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SPATIAL SCALE-MEASUREMENT, INFLUENCE, AND INTEGRATION (A MARTIN AND J HOLLAND, SECTION EDITORS)

# Mismatches in the Ecosystem Services Literature—a Review of Spatial, Temporal, and Functional-Conceptual Mismatches

Klara J. Winkler[1] · Marie C. Dade[2] · Jesse T. Rieb[2]

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## Abstract

**Purpose of Review** The objective of this review is to identify commonly researched ecosystem service mismatches, including mismatches concerning management and policies implemented to manage ecosystem service delivery. It additionally discusses how mismatches affect the ability to develop effective policies and management guidelines for ecosystem services.

**Recent Findings** Recent ecosystem service literature considers mismatches in the ecosystem, the social system, and as social-ecological interactions. These mismatches occur over three dimensions: spatial, temporal, and functional-conceptual. The research field incorporates not only ecological aspects but also social ones like the management and governance of ecosystem services. However, the focus of the reviewed literature is mainly on spatial and temporal dimensions of mismatches and the production of scientific knowledge, rather than the implementation of the knowledge in management and policies.

**Summary** Research on ecosystem service mismatches reflects the complexity and interconnectedness of social-ecological systems as it encompasses a broad variety of approaches. However, temporal mismatches received less attention than spatial mismatches, especially in regard to social and social-ecological aspects and could be a topic for future research. Furthermore, in order to develop effective policies and management guidelines, research must work closer with decision-makers to not only advance scientific understanding of ecosystem service mismatches but also create understanding and support the uptake of this knowledge.

**Keywords** Match · Governance · Scale · Level · Science-policy interface · Trade-off

## Introduction

The delivery of ecosystem services—the ways in which nature contributes to human well-being—is complex as it involves interactions across social-ecological systems [1–3]. Identifying which of these interactions play a key role in achieving specific desired outcomes for ecosystem service delivery, and understanding the nature of these interactions, can help to ensure effective management and policies for ecosystem services are implemented. In particular, in recent years, researchers have increasingly recognized that these interactions within and across social-ecological systems can create opportunities for mismatches to occur that can then affect the delivery and effective management and governance of ecosystem services.

As social-ecological systems are complex with many components at different levels and scales (definitions discussed below), mismatches can occur between all kinds of components that affect the delivery of ecosystem services. Depending on the context of the research and their own personal and academic backgrounds (including research traditions, objectives, and understandings), researchers can look at a variety of different mismatches within social-ecological systems.

A common kind of mismatch that is studied within social-ecological systems, and that can impact the delivery of ecosystem services, is scale mismatches. In the context of interdisciplinary social-ecological research, it is important to note

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✉ Klara J. Winkler
klara.winkler@mcgill.ca

[1] Department of Natural Resource Sciences, McGill University, Montreal, Canada

[2] Department of Geography, McGill University, Montreal, Canada

that there are slightly different understandings of scale between natural and social sciences, which have been documented over the last two decades [4, 5•, 6]. In landscape ecology, scale is understood as the spatial and temporal dimensions of a process or object, and scale mismatches are therefore often categorized as being either spatial or temporal [7]. However, within the social sciences, scale can refer to quantitative or analytical dimensions used to measure and study a phenomenon. These dimensions can be categorized as, among others, spatial, temporal, jurisdictional, or institutional and the units of scales are referred to as levels. For example, the levels of a jurisdictional scale could be administrative units such as municipal, provincial, national, and supra-national, and the ones of institutional scales the units are different types of rules like constitutions, laws, and operating rules [8]. Units for spatial and temporal scales can be the same for both ecology and social sciences measured in spatial and temporal measurements (e.g., $km^2$, hours, years), but in the social sciences, the units can be also qualitative descriptions (e.g., many generations ago, far away, in our community).

Within the ecosystem services literature, another particular type of mismatch is especially well studied: the mismatch between supply and demand of ecosystem services. Geijzendorffer et al. [9••] define ecosystem service mismatches as a "[difference] in quality or quantity occurring between the supply and demand of ES [ecosystem services]" (p. 321). This type of mismatch can occur across and within different scales and levels. For example, the amount of biotic pollination services desired might occur mostly within cropland, but the supply of pollination services provided by ecosystems is occurring at a much broader spatial scale and may not provide the amount of pollination services desired specifically within cropland [10]. Cumming et al. [11] suggest a similar definition, defining supply-demand mismatches as "functional mismatches between societal demand for ecosystem services and the capacity of ecosystems to provide these services in a sustainable manner" (p. 1142). As such, both definitions encompass mismatches that occur between and within stocks (e.g., ecosystem, society's perceptions, and knowledge) and flows (e.g., supply, demand) that affect the final delivery of an ecosystem service.

