Governing for Transformative Change across the Biodiversity–Climate–Society Nexus

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Transformative governance is key to addressing the global environmental crisis. We explore how transformative governance of complex biodiversity–climate–society interactions can be achieved, drawing on the first joint report between the Intergovernmental Panel on Climate Change and the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services to reflect on the current opportunities, barriers, and challenges for transformative governance. We identify principles for transformative governance under a biodiversity–climate–society nexus frame using four case studies: forest ecosystems, marine ecosystems, urban environments, and the Arctic. The principles are focused on creating conditions to build multifunctional interventions, integration, and innovation across scales; coalitions of support; equitable approaches; and positive social tipping dynamics. We posit that building on such transformative governance principles is not only possible but essential to effectively keep climate change within the desired 1.5 degrees Celsius global mean temperature increase, halt the ongoing accelerated decline of global biodiversity, and promote human well-being.

Keywords: Climate change, global biodiversity loss, transformative governance, society, IPBES, IPCC

The global scientific community continues to warn that increasing climate change and biodiversity loss will have reinforcing and codetrimental impacts on humanity. These impacts include increasing vulnerability to food insecurity, health risks and disrupted livelihoods, and even involuntary displacements leading to potential social unrest (e.g., IPBES 2019, IPCC 2021, 2022). As the window to avoid far-reaching and irreversible impacts on people and nature rapidly closes (IPBES 2019, IPCC 2021, 2022), the current actions to address these global challenges are insufficient (e.g., Ripple et al. 2017, Arneth et al. 2020). Strategies to address some of the negative trends have been proposed. However, the feedback loops and interactions among biodiversity, climate, and society at multiple spatial, temporal, and organizational scales—what we label in the present article *the biodiversity–climate–society* (BCS) *nexus*—are generally ignored (Pörtner et al. 2021). This is problematic because the connections among climatic, ecological, and social systems transmit risks from one system to another. Response strategies that ignore these nexus interactions may significantly misestimate those risks, thereby increasing the chance of irreversible environmental changes across the planet (Simpson et al. 2021).

To simultaneously address interlinked global challenges, the scientific community has increasingly emphasized the need for deep and urgent transformative changes across economies and societies. Transformative change is understood as game-changing shifts, or “fundamental, system-wide reorganizations across technological, economic, and social factors, including paradigms, goals, and values” (IPBES 2019: 14). Such emphasis by the global scientific community contrast with the policies being currently proposed that focus on incremental changes or changes restricted to actions that are accommodated within existing system structures and goals—for example, actions geared to increase energy efficiency within production life cycles under an overarching goal of constant and exponential economic growth. Given the current situation, we posit that incremental changes are unlikely to gain sufficient traction to be scaled up if they are not accompanied by broader system-wide institutional changes to create the structural conditions for such scaling up to occur. Incremental changes also risk being too slow to avoid severe negative impacts on people and nature. The Intergovernmental Panel on Climate Change's (IPCC) recent report (IPCC 2021) indicated that, if current emission levels continue, the 1.5 degrees Celsius

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temperature threshold could be surpassed this decade. Similarly, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) concluded in its *Global Assessment* that reversing the processes of biodiversity decline can only be achieved through intentional and transformative changes across economic, social, political, and technological systems (IPBES 2019). The need for transformative change was also one of the key messages to policymakers of the first joint workshop report by the IPCC and the IPBES (Pörtner et al. 2021), which pointed out the need for a system-wide reconfiguration of societal structures and institutions (i.e., conventions, norms, and rules), because these largely determine societal goals, values, and behaviors, all of which are essential to address the underlying drivers of the climate and biodiversity crises. In other words, bringing about transformative change requires transformative governance, which would need to address the inherent complexities of the BCS nexus, particularly around speed, scope, scale, and social impacts and feedback loops.

The question we attempt to answer in the present article is this: How can transformative governance be achieved for the BCS nexus? Although much literature has addressed transformative change in a general sense (e.g., Horlings 2016, Colloff et al. 2017, Barnes et al. 2020, Hysing and Lidskog 2021), the specific needs for transformative governance around climate and biodiversity have, to date, gone largely unidentified. We delineate key conditions required for shifting from (at best) a stepwise (incremental) agenda aimed at modest reforms to one that intentionally embraces deeper (i.e., tackling underlying or indirect drivers of change) and more rapid transformative potential to address fundamental BCS interactions, limits, and thresholds.

We draw on the frame of the BCS nexus of the first joint IPCC–IPBES report to which we contributed (Pörtner et al. 2021). We first outline how the elements of the nexus interact, such as through cobenefits, trade-offs, and codetriments, as well as the importance of both negative and positive tipping points, to identify the conditions for transformative governance for climate and biodiversity. To be transformative, governance approaches will likely need to include integrative, adaptive, and equitable elements in order to account for the social complexities of the BCS nexus.

To illustrate the opportunities, barriers, and challenges for transformative governance, we draw on four examples in forest ecosystems, marine ecosystems, urban environments, and the Arctic. Ideally, transformative governance would catalyze and create inclusive (but sometimes intentionally disruptive) approaches for upscaling of more effective and just interventions in the BCS space, such as by triggering positive social tipping points or by avoiding negative biophysical tipping points (Stadelmann-Steffen et al. 2021). But our examples show this is rarely achieved. By drawing on lessons from these case studies, we identify general but actionable principles that are likely to be required for transformative governance of the BCS nexus.

Key elements of the BCS nexus

The BCS nexus is characterized by a complex and dynamic interaction space. Recognition of these interactions can help avoid negative thresholds while achieving positive thresholds that enable transformative change.

Recognizing BCS interacting dynamics. The biodiversity and climate crises and their societal causes and consequences have traditionally been explored by focusing either on the biophysical level, including biodiversity (B)–climate (C) interactions, or on the societal (S) level, including policy interventions and institutional structures (for a summary, see Chapin and Díaz 2020). The IPCC–IPBES report argues that it is necessary to consider the joint three-way interactions among biodiversity, climate, and society in order to effectively maximize cobenefits and minimize trade-offs and codetrimental outcomes (Pörtner et al. 2021). In this section, we provide examples of how moving from a siloed approach of considering BCS component separately toward rethinking their interaction space as a nexus with explicit links between its components can lead to more positive outcomes in all three dimensions. We specifically consider how the societal dimension flows into and feeds out of BC interactions (figure 1). Such a nexus approach has the advantage of making the entire system better able to respond to the speed and scale of the coupled climate and biodiversity crises.

Biophysical interactions typically involve the relationships among climate, biodiversity, and ecosystem functioning, including productivity and carbon removal and storage (Duffy 2009) and the tolerance and adaptation limits of species and ecosystems (Pires et al. 2018, Hoegh-Guldberg et al. 2019). The social dimension refers mostly to issues of human well-being and justice, as well as to the associated governance challenges (i.e., the establishment of new institutions or the redesign of already existing ones that could help navigate the biophysical BC interactions). The social dimension depends in part on how the BC interaction occurs. For example, the impacts of biodiversity restoration projects on society can vary depending on the restored community composition (e.g., if restored species can be used as wild-harvested foods or were only chosen for carbon priorities) or on the degree to which climate change shifts the biogeographic distribution of restored species (Robledo et al. 2012, Wessels et al. 2021).

The social dimension also actively shapes BC interactions (Bennett et al. 2017). Take, for example, antipoverty interventions based on the simplistic assumption that well-being effects of economic growth automatically trickle down to small farmers. In fact, agricultural growth strategies can become a potent trigger of land grabbing to favor capital accumulation by the agribusiness sector while eroding the ecological resource base of agroecosystems and increasing social inequalities (Borras and Franco 2018, Ceddia 2020, Gras and Cáceres 2020). This, in turn, can cascade and amplify negative impacts on the BC interaction space, harming both biodiversity and climate. This may happen by

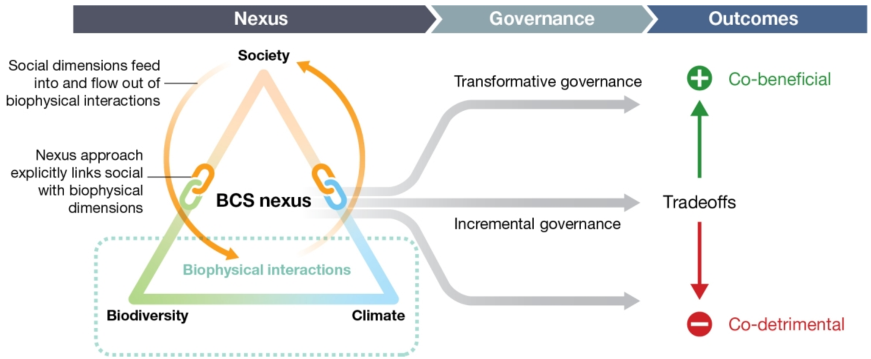

Figure 1. Outcomes of interactions within the biodiversity–climate–society (BCS) nexus. The triangle represents the BCS nexus, including biophysical interactions between biodiversity and climate and their explicit links with the social dimension. The interactions and outcomes of the BCS nexus shape the inputs and outputs to policy intervention. Transformative governance might help guide BCS nexus interactions toward more cobeneficial outcomes or, at least, toward those with minimal and controlled trade-offs, whereas incremental governance might lead to strong trade-offs.

replacing undisturbed biodiverse high-carbon storage ecosystems with agricultural monocultures that have poor carbon-storage capacities. Societal impacts then flow once again out of the BC interaction space: In the agribusiness example, a focus on maximizing short-term economic growth could lock in maladaptive responses, including land degradation and the displacement of smaller-scale landholders' resilient agricultural practices and institutions such as social norms for collective action (Albizua et al. 2019, Labeyrie et al. 2021). Other examples of societal impacts flowing out of BC interactions include the expansion of monoculture afforestation for carbon sequestration that misses the opportunity to increase native biodiversity and sustain local people's livelihoods (Abreu et al. 2017, Doelman et al. 2020) rather than supporting restoration efforts based on local knowledge and practices that might produce cobenefits for ecosystems and people (Reyes-García et al. 2019).

