stressors increases, river biodiversity becomes particularly susceptible to the combined impacts of multiple stressors that can severely affect their resilience to other unforeseen threats (Borgwardt et al., 2019; Grzybowski & Glińska-Lewczuk, 2019).

What makes rivers so susceptible to degradation is their linear structure; when rivers connectivity is disrupted at multiple points of its body (this is especially true for hydropower dams), migration of all systems becomes disrupted (Borgwardt et al. 2019; Vari et al., 2022). Alternatively, observations indicate (McCaffery et al., 2018) that after dam removal, rivers restore their natural flow regimes, reinstating seasonal variations that benefit aquatic life adapted to specific flow conditions. The sediment previously raped by the dam can move downstream, replenishing habitats and potentially restoring riverbeds and estuarine environments deprived of essential nutrients and minerals. By removing dams, routes of fish migration are reopened, potentially leading to increases in fish populations and genetic diversity. The area behind a dam often turns into a reservoir, offering a habitat that can greatly differ from the original river environment. Once the dam is removed, the river can reclaim this space, thereby restoring habitats for various aquatic and riparian species. Additionally, the stagnant water in reservoirs can heat up, leading to problems like algal blooms. A restored river flow can ameliorate water quality by encouraging aeration, diluting pollutants, and reducing water temperatures. With time, a revitalized river can reconnect with its floodplain, rejuvenating wetlands, supporting a diverse range of flora and fauna, and bolstering natural flood mitigation. It's worth noting that dams often foster environments conducive to non-native or invasive species. By restoring a river's natural flow and habitat, native species might have a better chance to thrive and outcompete these invasive species.

To sum up, dam removal can aid in returning a river system to its natural state, benefiting native species and enhancing biodiversity. Nonetheless, it's crucial to understand that dam removal has its challenges. Each situation needs individual evaluation to ensure the removal results in the anticipated ecological advantages.

Use of knowledge in policy making on national and local scales and how lack of knowledge plays out

Policies related to freeing rivers are now being developed and approved based on scientific research, employing cutting-edge knowledge on how to restore freshwater biodiversity. The most relevant are the following: Water Framework Directive[4], River basin management plans, Habitats Directive[5], Floods Directive[6], UN Convention on Biological Diversity[7], EU 2020 Biodiversity Strategy[8], Rural Development Programmes[9], Climate Change Adaptation Policy[10], Common Agricultural Policy[11], among others. These first documents are the key ones most strongly supporting river restoration endeavors.

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4 https://environment.ec.europa.eu/topics/water/water-framework-directive_en
5 https://environment.ec.europa.eu/topics/nature-and-biodiversity/habitats-directive_en
6 https://environment.ec.europa.eu/topics/water/floods_en
7 https://www.cbd.int/
8 https://environment.ec.europa.eu/strategy/biodiversity-strategy-2030_en
9 https://agriculture.ec.europa.eu/index_en
10 https://climate-adapt.eea.europa.eu/
11 https://agriculture.ec.europa.eu/index_en

Despite relevant policies and regulations being in place at the EU and national level, as noted by the European Centre for River Restoration, river habitats continue to deteriorate (ECRR, n.a.). This could be due to public and local communities' unwillingness to adopt these policies (Palomo-Vélez et al., 2023), even though they most certainly would bring about positive changes for the communities. The dual processes could act that prevent policies from being implemented. On the one hand, enforcement institutions might lack know-how on how to introduce relevant stakeholders into decision making, for example how to include communities in the river dam removal process. On the other hand, communities might lack understanding and motivation on why river dam should be removed, but at the same time communities might not trust the law enforcement institutions because of negative experiences in the past in other domains (e.g., when communities voices were neglected on important decision makings causing power imbalance). However, most often than not, reasons why policies fail to translate into biodiversity conservation actions are much more complex, including social, emotional and historical aspects (Batel & Küpers, 2022; Fox et al., 2016), that require very sensitive approach during the implementation process.

In Lithuania, the government has taken steps to implement the European Water Framework Directive by establishing responsible authorities to evaluate and decide on the removal of specific river dams, which is a positive move. Two instances of such dam removal projects were carried out at Salantai and Bražuolė rivers. However, we have observed that these initiatives faced fierce resistance and opposition from local communities. From various analyzed narratives it seemed that communities were not properly introduced and considered in the process which ended up with a backlash.

6.1.3 Biodiversity (loss) and urbanisation

Urbanization processes are deemed a direct driver of biodiversity loss. Covering one percent of the global surface, cities contribute to habitat loss and fragmentation, increasing temperature through urban heat islands, degradation and/or pollution of light, noise, air, soil, and water and lastly an increasing number of non-native/exotic species (Fenoglio et al., 2021), with impacts not only on the local biodiversity, but also on wider scales embedded in the regional context (Grimm et al., 2008). It has been shown that urban habitats show a reduced species richness and may accelerate a reduction of native species (Johnson and Munshi-South, 2017), due to the simplification and removal of vegetated inner-urban areas (McKinney, 2008). However, cities are also offering new and heterogenous areas for exotic species, often introduced by humans, or birds or insects that find refuge in built environments, such as buildings, which may even increase the provision of ecosystem services (Grimm et al. 2008). Previous studies have found that the more urban and denser the environment, the higher the number of non-native species. Further, there may be some beneficial conditions, such as increased use of fertilizer or water, that may create better living conditions for certain species compared to more rural and less "manicured" landscapes (McKinney, 2008).

Overall, there is little knowledge of how the impacts of loss of local species and the adaptation and evolution of non-native species to urban contexts, together with changing climate conditions, will play out in future (Alberti, 2023). Urban areas are highly diverse, that is, it is difficult to predict more generally how urban biodiversity will be impacted, as city size and age, density of the built environment, climate, or geography impact the local ecosystem and beyond (Norton et al., 2016). More so, besides biophysical conditions of the built environment, the socio-economic demographics of neighbourhoods have recently been identified as another core driver of urban ecosystems and related biodiversity, whereas wealthier neighbourhoods tend to show higher levels of biodiversity, a so-called luxury effect, which raises issues of social-environmental justice (Aznrez et al, 2023).

As humans strongly intervene, shape or even "construct" urban ecosystems, it is necessary to understand them as strongly linked with society and hence with governance structures, institutions, and broader norms, that is, urban biodiversity loss cannot be looked at without embedding it in broader social-ecological system thinking. Urbanisation constitutes a dynamic process which impacts human-nature interactions and relations (Alberti, 2023). In this context, conserving and/or restoring urban biodiversity in form of renaturing or rewilding interventions has been put on the global urban agenda, as a greater urban biodiversity contributes to a higher amount of urban ecosystem services, such as improved air/water/soil quality; mental and physical well-being and may even enhance economic growth (Grimm et al., 2008). That is, urban nature has increasingly been linked discursively with a higher quality of life of humans around the globe, and with that there is increasing political attention on integrating "greening" measures in urban planning and practice, especially surrounding debates on urban sustainability and resilience in the context of climate change (Long and Rice, 2019; Neidig et al., 2023). However, concrete integration of goals concerning specifically biodiversity loss are scarce (Norton et al., 2016; Elander et al., 2005).

Nowadays, while little is talked concretely about urban biodiversity (loss) in urban policy, related knowledge is mainly operationalized through a governance focus on implementing urban green and blue infrastructures as a form of nature-based solutions that provide multiple ecosystem services (Goodwin et al 2023). Here, the focus is on the provision of ecological corridors, urban parks, gardens, green rooftops, or facades (Babí Almenar et al., 2021). Those nature-based solutions are put forward as means and tools to help enhance e.g. urban resilience to droughts, inundations, heat waves and other extreme weather conditions, e.g., through drought-resistant trees and weeds or the implementation of water areas, with lack of knowledge what the introduction of a new species or targeted change of the local urban ecosystem in relation to the evolutionary dynamics may mean on the long term (Alberti, 2023). Here, the conservation of urban biodiversity is purely anthropocentric and instrumental and has turned into a very broad understanding of "green" interventions, that also includes small and low-carbon technologies as measures of climate change mitigation and adaptation (Hodson and Marvin, 2017; Goodwin et al 2023).