Over the past decade, the ecosystem service literature has increased and with it the literature dealing with mismatches and ecosystem services [12]. However, there remains little knowledge about the specific types of ecosystem service mismatches being studied or the implications of scale mismatches occurring between management and ecosystem service delivery. Understanding the types of ecosystem service mismatches that are commonly identified in the literature will allow us to describe the current state of ecosystem service mismatch research and identify the knowledge gaps that should be addressed in future research. Furthermore, it can provide insight into the implications of mismatches for delivering effective ecosystem service management. This information can help to illustrate scale-appropriate management and policy actions to achieve desired outcomes for ecosystem service delivery [11, 13•].

Here, we review the scientific literature regarding ecosystem service mismatches. In particular, we aim to identify the ecosystem service mismatches that are commonly researched within the literature, including mismatches in the scale of management guidelines and policies implemented to manage ecosystem service delivery. Based on our review findings, we discuss how mismatches affect our ability to develop effective policies and management guidelines for ecosystem services.

## Methods

In this review, we examine empirical literature focusing on (mis)matches connected to ecosystem services in a qualitative review. We focused on empirical literature, rather than conceptual papers, in order to learn about the mismatches observed in case studies, the approaches taken by researchers to identify them, and their potential implications for real-world management and/or policy decisions.

We conducted two searches each in the Scopus and Web of Science databases using the search terms "ecosystem service*" mismatch* and "ecosystem service*" match* in the fall of 2019. We excluded non-English publications in this review. This provided us with an overall snapshot of how ecosystem services literature discusses mismatches. As such, it reflects the breadth of ecosystem service mismatch research, though it is possible that a number of relevant papers may not have been identified using this approach because they did not use the keyword "ecosystem services" or were written in another a language other than English. For example, we might not have captured literature that discusses individual ecosystem services, but does not frame them as ecosystem services, such as food provision, pollination, or recreation. Similarly, we might also have missed literature that discusses what we would consider a mismatch without using that terminology (e.g., spatial patterns of ecosystem services interactions). However, we are confident that our approach helped us to achieve our aim to acknowledge and illustrate the many existing perspectives on ecosystem service mismatches rather than to find the exact share of the different perspectives in the scientific discourse.

Overall, we identified 569 unique papers from the four searches (Supplementary data 1). We screened the abstracts of these papers to exclude papers which were either non-empirical, unrelated to ecosystem service mismatches, or not accessible for us either because the main body was not written in English or because we had no institutional access. Of twelve papers that were non-accessible for us, two were likely relevant given the information in the abstract. This produced a final subset of 124 papers that we then reviewed in detail.

We used a two-step coding approach to review the final 124 papers. We first retrieved the sections of the text that discussed (mis)matches and the sections about management and then coded the paper. This two-step approach was important as the papers came from a variety of disciplinary backgrounds where the same phenomena might be described differently. As we were also interested in if and how the literature dealt with management and policy issues related to ecosystem service delivery, we copied those parts of the text into our coding document as well.

We then coded the mismatches discussed within each paper. To capture the full range of mismatches described within the ecosystem services literature, we define ecosystem service mismatches broadly as situations in which the quantity or quality of one component or process that is involved in the delivery of ecosystem services differs from another one. We coded each paper according to both the type of mismatch (or match) it identified (i.e., what was mismatched) as well as the dimension over which the mismatch occurred (Table 1). These different types of mismatches can be broadly categorized as (1) ecological-mismatches between ecological components (e.g., pollinators and plants) or processes (e.g., nutrient cycling or species interactions), (2) social-mismatches between social components (e.g., scientific and local knowledge), and (3) social-ecological-mismatches between ecological and social components (e.g., people's demand for ecosystem services and the ecosystem's capacity to provide them). We categorized the mismatch dimensions as spatial, temporal, and functional-conceptual, based on both the reviewed literature and existing frameworks by Cumming et al. [5•] and Cash et al. [8] (Fig. 1). We defined spatial mismatches as situations when two or more components or processes related to ecosystem service delivery do not align in space. Temporal ecosystem services mismatches occur when multiple components or processes related to ecosystem services delivery do not align at the same time. Based on the reviewed literature, we broadened Cumming et al.'s [5•] definition of functional mismatch and called it functional-conceptual. The original definition refers mainly to ecological functions, while we also included social functions (also called institutions) that do not align in the form of management and policies as well as different perceptions and knowledge types (e.g., traditional ecological knowledge) (Fig. 1). Our three categories of dimensions align with the different scales proposed by Cash et al. [8] to describe human-environment interactions, with our functional-conceptual dimension encompassing Cash et al.'s jurisdictional, institutional, management, networks, and knowledge scales.