Interactions in the BCS nexus from a particular action can be placed into three broad categories, each characterized by the outcomes of interactions across the biophysical and social subsystems: cobenefits (when the action leads to all BCS components to have positive outcomes), trade-offs (when the action leads to negative outcomes for B, C, or S, and the remainder positive or neutral), and codetriments (when the action leads to all BCS components to show negative outcomes; figure 1). Although these broad categories provide a useful heuristic, recognizing the complexities that underlie BCS interactions is important—particularly, the specific social–ecological or spatiotemporal context to be considered. For example, BCS interactions may involve nonlinearities in the shape of their association, including synergistic or saturating functions, cascades and feedback loops, and off stage (i.e., spatially and temporally distant and diffuse) environmental impacts (Pascual et al. 2017, Pörtner et al. 2021, Meyfroidt et al. 2022).

Broadly, these complexities call for a holistic understanding of BCS interactions, including considering how interactions change over time and have different effects across spatial scales. The restoration of diverse, high-carbon storage ecosystems provides an example of such complexities. Restoration might have immediate benefits for biodiversity and local populations and their future livelihoods via enhanced options for adapting to climate change (Colloff et al. 2020), but restoration might have delayed benefits for carbon storage, which might taper over time as the ecosystem matures (Bindoff et al. 2019, Leo et al. 2019, Yang et al. 2019). Another example includes runaway biodiversity–climate feedback loops in which human-induced biodiversity loss diminishes ecosystem functions, including carbon storage. This then leads to further warming, in turn triggering additional loss of biodiversity that may result in significantly larger climate and biodiversity deterioration than when considering each component in isolation and, therefore, underestimating the negative effects on vulnerable communities' well-being (Bergstrom et al. 2021, Trisos et al. 2021).

Transformative governance approaches and specific policy options can be improved by better understanding the speed, scope, scale, and impacts of the interacting BCS nexus components. Social–ecological systems include a mix of processes that operate at both fast and slow rates (Walker and Salt 2006, Walker et al. 2012). Examples of fast processes include political electoral cycles and fast turnover in dominance of exotic species, as well as short-lived climate forcers, such as methane or crop-production cycles. By contrast, slow processes include those associated with shifting socially shared values and visions about progress and well-being, ice-sheet melting, sea-level rise, and decomposition of soil organic matter. These slow processes can take generations. Addressing multiple interactions over vastly different time scales but potentially occurring at the same time requires institutional (including policy) flexibility, continual innovation, social learning and adjustment, and adaptation of governance arrangements (Ramm et al. 2018, Reyers and Selig 2020).

Understanding the scope of interactions should include attention to the considerable asymmetries inherent in the BCS space. The negative effects of climate policy interventions on biodiversity are more prevalent than the negative effects of biodiversity policy interventions on climate (Pörtner et al. 2021), with potential complementary effects across multiple ecosystems and scales (Manes et al. 2022). Similarly, the direct and immediate social impacts of land-based biodiversity and climate interventions are typically higher on rural than on urban populations (Karlsson et al.

2020). Multiple scales are also in effect in uneven ways in the BCS space; for example, climate impacts are driven by globally accumulating greenhouse gases, which can be felt in local and regional levels, whereas biodiversity loss impacts are almost always locally experienced and thereby affect the capacity of ecological systems to benefit people as local public good but whose aggregate global effect may be declining across global taxa and their associated gene pools (i.e., a global public good; Perrings and Kinzig 2021).

Governance institutions also cross multiple dimensions and scales—for example, from those based on collective action by local communities to global environmental agreements such as those under the Convention of Biological Diversity. This creates complexity for any specific level of jurisdiction to grapple with and temporal, spatial, and institutional scale mismatches (Bai et al. 2016a). Moreover, if these scales are not properly aligned, they can lead to institutional inertia. However challenging, integrating systems thinking into governance is much needed to address the increasingly telecoupled nature of BCS interactions (Liu et al. 2018, Simpson et al. 2021, Meyfroidt et al. 2022). Awareness of and devising mechanisms to adapt to the synergistic outcomes (both positive and negative) that are characteristic of the BCS nexus can help inform policy interventions to optimize cobenefits, minimize trade-offs, and avoid codetrimental impacts.

Negative and positive thresholds in the BCS nexus. In the absence of policy interventions to address the climate and biodiversity crises, the risks of exceeding biophysical limits and crossing critical thresholds that trigger tipping points can be high (e.g., Zhang et al. 2020). This would likely result in system feedback loops that propel the coupled biophysical BC space into a new state from which recovery may be difficult. Such shifts are often associated with abrupt changes in ecosystem function (i.e., red lines; Lenton et al. 2019). Biophysical tipping points generally occur over different temporal trajectories, with some being approached gradually, whereas others are more abrupt. In all cases, however, they could cascade through the social subsystem, affecting all human societies, likely exacerbating social inequality and the vulnerability of marginalized communities (Otto et al. 2017, van Ginkel et al. 2020, Simpson et al. 2021). Although many climate- and biodiversity-related tipping points in key biomes across the world are known (IPCC 2014, 2019a, 2019b, Steffen et al. 2015), predicting with relative high degrees of accuracy the likely location and timing of triggering conditions remains challenging (Scheffer et al. 2015).

The potential for feedback loops and nonlinear effects associated with BC interactions implies that when governing the BCS nexus, special attention should be paid to avoiding tipping points that negatively affect nature and people in irreversible ways. An example is the shifts from coral to algae-dominated systems on reefs. These shifts are driven by the rising temperatures associated with climate change (and are exacerbated by ocean acidification and local stressors such as overfishing and pollution) and have led to widespread bleaching of corals, allowing algal communities to become dominant (Bruno et al. 2019). This regime shift suppresses an important ecosystem engineer (i.e., corals), thereby causing the reef-associated fish assemblage to degrade, negatively affecting reef fisheries and fishers' livelihoods (Ainsworth and Mumby 2015). Another example involves the tipping point of shifts from sea-ice- to open-water-dominated systems, involving transitions from predominant sea ice (sympagic) and benthic productivity to primarily pelagic productivity caused by increased temperatures. This affects human societies, including Inuit communities, who directly depend on sea ice to hunt and as a base for transportation (Duarte et al. 2012, Steiner et al. 2021). In this case, the thresholds on environmental temperature for retaining sea ice are exceeded, altering biological community composition, trophic structure, and the downstream consequences for people, including harm to their livelihoods and cultural identity.

Despite research in cases such as coral reefs and kelp forests, the complexity of BCS interactions makes it challenging to identify the precise triggers of tipping points. Proactive climate and biodiversity conservation policies are therefore critical to staying well away from critical thresholds (IPBES 2019, Lenton et al. 2019, van Ginkel et al. 2020). Inherent uncertainties require prioritization of the precautionary principle, which, although it has been incorporated into multiple legal instruments, still often fails to be in full effect (Read and O'Riordan 2017). It is also possible to think of BCS-related positive social tipping points.

