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Inequality and the Biosphere

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Abstract

Rising inequalities and accelerating global environmental change pose two of the most pressing challenges of the twenty-first century. To explore how these phenomena are linked, we apply a social-ecological systems perspective and review the literature to identify six different types of interactions (or "pathways") between inequality and the biosphere. We find that most of the research so far has only considered one-directional effects of inequality on the biosphere, or vice versa. However, given the potential for complex dynamics between socioeconomic and environmental factors within social-ecological systems, we highlight examples from the literature that illustrate the importance of cross-scale interactions and feedback loops between inequality and the biosphere. This review draws on diverse disciplines to advance a systemic understanding of the linkages between inequality and the biosphere, specifically recognizing cross-scale feedbacks and the multidimensional nature of inequality.

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1. INTRODUCTION

Inequality is one of the key social challenges of our time, with far-reaching ramifications for human well-being (1–7). Similarly, unprecedented and accelerating changes to the biosphere have the potential to significantly impact societies across the planet (8, 9). In this article, we show that far from being independent, inequality and the biosphere interact in many different ways. We review research across a range of disciplines that explores the linkages between inequality and environmental change and find that most of the literature only considers the one-directional effects of inequality on the biosphere, or vice versa. Synthesizing across this body of research, we identify and describe six such one-way interactions (or "pathways") between inequality and the biosphere. However, given the well-documented potential for complex dynamics between socioeconomic factors and environmental change (10–12), we go beyond these one-way interactions to discuss examples from the literature that highlight the importance of considering cross-scale interactions and feedback loops between inequality and the biosphere.

In recent years, inequality has become an issue of widespread scientific, political, and popular interest. In the wake of the 2008 financial crisis, discussions about socioeconomic inequality have been brought to the fore by headline-grabbing books and reports, such as Thomas Piketty's *Capital in the Twenty-First Century* (13) and Oxfam's *An Economy for the 99%* (14), as well as social protest initiatives such as the Occupy movement. The most recent *World Social Science Report* (15) identified rising inequality as a major concern for the sustainability of economies, societies, and communities, and called for an urgent research agenda to improve our understanding of and responses to inequality. In addition to experiencing significant societal transformations, humanity has entered an era of unparalleled global environmental change (8). We have already transgressed numerous thresholds in critical Earth system variables, such as the concentration of carbon dioxide in the atmosphere and the loss of biological diversity, and we are approaching other boundaries beyond which lie heightened risks of irreversible damage to the biosphere and major shifts to a much less hospitable planetary state (9). Environmental changes have the potential to negatively impact human well-being by decreasing water and food security, threatening livelihoods, and increasing health risks (such as air pollution, extreme temperatures, and the spread of infectious diseases) (16–19).

Rising inequalities and accelerating global environmental change therefore represent two of the most pressing issues of the twenty-first century. To explore how these phenomena are linked, previous analyses have mainly focused on economic inequality and its effect on a specific environmental variable such as degradation or pollution, often using national-level data (20, 21). Comparatively less research is concerned with other kinds of inequalities (such as gender inequality) and the ways in which these different types of inequalities impact the biosphere (with notable exceptions, such as 22). When it comes to the effects of environmental changes on inequality, much of the research is focused on the disproportionate impact of climate change and related extreme events on the poor and vulnerable (e.g., 23–25), as well as broader impacts on socioeconomic indicators such as national income and economic growth (e.g., 26, 27). However, in the context of rapid global change and the inherent, complex interactions between social and ecological variables (28), there is an urgent need to expand these approaches and consider a wider variety of interconnections and feedbacks between inequality and the biosphere across multiple scales.

In this article, we aim to address this need for a broader consideration of interactions between inequality and the biosphere by taking a social-ecological systems perspective (29), which is inherently interdisciplinary and emphasizes that there is a dynamic interplay between the biosphere and socioeconomic variables such as inequality. Within this framework, we review the scientific literature to explore and describe pathways in which changes in the biosphere impact inequality in

society, as well as pathways in which inequality impacts the biosphere. The pathways we identify cover numerous spatial, temporal, and institutional scales. We then discuss diverse examples of cross-scale interactions and feedbacks, point out remaining knowledge gaps, and suggest future research priorities. We demonstrate the importance of considering changes in the biosphere when trying to understand inequality in society, as well as the importance of considering inequality as a key driver of environmental change.