**Table 1** Examples of ecosystem service-related mismatches representing different mismatch types (ecological, social-ecological, social) and dimensions (spatial, temporal, functional-conceptual), as found in our literature search

| | Mismatch *TYPE* | | |
|---|---|---|---|
| Mismatch *DIMENSION* | Ecological | Social-ecological | Social |
| Spatial | In the USA, approximately 40% of the areas where pollinator-dependent crops are grown have low abundances of wild pollinator species [14]. | Forests in Spain provide erosion control in local areas, but demand for erosion control by these forests comes from people across the country, rather than from local populations [15]. | The areas targeted by an urban reforestation program in the USA state of Florida did not necessarily overlap spatially with the areas where people's demand for tree-related ES was greatest [16]. |
| Temporal | Climate change is disrupting the seasonal rhythms of insect life cycles, potentially affecting the temporal overlaps between predator and pest species needed for biological pest control [17]. | Vultures provide important benefits to people by removing dead livestock, but the time when vultures are most active does not necessarily align with the time of highest livestock mortality, when people have the greatest need for his service [18]. | Mismatches between the time scales of payment for ecosystem services (PES) programs and the lives of smallholder farmers may impact the effectiveness of programs to conserve carbon and reduce poverty in East Africa [19]. |
| Functional-conceptual | Larval abundance of mussels in an aquaculture system in Chile did not always match larval recruitment onto substrates, potentially leading to less production than expected [20]. | The management plan of a regional park in Scotland was found to not target the features of the ecosystem that were most important for the provision of ecosystem services [21]. | Farmers' perceptions of ongoing climatic changes in Ghana did not match scientists' understanding based on historical weather records, impacting their willingness to participate in conservation programs [22]. |