Tipping points can also be understood from a social perspective. Social tipping points represent situations associated with large and abrupt shifts within the social system, which can lead to transformative change. Generally, social tipping dynamics are understood as processes linked to the spreading of norms, opinions, behaviors, and actions through social networks in ways that are difficult to stop or reverse (Milkoreit et al. 2018, Stadelmann-Steffen et al. 2021). Although attention is often paid to social tipping points with negative outcomes that are triggered by political, economic, or food crises, among others, positive social tipping points that involve actions with desirable social transformations are also possible. However, positive social tipping points have only recently come to the fore within a BCS nexus perspective (Franzke et al. 2022). The dynamics of positive social tipping are also often nonlinear, where a small social intervention by political and social actors triggers an accelerating feedback response that leads to a substantial and potentially irreversible change in the social system via positive contagious dynamics (Milkoreit et al. 2018, Stadelmann-Steffen et al. 2021). Examples of BCS-related positive social tipping points include well designed restoration programs that not only induce positive land cover changes in implementing communities but that have spilled over into other nearby areas, as well as benefits experienced by neighbors (Buxton et al. 2021). Likewise, rapid shifts in public opinion, as well as individual preferences, behaviors, and values leading to

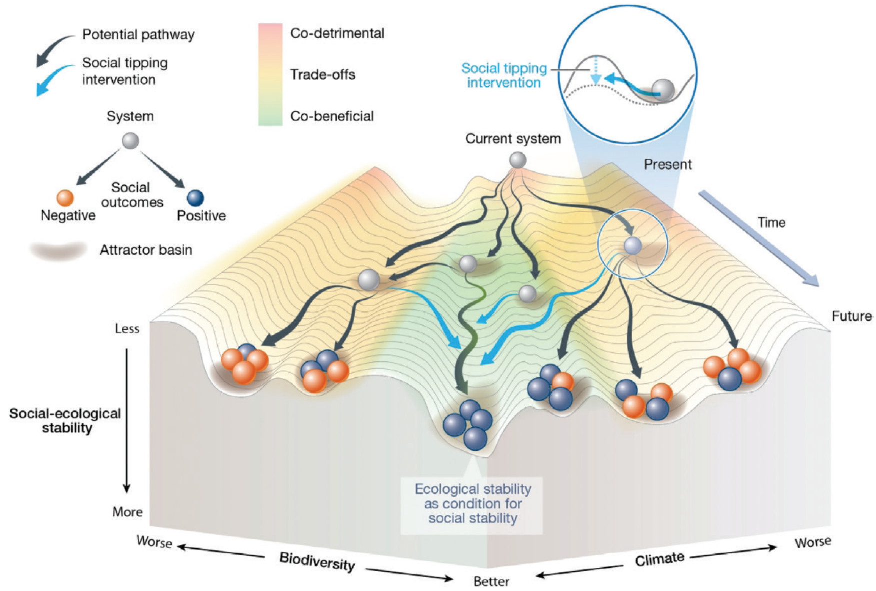

Figure 2. Social tipping points under the biodiversity–climate–society (BCS) system. Cobeneficial pathways are illustrated by movement toward desirable deep attractor basins in the BCS space (i.e., those that have positive cobeneficial outcomes across the three elements of the BCS nexus). Social outcomes are depicted by the color shading of the balls representing the state of the system over time. The landscape has different types of possible interactions: a cobeneficial one that society might aspire toward, depicted toward the center of the landscape; trade-offs in the BC space, depicted toward either side of the landscape; and codetrimental, depicted to the farthest ends of the landscape. Although fully cobeneficial pathways are an ideal to strive toward, it can be difficult to achieve fully positive outcomes in all three BCS dimensions (i.e., the middle pathway in the figure). Instead, the system might move away from a shallow attractor basin, with biodiversity–climate interaction trade-offs or negative social outcomes (deeper parts of the landscape represent greater system stability). Source: Adapted from Pörtner and colleagues (2021).

behavioral change in societies, such as the rapid uptake of electric vehicles beyond early adopters in Norway (Lenton et al. 2021), are examples of social tipping dynamics that could hopefully apply to the willingness to support the institutional changes needed to tackle the biodiversity and climate crises in effective and just ways (Brulle et al. 2012). Social tipping dynamics require technological, political, and behavioral processes. They are also a function of cultural conventions, including habits, norms, and regulations, and they are therefore hard to compare across different social contexts (Milkoreit et al. 2018). Although successful social tipping interventions in one social context may serve as an inspiration for others, it is important to not assume that all such successful interventions could become silver bullets across distinct social contexts.

Activating global positive social tipping dynamics through targeted actions (e.g., divesting from fossil fuels by a number of large investors, which could potentially trigger rapid and widespread divestment by others seeking to avoid losses) requires a mix of interventions that shift collectively shared norms and deeply held societal values (e.g., revealing the moral implications of continuing to burn fossil fuels). Activating social tipping dynamics also entails acting on psychological elements that underpin everyday individual behavior, including consumption choices (O'Brien 2020), and entails confronting the political inertia and resistance by strong vested interests that favors the status quo (IPBES 2019, Otto et al. 2020) and that takes advantage of the rigidity inherent in political and economic decision-making.

Actions are needed that disrupt the social mechanisms that maintain the status quo and that amplify reinforcing the global environmental crisis. Social tipping dynamics require identifying key intervention nodes at which small shifts, which are often hard to see (e.g., shifting values that are aligned with respect toward nature and future generations), can lead to activating strong motivations for behavioral change that can then spread quickly to become a major accepted practice (Markard et al. 2020). Figure 2 illustrates the idea that social tipping interventions might hasten BCS interactions toward cobeneficial pathways for people and nature.

Conditions and challenges for transformative BCS governance

Theorizing and defining transformative governance requires attention to the concepts of both transformation and governance. *Governance* generally refers to the use of a combination of formal and informal and public and private institutions (including norms, rules, and rulemaking systems) across actor networks at multiple levels (Biermann et al. 2009). Transformation implies fundamental changes across both societal structures and beliefs and behavioral dimensions such that new social–ecological systems are created, and it is contrasted with more reformist, shallow, or incremental changes that do not question current power structures nor lead to fundamental reorganizations (IPBES 2019). Therefore, transformative governance aims to engage societal actors with contested perspectives about what are desirable societal values and goals, whether transformation is indeed desirable (and to whom) or existentially needed, and who is included in decision-making to transform current institutional systems, particularly about vested interests who often oppose such actions (Bai et al. 2016b, Patterson et al. 2017, Blythe et al. 2018, Pickering et al. 2021).

What transformative governance would look like and how it is different from or related to existing theories of governance is a topic of much current discussion

Table 1. Comparing governance concepts across environmental issues.

Governance concepts	Definition and main theoretical focus	Relationship to transformative change	Applicability to the BCS nexus
Environmental governance	Processes, mechanisms and organizations by which multiple actors across governmental, market and nonstate sectors influence environmental actions and outcomes (e.g., Armitage et al. 2012, Lemos and Agrawal 2006)	Often reactive and is not specifically aimed at transformation	Focus on fit, scale, and hybrid forms of governance relates to BCS challenges
Earth systems governance	Examination of forms, effects and complexity of governance at and across multiple levels aimed at achieving sustainability (e.g., Biermann et al. 2010, Burch et al. 2019)	Because of conflicts across scales and norms across administrative boundaries, often lack capacity for fostering transformative changes	Focused on agents and architectures; less focus on feedback loops, systems and biophysical dynamics
Adaptive governance	Aimed at enhancing resilience by governing through continuous adjustments in response to feedback loops (e.g., Folke et al. 2005, Chaffin et al. 2014)	Can be transformative if aimed at changing system states, but often not aimed at doing so.	Applications to ecosystem management but not necessarily on multiscalar BCS thresholds.
Anticipatory governance	Building capacities and steering mechanisms in the present to govern future transformations through foresight, engagement, and integration (e.g., Guston 2014, Burch et al. 2019)	Aimed at managing transformations already occurring, but not necessarily sparking them	Generally applied more to technological innovations than environmental problems
Polycentric governance	Governance that manifests in nested scales and overlapping functions, often supporting institutional diversity (e.g., Ostrom 1990, 2010)	Does not explicitly address transformation	Elements of multiscalar interactions can help address telecoupling with a BCS nexus, but often applied to single sectors (e.g., polycentric climate governance)
Transformative governance	Governance that manages regime shifts across multiple scales in social–ecological systems while encouraging social change and innovation (e.g., Chaffin et al. 2016, Patterson et al. 2017, Visseren-Hamakers et al. 2021)	Explicitly aimed to achieve transformative change	Implicitly focused across sectors and scales given integrative approach; aimed at managing thresholds

Abbreviation: BCS, biodiversity–climate–society.

(see table 1). It is generally seen as governance that "has the capacity to respond to, manage, and trigger regime shifts in coupled social–ecological systems at multiple scales" (Chaffin et al. 2016). Although transformative governance is often depicted as being good for all, the reality is that the envisaged need for widespread changes across societies will most likely result in winners and losers. Therefore, it has been hypothesized that governance needs to be integrated, adaptive, and equitable across natural and social systems in order to be truly transformative (Visseren-Hamakers et al. 2021). Furthermore, not only should issues of social equity be at the core of transformative governance discourses, but, correspondingly, problems of justice and asymmetric power relations, corporate capture, or greenwashing need to be tackled as well (Teichmann et al. 2020, Kenner and Heede 2021, Supran and Oreskes 2021), because vested interests by powerful actors often limit or derail attempts at sustainability transformations (Blythe et al. 2018, Pickering et al. 2021, Visseren-Hamakers et al. 2021).