2. BACKGROUND AND DEFINITIONS

Inequality may occur in many different forms and contexts. Here we provide a brief background for the concept of inequality and define how we apply it in this review.

2.1. Inequality in Society

In 1754, the philosopher Jean-Jacques Rousseau defined what he termed "moral inequality" as the unequal distribution of privileges between people, resulting from prevailing institutions, norms, and beliefs (30). An unequal distribution of privileges can occur in many different areas of life, which the 2016 *World Social Science Report* (15) refers to as the seven dimensions of inequality: economic, political, environmental, social, cultural, spatial, and knowledge-based. These inequalities invariably intersect and potentially reinforce each other. For example, economic and knowledge inequalities often intersect with political inequality, as low income and education levels hamper the capacity of people to engage in decision-making processes (31).

Our definition of inequality focuses on inequality as a positive description of the variance in the distribution of a resource (32). In contrast, concepts such as wealth or poverty provide a positive description of the level of resources available (33). On the basis of these definitions, economic inequality can be high in a wealthy nation where most people live above a certain poverty line, or low in an impoverished country (**Figure 1**). Although this distinction is important in an academic setting, inequality and poverty are often conflated in everyday use, and some commentators consider the percentage of people living below a certain poverty line to represent a measure of economic inequality in society.

In the context of inequality as a measure of the distribution of resources, one can distinguish between vertical and horizontal inequality (34). Vertical inequality refers to an unequal distribution of a resource within a specified unit, such as the distribution of household income within a country. Horizontal inequality, however, refers to an unequal distribution between culturally defined or constructed groups, such as differences in income between genders, races, or ethnicities (34). In addition to being intrinsically unjust and discriminatory, horizontal inequalities are of particular concern in societies prone to instability, as they have been shown to raise the risk of violent conflict (3, 35, 36).

Such unjust inequalities are also often referred to as inequities. While inequality describes an unequal distribution of a scarce resource, benefit, or cost, and does not necessarily represent a normative statement, inequity is a normative term that evokes an unfair or unjust distribution of privileges across society. At the individual level, inequity is closely related to the concept of subjective inequality, which refers to a person's perceptions of existing inequalities and beliefs about what is just and desirable (37). Subjective inequality may be assessed using surveys, and has been shown to be an important determinant of behavior and social outcomes such as political affiliation, support for welfare programs, and class conflict (38–40). In contrast, objective inequality is assessed in terms of indicators such as household income and can be expressed using measures such as the Gini coefficient (41).

