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Time in and for nature-based solutions. No quick fix solutions for complex ecological and social processes

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ABSTRACT

Nature-based solutions (NbS) are an increasingly widespread tool in environment and development policies. They embody the idea that nature and natural processes can be purposefully used by humans to provide solutions to pressing environmental and social challenges. However, their potential to meet this ambition is contested, particularly in terms of the scale of the challenge, the risk of diverting attention from the need for decarbonisation, and examples of poorly implemented NbS projects. A largely overlooked but crucial factor concerning the effectiveness of NbS is time. In response to this gap, we develop a framework for systematising the ecological and social dimensions of time in NbS as well as the distinction between slow and fast processes. On this basis, we gather insights from a systematic literature review on key challenges related to slow and fast processes in both the ecological and social dimensions of time. For instance, the long maturation time of many species and ecosystems may be incompatible with the often short-term logic of NbS projects or with the dynamic character of ecosystems that may be challenging for continuous benefit provision. We also identify practical recommendations from the literature review for incorporating time into NbS design, for instance through adaptive monitoring, and we conclude with an urgent call for a more long-term perspective for NbS policies and practice.

1. Introduction

Nature-based solutions (NbS) are an increasingly widespread tool in national and international environment and development policies [1]. The United Nations Environment Assembly formally defines them as

> *'... actions to protect, conserve, restore, sustainably use and manage natural or modified terrestrial, freshwater, coastal and marine ecosystems, which address social, economic and environmental challenges effectively and adaptively, while simultaneously providing human well-being, ecosystem services and resilience and biodiversity benefits'* [2].

A constitutive characteristic of NbS thus is that they are underpinned by a biodiversity-positive approach. They embody the idea that nature and natural processes can purposefully be used by humans to provide solutions to pressing environmental and social challenges [2], prominently including water and food security, health, disaster risk reduction, and climate change [3].

Their synergistic approach motivates NbS' uptake across policy levels and actors. For instance, in 2022, the US government declared NbS to be 'one of the most effective and efficient avenues' to solve the climate crisis [4]. The European Commission [5] considers NbS as cost-effective interventions to tackle climate change and biodiversity loss while contributing to wellbeing and equity. NbS also feature prominently in outcomes of recent UNFCCC [6] and CBD [7,8] COPs and in most countries' Nationally Determined Contributions under the Paris Agreement and in many National Biodiversity Strategies and Action Plans under the CBD [9–11]. Moreover, private-sector attention to NbS has been increasing with companies turning to NbS for (voluntary) carbon offsets [12].

A considerable body of research documents positive effects of NbS. For instance, sound ecosystem management can contribute to climate change mitigation by preventing land-use change-related emissions and improving carbon sinks [3]. Moreover, by enhancing or restoring ecosystems, NbS can make them less vulnerable to climatic stressors [13],

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thereby contributing to climate change adaptation, e.g. coastal forests offering protection against rising sea levels [3]. Beyond climate change, documented benefits of NbS include positive effects of crop diversification, water conservation, and coastal habitat restoration on crop yields, food security, and poverty reduction [14,15] as well as positive contributions to air purification or water retention [16]. Much research documents benefits of urban NbS, with urban forests making significant contributions to reducing urban heat stress [16,17] and mitigating urban air pollution [18], and NbS projects for restoring biodiversity in urban rivers often supporting flood prevention, water quality, and recreation [19]. Finally, NbS are frequently considered less costly than technical or engineering solutions to prevalent environmental challenges [20].

However, the positive effects of NbS have been found to differ substantially [16], with access and tenure regimes being key mediating factors [13]. Moreover, it is a matter of considerable debate whether NbS are commensurate to the scale of the challenges [21,22]. Many NbS objectives related to biodiversity recovery, climate change mitigation, etc. require extensive landscape or seascape-level action [23]. For instance, green roofs need to be deployed across large urban areas and/or multiple neighbourhoods to help prevent runoff mitigation [24], whereas coastline stability may depend on upstream sediment loads [25]. However, most NbS today remain of limited scale, insufficient to address the magnitude of the threats [26]. The need for large-scale action moreover means that not all NbS benefits can be achieved simultaneously everywhere [24]. Some observers also suspect underreporting of negative effects and trade-offs and point to a lack of studies that compare the effectiveness of NbS with alternative approaches [27]. Others fear that NbS might be used as an excuse to slow down the decarbonisation of the economy [28,29], and given their vague definition, NbS have been used in many ways, including for biodiversity-damaging projects [1]. For instance, (monoculture) tree planting as a climate solution does not equate to establishing healthy, diverse forests [12]. Lastly, there are examples of poorly implemented NbS projects that violate local stakeholders' rights and well-being by not effectively including them in decision-making or by prioritising technocratic approaches and expert knowledge over local, traditional knowledge and worldviews [12]. Negative livelihood effects have, for instance, been observed where urban greening NbS led to gentrification and displacement [30–32] or where local stakeholders were excluded from using the freshwater produced via an NbS [33]. There is thus a danger that NbS create or reinforce social inequalities and vulnerabilities [33–35].