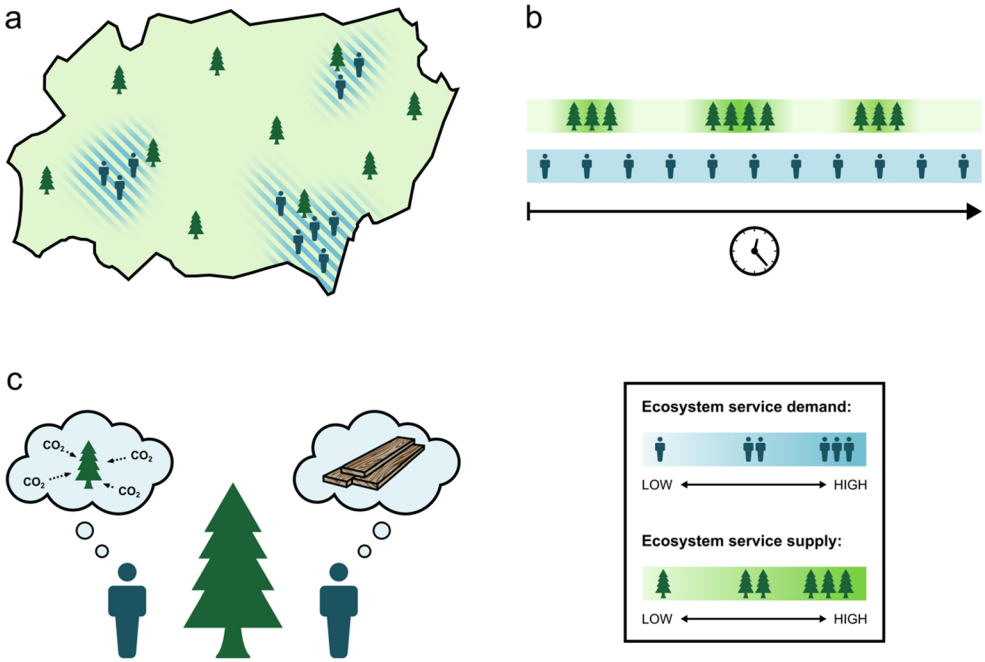


**Fig. 1** A conceptual model demonstrating the three dimensions of ecosystem services mismatches we identified in the reviewed literature, based on the Cumming et al. [5•] framework: spatial, temporal, and functional-conceptual. Spatial mismatches (**a**) occur when two or more components or processes related to ecosystem service provision do not align in space. For example, an ecosystem service may be supplied evenly across a landscape, while demand is concentrated in local areas. This may lead to some people not getting enough of the service, even if the overall amount of supply and demand is the same. Temporal mismatches (**b**) occur when multiple components or processes related to ecosystem service provision do not align in time. For example, demand for an ecosystem service may be constant over time, while the amount provided by the ecosystem varies, leading to unmet demand at some points in time. Functional and conceptual mismatches (**c**) refer to mismatches in jurisdictional, institutional, management, networks, and knowledge related to ecosystem service delivery. For example, two groups of people may have different perceptions of the ecosystem services supplied by a landscape, potentially leading to conflicts or misunderstandings in management

Since the aim of our paper is to illustrate the different perspectives on mismatches in the ecosystem services literature, papers could fall into multiple of the three mismatch dimensions described (e.g., dealing with both a spatial and temporal mismatch). We therefore recorded all dimensions discussed within each paper. Some literature described mismatches that only involved the ecological or the social system and were not specifically a scale or a supply-demand mismatch, but that still impacted the delivery of ecosystem services. We included these mismatches because we wanted to show the whole variety of mismatches that are connected to ecosystem services. Our coding scheme along dimensions and types (Table 1) allowed us to categorize all reviewed papers.

## Results

### Spatial Mismatches

We identified in our literature review spatial mismatches of the ecological, social-ecological, and social mismatch types. However, we find relative to the overall occurrence of the type within our reviewed data, more mismatches of the ecological and social-ecological type than of the social type (Table 2).

When ecological components and processes do not align spatially, the ecosystem components are unable to interact as easily, and ecosystem service provision is likely to decline or not occur at all. Much of the literature around spatial mismatches of ecological components and processes focuses on pollination and pest control, as these are two ecosystem services that are closely linked to particular interspecific

**Table 2** The number of papers that discussed each mismatch type and dimension. Because some papers discussed multiple mismatch dimensions, some row totals are different than the sum of their individual cells

| | Mismatch dimension | | | |
|---|---|---|---|---|
| Mismatch type | Spatial | Temporal | Functional-conceptual | Total |
| Social | 2 | 1 | 23 | 26 |
| Ecological | 14 | 12 | 4 | 27 |
| Social-ecological | 50 | 8 | 23 | 71 |
| Total | 66 | 21 | 50 | 124 |

interactions: the interaction between pollinators and the plants they pollinate and the interaction between pest species and their predators, respectively. For example, Koh et al. [14] looked at spatial overlaps between wild bees and pollinator-dependent crops, and found that a mismatch where 39% of the area of pollinator-dependent crops in the USA have low pollinator abundance, and Schweiger et al. [23] found spatial mismatches between butterfly species, which can contribute to pollination [24] and cultural ecosystem services [25], and the plants that they use. These spatial mismatches can be caused or exacerbated by anthropogenic forces, such as landscape management [26] or climate change [27]. Other studies explored spatial mismatches involving different aspects of biodiversity. For example, De Palma et al. [28] found a spatial mismatch between taxonomic and functional diversity of bees in Europe that provide pollination services, and Parravicini et al. [29] found a similar mismatch between species richness and taxonomic and functional vulnerability of reef fish globally, a group of species that can potentially provide a multitude of ecosystem services. While biodiversity is generally thought to be positively related to the provision of many ecosystem services, these relationships are complex [30] and the consequences of mismatches involving biodiversity for ecosystem services provision may not be easy to predict.

Spatial mismatches can also involve multiple ecosystem services (including ecosystem services bundles). For example, Braun et al. [31] discuss spatial overlaps between agricultural ecosystem services, carbon sequestration, and cultural ecosystem services, as well as a number of other environmental variables, and Paetzold et al. [32] propose looking at matches among multiple ecosystem services, in addition to their ability to meet people's demand, as an indicator of ecosystem quality. Identifying spatial matches among multiple ecosystem services is one of the most common ways of identifying ecosystem service interactions [33] and ecosystem services bundles [34]. Spatial mismatches among multiple ecosystem services can have important implications for the spatial prioritization of ecosystem management, for example, decisions to pursue a "land sharing" versus a "land sparing" approach to urban development [35], particularly when trying to manage for multiple benefits.