At the early 20th century, urban biodiversity has been mainly understood and valued for its agricultural value, e.g., through practicing subsistence farming. With industrialization processes taking place in and around cities in the mid 20th century in European cities, urban biodiversity turned into a recreational good enjoyed by the upper classes, e.g. through bird watching, and eventually became embedded in (neoliberal) market dynamics and highly instrumental to urban economic agendas (Angelo, 2019, 2021). As there is increasingly internationally an "one-type-fits-all"-approach to implement urban "nature", the use of local knowledge is diminishing, leading to shallow and place-detached meaning of urban nature and related biodiversity, which has increasingly been captured by market dynamics. A greener and more bio-diverse city may for example enable higher property prices and is more and more considered a driver of displacement and gentrification processes, leading to an unequal distribution of urban nature's contribution of people (Anguelovski et al., 2022). Further, "green" measures under the rationale of climate change mitigation and adaptation are increasingly financed through private capital, such as green bonds, which embeds urban biodiversity in a logic of financial returns (Garcia-Lamarca et al., 2023).

6.1.4 Biodiversity (loss) and forestry

Globally, forests cover 30.8% of the total land area, with forests in Russia, Brazil, Canada, USA and China comprising more than half of the world's forest. Although the total forest area has decreased from 32.5%, deforestation progress has somewhat slowed. The main reason for deforestation has been agricultural expansion, and has been concentrated to Africa and South America, while both Europe and Asia have seen a net gain in forest area during the period (FAO, 2020). Temperate forests have increased during these years, mainly due to plantation in China and global farm abandonment.

Boreal forests which dominate both Scandinavia and Russia have not changed in area, but this does not reflect unchanged forests since there has been increased plantation, harvesting and conservation efforts depending on the region in question. Overall, there has been a substantial decrease in intact forest landscapes with little signs of human impact and high biodiversity values and a mirrored increase of forest plantations with considerably less biodiversity (Purvis et al., 2019). In the global forestry sector, high-income OECD countries reduced industrial roundwood harvesting, offset by an increase in low and middle-income countries (Balvanera et al., 2019).

In Europe (Russia excluded), forests cover around 34.8% of the total land area, primarily concentrated in northern Europe. Coniferous trees dominate the largest forest group (46%), also concentrated in northern Europe, followed by broadleaves (37%), while mixed forests cover 17%. Over the past 30 years, the European total forest area has expanded, but some countries, including Portugal, Bosnia Herzegovina, Albania and Sweden, experienced a decrease (Köhl et al., 2020). European forest biodiversity is threatened and has largely followed the global trend of biodiversity loss, although forests in general display the most positive trends in conservation status in Natura-2000 assessments. However, there is also ongoing fragmentation of the forest landscape, which is often considered negative in terms of biodiversity (Muys et al., 2022: 25). Deadwood, crucial for ecosystem function, has increased since 1990, likely due to climate-induced disturbances and increasing closer-to-nature forest management in some areas (Pötzelsberger et al., 2021). However, deadwood's use as a biodiversity indicator is limited, as in Sweden, the current increase is dominated by storm-felled trees not yet at advanced levels of decay (Jonsson et al., 2016).

In the European forestry sector, a currently contentious issue is the potential conflict between climate mitigation strategies and confronting biodiversity loss. Forests are crucial for the European bioeconomy's development, emphasising a shift from fossil resources to renewable biomass. However, this transition is expected to increase wood demand, leading to increased harvesting and potential adverse effects on forest ecosystems (Schulz et al., 2023). Such strategies also reinforce extractivist tendencies in the economy, despite a rhetorical turn towards terms such as circularity and renewability (Holz, 2023). Also, uncertainties exist about the possibility of scaling up harvesting to meet EU greenhouse gas emission reduction targets. EU policies such as the EU Forest Strategy and the EU Biodiversity Strategy, focusing on forest conservation, contradict climate mitigation policies (Blattert et al., 2023). Considering constraints to harvest increase such as forest owner behaviour, financial incentives, policies on national and EU levels etc, Lerink et. al estimate that harvest increase in Europe will not be able to reach future demands without a massive, coordinated effort (Lerink et al., 2023). Nonetheless, since 2015 there has been a large increase in harvested forest area and thus also of biomass loss, with a large concentration to the Nordic and Baltic Countries as well as the Iberian Peninsula. This change is related to the growing demands of the bioeconomy (Ceccherini et al., 2020).

According to the EU Biodiversity Strategy, 30% of the land area should be protected by 2030, and 10% of the land area in nature reserves which includes 'all remaining primary and old growth forests (Directorate-General for Environment (European Commission), 2021).' The EU Forest Strategy, while emphasizing the important role of moving from fossil resources towards a bioeconomy, also states that 'in the short to medium term, i.e. until 2050, the potential additional benefits from harvested wood products and material substitution are unlikely to compensate for the reduction of the net forest sink associated with the increased harvesting' (European Commission, 2021). There is thus a certain pressure from the EU for increased forest conservation efforts in the coming years, while the move towards a bioeconomy remains in policy documents.

There are several strategies available to try to balance biodiversity conservation with reaching intended forestry production targets on a European level. However, this is also complicated due to linkages to the global forest sector. Rosa et. al for example estimate the impact of different forest management practices on global species extinction under different climate change mitigation scenarios in Europe (Rosa et al., 2023), concluding that an increasing area of unmanaged forest land would lead to a larger reliance on imports of forest biomass from more vulnerable biodiversity regions, thus resulting in increasing global species extinction. In comparison, closer-to-nature forestry (also called continuous cover forestry) of a larger part of the forest land would decrease global species extinction, although this would be unable to meet the demands for biomass under high climate mitigation scenarios. Closer-to-nature forestry where only a selection of trees is harvested on each surface, is currently used on between 22 and 33 percent of European forests. The largest concentrations are located in south-central Europe and Germany, while it is substantially less developed in Baltic and Scandinavian countries such as Sweden, Finland, Estonia and Lithuania, but also on Ireland and Portugal among others (Mason et al., 2022).

In Sweden, where the primary BIOTraCes case study on forestry is situated, the limited adoption of closer-to-nature forestry is highly related to path-dependencies in Swedish forestry and there are strong historical dimensions in current forest biodiversity trends. Prior to industrialization, Swedish forests were used extensively for grazing and the collection of various secondary resources for thousands of years, and regional-local variations in usage created a highly diverse forest landscape (Westin et al., 2022). During industrialization the high demand for wood led to vast deforestation in Sweden, starting in the south and continuing north between c. 1850-1930 (Emanuelsson & Petersson, 2009: 313). Followed by state concern against the economic unsustainability of the ongoing deforestation, state-led plantation projects were initiated in line with new forest legislation in the early 20th century. A concern for increasing forest growth and calls for effectivization led to a move away from selective harvesting to clear-cutting, also supported by results from the National Forest Inventory. Clear-cutting, with some more recent modifications for ecological concern has since dominated Swedish forestry and its connected institutions at least since the mid-20th century (Lundmark et al., 2013; Simonsson et al., 2015). Changing to more biodiversity-friendly forest management under these circumstances is difficult, since the available domestic markets, technologies, expert advice, organizations, value chains and forest politics are coloured by this historical development (e.g. Angelstam et al., 2022; Löfmarck et al., 2017). However, there is potential to develop alternatives within the non-industrial private forest owner group, which often consider other values than the purely economic as more important (e.g. Lidestav & Westin, 2023). This group is also the focus of the Swedish Biotraces case study.