Important scale, context, and design conditions hence need to be in place for NbS to live up to their potential to use nature for addressing additional social and environmental challenges. Here, we argue that time is a further tremendously important factor for NbS success. NbS are not always an immediate solution to environmental problems because some NbS need time to unfold their environmental benefits, or they are not a durable solution because some species or ecosystems lose their functions over time. Moreover, NbS interventions are not consistently designed in line with the time requirements of the natural processes they rely on and in line with the political decision-making processes required to implement them.

Suffice it here to provide one example of experiences with NbS projects that drew our attention to the importance of time in NbS. It illustrates how NbS projects can fail when ecological and social time are not sufficiently considered in the project design. The Berbak Carbon Project on the island of Sumatra (Province of Jambi, Indonesia) was planned as a forest carbon offset, producing credits to be sold at the voluntary carbon markets. However, neither were credits issued nor was the project able to successfully restore degraded ecosystems [36,37]. One of the reasons in addition to the wider political economy of deforestation in Indonesia was the insufficient consideration of the duration of ecological and social processes. First, project funding periods did not correspond to the amount of time required to rewet and rehabilitate a degraded coastal peat swamp. As a consequence, not well-maintained replanting efforts were destroyed by reoccurring peat fires during the dry seasons and in particular during the fire crisis in 2015 and 2016. Second, the project approval process by forest authorities was challenged by the simultaneous decision of the district government to transform parts of the project area into a new settlement. Thus, the timing of the political decision-making process was not aligned, further challenging project implementation and illustrating the political and ecological risks associated with forest carbon offsetting [37]. Such challenges may occur in other types of interventions into social-ecological systems as well and may not per se be unique to NbS [38]. However, considering that the mere notion of solutions 'permits a perception that NbS promote quick, tidy outcomes' [39, p. 53], a critical scrutiny of time considerations in NbS seems to be particularly warranted.

So far, however, time seems to be a marginal factor in the design of NbS interventions. A recent study [40] identifies a lack of reporting on mechanisms that may support long-term resilience as a major gap and calls for more research on long-term mechanisms. Relatedly, Cohen-Shacham et al. [41] observe that key policy frameworks such as IUCN's [42] global principles for NbS include only vague references to NbS' long-term stability. Further, time plays a very limited role in NbS research, with only some recent studies pointing to the importance of timing [43] and variable effectiveness of NbS interventions over time [44]. Short-term studies face time constraints when trying to capture the longer-term effects of an NbS intervention [45]. Considerable knowledge gaps thus exist about the long-term effects of NbS [40,46], and there is a lack of good practice examples of how time requirements have been integrated into NbS project design. As a result, NbS project developers generally lack systematic evidence from previous experience that could guide time-sensitive NbS project design [47].

In this article, we address these knowledge gaps and challenges by collecting scattered evidence from studies that even marginally address the effects of time on NbS success. The next section provides a conceptualisation of the role of time in social-ecological research to provide a conceptual basis for analysing NbS from this perspective (Section 2). After a summary of the systematic review method (Section 3), we present insights from the literature into how ecological and social time are important factors for NbS success and what recommendations follow for NbS design (Section 4). We conclude with a plea for adopting a long-term perspective in NbS projects (Section 5).