Social-ecological, spatial mismatches between ecosystem service supply and demand can occur when there is a spatial disconnect between the quantity or quality of a service provided, or potentially provided by an ecosystem, and the quantity or quality that people desire [9]. Much of this literature focused on mismatches in the location of a service's supply and demand. For example, Xiao et al. [36] showed that the demand for recreational activities in forests is not matched by the available forests in suburban Beijing. However, there can also be mismatches in the spatial scale at which supply and demand occur. For example, García-Nieto et al. [15] found that erosion regulation is supplied at the local scale, but the demand for this service occurs at the regional or national scale. Spatial supply-demand mismatches can be a result of land use planning decisions. For example, the zoning of urban and rural areas can cause a spatial disconnect between supply and demand, as demand is primarily located within urban areas but many of the ecosystem services urban residents desire are located in the rural areas, such as food production and air quality regulation (e.g., [37–39]). When mismatches in the location of supply and demand occur, people may be able to compensate by traveling to different locations to access ecosystem services [40] or by using non-ecosystem-based alternatives [41]. Otherwise, these mismatches have the potential to lead to unsatisfied demand and unsustainable management of ecosystem services, which can have negative impacts on both ecosystem health and human well-being [9••].

Social, spatial mismatches are not frequently studied (Table 2). Dawes et al. [16] showed that urban areas reforested through a state program in Florida did not necessarily spatially overlap with areas where demand was for tree-related ES. Sylla et al. [42] illustrated how to avoid spatial mismatches between the spatial units used in research and the ones municipal policies work in. Both papers indicate a need to coordinate better between policies and other aspects of society such as demand or research.

## Temporal Mismatches

Similar to spatial mismatches, a number of papers discussing temporal mismatches involving the ecological components of ecosystem services provision focused on pollination and pest regulation. Both of these services are driven by interspecific interactions that are highly temporally dependent. Pollination, for instance, may need to happen at a very specific time to be effective [43], and even when pollinators and plants overlap spatially, there can still be temporal mismatches that affect pollination and pollinators. Crop resources must be available at the times that pollinators need them in order to maintain diverse populations of pollinators [44]. Consequently, changes in agricultural management practices, such as efforts to intensify agricultural systems by moving planting dates earlier in the year, must consider whether they might lead to temporal mismatches with pollinators [45]. Similarly, predator-prey interactions, such as those required for biological pest control, are sensitive to temporal mismatches due to the life cycles of the organisms involved [46]. Climate change is expected to cause or exacerbate mismatches between species across many different environments and types of organisms [47]. This can impact the provision of ecosystem services, including pollination [48] and pest control [17, 49] as well as other ecosystem services that are related to species interactions. For example, temporal mismatches between plant phenology and functionally related organisms like herbivores, predators, pollinators, and seed dispersers may have implications for disturbances,

such as species invasions or fire [50], and temporal mismatches between bird populations and their habitat [51] may have potential consequences for ecosystem services such as hunting, birdwatching, and pest control. The success of movement of species in response to climate change, whether intentional, as in assisted migration [52], or unintentional, as in invasive species [53], is influenced by functional matches and mismatches between species and their new communities, potentially affecting the ecosystem services these species can provide. For example, temporal matches between primary producers, herbivores, and predators are critical for regulating algal blooms, an important ecosystem service in ecosystems facing increased eutrophication [54].

Social-ecological, temporal mismatches can also occur for ecosystem service supply and demand. This occurs when services are provided at different times, or at different temporal scales, than when people want or need them. For example, in some regions, carcass removal by vultures is an important ecosystem service, and Dupont et al. [18] identify a temporal mismatch in the breeding season of the vulture, the time when this species provides the most carcass removal, and the peak season for livestock mortality, when demand for carcass removal by farmers is highest. Temporal mismatches also occur when demand for ecosystem services changes over time due to shifts in society. This can include, for example, population growth, driven by changing lifestyles, values, and healthcare within societies, leading to increased demand for agricultural ecosystems services supplied by a landscape, over time [55], or increasing demand for pollination services, and the food they provide, as wild pollinators experience a decreasing trend in abundance over time [56]. Mismatches may also occur when supply and demand occur at different temporal scales, when the time frames do not match within which the supply and demand of an ecosystem service occur [11]. For example, groundwater aquifers can often take years to replenish groundwater supply but demand for this service can occur on a daily basis [57].