After this discussion on biodiversity loss in high impact sectors and on how the knowledge of underlying causes could be used (environmental impact assessments) in policy making and decision taking on national and local scales in these high impact sectors, a short reflexion on the detrimental effects of not knowing, neglecting, misinterpreting, or denying the exact causes of biodiversity loss is put down here.

6.2 How lack of knowledge plays out

Lack of knowledge in a high impact sector normally cause illimitation of economic activities and the forgetting of traditional knowledge. This will be elaborated below, with some examples.

Meinard and Quetier (2014) highlighted a significant gap between scientists and the general population in understanding biodiversity, with scientists assuming that laypeople comprehend the definition. Biodiversity communication seeks to translate scientific knowledge into a message accessible to a broader audience, fostering awareness and inspiring actions for biodiversity conservation (Doley & Barman, 2023). In a survey by the European Commission (2019), only 41% of respondents were familiar with the term; fortunately, 50% of respondents consider that biodiversity is threatened by intensive agriculture. Therefore, a growing disconnect between the population and nature may result in inaction (Soudière, 2023). Lack of knowledge and awareness about nature may lead to less motivation to conserve biodiversity and understanding of ecosystem services provided by the natural environment (Soga & Gaston, 2023). Likewise, other studies (Hughes et al., 2018; Whitburn et al., 2020) found that individuals with a low understanding of and interest in nature are less inclined to endorse policies and management actions that prioritize the well-being of the natural environment.

Gómez-Baggethun et al. (2010) observe the connection between the intensification of agricultural practices and the decline in traditional agricultural knowledge. They examined the transfer of traditional knowledge within rural communities associated with protected areas in Doñana, southwestern Spain. Their investigation focused on shifts in knowledge of local agricultural and livestock practices among 198 informants spanning three generations. This period encapsulates the transition of the area from an economy heavily reliant on local ecosystem services to a market-oriented economy with intensified production systems. Gómez-Baggethun et al. (2010) also observed a significant intergenerational reduction in traditional ecological knowledge in Spain, primarily attributed to the accessibility of modern technology for co-producing provisioning ecosystem services. This observation aligns with recent reports indicating declining trends in traditional pasturing practices in Hungary since the 1940s (Varga et al., 2016) and Romania (Hartel et al., 2017).

Some research questions one can take on board in the case study is:

- What knowledge or knowledges are used for decision making in the local and national context of your case study, and in case of knowledge ignorance: who benefits?
- How does urbanization impact their hinterlands, namely peri-urban and rural landscapes, and biodiversity?
- What types of local knowledge and needs regarding local biodiversity exist that go beyond institutional approaches and so-called "expert" knowledge of urban planners?

6.3 Inspiration from other governance models

Despite the challenges, there are inspiring examples of successful governance and practices prioritizing agricultural productivity and biodiversity conservation.

<u>Agricultural Traditional Knowledge</u>

Local initiatives, such as community-supported agriculture and agroecological farming, showcase the potential of grassroots efforts in promoting biodiversity-friendly practices. These initiatives often draw on traditional knowledge, demonstrating that sustainable agriculture can align with local wisdom that contributes to preserving, administering, and conserving natural resources (Das et al., 2021; Ulian et al., 2020; Uprety et al., 2012). However, not all traditional practices and belief systems are ecologically adaptive, and not all traditional knowledge exhibits ecological wisdom (Uprety et al., 2012). Some may turn maladaptive due to evolving conditions, lose significance when taken out of their original context, or become irrelevant over time, as Charnley et al. (2007) highlighted.

<u>Example of the right to seeds as manifestation of the cultural identity of rural communities.</u>

Traditionally, seeds are selected, cultivated, and improved along the years, passed on from one generation to another, and exchanged between people (Eco Ruralis, n.d.). They are more than a simple commodity and are as important as land and water. Seeds carry a reservoir of knowledge about their cultivation, breeding, and use of the resulting crops. They connect people and offer status and power to the ones who manage and hold the knowledge about them (such as the women in some villages). Seeds are part of the cultural identity of rural communities. Girard and Frison (2021) (citing Howard, 2010) recognized this reality by underlining that the cultural norms were an essential factor governing biodiversity conservation at the local level in peasants' communities. The United Nations (2019) defended people's right to seeds and showed that it includes (among others) the right to the protection of traditional knowledge about plant genetic resources for food and agriculture, and the right to fairly benefit from the advantages that come from using plant genetic resources for agriculture and food. The respect of peasants' right to traditional seeds contributes to the recognition of and cognitive justice for traditional knowledge and knowledge plurality in peasant farming (Coolsaet, 2016). Recognition allows cultural diversity to exist and be socially accepted, and cognitive justice ensures that different practices have the right to co-exist (Coolsaet, 2016)

One good practice example about how to respect peasants' right to traditional seeds is given by Eco Ruralis (Romania). Eco Ruralis is an association of farmers that, among others, promotes traditional landraces seeds (Eco Ruralis, n.d.). Since 2013, it publishes a catalogue of seeds per year that are freely distributed each spring to all people who request them. The seeds come from the association members that cultivated them in the previous year on their land. Traditional landraces of tomatoes, cucumbers, beans, aromatic herbs (e.g., Lovage, Levisticum officinale) are some of the most requested seeds.

Another example of traditional knowledge and landraces conservation comes from the Biological Research Center of the Botanical Garden Vasile Fati, Jibou (Salaj county, Romania). They saved and breaded over 20 traditional landraces of apples and pears that were documented in the region for over 100 years and identified apple varieties by corroborating phenotypic and genotypic data (Sicora et al., 2023). Trees were marked with transponders to give them an electronic identity and the information was integrated into a dynamic database. The team engaged people from the region through seminars in the traditional knowledge transfer by revitalizing grafting techniques, and by establishing in people's orchards some experimental batches with traditional apple trees obtained by grafting branches from traditional apple trees. To ensure that traditional apple and pear landraces have the chance to survive, the Botanical Garden sells saplings, trains people how to plant and take care of the trees, educates them about the characteristics and benefits of the traditional landraces, and raises awareness about the particular taste of each apple variety.

Agricultural Knowledge Transfer (KT)

Van den Ban and Hawkins (1996) understand Agricultural Knowledge Transfer (KT) as a systematic procedure that provides multifaceted support to farmers, and Cawley et al. (2023), similar to Läpple et al. (2013), posit that the principal objective of agricultural KT services is to enhance farm performance by bridging the gap between evolving research and on-farm applications, mainly through the introduction of innovative technologies. The fundamental goal of Agricultural KT is to increase farmers' competencies, enabling them to enhance their farm performance by refining their problem-solving skills. The success of knowledge transfer depends on farmers' absorptive capacity, determining their proficiency in comprehending, acquiring, and implementing new knowledge (Cawley et al., 2023).

Irish case: In the context of Irish agriculture, both public and private consultants contribute to agricultural KT. Established in 1988, Teagasc serves as the primary public entity responsible for delivering agricultural research, advice, and training (Teagasc, 2024). Notably, Teagasc adopts an organizational structure that underscores the significance of integrating research with effective KT. This commitment is evident through the allocation of 35% of its annual budget to the KT Directorate, with 23%

designated explicitly for advisory services and the remaining portion dedicated to education. Furthermore, Teagasc operates a fee-for-service model, wherein KT clients contribute financially, generating additional income to sustain the KT service. Teagasc extends its advice to approximately 45,000 clients annually, tailoring the level of engagement based on client demand. Service options vary from a fundamental offering, providing access to the latest research, events, and a scheme assistance plan, to more comprehensive services encompassing monthly discussion groups and on-farm consultations. The geographical reach of this service spans 55 locations nationwide, with a workforce of over 250 advisers fulfilling various roles (Cawley et al., 2023; Prager et al., 2016; Teagasc, 2024).