2. Embedding the NbS concept in analyses of time

We broadly understand time as the passing of events [48] and are specifically interested in time as a variable that influences the success of interventions, such as NbS, in social-ecological systems. Social-ecological systems comprise ecosystems and human societies in an integrated and interdependent relationship with reciprocal feedback loops. In order to live up to their objective of providing social and environmental benefits through the recourse to natural processes, NbS have to maintain both subsystems and their interactions [40]. While we deliberately approached our own review of time-related insights from the NbS literature largely inductively, we thus started from a few key conceptual distinctions regarding time in social-ecological systems in order to provide guardrails for structuring and making sense of our results. With this in mind, in this section, we very briefly note how a time perspective can address the past, present, and future of social-ecological systems before we turn in more depth to analytical distinctions between social versus ecological time and their intersection with the distinction between short versus long durations.

Fundamentally, the current states of ecosystems have developed through certain historical trajectories, and they can have different trajectories in the future. Likewise, present-day governance can be influenced by past experiences and path dependencies, and it can be forward-looking with specific visions for the future in mind [49]. However, while these perspectives may be tremendously helpful in understanding and explaining why and how certain current states came into being and what might be their future prospects under different scenarios, they do not offer directly applicable conceptual tools for analysing the challenges and prospects for success associated with the design and implementation of specific NbS interventions.

For this, we turn to the cross-cutting distinctions between social and ecological as well as short and long times. The appropriateness of the former is the subject of a long-standing debate in parts of the social sciences and humanities. On the one hand, a distinction is frequently drawn between time as context independent, as in ecological time, which is constituted through the human-independent sequence and evolution of biophysical processes, or time as a social construction, constituted through the social order and the duration of social and governance processes, as in social time. This distinction mirrors a broader nature/society divide. On the other hand, some understand the social and natural aspects of time as closely intertwined (see [50] for a concise review). Following the latter perspective, which we endorse, the social organisation of time is influenced by the rhythms of nature while changes in social organisation also impact societies' relationship with nature [51,52]. In the first regard, for instance, the rhythms of traditional societies depend strongly on the natural cycle of growth and decline [52]. Moreover, environmental change itself and the pace at which it affects people differently have an impact on how they (have to) organise their lives in time [53]. At the same time, human social practices shape the temporal patterns of the environments they live in. For instance, with the domestication of livestock, different species gained bigger impacts on the cycles of nature [54].

Note that a meta-theoretical understanding of ecological and social times as intertwined nevertheless allows us to distinguish analytically between the two. Accordingly, we argue that we can analyse time in the social and ecological components of current social-ecological systems separately, but that their alignment is crucial for the ability of a social-ecological system to function smoothly [55]. By distinguishing between social and ecological time, we thus aim to outline analytical guardrails that allow us to identify crucial areas of alignment or misalignment in the planning, implementation, and management of NbS (for a general discussion of time in planning processes see [56]).

Alongside the divide between ecological and social time, and cutting across it, another key distinction for analysing time in social-ecological systems is between slow and fast processes [57,58]. It is to some extent artificial as it presents two ends of a stylised continuum with many options in between, but it may help analytically in assessing the functionality of NbS interventions. Obviously slow ecological processes are those that play out over evolutionary and geological timescales [57], but we suggest that we can also consider 100 years for the growth and maturation of a newly planted forest as long time scales. In contrast, fast ecological processes relate to abrupt, discontinuous, or short-lived events or developments; they occur in the present, recent past, or near future. There are no social processes comparable to ecological and geological timescales, but the distinction between slow and fast social processes can still be helpful [57]. For instance, local administrations commonly have short-term action and decision-making cycles. In contrast, changes in administration often evolve through long processes. Especially in the field of environmental management, there is thus often a discontinuity between short-term actions and their fit with long-term strategies and goals [46].

From a perspective of NbS functionality, the distinction between ecological and social time becomes particularly relevant when there are mismatches between the short or long duration of these two. Such mismatches in time horizons often account for a lack of effectiveness of interventions in social-ecological systems. Ideally, managers of interventions in ecological processes have the mandate and the power to act in alignment with the time horizon of the respective process. In contrast, temporal mismatches occur when the time horizons of management and of ecosystem processes do not align appropriately. Such mismatches can arise from both social and ecological processes. An example of socially-driven mismatches is when changes in technologies outpace changes in management institutions. Thus, effective fish harvesting techniques have allowed the overexploitation of fish stocks without regional or global institutions being able to keep pace with issuing appropriate regulations. Ecological processes of reproduction or dispersal are thereby undermined. Mismatches can also arise through ecological change or unexpected ecological responses to management, such as in rapid regime shifts. As an example, disease outbreaks and predator-prey interactions can create spatial and temporal fluctuations in the population sizes of species that humans depend on and thereby have impacts on food webs and the times at which certain resources are available [55]. The misalignment between social and environmental time horizons is also among the causes of the environmental crisis. Adam [49] shows how industrial time is imposed on the rhythms and fluxes of ecosystems with negative consequences for their health and recovery. In particular, since the middle of the past century, the so-called "great acceleration" – the tremendous speeding up of industrial processes – drives environmental decline by outpacing natural adaptation and recovery processes [59] (see also [60–62]).