Transformative governance needs to account for BC interactions while addressing structural and systemic social conditions and drivers of change (including cultural and economic). In other words, transformative changes for the BCS nexus need to be integrative (across scales, issues, and sectors), equitable (*sensu* inclusive and pluralist; i.e., giving voice to those whose interests are currently marginalized and who rely on different knowledge systems) and adaptive (incorporating flexibility and learning by continuous engagement with stakeholders and rightsholders in incubating, facilitating, accumulating, and sustaining innovative practices; Visseren-Hamakers et al. 2021). These conditions can be translated into the BCS nexus in terms of governance systems that seek to set meaningful integrative societal objectives (e.g., such as those related to the United Nations' [UN] sustainable development goals) that minimize climate risks while maximizing biodiversity protection, seeking to avoid hard trade-offs or codetrimental outcomes; recognize the diverse worldviews, values, and epistemology of different actors, including those worldviews that have historically been marginalized, particularly those of Indigenous peoples and local communities (IPLCs), who also tend to be significantly more directly reliant on the natural resource base and are therefore especially vulnerable to codetrimental BC interactions; and avoid interventions that may lock in maladaptive development pathways that are prone to trigger negative biophysical tipping points or undermine conditions for propelling positive social tipping dynamics.

Some emerging political discourse, such as the conversations embodied within the 2050 vision of “living in harmony with nature” (Locke et al. 2019) focus on achieving BCS cobenefits. But few positive examples of integrated, equitable, and adaptive governance approaches within the BCS space are available, and even fewer offer detailed guidance about what combination of objectives, actors, levels, information, and participatory decision-making approaches can ensure desirable (i.e., effective and just) governance approaches (Albert et al. 2021). Even for these positive cases, demarcating governance approaches into those that can be deemed truly transformational, rather than having incremental (*sensu* reformist) potential, is challenging (IPCC 2022).

Key focal areas for governing the BCS nexus

We use four focal areas of interest for the BCS nexus (i.e., forest ecosystems, marine ecosystems, human urban environments, and the Arctic) to illustrate key enabling conditions and challenges that might be encountered when trying to build more transformative approaches to governing the BCS nexus. These four focal areas cover a wide range of broad social–ecological systems. For each focal area, we discuss key interactions in the BCS space. We also reflect on the extent and mechanism of the key elements of transformative governance that might be applied under the nexus perspective. The governance approaches that are analyzed include Reducing Emissions from Deforestation and Forest Degradation (REDD+) programs in the tropics, the use of fisheries subsidies in the world's oceans, new developments in green urban planning, and codesign of natural resource management in the Arctic including recognition and incorporation of indigenous and local traditional knowledge. We also note some associated representative examples from across different ecosystems and disturbance types (box 1) that help illustrate the opportunities and challenges of various governance models that are being applied around the world. These four case studies also allow us to identify a series of basic principles that would need to be applied for governance to be truly transformative.

Governing tropical forest systems with REDD+. REDD+ programs have emerged in much of the tropics to reduce deforestation and enhance forest carbon stocks, given that carbon losses from deforestation have risen since the Paris Agreement was signed (currently nearly 4.9 gigatons of carbon dioxide per year), and many of these areas of degradation and deforestation are biodiversity rich (Palomo et al. 2019). Major drivers of forest loss include commercial agriculture in REDD+ countries (Hosonuma et al. 2012, Curtis et al. 2018) and feedback-loop mechanisms that have already appeared. For example, carbon-sink capacities have diminished by one-third in major tropical forest basins such as the Amazon and the Congo, which are suffering combined effects from biodiversity loss, drought, higher temperatures, and deforestation (Hubau et al. 2020), with real concerns that such forests may reach a tipping point, becoming carbon sources rather than sinks. At the same time, continuing social inequities in both basins, such as the benefits of deforestation to migrants on frontiers and uneven rights accorded to Indigenous peoples, have amplified the governance challenge (Megevand 2013, Pereira and Viola 2021).

REDD+ investments have been prioritized to simultaneously provide carbon sequestration and biodiversity cobenefits (Gardner et al. 2012, Phelps et al. 2012) but generally lack a global equity perspective (Palomo et al. 2019). Comprehensive BCS integration has been difficult; a survey of 80 REDD+ projects showed that, although most of them touted biodiversity cobenefits, 40% had no specific goals or monitoring for them (Panfil and Harvey 2016). Furthermore, although many REDD+ programs have proposed social safeguards, particularly via equity considerations, the social outcomes have been mixed, with few examples of social cobenefits across multiple dimensions (Hajjar et al. 2021). This is largely because of altered resources provisioning and access by forest-dependent communities and conflicts over land tenure issues and inequitable benefit sharing (Patel et al. 2013, Pascual et al. 2017, Alusiola et al. 2021). REDD+ projects have bifurcated into those mainly providing some social benefits (e.g., in Indonesia where Indigenous communities used REDD+ programs to assert land rights claims; Setyowati 2020) but where climate-biodiversity cobenefits are unclear and those projects that have focused on biodiversity–climate cobenefits to the exclusion of social concerns, including unequal distribution of burdens on local people because of displacement of ecosystem services access (Pascual et al. 2017) and insufficient attention to legal rights of communities that have incurred high costs in project implementation (Luttrell et al. 2013).

One problem with REDD+ and other offset-type mechanisms is that they are not sufficiently adaptive, because they are unable to respond quickly enough to ecosystem state changes (e.g., driven by disturbance, wildfires or invasive pests, or increasingly, climate change) because of the complexity of monitoring and results-based payment requirements (Nguon and Kulakowski 2013). So far, little evidence exists that REDD+ has enabled conditions for positive social tipping points (i.e., forest management that shifts values and scales up behavioral change). Moreover, concerns have been raised about potential negative indirect impacts—particularly, crowding out intrinsic social motivations for forest conservation when REDD+ favors the commoditization of forest carbon to fit carbon market requirements set by actors that have little knowledge or concern for BCS interactions at the local level (Baynes et al. 2021).

The mixed results to date demonstrate that integration of BCS governance through existing REDD+ approaches has been challenging, with siloed approaches continuing

Box 1. Examples about challenges and opportunities for transformative governance.

Governing REDD+ in the Brazilian Amazon.

We present four examples about the challenges and opportunities for transformative governance in the BCS space in forested, marine, urban and Artic contexts.

Brazil plays a key role in REDD+ because it harbors a large portion of Amazon forests while facing critical levels of deforestation that have accelerated in the last years. Brazil was the first country to receive results-based payments (almost US$100 million) to reduce carbon emissions in 2014 and 2015. Brazil implemented REDD+ (UN-REDD 2018) through a special program (Floresta+) that aimed to incentivize conservation and the recovery of native vegetation. However, after 15 years, many projects that were focused on the BCS nexus remain on paper only, and some funded projects coordinated by local communities have been interrupted (e.g., the Suruí Carbon Project), with questions raised about their legitimacy (Nantongo 2017). The governance space has been diminished because of political change and a lack of attention to equity by the Bolsonaro administration, whose current interest is confined to reinforcing the voluntary carbon market, putting into question deeper transformative approaches in the context of the Amazon through REDD+. This also runs the risk of triggering negative biophysical tipping points, leading to irreversible transitions to a less productive dry forest system.

High seas fishing and governance.

The high seas encompass about 40% of the planet surface, rendering it the largest ecosystem in Earth. Human activities have been expanding and intensifying in the high seas—in particular, fishing (Merrie et al. 2014) supported by government subsidies even when fish stocks are overexploited and fishing becomes unprofitable (Sala et al. 2018). Because of its remoteness and vastness, operating in the high seas contributes disproportionately to carbon emissions, rendering high seas fisheries those with the highest carbon footprint (Mariani et al. 2020, Sala et al. 2021). Biodiversity in the high seas is affected by overexploitation of targeted and nontargeted species, climate change, pollution, and other extractive activities (Bindoff et al. 2019, IPBES 2019). A process is ongoing within the UN Law of the Sea to address governance gaps in the high seas. To succeed, this process needs to raise its ambition and aim for transformative change under the focus of the BCS nexus, rather than provide quick fixes to the current status quo. For example, in the case of governing BCS challenges, only about 5% of the Southern Ocean is protected. The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), the body responsible for Antarctic marine conservation, adopted the Ross Sea Marine Protected Area in 2016. This is the world's largest marine protected area, and CCAMLR is the only management body to have adopted no-take marine protected areas (MPAs) in the high seas at the time of its designation (Brooks et al. 2021). However, the CCAMLR has not been able to agree on new MPAs in the Weddell Sea, the Antarctic Peninsula, and East Antarctica, the latter of which was first proposed in 2011 (Syal 2021).

Redlining and tree planting in urban areas.

Tree-planting schemes are often restricted to cities with already high socioeconomic status or well-off locations within cities. This leads to social inequity in who benefits from urban tree planting policies (Pataki et al. 2021). Through redlining and institutional racism, locations with lower socioeconomic status within cities are already more sparsely planted and therefore warmer and more vulnerable to heatwaves (Schell et al. 2020) The elevated temperature in these locations cascades to further economic depression because of elevated cooling costs and exacerbated health conditions. However, these interconnections provide an opportunity for transformative change with cobenefits: Urban tree plantings that are diverse and implemented in different socioeconomic contexts in cities can achieve climate mitigation and biodiversity conservation and can aid in social well-being.