We identified only one study on social, temporal mismatches (Table 2). Wilkinson et al. [58] found that between 1929 and 2010, strategic spatial plans in the cities of Stockholm and Melbourne showed only very little continuity in addressing the same ecosystem services throughout time. The authors highlight in their paper the need to pay more attention to time-scale mismatches which we echo as a result of our review eight years later.

## Functional-Conceptual Mismatches

There were only a limited number of ecological, functional-conceptual mismatches in the reviewed literature. The ones identified had two foci: (1) trait (mis)matches and (2) mismatches between natural and restored ecosystems. The studies following the first focus identified mismatches in traits that would otherwise be expected to be correlated, for example, a mismatch between the abundance and recruitment rate of mussel larvae [20]. The other studies [59, 60] compared the provision of ecosystem services or function of natural and restored ecosystems formulating this comparison as a question of (mis)match.

Social-ecological, functional-conceptual mismatches can occur due to a disconnection between human actions (e.g., demand, management) and the state or potential of an ecosystem, which can be either due to demand exceeding supply or demand for different services than those supplied. Most of the studies where demand exceeded supply were in the context of working landscapes (e.g., [56]), except for Arbieu et al. [61] who showed that people wanted more wildlife than was present in South African protected areas. In working landscapes, these types of mismatches can create challenges if managers want more from the ecosystem than what is possible, as they might adopt measures that harm rather than maintain the state of the ecosystem [62]. For example, too much fertilizer or irrigation might have local consequences for the field but also broader impacts on the surrounding ecosystem [63, 64]. Thus, it is important to consider the local specificities in management decisions for working landscapes [65, 66]. When there were mismatches in the types of supply and demand, people either expected the ecosystem to provide services it was not capable of providing (e.g., [67–69]) or lacked awareness that certain services were provided [57]. This situation is often created by standing rules and regulations, such as planning, connectivity, and management, that do not target the right aspects for the provision of the ecosystem services in demand [21, 70].

We found mismatches in perceptions, knowledge types, and between the two. This is often connected to an epistemological understanding that different knowledge types exist and that people can have different perceptions on the same aspect of ecosystem service delivery [71]. A common mismatch is between Western science knowledge and either people's perceptions, or other knowledge systems, such as local and traditional ecological knowledge [22]. This mismatch exists not only between Western science and indigenous communities, which often have their own knowledge systems (e.g., indigenous medicine), but also between Western science and other Western knowledge systems (e.g., farmers in Western, industrialized countries). An additional form is between Western science and the lived reality of people which is often described as perception [72]. These mismatches can also be within one of the knowledge systems and people's perceptions, for example, understanding and assigning importance of an ecosystem service can vary between different scientific disciplines [73]. These mismatches have direct impacts on decision-making at all levels because perceptions and knowledge can vary across decision-making entities, and the knowledge that is applied in higher-level decision-making might influence, or

even undermine, other knowledge types and truths. For example, some Swiss landscapes are changing their focus from agriculture to energy production, and people's perceptions of this process differ between the national, regional, and local levels [74]. Lee et al. [19] illustrate how regional actors with their economic knowledge are dominating local small-scale farmers in East Africa and thus undermining the local knowledge with knowledge based in Western science. These mismatches shape management and policies and thus the ecosystem service delivery.

### Management and Policies for Ecosystem Service Delivery

About half of the reviewed papers connected their research with management and policies. The degree to which the reviewed papers engaged with decision-making for policy and management varied widely. Many only mentioned that their results should be considered for decision-making by local resource managers (e.g., farmers) or for policymaking (e.g., agricultural or conservation laws), but did not necessarily elaborate on the process, impact, or potential mismatches.

In the reviewed literature that included management and policies, the institutional level of policies or management actions mostly matches the scale of the ecological components or ecosystem services they were targeting. A small number of studies focused on management occurring at a different scale to the ecosystem service, creating a mismatch. This can occur for various reasons. One is that the ecosystem service is measured at a different scale than that at which it is managed. A prime example is carbon storage, while the effect of carbon storage can be seen globally; it requires local actions to alter the amount of supply. This is demonstrated in Lee et al. [19] who study global carbon storage and the effects of regional carbon markets for local smallholder farmers in East Africa. Another reason for scale mismatch between ecosystem services and management is when ecosystem services or the ecological components are vast or mobile and thus require management or policies across a bigger area. Biggs et al. [75] use the Olifant river in South Africa to illustrate how federal, regional, and local policymaking is impacting the river, its ecological status, and provided ecosystem services.