Similar mismatches to those that cause social-ecological systems to fail can also hamper finding solutions for the recovery of species and ecosystems. For instance, some ecological problems, including the management of long-lived and slowly reproducing species like redwood trees, baobabs, whales, and elephants, require consistent, long-term policies that transcend most governments' short-term planning horizons. Conversely, large bureaucracies and cumbersome organisations may need too much time to address rapid ecological changes that demand immediate management action, such as the sudden introduction of an invasive species [55]. In particular, identifying and responding to long and slow environmental change frequently confronts short-term oriented human societies with tremendous challenges [63]. Ultimately, there may be trade-offs between slow and fast processes in NbS, as people tend to prioritise benefits in the present over those that are expected in the future [64].

Summing up, sensitivity is needed for the differences in speed of human and non-human processes as well as for how such processes are or are not synchronised [49]. This helps to draw attention to major temporal features that are not linked to our senses or lived experiences such as latency of effects, very short or very long rhythms, the times embedded in organisms, ecosystems, economic systems, etc. [54]. It is these types of challenges for temporal alignment that we are particularly interested in with regard to the potential of NbS.

3. Methods

We focus our review of insights regarding time in NbS on peer-reviewed academic literature for two related reasons: First, while there may be a significant primary body of informal knowledge about the temporal aspects of NbS, this is not readily accessible. A Google search for grey literature, using the same search terms as our academic literature search, did not yield any meaningful results. Second, academic literature, especially if grounded in case studies, can systematically incorporate diverse sources of knowledge and experiences. Starting from these assumptions, we collected and analysed relevant publications in three steps.

First, in November 2022, we searched the scientific database Web of Science for relevant key words (see appendix 1). For NbS, the search included the term 'nature-based solutions' as well as more narrow concepts covered by its umbrella character, such as ecosystem-based solutions, ecosystem-based adaptations, ecosystem-based mitigations, or nature climate solutions [3, p. xi]. We excluded the acronym 'NbS' from the research as it is used in various contexts outside sustainability studies.[1] We combined the NbS-related search terms with a range of search terms related to time as the passing of events [48]. As such they are compatible with the conceptual distinction between social and ecological time and therefore capture the time-related building blocks of NbS intervention. The search included title, abstract and key words of articles and covers publications from 2010 to 2022, which is the period within which the NbS concept has gained traction. After removal of duplicates, this initial keyword search resulted in a list of 989 articles.

Second, we screened the content of these articles in order to identify those of immediate relevance to our research question. At this stage, we eliminated articles that use NbS-related keywords merely to label certain activities or natural processes, but without engaging in any depth with the characteristics of an intervention, e.g. by outlining its setup. We also removed articles that discuss temporal dimensions but not in direct relation to NbS' potential to meet environmental and societal objectives. In addition, we removed entries from the list if they provide time-related information that is not of direct relevance to the trajectory of NbS, such as timing in scientific experiments, or descriptions of ecological background conditions (such as which regions are important for "temporary water storage"). We also excluded articles with a very limited time horizon such as weeks or inter-annual variations and articles that merely include general references to the future or historical background information. In contrast, we maintained articles in the list if they engage with the unfolding of NbS-type interventions, notably how an NbS measure develops or should develop over time, descriptions or assessments of whether NbS-related processes are slow or fast, or descriptions or assessments of their historical or future trajectories. In addition to this shortening of the initial list, we deliberately included four articles [46,65–67] we discovered in our general search on the topic and that we consider of high topical relevance, even though they did not emerge in our systematic Web of Science search.[2] The fact that they do not address aspects of time in a systematically different way than the papers we identified in our systematic search makes us confident that our search approach led us to identify the key concerns being addressed in the literature. This selection procedure resulted in 46 articles for detailed analysis (see appendix 2). The wide discrepancy between these 46 articles and the initial list of 989 articles reflects the character of NbS as a catch-all-term that is often used to reach a wider audience [21]. Moreover, it highlights how temporal considerations are an overlooked analytical category in NbS research.