Inuit comanagement of marine ecosystems.

Inuit codevelopment and comanagement are key components of recent marine conservation efforts in the Canadian Arctic (e.g., Steiner et al. 2021). The Tuvaijuittuq MPA, off the northwest coast of Ellesmere Island, is considered unique because of the presence of multiyear pack ice. It is also recognized as a culturally and historically significant region long used by Inuit for travel and harvesting and is the only MPA specifically designated because of its sea–ice ecosystem. Likewise, the Anguniaqvia Niqiqyuam MPA and the Tarium Niryutait MPA have the objective to maintain habitat and support populations of species such as beluga whales, Arctic char, and ringed and bearded seals, all of which are key species for Inuit subsistence. The Government of Canada and the Qikiqtani Inuit Association recently signed the Inuit Impact and Benefit Agreement, which was required for the establishment of the Tallurutiup Imanga National Marine Conservation Area (NMCA), which states that "Inuit Qauijimajatuqangit (traditional knowledge) will inform future decision-making for the management and protection of the NMCA, and the NMCA will protect Inuit harvesting rights… while ensuring the protection of species at risk and their habitat" (Parks Canada 2021). The codesign of conservation objectives by Inuit and federal parties allows for a rights-based approach to governing conservation areas that includes Inuit active participation and represents a governance approach that can provide cobenefits in terms of protecting species and ecosystems, climate change adaptation and mitigation, and sustaining Inuit livelihoods and subsistence harvesting.

to dominate the forest sector (McElwee et al. 2016, Morita and Matsumoto 2018). Movements toward improved and integrated forest governance have included more attention to both cross-scale and cross-stakeholder models in jurisdictional approaches, which focus on subnational governments or watersheds in which collaboration is intended to apply to all stakeholders within the jurisdiction (Wunder et al. 2020, von Essen and Lambin 2021). However, the potential for success of jurisdictional approaches depends on engagement of multiple stake- and rightsholders, buy-in across policy

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Box 1. Continued.

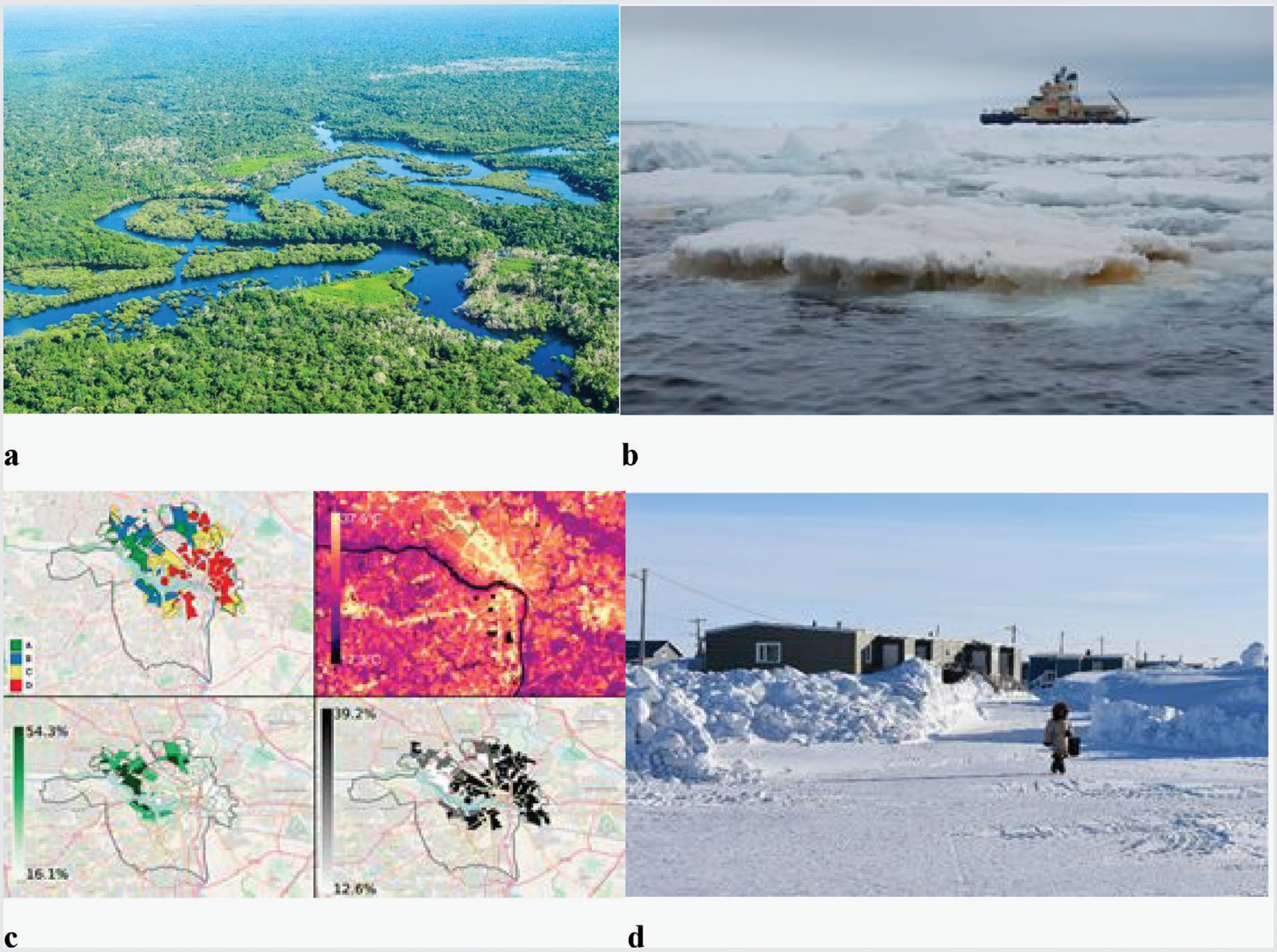

Figure 3. (a) Many REDD+ projects have been targeted to the Brazilian Amazon. Photograph: Neil Palmer/CIAT/CIFOR). (b) Research vessel in Ross Sea Marine Protected Area. Photograph: Argonne National Laboratory, CC BY-NC-SA 2.0). (c) Association between reduced tree cover (bottom left), increased pavement cover (bottom right), increased temperature (top right) and redlining (top left; category D)—that is, areas designated as hazardous for home loans by the Home Owners' Loan Corporation in the United States. Source: Modified from Hoffmann and colleagues (2020). (d) Community of Paulatuk in Darnley Bay, Canada, which harbors the Anguniaqvia niqiqyuam Marine Protected Area.

scales, and efficiency of investments, which all face challenges (Myers et al. 2018).

Given the current visions about REDD+, especially by international donors, its role in fostering deeper transformative change is likely to be unachievable (Lund et al. 2017). One main challenge is that the outcomes from REDD+ are highly dependent on the distribution of international funds, and significant uncertainty remains around the effectiveness of market incentives versus development aid approaches in being able to properly value and balance across the BCS nexus (Asiyanbi and Lund 2020, Streck 2020). For example, integrated REDD+ approaches that include biodiversity monitoring and social equity are likely to suffer in competitive markets funded by carbon pricing or as transactional expenses covered through traditional development aid (Pascual et al. 2018, Garcia et al. 2021). Further concerns have been raised that offset-type mechanisms (including REDD+) can create perverse incentives for inaction on fossil fuel reductions and perpetuate policy lock-in and unsustainable long-term emission trajectories (Asiyanbi and Lund 2020). This also comes at the expense of integrating behavioral change and social tipping points (e.g., consumer demands for deforestation-free products or reduced consumption of luxury forest goods). The inability of forest offset markets to price in disturbance risks or to account for evidence of slowing carbon sink capacities of forests, not to mention evidence of systematic overcrediting in existing markets, prevents REDD+ from being anticipatory—for example, with respect to climate change impacts. Together, this indicates a great difficulty of carbon markets to understand and effectively respond to feedback loops in the BCS space (Hurteau et al. 2019, Badgley et al. 2022).