CAP example: The new Common Agricultural Policy (CAP) for 2023–2027 understands the value of advisory services to share information and knowledge among farmers. The CAP wants to improve Agriculture Knowledge and Innovation Systems (AKIS) by investing more money and encouraging more farms to new farm practices (European Commission, 2023). Advisory services, also called Knowledge Transfer (KT) services, are very important in distributing advice and knowledge from experts to farmers. They also support peer-to-peer learning through participatory activities like discussion groups and events (Cawley et al., 2023).

Payment for Ecosystem Services (PES)

The role of technical assistance in the case of the Regional Integrated Silvopastoral Approaches to Ecosystem Management Project in Costa Rica. The paper by Garbach et al. (2012) underscores the potency of technical assistance, especially for conservation practices with substantial private benefits, as it aligns with the diffusion of innovation theory, predicting that once landowners understand how to attain these benefits, they are more likely to adopt the practices. The Regional Integrated Silvopastoral Approaches to Ecosystem Management Project (RISEMP) pilot, conducted from 2002 to 2008, continued the initial phase of PES in Costa Rica from 1997 to 2000. A survey of 101 cattle farmers in Costa Rica was conducted after the RISEMP PES pilot to assess the adoption of silvopastoral conservation practices involving reintroducing trees and shrubs into permanent pastures, offering both public and private benefits. RISEMP aimed to boost the adoption of silvopastoral practices in degraded systems using PES incentives and evaluate the resulting enhancements in ecosystem function and socioeconomic well-being. For widely adopted practices among farmers, the impact of PES payments alone was limited, but adoption rates increased with the inclusion of technical assistance. Technical assistance proved particularly effective for integrating simple live fences and low-density tree plantings into permanent pasture systems. The significance of technical assistance, often overlooked in discussions on market-based policy tools like PES, lies in its direct role in reducing the costs associated with practice adoption by providing information or subsidizing material costs. In the RISEMP program, technical assistance included guidance on incorporating new plants, and occasionally supplying cuttings and other materials.

Grassroot Global Governance for Integrated Watershed Management

As mentioned in deliverable 1.5 inspirational governance examples can be found in Ecuador. These have been discussed in the theoretical framework of the Grassroot Global Governance (GGG). Here local actors managed to influence policy frameworks on integrated watershed management at national and international level. Kauffman (2016) describes and analyses the implementation of Integrated Watershed Management reforms across six regions in Ecuador, including Ibarra, El Chaco, Pastaza, Celica, Tungurahua, and Zamora. The reforms drew inspiration from international policies and their advocates in a bottom-up process. The reforms were pushed forward by various local stakeholders, including communities, NGOs, farmers, and others, who engaged in activities such as protests, establishing stakeholder networks and pressuring resistant local stakeholders to act. The interactions and interdependencies among local stakeholders generated momentum for the implementation of these reforms for sustainable water management. Regions with distinct agendas, needs and capacities were able to reach an agreement that differed from the international and national policy agendas. One Ecuador’s case, the Tungurahua case, was unique in how it blended global Integrated Watershed Management principles with local indigenous norms, particularly the concept of "sumak kawsay" or "buen vivir," The work of the locals is positioned in the intersection of policy, economy and environment.

The mix of global and local perspectives created a novel governance arrangement that now serves as a model for sustainable development. Tungurahua's innovative local governance system gained recognition and resonated with other Ecuadorian communities and organizations, including national indigenous movements. Ecuador's success story is inspiring new international governance structures, such as the Global Alliance for the Rights of Nature, which aims to promote the global application of "buen vivir" and alternative approaches to sustainability. Ecuador's efforts and the success of its National Plan for Buen Vivir have led to changes at the international level. The UN General Assembly now holds annual dialogues dedicated to "living in harmony with nature," aligning with the principles of "buen vivir." This has resulted in annual reports on achieving sustainable development rooted in this concept.

7. Diverse perspectives on cause of biodiversity loss

7.1 Puzzling inspirational examples

The way people perceive nature depends on culturally defined value and belief systems (Verschuuren, 2007). These values and belief systems may have spiritual dimensions, which are often understudied. They may be difficult to include as distinctive knowledge on values and believe systems in ecosystem management. Such knowledge often is inaccessible or difficult to be understood by conservationists in a western scientific tradition (Verschuuren, 2007). Accounting for different worldviews and their corresponding values is a challenge for policy makers and conservationists, even in Europe (Molnár et a. 2023). Cultural and spiritual values of nature relate to the importance of cultural traditions on relating to nature expressed in language, knowledge, and expressions in arts and craftmanship.

Below we will provide some puzzling examples of ethnic worldviews and ask rhetoric questions what this would imply for our thinking on causes or underlying causes of biodiversity loss.

Inside or outside nature

We may begin with the fundamental question if one will use the concept of *cause* if one sees oneself as part of nature. If we listen carefully to Eriel Tchekwie Deranger, co-founder of Indigenous Climate Action (ICA) and founding member of the Global Indigenous Youth Caucus, we hear her say that western societies externalize environmental problems as a problem happening outside and in need of proper management (Eriel Tchekwie Deranger, 2022). But if one sees oneself as a part of nature and thus inside the environmental problem, would one use or need the concept of '*cause*'? On the other hand, vice versa, North American Indians were convinced that a live giving breath went through earth, water, air, fire, plants and animals. Myths say that nature is full of spirits, and one has to bring offers not to annoy them (Schouten, 2005). This can be seen as a reciprocal relationship with nature, but does the ecologist see any causation here?

Everything connects to everything ('All is One')

This view lies at the heart of shamanism, as in many other religions and cultures. After near extinction of practicing shamans in the 20th century, their performances emerged in the last two decades as a key strategy in promoting ethnic distinctiveness (Langdon, 2016). For instance in Brazil they acted in discussions for indigenous rights.

The shaman worldview contrasts western thinking because in the west relations are merely the reflection of experience or observing. When it's not observed and documented, or proven in another way, a relation does not exist. Causes are proven relations, where one phenomenon influences another and invokes change. If everything is connected to everything, there are no singular relationships and no direct causes. All change is caused by a multitude of relations.

Do our thoughts mirror the world as it is?

A similar fundamental problem arises when one sees humans and nature not as objects with all kinds of relations, but as a system of relations with no objects (Akomolafe, n.d.). Akomolafe sees humans as '*deluded, wrapped in layers of illusions, buried in cascading folds of stories, devoid of a safe core, and without a perceivable boundary*'. According to Akomolafe, humans think that his thoughts mirror the world as it is – and that when one speaks about the world, he really is describing things as they are. But if the world consists of a system of relations, this cannot be true. So how should we understand 'causes' if change is the basis of existence?

How time is seen

Time can be seen as linear or cyclical. Modern Western cultures tend to view time as linear, with a clear beginning and end. Time is viewed as being limited in supply, which shapes how people structure their lives, especially at work, with schedules, milestones, and deadlines. The concept of evolution is also based on a linear conception of time. Linear-oriented people may see the future of a phenomenon as a product of planning.

In many non-Western cultures, time may be viewed as cyclical and endless, as was the case in ancient Egypt. Every day, the sun rises and sets, one season follows another, people grow old and die, but their children reiterate the process. In a circular understanding, there is abundance of time. When time is abundant, more emphasis can be placed on doing things the right way, and maintaining good relationships, rather than meeting deadlines. A cyclic culture might visualise the future as a curved road which takes in scenery and ultimately might lead back to conditions similar to what we experience right now (Source, anonymous, 2023).

So how does circular understanding of time affect causes? Do we understand the importance of time in our own thinking on causes?