In the third step, we analysed the final set of 46 articles in depth, through close reading and clustering of their content. While our analysis is mostly inductive, it is informed by the distinction between social and ecological temporalities. After marking all text passages relevant to social and ecological time, we clustered them sub-topic-wise as reflected in the below results report.

4. Results

Time does not receive significant attention in the literature. The papers in our final sample are those that address the time dimension at all. In most cases, this means that the authors include side observations on the influence of the passing of time on the success of an NbS intervention, without, however, giving this much systematic and conceptual attention. Only few articles in our sample explicitly emphasise the need to give more consideration to time. Knowledge gaps are noted regarding natural processes and their duration as well as regarding governance processes and the extent to which they are aligned with the requirements of natural processes: A review of forest NbS [40] shows that many previous studies do not report on many mechanisms that are key to long-term resilience, including stand and landscape heterogeneity or genetic diversity. This limits available knowledge of NbS' potential to contribute to long-term resilience. One explanation for such gaps is that NbS are a relatively novel approach so that little research on their development over time is available [47,68]. Moreover, the relatively short duration of most research projects makes it difficult to generate sufficient information for policy makers and practitioners to take well-informed long-term decisions [46,47].

Starting from this caveat, our below review results should primarily be understood as initial, largely inductively generated hints at the temporal mechanisms at play in NbS. They provide vantage points for deeper, more systematic analysis that specifically zooms in on the time aspect. That said, we do not observe systematically different insights from studies in our sample that are past-oriented versus those that are future-oriented (slightly more than a quarter of the sample). Rather, both types of studies allow for insights regarding the social and ecological time aspects of NbS, and within both types of studies, we find longer or shorter time frames of analysis. In the following, we therefore focus on the primary analytical distinction between ecological and social times as well as the matches or mismatches between slow and fast processes as the broad analytical lenses that provide some guardrails to our otherwise inductive analysis.

4.1. Observations on ecological time requirements of NbS

The key insight from the literature about the ecological time dimension of NbS is how the maturation time of different types of NbS, i.e., the time before they continuously provide benefits, can vary considerably between fast and slow processes, depending on ecosystem context. This may range from a few months, for instance before green wall systems are operational for greywater treatment [69], over several decades, such as the restoration of saltmarshes [70] or degraded mangrove coasts [71], up to around 100 years that forest carbon projects may aim for as a regional baseline for carbon storage potentials [72]. Because of the slow ecological processes underlying many NbS, postponing NbS action has been identified by Qin et al. [67] as a significant impediment to climate change mitigation. Their simulations show not only that postponed NbS action will delay the achievement of maximum mitigation levels, but also that postponed NbS action will reduce the net present value of mitigation. In all of this, the specific environmental conditions of the wider project context may prolong the time before the effects of an NbS materialise. For example, extreme climatic conditions such as (unexpected) winds, and high temperatures can cause backlashes or delay planting operations in the first place [47].

Even after NbS projects have started to deliver benefits, their ability to do so continuously and at constant levels may vary significantly as most ecosystems develop in dynamic and non-linear ways, sometimes even as a result of an NbS project [73]. For example, novel threats for NbS may arise over time and may undermine their long-term resilience, limiting their potential to be effective in the longer run [40]. Lastly, while not all types of NbS need a long time horizon to mature, they may still need continuous maintenance to sustain their functionality over extended periods of time [69,74], which may entail considerable costs [71]. Nevertheless, some types of NbS, such as the salt marshes used for flood risk reduction analysed by Vuik et al. [75], may be more cost-effective in the long run than artificial and hard engineering solutions.