## Discussion

Our results show that different types of mismatches related to ecosystem service delivery exist and are researched. Since the social-ecological systems that provide ecosystem services are complex and multi-layered, researchers have chosen different research perspectives to identify different types and dimensions of mismatches, with some focusing more on the ecological or the social side or on the interaction between the two. We selected three dimensions (spatial, temporal, functional-conceptual) in order to illustrate the variety of mismatches discussed in the reviewed literature. While spatial and temporal mismatches might be more aligned with the traditional research approaches in landscape ecology, mismatches between management and policies and the ecological system and ecosystem services are also commonly discussed within the literature.

### Mismatches Can Have Negative Consequences

The reviewed literature demonstrates that ecosystem service mismatches can have negative ecological consequences which management and policies should aim to minimize or eliminate. Negative ecological consequences could include the loss of ecosystem services in terms of both quantity (e.g., less fish in a water body), and quality (e.g., the fish is toxic). Besides this potential loss of ecosystem services, mismatches can also have negative impacts on other ecosystem properties, such as resilience, which could reduce the ability of a system to respond to changes and thus it may not be able to provide certain ecosystem services in the future. For example, a decrease in pollinator diversity while there is an increase in pollination demand can reduce ecosystem service resilience as there is an increased strain on a smaller group of pollinators to meet demand, which can lead to an ecosystem becoming more vulnerable to species loss and disturbances [30].

Ecosystem service mismatches can also have negative social consequences. These social consequences can be unmet needs, unintended effects which are temporally or spatially distanced and as such are not noticeable, and the aggravation of power imbalances. Management decisions can alter the supply of ecosystem services within landscapes, which can lead to less of an ecosystem service being supplied than what is being demanded (e.g., [62, 76]). A prime example is fertilizer application and changing farm management which can alter the supply of nutrient regulation in the soil, potentially leading to a decrease in the provision of that ecosystem service while demand for it remains the same [77]. This can have severe consequences for human well-being when the mismatch involves essential needs like food or clean drinking water.

Policies and management can have effects on ecosystem services which are temporally or spatially distanced, so decision-makers do not notice these mismatch consequences. One example is the Biofuel Directive of the European Union which encouraged the growth of crops that needed to be pollinated by insects. The increase of insect-pollinated crops throughout Europe increased the need for pollinators (pollination demand) while simultaneously reducing the amount of habitat for wild pollinators (pollination supply; [10, 56]), exacerbating a supply-demand mismatch.

Power imbalances give people the capacity to decide who can access ecosystem services. Land use policies including policies on land conservation and ownership can lead to mismatches through regulating both supply of and access to ecosystem services. For example, property rights may restrict who can access the supply of certain ecosystem services on a property, which can result in the demand of some stakeholders not being met [78].

## Incorporating Mismatch Research into Decision-making

Knowledge about mismatches can help to effectively manage and govern ecosystems. For ecological mismatches in time and space, decision-makers can aim to create management plans and policies that deal with the mismatch. If the mismatch involves a social component, decision-makers need to change the rules in place for the social component to alter it [79].

Decision-makers can use knowledge from mismatch research and incorporate it in their management and policies. One approach is for decision-makers to base their decisions on Western science to inform themselves both about the content (through, e.g., ecological research) and the process (through, e.g., governance research). For example, interregional ecosystem services flows, which deal mainly with spatial mismatches, have increasingly gained attention in research [80••, 81, 82]. This research does include research not only on the ecosystem services flows but also on the rules and regulations influencing these flows [83]. This knowledge can then inform international management guidelines and policies with changes implemented on more local scales [84•]. For this reason, a polycentric governance approach is needed for not only international agreements and conventions (e.g., Convention on Biological Diversity and its Protocols) but also local policies and management guidelines that are put into action in specific locations [83].