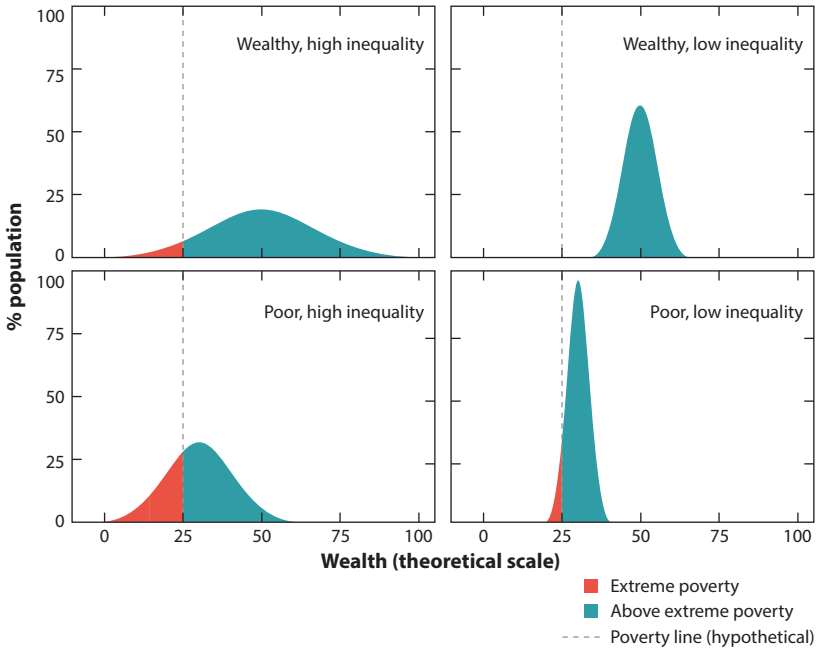


Figure 1

The difference between wealth and inequality. Whereas wealth or poverty of any unit (e.g., a country, a community) is often represented as the average value of a statistical distribution, inequality represents the variance of the same distribution. Here, four simplified cases are expressed with regards to mean and variance of wealth. The dashed vertical line represents a hypothetical poverty line, analogous to established poverty definitions of, e.g., the average income of less than US$1.90 per person per day, defined as extreme poverty by the World Bank (**http://www.worldbank.org/en/topic/poverty/overview**). The fraction of the population experiencing extreme poverty can be similar in the cases of high wealth and high inequality (*top left*) and low wealth and low inequality (*bottom right*).

2.2. Inequality in Nature

Inequality is not restricted to society but occurs throughout the biosphere (42). For the purposes of this review, we define the biosphere broadly as the global ecological system integrating all living beings and their relationships in the thin layer of life between the Earth's crust and outer space (43). The biosphere is naturally unequal, meaning that there exists an inherent environmental or resource heterogeneity across the globe, and within regions or countries (42). For example, not all places on Earth are equally endowed with access to energy resources, freshwater reserves, or appropriate biophysical conditions for large-scale agricultural production. Early in human history, these differences in initial endowments of natural resources led to an inequality of opportunity for societal development and economic expansion in different parts of the globe (44, 45).

Of course, in recent centuries there has been a notable decoupling between resource endowment and the potential for societies to develop, due to trade, regional or global conflict, colonialism, industrialization, technological advances, and globalization. It is no longer possible to directly link a country's economic performance to its endowment of natural resources, as discussed in an already established literature on the "resource curse" and its potential causes and consequences (46–49). To delve deeper into an analysis of whether, or to what extent, the initial endowment of natural resources plays a role in defining the trajectory of a country's economic development (as opposed

to factors such as institutions, market dynamics, geopolitics, gender roles, or ethnic conflict) is beyond the scope of this review. However, it is important to note that biospheric conditions have, over the course of human history, arguably contributed to establishing inequalities in society, either directly or through their interaction with institutions that arose as a consequence (50, 51). The persistence of these institutions (e.g., property rights, extractive resource management policies, public education systems) can maintain inequalities over long periods of time and have resulted in the current status quo (52). This includes the inequalities between the global North and South, developed and developing nations, and indigenous peoples and western culture. Given this status quo, the remainder of the review focuses on more dynamic interactions between the biosphere and inequality—interactions that occur not over the course of millennia or centuries, but over much shorter timescales.

3. A SOCIAL-ECOLOGICAL SYSTEMS PERSPECTIVE ON THE INTERACTIONS BETWEEN INEQUALITY AND THE BIOSPHERE

The social-ecological systems perspective considers the biosphere and human well-being to be inherently and inextricably intertwined and coevolving: People are not only embedded in and completely dependent on the biosphere, but they are also influencing it from microscopic to planetary scales (9, 12). Social-ecological systems are complex and adaptive, characterized by variables that interact through amplifying or dampening feedbacks across scales in space, time, and organizational hierarchy (11, 29, 53). These cross-scale dynamics can result in novel or nonlinear behavior that may cause surprising shifts in the way the system is structured and functions (28).