As NbS may have different ecological effects over time, a challenge frequently encountered in the literature is the occurrence of trade-offs between short-term and long-term benefits [76]. For instance, rewetting peatlands initially releases methane and increases emissions, but it eventually lowers emissions by decreasing soil carbon loss, and it sequesters additional CO_2 in the long run. The accounting horizon thus crucially determines whether an NbS intervention will be considered effective [77]. Decision makers may then sometimes face the question of whether an NbS project should privilege short-term (e.g. forest fire

[1] e.g. for nano-bubbles, native banana starch, newborn bloodspot screening

[2] We came across these articles in our general research on the topic. They engage with the question of our research but have fallen through our initial search through title, abstract and keywords.

prevention) or long-term (e.g. carbon accumulation) objectives [72,78]. In practice, NbS have often been managed for short-term success while ignoring long-term needs. For example, forests are frequently managed to avoid short-term risks, but they are rarely managed to maintain genetic diversity or landscape heterogeneity [40]. A study on ecosystem-based adaptation projects in Nepal and Mauritania has found that some impoverished community members prefer using degraded ecosystems for current livelihoods over restoring them for future benefits [47]. However, if the focus is exclusively on short-term targets and actions, this may limit the capacity of NbS to be effective over time and deliver their full potential [40]. And yet, garnering political and societal support for NbS that have negative consequences in the short run but positive consequences in the long run may be particularly challenging [77].

4.2. Observations on social time requirements of NbS

Similarly to Turner et al.'s [40] observation that social aspects of forest NbS receive less attention in the literature than ecological aspects, we find that social time is less frequently considered than ecological time in the literature we reviewed. That said, key concerns related to social time are stakeholder involvement and changing stakeholder expectations over time as well as the alignment of governance temporalities. Concerning the former, stakeholder involvement both in the design and implementation of NbS may require significant time. In particular, participatory governance processes and stakeholder consultation processes are frequently time consuming [73]. This is the case even more so when indigenous peoples or marginalised groups are involved and their meaningful engagement needs to be ensured [79]. Considerable time investment may notably be needed before the start of an NbS project to explain its expected benefits to different stakeholders [71]. Where different types of solutions have previously been the norm, such as hard infrastructure in coastal protection contexts, introducing new "soft" ecosystem-based approaches may trigger lengthy processes of searching for compromise as stakeholders with different backgrounds may favour different approaches based on their respective expertise [47].

Some authors also document how stakeholders' expectations and support may change in response to developments initiated by NbS projects. For instance, community risk perception can evolve over time and therefore can have an impact on the perceptions of co-benefits from NbS interventions [73]. Moreover, conflicts can arise during the evolution of NbS due to different expectations or changing perceptions of benefits and disadvantages that stakeholders receive from an NbS over time [73,80].

Concerning governance of NbS projects, scholars mostly focus on the wider organisational (political-legal) context, which may have two time-related types of implications. First, the literature suggests that the context as such can be more or less conducive to the fast realisation of an NbS project. On the one hand, an NbS project may face complex and therefore time-consuming social and governance conditions that may protract decision making, such as land use conflict, inefficient governance structures, etc. [47]. On the other hand, higher-scale institutional design features such as tenure security for the local population, and land-sharing and benefit-sharing mechanisms, can improve and stabilise the longevity of a project [77,81,82]. Second, potential mismatches between the timelines of project decision-making structures and those of the wider administrative system in which they are embedded might challenge the effective implementation of NbS. Short-term action and the rhythm of decision-making cycles that characterise administrations frequently do not align well with the long-term planning, implementation, and maintenance processes, including long-term funding provision needed to support an NbS action throughout its potential lifetime. Moreover, mismatches have been found to arise when policy objectives change during new policy cycles, with impacts on the long-term visions for NbS [46]. Overall, while the social and governance aspects of NbS do not play out on the same time scales as some ecological processes, they should by no means be neglected in NbS planning and analysis.

4.3. Recommendations for addressing time-related challenges

What we find missing in the literature we reviewed is a deeper analysis of the potential mismatches between social and ecological time requirements in NbS. And yet, the reviewed articles offer several recommendations on how the social sub-system can (better) respond to the requirements of the ecological sub-system in NbS. Such recommendations are notably grounded in observations concerning the frequently long time horizons for NbS maturation and maintenance. First, considering the maturation time of NbS in conjunction with the fact that the impacts of climate change and the opportunity costs of not acting will rise over time, Agaton et al. [83] recommend to start deploying NbS as soon as possible and not postpone such projects. Second, despite high costs, more permanent project design has been identified as helping to prevent rollbacks and supporting better project results such as in the case of countering deforestation [82].