Furthermore, in recent years, there has been more emphasis on the communication of research findings to users, which can also help to reduce occurrence of mismatches. For example, one way is to engage in the science-policy interface, a space in which science works directly with policymakers. This involves an interactive process that not only provides information but also accompanies policy formulation processes in order to adapt to the needs and constraints of the knowledge users [85, 86]. Eklipse, originally initiated by the European Commission, collects requests from political entities in Europe to support policymaking with scientific facts. Among others they have worked for the Swedish Board of Agriculture (a government agency) to support the agency in the most recent negotiations of the European Common Agricultural Policy (CAP) by providing scientific (and other) information on the mismatch between the uptake of changes in farm management and the provision of ecosystem services [87]. Another approach that is increasingly used is participatory processes. Karrasch et al. [88] worked over 4 years with a group of 14 local actors representing different sectors in Northern Germany on land use decisions and future land developments. The process increased the participants' understanding not only of the perspectives of the other participants but also of scientific predictions of future developments. As a result, they realized that the land use plan did not match future flood potential due to climate change, and they agreed on a change in the plan.

Despite these approaches to increase the uptake of research findings in management and policymaking, and reduce the occurrence of mismatches, we want to highlight that social-ecological systems are complex and multi-layered and often overlap with other systems. For this reason, it is illusionary to find a perfect fit between ecosystem and management and policies [89]. However, approaches such as adaptive management and flexible policies will allow managers and policymakers to adapt to changes and react to newly occurring mismatches in an effective manner.

## Future Research Directions

Although there are a number of research approaches that can increase involvement with decision-makers to help reduce occurring mismatches, our review also identified a number of mismatches related to ecosystem service delivery that currently receive little research attention. These mismatches need to be addressed in future research to further ensure effective management of and policies for ecosystem services.

We found that temporal mismatches of ecosystem services, especially with respect to management and policies, were hardly researched. As presented in the "Results" section, the reviewed literature covered spatial and temporal ecological mismatches and spatial mismatches of ecosystem services are increasingly covered often under the keyword interregional ecosystem services flow. Unfortunately, long-term mismatches (over longer time periods like years and decades) have been given little attention. A reason might be the character of Western science, which is often based on projects over two or 3 years and not decades. One potential way forward could be the standardized integration of social aspects into long-term ecological research (LTER) which have already started over the last decade to include increasingly social aspects, but more on a case-by-case basis [90]. The consideration of different speeds of change of the components in a mismatch (e.g., species abundance or population growth) and legacies [91] might also add another perspective on temporal mismatches which have not been researched extensively in the ecosystem service research.

Furthermore, mismatches can be understood as patterns and classified as recurring mismatch patterns, such as the dimensions and types we defined for our review. In order to better understand how mismatches occur and how to manage

and govern them, research should pay more attention to the drivers of ecosystem services mismatches (cf. [92••]). We speculate that the same patterns may have a similar or the same set of drivers. Thus, an understanding of which combination of drivers creates which mismatches will also help to design management plans and policies that more effectively handle mismatches in order to minimize the negative consequences.

Last, we want to encourage more landscape ecologists to embrace complexity in their research on ecosystem service mismatches, for example, the interplay between individual scales (such as between spatial and temporal scale), to learn more about the ecological and social processes that influence mismatches. Here, we can only speculate that mismatches on one scale (e.g., temporal) might reinforce mismatches on another scale (e.g., spatial). Another layer of complexity can also be added through interdisciplinary work on the topic between landscape ecologists and governance researchers. We are confident that after a phase of introduction to approaches and terminology, the gained insights on ecosystem services mismatches and their consequences for effective management and policies will help to push scientific insights forward and contribute to more sustainable management of ecosystem services for human well-being.

## Conclusion

Research on mismatches related to ecosystem services delivery is manifold. Due to the interdisciplinary character of the research field and the complexity of social-ecological systems and their interactions, researchers apply a variety of approaches and classifications which are partly overlapping. In the context of landscape ecology, spatial and temporal scales are often used to illustrate the mismatches between different components in the studied systems. Furthermore, management and policy implications remain only partly on the radar of published literature. Little research shows how research findings are implemented or changing actual management or policy decision-making processes. A greater involvement in interdisciplinary research with the different social science disciplines, and in transdisciplinary research with decision-makers, might allow for the development of a stronger common understanding and up-take of ecosystem service mismatch research findings in decision-making.

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## Declarations

**Human and Animal Rights and Informed Consent** This article does not contain any studies with human or animal subjects performed by any of the authors.

**Conflict of Interest** The authors declare no competing interest.



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Papers of particular interest, published recently, have been highlighted as:
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- •• Of major importance

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