In the context of social-ecological systems, we argue that inequality can be seen as a key variable that interacts with multiple other social and ecological system components across scales (**Figure 2**). We therefore expect cross-scale dynamics and feedbacks to play a role when considering interactions between inequality and the biosphere. However, there are also interactions between the biosphere and society that are not necessarily influenced or mediated by inequality. Personal enjoyment of nature, for example, and the individual relational values that are fostered through interaction with nature (54), may be considered independent of inequality. Here, however, we focus solely on the pathways in which inequality plays a role.

In the following sections, we outline six pathways that we identified in the literature to illustrate social-ecological connections between inequality and the biosphere. We begin by describing two situations in which changing conditions in the biosphere increase or decrease inequalities in communities, through sudden shocks such as extreme weather events and disease outbreaks (Section 3.1.1), or through more gradual environmental change such as shifting climate patterns (Section 3.1.2). We then describe four situations in which societal inequalities affect the biosphere by influencing human actions, through perceptions of inequality and fairness (Section 3.2.1), personal aspirations (3.2.2), the level of cooperation in groups managing a common environmental good (Section 3.2.3), or decision making in cases of market concentration (Section 3.2.4).

3.1. Changes in the Biosphere Lead to Changes in Inequality

Inequalities between groups of people may be exacerbated or diminished by changes in the biosphere, both by sudden and abrupt changes such as extreme weather events and other environmental shocks, but also by more incremental changes in key biophysical variables such as climate patterns and species distributions.

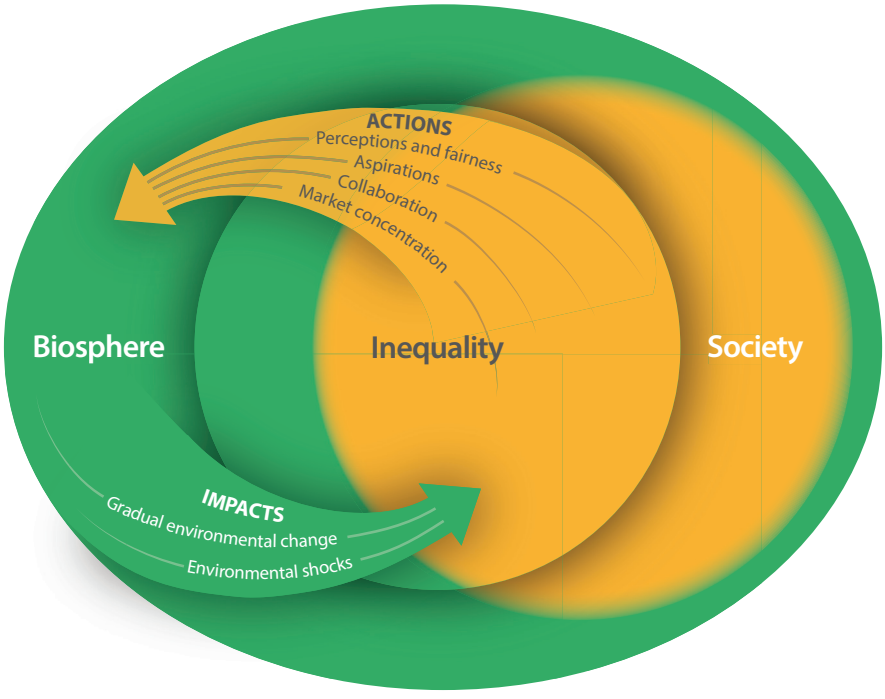


Figure 2

Interactions between inequality and the biosphere in social-ecological systems. Inequalities exist in both society and nature, although we focus on the former. The biosphere, which underpins all of society, directly impacts inequality through environmental shocks or gradual environmental change. Inequality has an effect on the biosphere through human actions, which can be shaped by an individual's perceptions and sense of fairness, as well as their aspirations. Beyond the individual, inequality can influence the actions of groups or institutions by shaping cooperation in sustaining the local commons, or through market concentration. These pathways of interaction represent a subset of possible interactions and a starting point for further research.