Fisheries management in the world's oceans. Having multiple objectives in relation to the individual components of the BCS nexus is increasingly common in marine conservation and fisheries management (Bryndum-Buchholz et al. 2021, Cheung et al. 2021). Although marine ecosystems contribute to regulating climate and supporting people's livelihoods, food and culture (Bindoff et al. 2019), human activities, including fishing, are affecting oceans' essential regulating, material, and nonmaterial contributions to people (IPBES 2019). Globally, the biomass of commercially exploited fish stocks has more than halved since the 1950s (Watson et al. 2013), with some populations considered at high conservation risk from both overfishing and climate change (Dulvy et al. 2014, Cheung et al. 2018, Pollom et al. 2021). Simultaneously, BC interactions in marine life include the dangers of progressive warming, acidification, and hypoxia of ocean waters and by associated extremes, especially marine heatwaves, or by the exacerbating interactions of these direct drivers (Pörtner et al. 2014, Deutsch et al. 2015, Parker et al. 2017, Tripp-Valdez et al. 2017, Dahlke et al. 2018). The impacts of these changing ocean conditions vary among life stages, species, and regions. For example, the strongest impacts are often experienced by embryonic and early life stages of marine fishes and invertebrates (Dahlke et al. 2020) and in regions where rapid warming and loss of oxygen occur currently (Deutsch et al. 2015, Reddin et al. 2020, Sampaio et al. 2021). Biological responses to these environmental changes include poleward biogeographical shifts, the loss of spawning habitat, increased local mortalities, reduced productivity of calcifiers and carbonate habitats, and shifts in species interactions and in ecosystem composition and functions (Hoegh-Guldberg et al. 2014, Pörtner et al. 2014).

Ocean biodiversity–climate interactions feed back into the social sphere through declining catches in fisheries (Bindoff et al. 2019). In addition, the social component can be mostly associated with economic and governance drivers behind exploitation of fisheries (Finkbeiner et al. 2017). Specifically, social and economic factors such as fishing capacity-enhancing subsidies and ineffective fisheries governance and management contribute largely to historical overfishing (Hatton et al. 2021). In many cases, the effects of these socioeconomic drivers are exacerbated by environmental changes. At the same time, BCS interacting outcomes on fisheries often have the strongest impacts on small-scale artisanal fisheries and the associated low-income groups because of systemic vulnerabilities driven by their high dependence on fishing for income, livelihood, and nutrition and low capacity to adapt to changes in resource availability or access (McClanahan et al. 2015). Furthermore, small-scale sectors are often powerless to address the structural drivers that underpin overfishing and climate change (Pörtner et al. 2014, Chuenpagdee and Jentoft 2018).

Positive feedback dynamics leading to biophysical tipping points are observed in ecosystems that are important to biodiversity and that provide benefits to coastal communities (Eddy et al. 2021). Overall, climate change is projected to result in declines in potential catches of fishes and invertebrates globally, particularly in tropical regions (Bindoff et al. 2019, Tai et al. 2021), with cascading negative impacts on economics and employment levels (Sumaila et al. 2019, Cheung et al. 2021). Although overfishing continues and fishing efforts may increase to compensate for these negative climate effects on yield in the short term, overfishing will exacerbate the climate impacts on fisheries in the long term. Furthermore, the removal of ocean biodiversity and biomass and the disturbance of seabed carbon storage through excessive bottom trawls (Sala et al. 2021) exacerbate unfavorable BCS interactions through other feedback mechanisms. For example, declines in marine animal biomass affect their capacity to sequester carbon from the surface to the deep ocean through various pathways, from sinking fecal pellets to carcasses (Mallo et al. 2019, Mariani et al. 2020, Saba et al. 2021). Moreover, marine and coastal blue carbon storage mechanisms are being disturbed by climate warming and associated loss of habitat (Marbà et al. 2015).

On the governance side, integrative spatial planning of marine areas can ideally balance multiple human demands and sustain healthy ecosystems while also dealing with the impacts of climate change (Frazão Santos et al. 2020)—for example, well planned marine protected area networks (Sala et al. 2021). To be more integrative, combining careful spatial planning of marine protected areas together with the removal of harmful fisheries subsidies offers an immediate opportunity for transformative changes to substantially reduce overfishing (Cisneros-Montemayor et al. 2016, Sumaila et al. 2021) and the associated loss of carbon-sequestration potential and stock. This would also contribute to reducing carbon footprints from capture fisheries (e.g., because of fuel oil subsidies that increase emissions from this sector; Mariani et al. 2020).

Nearly half of the world's fishing efforts—particularly, deep-sea bottom trawling (which is associated with significant carbon emissions)—are estimated to be unprofitable without subsidies (Sala et al. 2018). Some subsidies are especially detrimental to adaptive management strategies because they skew incentives, are mismatched to ocean and ecosystem scale, and often lock in harmful fishing practices (Grafton 2010). Eliminating harmful subsidies would also improve the efficiency of the fishing sector with greater potential to benefit coastal and small-scale fisheries, increasing the sector's equitability (Cheung et al. 2017, Schuhbauer et al. 2017, Sumaila et al. 2021). In addition, harmful fisheries subsidies often disproportionally favor industrial fisheries, putting disadvantages on small-scale fisheries that are supporting the livelihood and well-being of coastal communities, particularly in developing countries (Schuhbauer et al. 2017). Small-scale fisheries are often considered underrepresented in terms of their worldviews, values, and knowledge systems in fisheries governance (Kaltenborn et al. 2017, Johnson et al. 2019).

However, despite long-standing research on the harmful effects of fisheries subsidies (Sumaila and Pauly 2007) and the robust evidence of the large potential BCS cobenefits of their removal, examples of transformative ocean governance across scales (international, national, and local) have rarely been explicitly integrated within a BCS nexus frame. Reframing subsidies as not only a fishing or biodiversity issue but as one of climate and carbon as well could bring more active consideration of ocean-based solutions in policy discussions at the international and national levels (Machado et al. 2021, Sala et al. 2021, Sumaila et al. 2021). At the same time, ensuring social equity would require attention to any vulnerable fishers that depend on subsidies not being harmed by their removal (Harper and Sumaila 2019, Merayo et al. 2019).

Integrating BCS policies in cities. Cities, where the majority of the human population now resides (United Nations 2019), have substantial impacts on biodiversity and climate change and, in many cases, enhance codetrimental effects and their associated risks (Haase et al. 2012, McDonald et al. 2020, Zhao et al. 2021), with some notable exceptions (e.g., cities as bioarks of biodiversity; Shaffer 2018). Given the strong BCS interactions that occur within urban administrative boundaries (Grimm et al. 2008, Elmqvist et al. 2013, Bai et al. 2018, Roches et al. 2021), cities also provide a ready opportunity to optimize BCS cobenefits—for example, via urban nature-based climate solutions (McPhearson et al. 2015, Haase et al. 2017, Raymond et al. 2017, Seddon et al. 2020). An integrative systems approach to urban governance that simultaneously accounts for each BCS component and its interactions is required in most urban contexts (Bai et al. 2016a). To date, only incremental, stepwise progress has been made to understand bilateral interactions. For example, biodiversity–society interactions have been examined from the urban ecosystem-services perspective, including renewed attention to urban nature as a food source, especially for marginalized groups (Marselle et al. 2021). Similarly, climate–society interactions have been examined from the perspective of the climate change and health nexus (Endlicher et al. 2008). However, a focus on biodiversity–climate interactions in urban areas is lagging behind. Many cities consider increased urban density as a means to achieve climate mitigation via reduced transportation-energy requirements, but this often leads to reduced urban green cover, with negative impacts on biodiversity (Lin et al. 2015) and human health (IPCC 2022). However, devoting renewed attention to careful governance of biodiversity–climate interactions is vital as increasing evidence emerges on the critical role of urban green infrastructure in mitigating extreme climatic conditions (e.g., via heat island effects) that tend to affect the well-being of the more vulnerable directly (Zolch et al. 2016) and indirectly—for example, via green gentrification and planning processes that add to environmental injustice (Anguelovski et al. 2019, Schell et al. 2020). Biodiversity–climate interactions themselves feed back to the social sphere with positive effects of urban vegetation and biodiversity on climate mitigation and, in turn, on human health, as became readily apparent through COVID-19 lockdowns (Bowler et al. 2010, Imran et al. 2019, Roll et al. 2021).

Adopting an integrated systems approach would partly enable the conditions for transformative governance in urban planning. For example, bright spot opportunities are possible in urban contexts, such as sponge cities in China, which use green roofs, urban wetlands, pervious pavements, and rain gardens, among other innovations, to absorb water during storms. These innovations can also lead to cobeneficial outcomes in the BCS space (Zevenbergen et al. 2018). However, the traditional mental model of cities as a place rather than a system and the siloed design of and inertia in many urban institutions mean that integration remains challenging (Bai et al. 2016a). This is true not only across but even within each BCS component. For example, the integration of mitigation and adaptation measures within the climate domain is difficult (Silva et al. 2012). For many cities, limited financial capacity leaves little room to look beyond the bare minimum of providing basic municipal services (Gouldson et al. 2016, Colenbrander et al. 2018). Even cities that are willing and able often find themselves constrained by the lack of information and understanding or proper decision-support tools that are tailored to their context (Bai et al. 2018).

To achieve urban transformative governance, several enabling conditions should be met. These include institutional redesign that enhances the inclusive collaboration in and the accountability of decision-making, promoting regenerative culture and design, stronger science–policy links to coproduce locally tailored knowledge and understanding, and enhanced financial capacities of cities through both empowering and enabling conditions from national governments and building innovative partnerships across social sectors (Bai et al. 2016a, Norström et al. 2020, Thomson and Newman 2020). In addition, breaking away from negative system inertia, building positive inertia, and changing the urban system's identity are crucial to create the conditions for social tipping points (Irvine and Bai 2019). Urban sustainability experiments in cities have proven to be effective in this (Bulkeley and Castán Broto 2013, Evans et al. 2016. Marvin et al. 2018, Irvine and Bai 2019). At the same time, innovative practices need to be shared across cities to facilitate colearning for more adaptive and equitable urban planning that can feed larger-scale transformative change.