Manage or adapt? The Carpathians vs. Mongolia

European cultures aim for human-led management of land and water to increase the provision of ecosystem services (the word management originates from the Latin manus, meaning hand, cf. keep in hand, control) (e.g. Babai et al. 2014), while other cultures emphasize adaptation, and often aim for no change (see e.g. Garde et al. 2009). Mongolian herders, for example, aim to live in harmony with nature and to understand how nature functions (Gantuya et a. 2021). They do not fight against nature, but prefer to adapt and aim for no change; indeed, they are afraid of change. Herders believe that, if there is a change in nature, then something must be wrong, and only people do bad things. They also do not feel they have the right to move species in the landscape (e.g. wild vegetables or medicinal plants). They emphasized that you are expected to help nature to regenerate herself (overused pastures) and to clean herself (from weeds). Mongolian herders speak about nature as being an active agent, providing water, air, pastures, etc., as well as knowledge how to use these resources properly. "If we can save and protect it (nature), there is nothing else we can do. All we can (actually must) do to help nature is to use everything properly, appropriately. People should not pollute nature and water, cut many trees, dig into the soil or do mining, and they should prevent fires."

The journey of the soul

In the Zulu belief, the soul makes a journey through the sea and the sky. Every being has a time in this world. When time comes, one returns to his ancestors in the sea. After being buried in the ground, the rain squeezes out the soul. One will be reborn in a new underwater world, swimming downstream in a river and following the voice of his grandmother, coming from the sea. When the soul reaches the point where the river meets the sea, the soul takes up more memories of the world. The soul swims to the deepest of the sea and finds very old people living there and waiting for it. (Source: Mthombeni, 2023). How can one discuss the wellbeing of the ocean and the causes of pollution in this Zulu context?

If BIOTraCes pleas for including marginalized perspectives, this can become truly challenging. Must one see these examples as a mere coexistence of simultaneous realities? Or can such different worldviews indeed be bridged by reflection and learning? The best thing to do is listening to stories like these, and humbly wonder how they reflect deep relationships with nature, and what that means in terms of wisdom to take care of the world.

7.2 Bridgeable and insurmountable differences

Various stakeholders of a specific site (a park, a forest, a mountain, or a river basin) often have diverse, deeper or shallower understanding of how local nature and society, i.e. how the local social-ecological system works. Furthermore, understandings based on science or on less science-impacted local, traditional knowledge can also differ. These differences can be big or small, but the question is whether they are bridgeable or insurmountable (Mistry and Berardi 2016, Ban et al. 2018).

Interpretation of causes of local changes (or the stability of a system) often depends on what data, information and knowledge is available for the 'interpreter', let it be a scientist, a decision maker or a local knowledgeable person. Conflicts often arise because of information asymmetries and different values and worldviews around interpretation (Hill et al. 2020). Sharing data, information and knowledge among stakeholders may thus help avoid or resolve these types of conflicts.

Sharing causal explanatory models about changes and their drivers among stakeholders can point to cases where science and local knowledge can complement each other, consequently bridging is beneficial for both stakeholder groups. Science can especially contribute to the understanding of those local phenomena and causes that are not perceivable by local citizens (e.g. changes in soil microfauna, intricate connection of local and global ecological processes), while local knowledge can be richer on how the area has changed at fine spatial and temporal scales (cf. oral history), about hidden relationships of indirect and direct drivers, and how certain changes impact local livelihoods (Biró et al. 2024). Local knowledge can be more place- and space-based, more deeply rooted in local history and culture, more holistic, but it can also be shallow along certain dimensions, or even wrong (cf. misbeliefs, misunderstandings), and its reliability and validity can be strongly affected by rapid social-ecological changes or the shifting baseline syndrome (Fernández-Llamazares, A. et al. 2015).

Local explanatory causal models can be tacit, rarely shared and discussed verbally among locals, let alone with scientists and decision makers. Furthermore, locals may explain changes by indicators that are regarded scientifically less objective (e.g. the changing health and colour of a forest) or are outside the scope of science (e.g. change of sacredness, spirituality) (Lyver et al. 2018). The more different the worldview of locals is from the scientific worldview, the higher are the chances that the two models cannot be merged into one coherent and mutually agreed model. In Europe the Sami worldview and some marginal local worldviews (e.g. traditional herders in marginal areas, Kis et al. 2017) are substantially different from the mainstream, Christianity, and science-based worldviews (Molnár et al. 2008, Hartel et al. 2017, see examples in Roué and Molnár 2017). In these cases, bridging is more challenging and less possible. However, even if the models (and key values and interests) of the stakeholder groups are different, stakeholders may be able to agree on the main management decisions because the consequences are beneficial for both groups (e.g. in the case of conservationists and traditional herders about relatively intensive marsh grazing in protected areas; Biró et al. 2020).

If the existing causal models about the local social-ecological system are insurmountable, parallel validation and analysis can be more adequate than integrating one model into the other (see e.g. for global biodiversity targets: Forest Peoples Program et al. 2020). Integration of local marginalized understandings into purely scientific models can even be unethical, as it may select certain aspects and neglect others that are vital for local stakeholders (Hill et al. 2020, McElwee at al. 2020). If the models are less different, which is usually the case in most European landscapes (Hernández-Morcillo et al. 2014), the Multiple Evidence Base approach (MEB, Tengö et al. 2014, 2017) or other ways of bridging can be effectively used to weave together different perspectives and understandings (see more about methods in the next section). Boundary crossing experts may be useful during the bridging process (Ulicsni et al. 2019).

8. Conclusions

8.1 Conclusions

The aim of this report is to provide conceptual inspiration and methodological guidance for the disclosure of "opportunities for leverage and upscaling" and for the case studies in assessing the added value for nature of including marginalized groups, identities, values, knowledge, and perspectives, resulting in pluralizing nature-positive futures for just decision making. To this aim we discussed the basics of biodiversity as an attempt to address the full complexity of nature. We have shown methods with which biodiversity (loss) is measured. This information was needed to have a fundamental discussion on "causes". One the one hand we discussed causes and underlying causes in the light of governance. Many examples show the pluralism in thinking about causes, underlying causes, indirect drivers and so forth. They show us that how one sees causes is interrelated with how one defines its relationship with nature. Underlying causes is not an objective category that holds for all perspectives on nature and biodiversity.

Nature responds to pressures and drivers of change in a complicated way. If a pressure is taken away, or is a cause is removed, this does not necessarily imply that nature recovers to its previous state. It may lead to the proliferation of foreign invasive species. A preliminary ecological assessment will be needed to have more certainty of what happens after changing a pattern of causes.

Even though scientific knowledge on causation frameworks has made huge progress, this does not mean that this information is being used in decision making processes in a sector of high impact. The relation between governance and causation is complicated and highly contextual. For instance, inhabitants may see an unnatural situation as natural, because of its endurance. Or economic actors will not change their activities unless inequivalently has been proven that they and no one else are responsible for affecting nature. One needs to understand the discourse on causes of biodiversity loss, coming from various actors and different scales of societal organization. In the end it boils down to the question how open governance is for knowledges sprouting from human nature relations shedding a distinctive light on causation that are unfamiliar.

8.2 Contrasting business as usual with societal partners approaches

A profound comparison of how nature is seen and how biodiversity is affected in a high impact sector, including its governance, and the practices of societal partners that can be qualified as biodiversity innovations may shed a light on blockage and leverage. The question here is what consequences there are in terms of behaviour and new causation frameworks towards a nature positive society from distinctive human nature relations that are unfamiliar to the governance system in a specific high impact sector. It is advised to take this question on board in the case studies. If BIOTraCes' cases show the relevance of distinctiveness in human nature relations, a deep leverage point has been disclosed.

8.3 Assessing benefits of inclusion

To assess the benefits of inclusion of other human nature relations and with that of other causation frameworks, one must build on the comparison mentioned above, and ask the question: how nature will respond to the biodiversity innovation. As explained above, this is not an easy and straightforward question. To answer this question, one needs an ecological assessment. In this assessment attention should be paid to ecosystem relations on the short and long term, on relations between abiotic and biotic processes, to ecological resilience and ecological vulnerabilities.