3.1.1. Environmental shocks and extreme events. Natural disasters such as storms, floods, droughts, epidemics, and wildfires pose threats to a wide range of communities and tend to exacerbate existing inequalities in their wake. This is because the risks posed by natural hazards to a system are a function of both the exposure and vulnerability of that system (55). Due to a combination of factors, low-income communities are more often in the way of harm; i.e., they experience disproportionately high levels of exposure. Households tend to sort into locations based on their ability and willingness to pay for various amenities, environmental quality being one of them (56–58). This equilibrium sorting results in a tendency for low-income households to be outbid by the wealthy, and hence cluster in more exposed and degraded areas (59). Moreover, in evacuation scenarios, the poor, disabled, and elderly often lack the means to evacuate, leaving them at risk in the danger zone (60, 61).

In addition to elevated exposure, lower-income individuals are often more vulnerable to the impacts of disasters. Vulnerability has been defined as the "propensity or predisposition to be adversely affected" (55, p. 5), or—more specifically—"the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard" (62, p. 8074). There are many factors that have been shown to influence vulnerability, including socioeconomic status,

HURRICANE KATRINA

Environmental disturbances can throw socioeconomic inequalities into stark relief; inequalities in turn mediate the impact of extreme disturbances, often placing the heaviest burden on those least prepared to mitigate and adapt. Hurricane Katrina's landfall in New Orleans is a salient example. When the levees broke in 2005, floodwaters surged into low-lying areas that were mostly populated by the economically marginalized—notably minority African-American communities. Their exposure to the disturbance was further exacerbated by their lack of access to transport, and thus ability to evacuate. Their vulnerability was heightened by a lack of insurance, less robust housing (e.g., lack of flood and other disaster-proofing), and limited resources to rebuild and recover. As a result, there was widespread land abandonment in marginalized communities in the wake of the disaster, which—together with a shortage of government services and maintenance—led to changes in the ecological conditions in those areas (149). Perhaps most notably, invasive species and species of concern were able to gain a foothold, including disease vectors such as mosquitos and rodents. This ecological process therefore resulted in a public health risk and contributed to the cycle of disinvestment and abandonment in the affected neighborhoods. As this example shows, a social-ecological feedback was created in which an extreme environmental disturbance interfaced with socioeconomic inequality to change the ecology of a city; in turn, these changes in ecological condition negatively impacted human well-being and development, thus further increasing the vulnerability of marginalized communities to the next extreme event.

gender, race, occupation, education, and special needs (63). Poorer individuals are often more vulnerable to external shocks (64), as they lack the adaptive capacity to reduce their vulnerability (55, 65). For example, lower-income households are less likely to disaster-proof and insure their homes to prepare for and respond to natural disasters such as hurricanes. Such dynamics were especially evident during Hurricane Katrina, which had vastly different impacts on New Orleans's high- and low-income communities (66), widening inequalities in the city (see sidebar, Hurricane Katrina). In the United States more generally, income inequality was found to increase by 5.4% for every 100 billion US dollars in economic damages caused by hurricanes in coastal states (67).

Although extreme events may increase inequalities (67–70), much depends on how people respond. In Honduras, for example, Hurricane Mitch caused widespread destruction in 1998, hitting poorest households the hardest. However, in the wake of the disaster, poor communities mobilized to effect institutional changes that led to a more equitable distribution of land and a reduction of forest conversion rates (71). These changes resulted in improved social-ecological outcomes such as income diversification and forest conservation, as well as more resilient communities that were better equipped to cope with similar storm events in the future. As this example shows, biosphere impacts can lead to societal adaptations and mitigation strategies that reduce inequality in the longer term.