Several studies suggest approaches for implementing such a long-term perspective. This includes the development of a shared long-term future vision, which addresses both short-term incentives and long-term socio-economic prospects as a helpful tool for gathering support and input for NbS projects [71,84,85]. Some authors suggest a scenario-building approach as a useful complement, which requires gathering knowledge about the properties of the envisaged NbS, especially how long they take to unfold impact, how long they can be expected to provide that impact and what are the expected long-term responses to the planned interventions [47,71].

However, even though initial and long-term plans are crucial, some authors are also wary that NbS are typically ecologically and socially highly dynamic processes, and change in resources and institutions may be a continual feature, especially in the longer run. In response, these authors suggest an adaptive (learning-by-doing) approach to NbS, which allows for experimentation, continuous learning from failures and adjustment of planning to system-wide changes over time [71]. To this end, some authors suggest allocating sufficient time and resources for ongoing engagement with local communities, powerful corporate actors with competing interests and other stakeholders [47,84]. Regular meetings through time have been identified as a promising long-term resilience mechanism because they allow responding to new risks as they emerge [40]. To add to their complexity, NbS do not operate in vacuum but are part of, and embedded in, historical dynamic processes, the wider governance context and political economy. In response, some suggest that NbS should adopt a landscape or seascape approach for planning, implementation and monitoring of their activities [75] so as to take into account temporal interactions between the NbS and surrounding socio-ecological processes.

Another important lesson for the long-term consideration of NbS is the importance of continuous monitoring [38,75,86]. Not least, this helps prevent the premature declaration of success as ecosystems may develop in dynamic ways [38]. Because the natural systems addressed by NbS change over time, monitoring approaches must be flexible and must constantly be adapted to changing circumstances. To better support long-term success, monitoring should thus be designed for learning and improvement. That is, monitoring should cover easily identifiable biophysical and socio-economic benefits, but it should also provide information that supports long-term learning [38]. Repeated analyses should be undertaken and iterative learning institutionalised so that it can continue even after the end of the NbS intervention.

At the formal end of an NbS intervention, in particular of NGO or donor-driven projects, which are typically limited to a few years, the question arises of how their long-term success can be ensured. Some authors have identified effective exit strategies as crucial, i.e. strategies that detail how the innovations introduced by the project will be maintained after its formal end [47]. A typical post-project challenge reported in our reviewed literature are unspecified responsibilities for the maintenance of project structures and innovations, which poses a risk to the continued delivery of the desired socioeconomic and environmental benefits [46]. In response, exit strategies should assign the responsibility for NbS maintenance to local actors. A good practice example is the conclusion of memoranda of understanding with regional universities about continuance of monitoring after the NbS project ends. Finally, regular revision of the exit strategy is recommended to react to nuances of the context that are inevitably unknown at the start of a project and as socioeconomic conditions change over time after the end of a project and therefore the willingness of local stakeholders to invest in maintenance of an NbS project [47].

5. Discussion and conclusion

Drawing together, we show how time is an important yet insufficiently considered factor for the success of NbS. Our review thus complements the ongoing discussion about the merits and pitfalls of NbS [27,45]. Time, understood as the passing of events, has ecological and social dimensions, and these may overlap in important regards. Though casting our net broadly, we identified only 46 peer-reviewed articles that in some, often marginal, way engage with the importance of a time perspective for NbS.

The first key insight from articles concerning the ecological dimension of time is that maturation times of NbS can differ considerably, but are often lengthy, e.g. in case of the regrowth of forests or mangroves. Second, the non-linear development of NbS leads to variable benefit provision over time. Third, there may often be trade-offs between the short and long-term ecological benefits of NbS. Concerning the social time dimension, the reviewed literature first underlines the significant time requirements of stakeholder involvement in NbS, e.g. for mediating land use conflicts, which does not end after project implementation. Second, stakeholders' support and expectations may change over time depending on the development of an NbS project. Third, the wider governance and political economy context can be more or less conducive to the timely realisation of NbS (benefits). Fourth, and relatedly, NbS project time frames may be misaligned with the time frames of the wider governance context.

In response to these observed patterns and challenges, the reviewed literature provides a few suggestions for enhancing NbS success. The potentially most straightforward suggestion is to plan NbS projects for long-term horizons, which can be complemented by shared future visions and planning of effective exit strategies. Second, an adaptive reflexive learning approach, including for monitoring, is recommended to be able to constantly adjust to changing context conditions and project-induced developments. Third, the literature supports a landscape or seascape approach to deal with the complexities of the wider governance context. Finally, exit strategies that clearly assign responsibilities for post-project maintenance are key for long-term success.