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Annex: Examples of presenting complex driver interactions

a) Example I

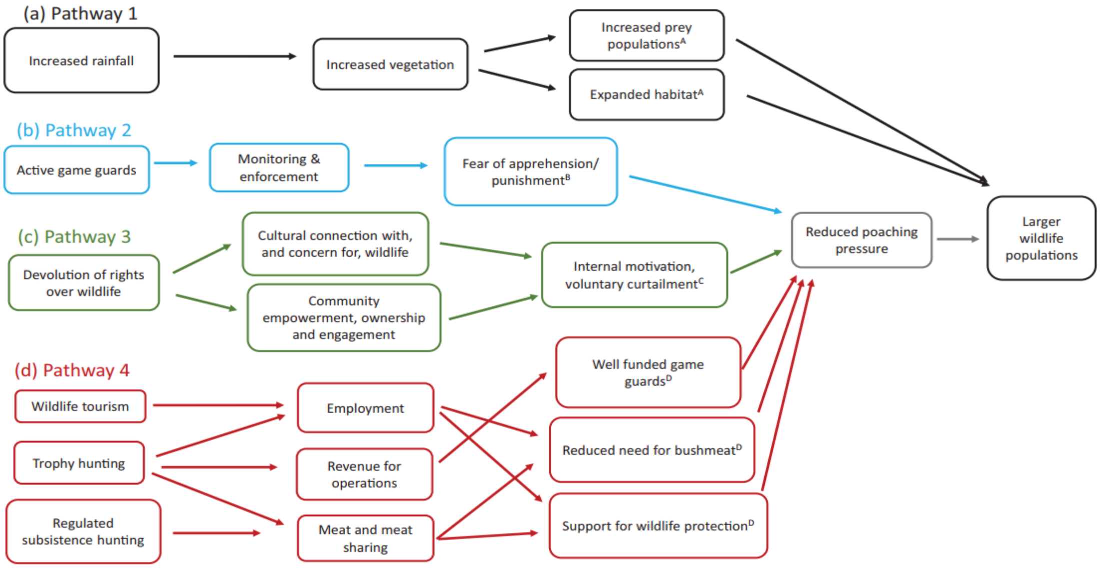

Figure 9.1 Diagram of hypothetical causal pathways to outcomes of Namibian conservancies based on process tracing. Superscript letters are used to denote the key causal mechanism for each pathway that is hypothesized to lead to larger wildlife populations; A = ecological, B = external motivation, C = internal motivation, D = economic incentive (from Cheek et al. 2023).

b) Example II

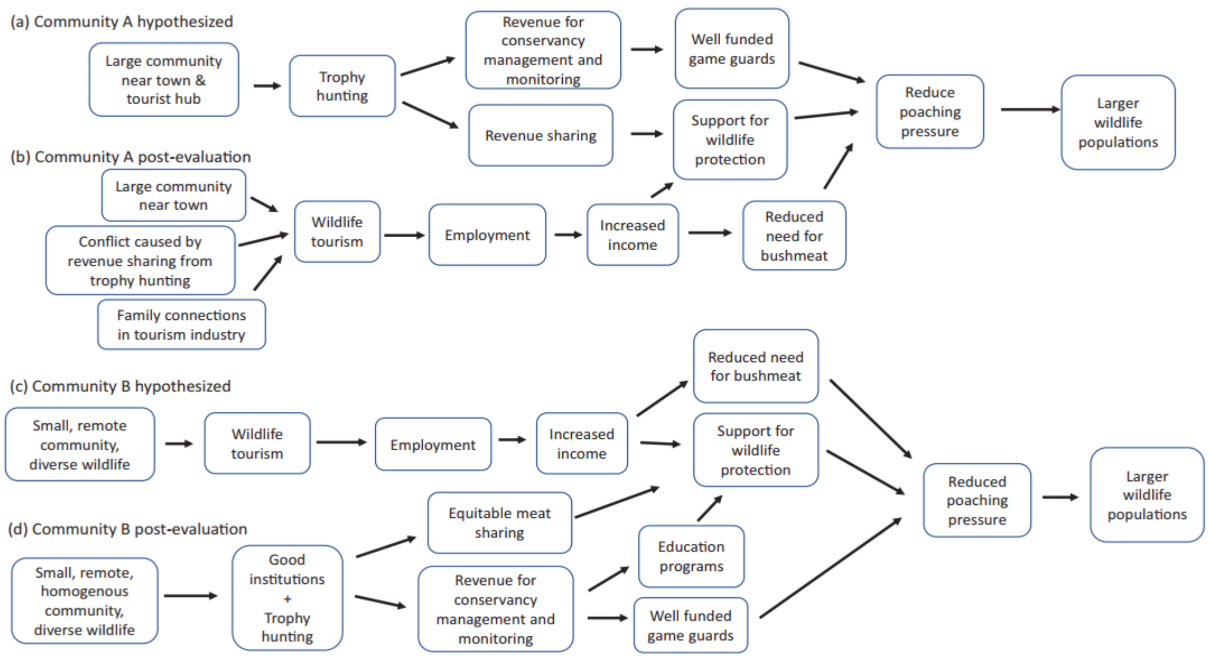

Figure 9.2 Diagram of hypothesized and post-evaluation causal pathways of the impacts of Namibian conservancies on wildlife populations based on realist evaluation (from Cheek et al. 2023).

c) Example III

Driver interactions are complex, among direct drivers, among indirect drivers, and especially among indirect and direct drivers (IPBES 2018). The IPBES Europe and Central Asia Regional Assessment (IPBES 2018) applied qualitative systems modelling methods and used causal loop diagrams to structurally map the dynamic inter-relationships within and between indirect and direct drivers of change in biodiversity and nature's contributions to people. Causal loop diagrams provide a concise format for describing complex interconnected system structures and behavioural directionality. Causal loop diagrams use arrows to indicate direct causal relationships between independent and dependent variables. These relationships can be either in the same direction, represented by a positive (+) sign, or in the opposing direction, represented by a negative (–) sign. Thus, if independent variable A connects to dependent variable B by an arrow with a plus (+) sign, the underlying logic of the causal loop diagram is that an increase (decrease) in A's behaviour will lead to an increase (decrease) in B's behaviour. If the arrow connecting A to B is accompanied by a negative (–) signal, then the diagram indicates that an increase (decrease) in A will lead to a decrease (increase) in B. In some cases, variable concepts have been amalgamated or broadly aggregated, or otherwise relationships between independent and dependent variables have been strongly simplified, in such a manner as to impair the clear directionality of a relationship. In these cases, arrows are not represented by a sign.