Besides extreme weather events, other environmental shocks such as epidemics of zoonotic and epizootic diseases can severely disrupt communities and entire regions by impacting human and livestock health (17, 72). For instance, inequalities between countries were exacerbated by the 2014–2015 West African Ebola epidemic, which not only had devastating personal and social impacts, but also resulted in significant contractions of GDP and increased levels of poverty across the region, especially in the most affected countries of Liberia, Guinea, and Sierra Leone (73). As with extreme weather, the ability of individual communities to adapt to and overcome disease outbreaks depends on their initial level of exposure and vulnerability. When significant events such as hurricanes, droughts, or disease outbreaks occur in frequencies and severities that challenge the capacity of individuals, groups of people, or communities to cope and adapt, it may result in

a downward poverty spiral for some individuals or households and the formation of poverty traps (74–76). This may widen existing inequalities in those communities, and further increase exposure and vulnerabilities to future events.

3.1.2. Gradual environmental change. Slow-changing environmental variables play significant forcing roles in the dynamics of social-ecological systems (77). Climate change, for example, may gradually affect the distribution of commercially important species and areas suitable for agriculture (78–80). Recent assessments have highlighted likely yield losses due to climate change in many agricultural regions (81). However, these impacts vary across space—although there is strong consensus for tropical yield losses, some temperate agricultural production systems are predicted to experience yield increases (82). These dynamics may lead to a poleward migration of agricultural productivity (83). By providing new economic opportunities in already productive areas, while further restricting options in low-productivity areas, these gradual environmental changes can contribute to the widening of inequalities across regions. At the subnational scale, Hsiang et al. (84) show that poorer counties in the United States face higher climate-related damage costs (including damage to agricultural yield) than richer counties, resulting in a significant transfer of wealth northward and westward and an increase in pre-existing regional economic inequality across the country.

Similarly, climate change has been shown to impact the distributions of marine species, as well as the productive capacity of numerous fish stocks (85). Many of the countries that are most vulnerable to impacts of climate change on their fisheries are among the world's least developed (86, 87). In these countries, where fisheries play a critical role in national economies, as well as for local livelihoods, and where capacity to adapt to changing conditions is limited, climate change is likely to reinforce economic hardship and might hamper development and poverty alleviation (86, 88, 89). This may increase inequalities within countries, but also further widen the gap between developing and developed nations.

In addition, gradual environmental changes may exacerbate horizontal inequalities at local scales. In the context of gender inequality, research finds that the depletion of aquatic resources (due to overfishing, for example) affects the livelihoods of men and women differently in subsistence and small-scale fishing communities (90, 91). In some parts of sub-Saharan Africa, for instance, where women generally have limited access to aquatic resources to begin with, increasing resource scarcity may not only reduce women's income, but may also drive women to engage in "fish-for-sex" transactions to secure a steady food supply for themselves and their families, which increases the incidence of sexually transmitted diseases such as HIV/AIDS (90, 92, 93). Furthermore, the burden of care for HIV/AIDS-affected adults, and those with other illnesses, usually lies with women (94, 95), thus compounding their economic and educational marginalization as a result of changing environmental conditions.

3.2. Inequality's Effect on the Biosphere

Inequality affects the biosphere indirectly through its influence on human actions, which then impact environmental quality and natural resource use. Numerous recent studies have focused on one-way interactions between inequality and environmental degradation, mostly looking for patterns across countries. For example, Berthe & Elie (20) review econometric studies that analyzed inequality's effect on environmental pressures and policies. The inequality measure in almost all cases was the Gini coefficient, and the scale was always above local (i.e., state- or country-level). In these kinds of studies, the effects of income inequality on environmental quality indicators such as CO_2 emissions, as well as air and water pollution, are not always conclusive (20, 21, 96, 97). When

it comes to biodiversity, however, there is robust evidence linking inequality to falling species diversity at the national scale (20, 98–100). It has been suggested that these trends may be due to the vulnerability of biodiversity (particularly immobile vascular plants) to highly localized human pressures and habitat destruction associated with income inequality (20, 100). Although there are numerous studies that explore high-level, aggregate economic and environmental data, there is still a need for an examination of the specific underlying pathways linking different kinds of inequalities to behaviors that affect the biosphere positively or negatively (20, 21). In the following sections, we describe four such pathways that operate from the individual or local level to increasingly broader spatial and institutional scales.