Given that the reviewed literature addresses the above aspects and recommendations only very briefly, more research is clearly needed for a more sound and nuanced understanding of the complexities of NbS. Broadly speaking, more long-term data collection concerning the ecological capacities of NbS as well as greater sensitivity to the social processes in which the former are embedded are needed. This should be complemented by the inclusion of non-English literature and interviews with NbS practitioners and stakeholders. Against this background, three specific desiderata for future research stand out: First, potential mismatches between social and ecological time are rarely openly addressed, but they may have major implications for the success of NbS and therefore need to be better understood. This should include a more fine-grained understanding of the different time-requirements and therefore different potentials for mismatches between different types of NbS, as well as strategies for avoiding or overcoming such mismatches. Second, the influence of the wider governance context on a specific NbS points to the need to think beyond time scales of NbS in isolation and to analyse the intersection of time and geographical scales [25,87] for NbS. Third, while the reviewed literature identifies the potential for trade-offs over time, particularly the danger that short-term successes may be privileged over long-term successes, it does not go beyond stating the fact. Not all trade-offs may be resolvable, but more systematic thinking about the parameters that could guide decision making in situations of NbS trade-offs is needed.

Besides suggestions for future research, our review yields tangible implications for the policies and practice of NbS. The most important lesson for NbS projects is the need to adopt a long-term perspective to account for slow ecological and social processes as well as for dynamic changes over the course of a project. This goes beyond developing long-term, yet adjustable, strategies to include long-term financial backing. Both are not the rule in most current NbS projects [40]. But of course, such a long-term perspective comes with new challenges, notably raising questions of accountability and political legitimacy [52]. Decisions to designate and start the implementation of an NbS can be made during a governmental term or electoral period. The positive or negative impacts of an NbS intervention usually last longer. The same might apply for non-implementation of NbS which could create harm for humans as well as for flora and the non-human fauna. Likewise, trade-offs between short-term and long-term benefits may become more immediately pressing once projects are systematically planned from the start. In short, our review suggests that the inclusion of a time perspective may lead to a fundamental rethinking of NbS project design.

As a final point, our insights put recent high-level political support for NbS into perspective. Signatories to the UNFCCC COP 28 Joint Statement on Climate, Nature and People affirm their commitment to employ ecosystem-based approaches such as nature-based solutions for the progressive scaling of finance and investments for nature and climate [88]. The CBD's Kunming-Montreal Global Biodiversity Framework (GBF) [7] includes a commitment by state parties to use ecosystem-based approaches such as nature-based solutions for restoring, maintaining, and enhancing nature's contributions to people by 2030 (target 11). In both cases, there is a danger of overestimating the contributions that NbS can make in the few years that science says remain to keep global warming below 1.5°C and to bend the curve of biodiversity loss and reach the targets of the GBF by 2030. As our review shows, both the adjustment of governance processes to support NbS and the unfolding of their ecological benefits may often take considerable time. This once more underlines that the rapid phase-out of fossil fuels and the strictly sustainable use of biological resources should be the utmost priority [12].

CRediT authorship contribution statement

Ina Lehmann: Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Julia Grosinger:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Steffen Bauer:** Writing – review & editing, Funding acquisition, Conceptualization. **Jean Carlo Rodríguez de Francisco:** Writing – review & editing. **Katarzyna Negacz:** Writing – review & editing. **Jonas Hein:** Writing – review & editing, Writing – original draft, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

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

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Annex 1 Search terms

NbS-related search term		Time-related search term
"nature based solution*"		Time
"ecosystem* based solution*"		Temporal*
"ecosystem* based adaptation"		Duration*
"ecosystem* based mitigation"		Length*
"natur* climate solution*"	AND	Extent
		Legac*
		Future*
		Histor*
		Slow
		Fast

Annex 2 Articles included in the systematic review

C.B. Agaton, A.A. Collera, 2022.Now or later? Optimal timing of mangrove rehabilitation under climate change uncertainty. For. Ecol. Manag. 503, 119,739 https://doi.org/10.1016/j.foreco.2021.119739.

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Data availability

No data was used for the research described in the article.

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