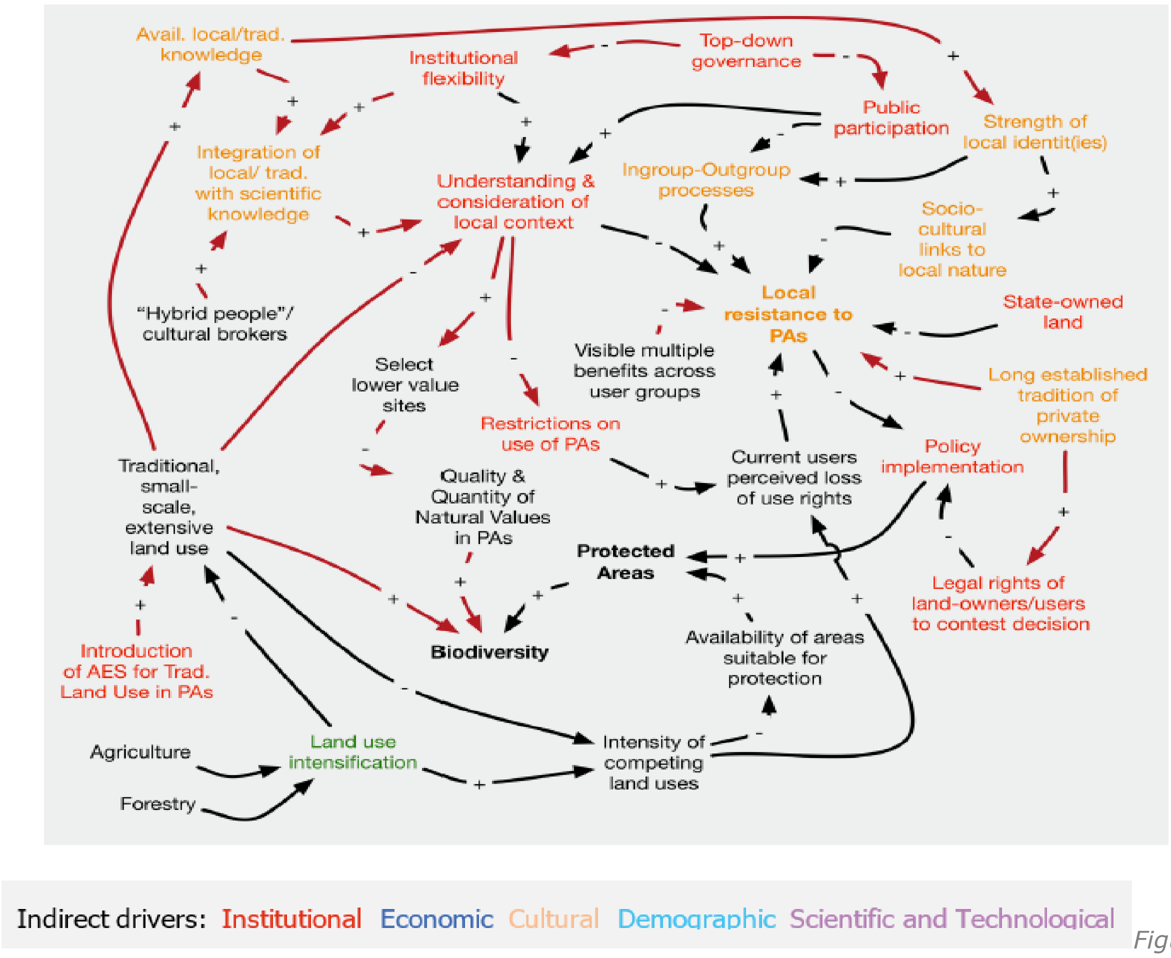

Figure 9.3 Consideration of local contexts, knowledge and identities in the design and establishment of protected areas helps to avoid local resistance (IPBES 2018).

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d) Example IV

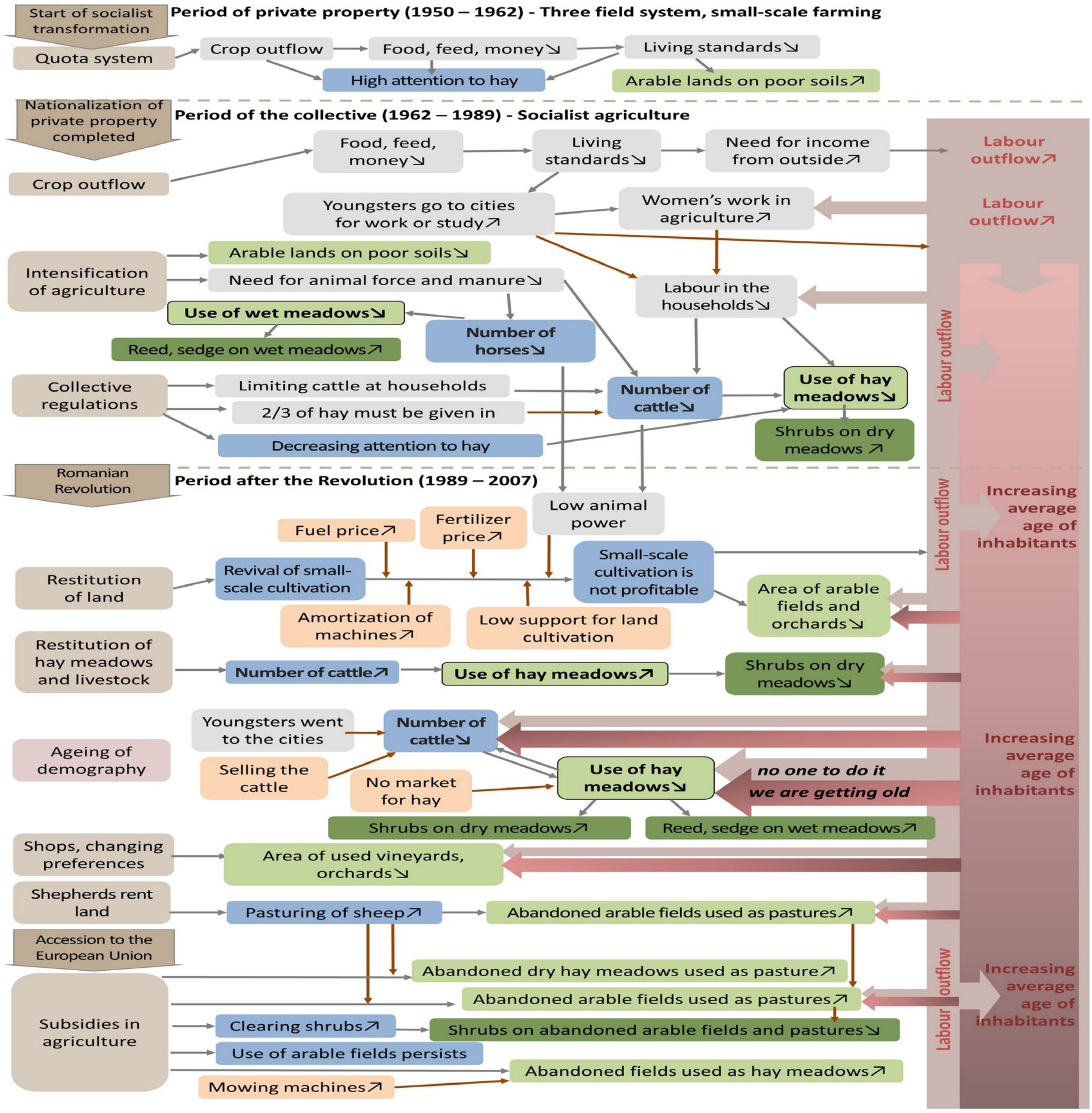

Figure 9.4 Interaction of indirect and direct drivers and their impact on vegetation change in a transforming cultural landscape (Biró et al. 2024).

The figure shows the ecologically relevant driver interactions in the studied villages that were mentioned in oral history interviews (Kalotaszeg, Romania).

- Dark brown boxes indicate country-scale historical events initiating the transitions between historical periods.
- Light brown boxes indicate nine country-scale initial drivers of land-use change; the one exception (ageing, shown in purple) is initiated by two mutually reinforcing local internal demographic drivers.
- Grey boxes: other indirect socio-economic drivers.