Governance of drivers of change in the Arctic. The Arctic is experiencing accelerated changes in climate and biodiversity (AMAP

Table 2. Lessons from case studies regarding BCS nexus perspectives and transformative governance potential.

Case studies	Multifunctional actions recognizing BCS feedback loops	Integration across scales and BCS nexus elements	Opportunities for social tipping points	Engagement of multiple actors and coalitions	Recognition of social equity dimensions
Governing tropical forest systems with REDD+	Slow to respond to ecosystem state changes and lack of clear BCS nexus approach	Some potential for jurisdictional approaches across scales, but currently not widespread	Limited because of focus on producers not consumers	Limited and mostly where IPLCs are more involved	Limited because of market-pricing focus
Fisheries management in the world's oceans	Lack of focus on the many BCS feedback loops in the design and elimination of harmful fisheries subsidies	High potential for BCS nexus focused fisheries policies but currently largely insufficient	Limited opportunities because of barriers from competing interests between countries and sectors particularly industrial-scale fisheries	International and local coalitions that focus on specific issues, but limited consistent coalitions on BCS nexus	Limited because of differences in economic and political powers between countries, and between industrial and small-scale fisheries
Integrating BCS policies in cities	Siloed approach in many urban institutions means integrated BCS actions remains limited	Some incremental progress has been made regarding bilateral interactions between nexus elements	High potential via continued sustainability experiments in individual cities and cross city learning and upscaling, although breaking away from negative system inertia remain challenging	High potential but still rather limited inclusive collaboration in urban planning and accountability of decision-making	High potential but social equity not sufficiently prioritized in urban decision-makers' greening agendas
Arctic ecosystems climate change, and the Inuit	Inuit traditional knowledge is key for integrating BCS nexus into multifunctional actions, but these are still mostly lacking	National, regional and international Arctic policies are increasingly coordinated but largely lacking a BCS nexus perspective	Advancing on issues of land entitlement and ownership by Indigenous peoples needed	Some advances at regional levels through Inuit traditional knowledge inclusion Multiactor coordination on international levels	Power relations need to balance to better recognize leadership and self-determination of Inuit and northern communities

Abbreviation: BCS, biodiversity–climate–society.

2021, IPCC 2019a, 2021). Climate change, primarily generated outside the Arctic (Carter et al. 2021), is changing species compositions and lowering ecosystem resilience; this, in turn, has social impacts—for example, through declining food availability; requiring changes in traditional harvesting times, locations, and techniques; and the erosion of cultural security (ICC 2008, Steiner et al. 2019, AMAP 2021). BCS interactions feed back to limit the capability within human communities to reverse or decelerate the experienced changes (Huntington et al. 2019, Steiner et al. 2021). For example, historical marginalization and conflicting traditional and Western lifestyles have induced trauma in Inuit communities, and these likely amplify climate-change-related risks (Huntington et al. 2019, Mitchell et al. 2019).

Governance plays a central role in linking the drivers of change, nature, and people in the Arctic context, and to achieve transformative change, representation of Inuit in governance is a critical issue (Reyes-García et al. 2022). An integrated and inclusive BCS governance approach is engrained in the stated Inuit priorities that highlight the protection and advancement of their rights and interests, support for healthy ecosystems, the need to face climate change, and support for coproduced knowledge based on research that is meaningful for Inuit communities and their governance approaches (Inuit Tapiriit Kanatami 2019). Multilevel governance has allowed these priorities to be heard. For example, at the international level, the Arctic Council, which includes six permanent Indigenous participants, has amplified the voice of Arctic people affected by climate change impacts and has mobilized action (Koivurova 2016). The Inuit Circumpolar Council (ICC) has developed the comprehensive Inuit Arctic Policy to strengthen circumpolar unity, promote Inuit rights and interests internationally (including long-term policies that safeguard the Arctic environment), and seek full and active partnership in the development of the circumpolar regions (ICC 2010).

However, the Arctic covers multiple nations and, although the ICC provides a unified voice, transformative governance also needs to happen at the national or regional level, and the status of transformation can vary extensively across the Arctic. For example, within Canada, Inuit governance is established nationally (Inuit Tapiriit Kanatami) and regionally, to a large part related to land-claim agreements between the Inuit people and the federal government. Elsewhere, potentially diverging definitions of land entitlement and ownership by Indigenous peoples and countries can make transformative governance more challenging. The norms and rules of the Inuit nations that frame the governance of their natural resources can support both climate mitigation and adaptation efforts—for instance, by directly influencing regulations and agreements, including through ocean-based local measures (e.g., conservation areas). Although local measures may have limited roles to mitigate climate change

(IPCC 2019a), they can still help to effectively address local risks, and they have potential cobenefits.

To ensure (equitable) transformative change, codesign and comanagement by Inuit and provincial governance institutions is essential. Improved adaptive governance can also be driven through the coproduction of knowledge—for example, by Inuit involvement in climate science. Such changes would require power relations between the Inuit and external scientific communities to be more equitable. This is particularly relevant when setting research agendas and participating in research (including an increased emphasis on Indigenous and local knowledge; Loseto et al. 2018, Waugh et al. 2018, Sidik 2022), by carrying out coastal monitoring, improved and accessible weather and seasonal predictions and climate projections and by investing in enhanced trauma-informed mental and physical health care (Pörtner et al. 2021, Trisos et al. 2021). Decolonizing the way knowledge is produced and used in the context of BCS interactions in the Arctic requires empowering Inuit communities to use, design, manage, and lead science (Huntington et al. 2019). Decolonization and self-determination are necessary to have the Inuit represented and their voices heard (and to ensure these voices have weight) outside the Arctic to influence decisions that affect them indirectly, given that carbon emissions are concentrated outside the Arctic but also given that the impacts are felt most heavily in the Arctic.

Any such measures require evaluation in terms of social equity among Inuit and Northern and subpolar communities and within the communities themselves. The leadership and self-determination of the Inuit and Northerners in the assessment of climate-change impacts, in developing climate research needs, and in implementing adaptation measures can foster transformative governance of the Arctic under a BCS nexus. This includes continuing to strengthen the capacity of Arctic and Northern communities and the capacity of Indigenous peoples to acquire and apply available data and research, participate in research, and develop methodologies and approaches for climate change communication (Kukutai and Taylor 2016). Regional governments or community organizations need to be involved in the distribution of benefits that result from such measures.

The case studies help both to identify BCS interactions, key opportunities, and the current challenges for policy interventions and to catalyze transformative governance, which could be upscaled with a BCS nexus perspective (table 2). The examples show that existing approaches to governing the BCS nexus are largely siloed, fragmented, inconsistent, rigid, and slow, which prevents them from being effective when the most serious BCS challenges are cross-cutting, feedback loop oriented, nonlinear, and potentially fast. In fact, most current governance approaches to deal with BCS interactions do not sufficiently address their causes and impacts at appropriate scales, nor do they adequately engage the range of actors (from global to local) who have divergent worldviews and their associated values about human–nature relations (ranging from corporations to cities to IPLCs). Furthermore, very rarely do governance approaches in the BCS space consider feedback effects and trade-offs, nor do they often aim to spark social tipping points.

Principles for transformative BCS governance under the BCS nexus

Given the unprecedented scope and speed of existing and projected climate and biodiversity interactions and changes, transformative governance at the BCS nexus is critical, also in light of the widening implementation gap indicated by global targets to be widely missed. A reflexive approach is needed to address the failures and challenges of existing ideas and mechanisms about governance (table 1) and to identify the necessary conditions for deeper transformation. Operating with a BCS nexus approach implies recognizing the biophysical limits and interactive dynamics in the BC space, in addition to the distributive benefits and costs of any policy intervention across different social sectors and groups (Pörtner et al. 2021). In addition, where policy interventions facilitate transforming social structures to create the necessary conditions for tipping positive social behavior (e.g., by shifting norms, rules, and—ultimately—social values), they are more likely to succeed in addressing the climate and biodiversity crises. Therefore, governance systems will need to bring about behavioral changes across all relevant actors while targeting larger structural issues at the root of the coupled climate and biodiversity crisis. In other words, transformative governance requires combining short-term nudge-based policy instruments and approaches that may buy humanity some time to address the climate and biodiversity crises with deeper institutional (including regulatory) changes and adaptive management approaches.

Therefore, transformative governance for the BCS nexus needs to be based on understanding the specific feedback loops and interactions in the BCS space, to aim at integrating and redesigning institutions at different levels and scales, to acknowledge meaningful and equitable participation of a wide range of social actors (stakeholders and rightsholders) across coalitions, to have a concern for equity of outcomes at its core, and to build in the potential for positive social tipping points to tackle both changes in individual agency and structural resets that are needed. These conclusions come from our understanding of the specificities of the BCS nexus (see the “Key elements of the BCS nexus” section), our reading of the governance literatures and their limitations (see the “Conditions and challenges for transformative BCS governance” section), and the case studies (see the “Key focal areas for governing the BCS nexus” section), which provide a sense of these challenges and barriers as well as opportunities for reframing transformative governance to overcome them. We therefore highlight five principles that we believe policy interventions could follow to facilitate moving from reformist (incremental and shallow) to deeper transformational governance for the BCS nexus (figure 4). These five principles are as follows.

Focus on multifunctional interventions. Overall, the focus should be on investing in toolboxes of adaptive solutions (Vira and

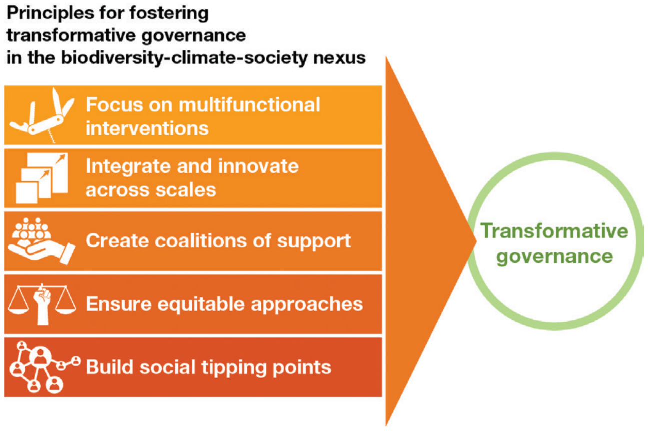

Figure 4. Key principles can facilitate transformative governance across the biodiversity–climate–society nexus.

Adams 2009) that recognize the complexity of feedback loops and trade-offs, rather than single silver bullets that rely on simplified or overly optimistic assessments of success without accounting for counterfactuals, difficulties in scaling up, or unintended offstage burdens (e.g., Pascual et al. 2017, Bastin et al. 2019). This implies accepting solutions for multifunctionality rather than maximizing performance on single indicators (such as greenhouse gas removal or installed renewable energy) to produce multiple benefits to a diversity of actors (Gren et al. 2010, Brauman et al. 2020). For example, the failures of REDD+ to generate biodiversity and socioeconomic cobenefits across the BCS nexus are in part a result of mechanisms for funding that have stressed optimizing the climate element rather than accepting higher transaction costs that would also bring benefits to both nature and people. Interdisciplinary and place-based transdisciplinary approaches that involve the coproduction of knowledge can help build such resilient toolboxes for multifaceted solutions (Seppelt et al. 2018), as was noted in the Arctic case study, where marine protected areas serve multifunctional roles for Inuit communities and others.

Integrate and innovate across scales. Global BCS governance is still largely tackled in silos, by specialized reports and negotiations, and by dedicated experts who work in separate ministries and who are assigned to separate international conventions (e.g., the UN Framework Convention on Climate Change and the Convention on Biological Diversity). International secretariats are increasingly facilitating cooperation, but it is crucial to align content and messages across key reports and multilateral environmental agreements that relate to biodiversity, the climate, or the oceans, but this alignment is currently still very limited (van Asselt 2011, Solecki et al. 2017, Smith et al. 2019, Stephens 2019). Current global governance approaches also have nation-states at their core. This limits the flexibility of cross-boundary governance models, even though the drivers of vulnerability often occur at the larger regional scale (Birkmann et al. 2021) and even though strong and equitable responses are often grounded at the local scale, as is seen in urban contexts. At the same time, although an enhanced and coordinated global system for governing BCS interactions is needed (i.e., through more integration of institutions), giving space to regional or local autonomy is equally important. Therefore, transformative governance should be sensitive to local people's autonomy and rights of self-determination, especially with regard to Indigenous peoples and local communities, so that they also have the capacity to decide what is meant to be just and sustainable according to their worldviews, values, and knowledge systems. The Arctic case study shows that local self-determination and the use of appropriate local knowledge systems can enhance adaptive and equitable governance but that it cannot work alone, especially when the drivers of biodiversity loss and climate change are happening elsewhere.

Create coalitions of support. Transformative governance requires opening political opportunities and building political will. Political opportunity can be created in part by various actors from the private sector, civil society, and governments by intervening in creative ways to enable broad and focused public support (Chan et al. 2020). However, not all actors are equal in terms of their responsibilities in driving carbon emissions and biodiversity loss, nor in terms of their vulnerability to their impacts (Milner-Gulland et al. 2020). For example, the private corporate sector is a major driver of carbon emissions and biodiversity loss, and it often represents powerful and vested interests rather than collective ones aligned with the common good (IPBES 2019, Nyström et al. 2019). As was seen in the fisheries case study, one reason subsidy reform has been advocated for many years—but rarely implemented—is precisely this power misalignment (Sumaila et al. 2021). Therefore, approaches to tip powerful private sector interests that benefit from subsidies toward more sustainability should involve strengthening the coalition of interests advocating for reform, such as by including the full range of BCS benefits in socioeconomic analyses and enjoining local priorities and interests (such as the food security of small-scale fishers) in political coalitions.

Ensure equitable approaches. Equity-based approaches to addressing the BC nexus can deliver multiple benefits in ways that strengthen all three dimensions. For example, policies that target the most poor and vulnerable people and that link mitigation and adaptation, such as using renewable energy to increase rural electrification or using revenues from a carbon tax to increase social assistance, could support the eradication of poverty under near-term climate change (Hallegatte et al. 2016, Aklin et al. 2018). Integrating climate and biodiversity risks into the design of social protection programs can help build long-term resilience and large-scale social support, especially by the more disadvantaged social groups (Hallegatte et al. 2016). For example, public works programs can deliver biodiversity, climate, and social benefits by targeting ecosystem conservation and carbon sequestration, as is exemplified by South Africa's Working for Water Programme, which restores river catchments to reduce fire risk and increase water supplies in regions prone to droughts from human-induced climate change (Turpie et al. 2008, Norton et al. 2020). Ignoring the societal dimension in interventions, such as REDD+ programs that have failed to address legal rights or benefits, diminishes joint biodiversity and climate outcomes rather than improving them.

Build social tipping points. Transformative change to address the intertwined underlying drivers of the mutual climate and biodiversity challenge involves dealing with the overconsumption of natural resources (including terrestrial and marine biomass), raw materials (e.g., minerals), and unsustainable energy (including fossil fuels, large-scale renewable energy infrastructure and bioenergy crops; Pörtner et al. 2021). Capturing offstage (diffuse, distant, and delayed) impacts along commodity value chains, including leakage effects, would likely have significant potential for inducing a shift across consumption and production decisions (Pascual et al. 2017). Such a shift to more ecological economies will necessarily also involve a range of behavioral and institutional changes. Therefore, tools designed to facilitate inducing social tipping dynamics, supported by grass-roots mobilizations, while at the same time anticipating BCS interactions, are more likely to be successful than ones that fail to build these concepts in. This has potential consequences for the current penchant for voluntary or market-based measures, which tend to be less effective or associated with less impact (e.g., slower carbon reductions) than regulatory approaches (Auld et al. 2014). They also tend to be less equitable than interventions with inclusive processes to guarantee participation from the affected communities from the start (Hill et al. 2016) or with mechanisms to ensure fair benefit sharing, as is seen in the REDD+ example above.

A transition toward transformative BCS governance is not only possible but potentially underway, and many local—as well as national and international—initiatives provide some hope, such as the European Union's Green Deal or Greta Thunberg's School Strike for Climate, both of which have demonstrable potential to spur social tipping dynamics toward ambitious implementation. Ensuring that this transition gathers momentum and deepens across local, national, and international scales and organizations to foster a shared future will require transformative governance at the BCS nexus.

Conclusions

There is an urgent need to further develop and imbue ideas of transformative governance associated with different contexts, including a diversity of institutional settings, with a BCS nexus perspective. International science-policy initiatives are already aware of the need to enhance a nexus and transformative change perspective—for instance, the IPBES assessment on the multiple values of nature, which is to be complemented by forthcoming assessments on transformative change and the nexus among biodiversity, water, food, and health. We hope that this effort by the global scientific community will be followed by the integration of biodiversity and climate sciences through enhancing the BCS nexus perspective. In addition, we suggest that future research may be focused on how the five principles outlined above could be applied in different social–ecological contexts and what synergies and trade-offs may result from the principles. This line of research could also provide novel insights that shed light on the types of social resistance and political lock-in processes that need to be overcome when applying the principles. In addition, the research community can help to further understand the conditions for interventions to shift away from stepwise incremental change (i.e., the dominant reformist agenda) and instead focus on the conditions for interventions to become accumulative and genuinely (i.e., deeply) transformative.

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