- Orange boxes indicate country-scale external drivers exacerbating driver interactions. Light green boxes: direct drivers of vegetation changes: land-use change (without borders) and land-use intensity change (with borders).
- Dark green boxes: vegetation changes.
- Blue boxes: changes in livestock numbers and the main characteristics of management practices affecting driver interactions.
- Demographic consequences of driver interactions are shown on the right with arrows highlighting delayed effects.
- Brown arrows show exacerbating effects.
- Arrows beside the text indicate direction of change.

e) Example V

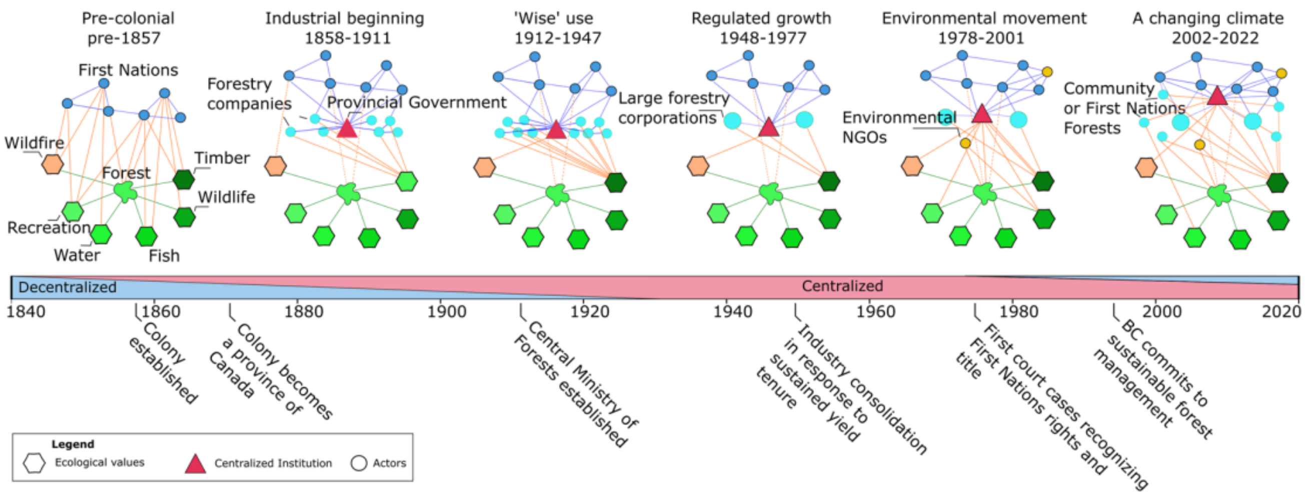

Figure 9.5 Simplified institutional structure around forest use in British Columbia as it has transformed over time since colonization. Note increasing diversity of actors (new coloured circles), but persistence of centralized provincial government (red triangle) through time. (Sutherland et al. 2023).

f) Example VI

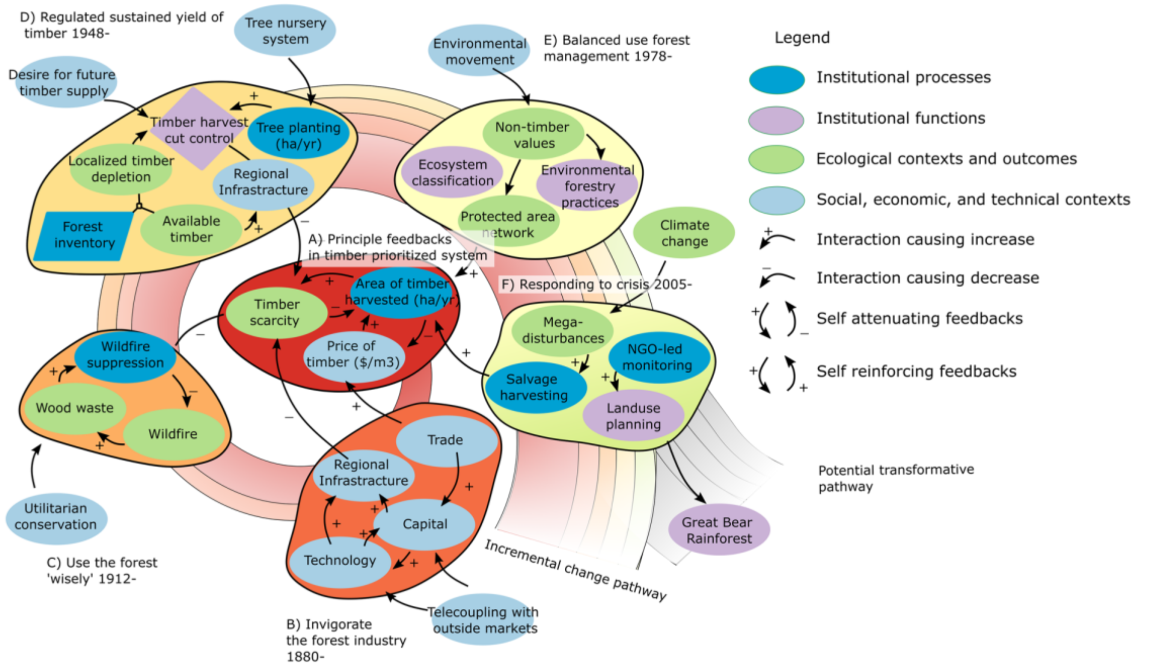

Figure 9.6 Historical sequence of institutional functions introduced to overcome A) self-attenuating feedback that limit growth in the forestry system. B) Infrastructure, investment, technology, and trade invigorated the forest industry and allowed it to scale up. C) Utilitarian ideals of 'using the forest wisely' inspired policies to reduce waste and suppress fire and D) regulate harvest rates through a new sustained yield tenure system and tree planting.

g) Example VII

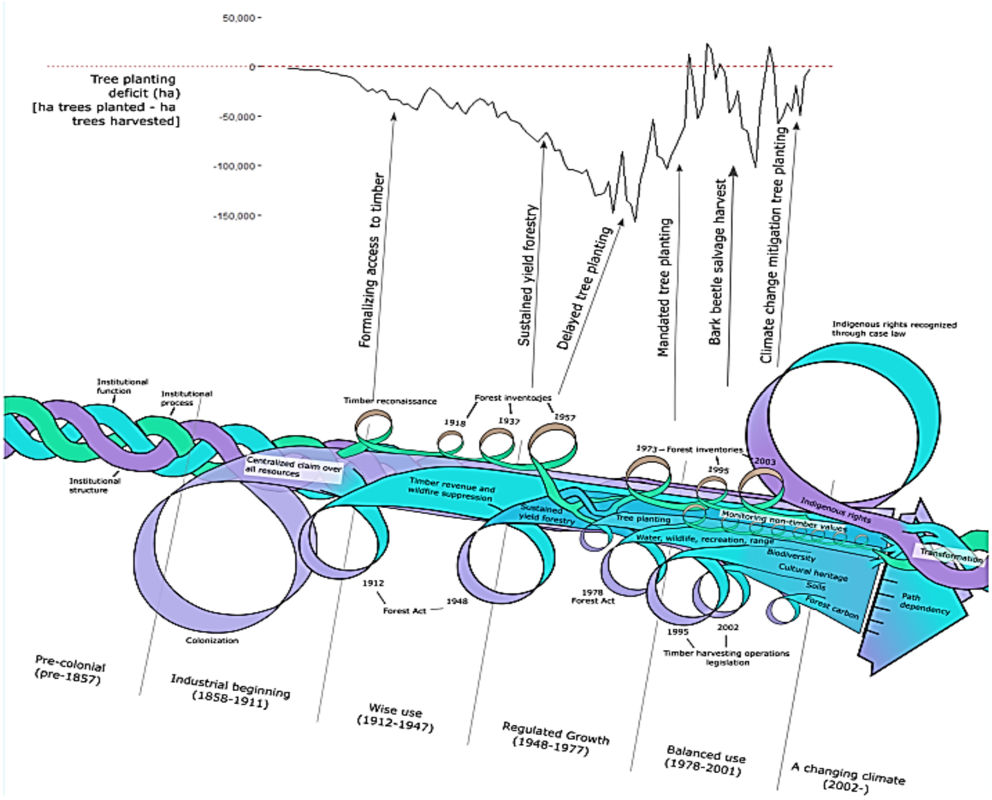

Figure 9.7 Stable and lagged dynamics within the British Columbian social-ecological system (SES) pathway from the 1800's to 2020. An outcome of complex SES dynamics is represented here by the tree planting deficit, which is the difference between the area of trees planted and the area harvested. Loop size approximates the significance of the change in relation to the overall pathway. Arrows indicate emergent effects on the tree planting deficit.