3.2.1. Perceptions and sense of fairness. Perceptions, which are deeply socially determined, are an important precursor for behaviors (101). Recent studies show that it is the perception of income and wealth inequality, as well as a sense of economic fairness, that drives individual behaviors and informs preferences, rather than inequality per se (40, 102, 103). Hence, we argue that subjective inequality (one's perception of inequality and beliefs about what is just and fair) can be a significant driver of behaviors toward the biosphere (104). For example, perceptions of inequality and fairness, together with the emotional response of jealousy, have been shown to play an important role in the success or failure of marine protected areas (MPAs) (105). These MPAs are increasing in number across the world and are touted as win-win interventions that benefit both people and the environment, but many fail to reach their objectives (106). The distribution of net benefits from MPAs is an important factor influencing individuals' compliance and enforcement of the area's rules and boundaries. If there is a perceived inequality and unfairness in the access rights to an MPA, jealousy may lead some to encroach upon and even actively sabotage the area, despite otherwise harboring generally positive attitudes toward the MPA and deriving benefits from it (105).

A sense of fairness can also be influential in environmental decision making at a global level. The real and perceived economic and political inequalities between industrialized and developing countries are significant factors in climate policy negotiations, with far-reaching repercussions for the environment (107). For example, heightened tension and mistrust between developed and developing nations were a major contributor to the failure of the Copenhagen Accord of 2009 to limit global greenhouse gas emissions, undermining the potential to commit countries to a binding agreement and avoid catastrophic climate change (108). When rich countries are unlikely to consider fairness or take part in redistribution efforts, poorer nations are not willing to compensate for the wealthier nations' inaction (109).

3.2.2. Aspirations. Inequality (regardless of whether it is perceived as fair) can be a potent driver of behavior in combination with an individual's aspirations to adhere to social norms, achieve goals, or emulate peers who are viewed as more successful (110). Depending on what those goals are or what constitutes success in a given society, this can lead to environmentally harmful behaviors. For example, if the possession of material goods is highly valued (in other words, one's well-being is partially influenced by relative consumption), the less successful will try to follow the consumption patterns of the successful. This behavior reinforces the value placed on material goods, driving the successful toward ever higher consumption patterns in order to distinguish themselves from the less successful (101)—thus exacerbating the cycle of environmentally damaging overconsumption. Similarly, aspirations to achieve certain levels of socioeconomic status and an adoption of western diet norms are driving an increase in meat consumption (especially beef) in emerging economies such as China (111), which has significant negative impacts on the biosphere (112, 113; see also the sidebar, Meat Consumption and Deforestation).

MEAT CONSUMPTION AND DEFORESTATION

Inequality in society highlights the differences in lifestyles between the rich and the poor. In many parts of the world, aspirations to achieve higher standards of living and socioeconomic status are leading to an increase in meat consumption (especially beef) among the middle class (see Section 3.2.2). The impacts of global meat consumption on land use change and habitat loss can be significant, especially in the Amazon region (158). In the Brazilian Amazon, for example, cattle ranching has been linked to 65% of deforestation (159). Similar trends are becoming apparent in the Madre de Dios region of Peru. Here, global demand for beef is driving the conversion of thousands of hectares of forest into pastures—a process that is assisted by extensive road development (159). Moreover, the building of roads and development of infrastructure are facilitating an expansion of gold mining in the region, further exacerbating forest losses (160). This environmental degradation is not only concerning because it contributes to global greenhouse gas emissions and climate change. It is also having a disproportionately negative impact on the well-being of local indigenous communities by significantly impacting water quality and health (161, 162). In addition, research suggests that economic inequality (based on household consumption) is higher in Peruvian mining districts than in comparable nonmining areas (163). This example illustrates how aspirations—that are driven in large part by inequalities between societies at the global scale—can impact individual choices (i.e., the demand for meat) in one part of the world, and result in devastating changes in the biosphere at very local scales in completely different parts of the world. These changes in the biosphere can then exacerbate socioeconomic inequalities in affected communities, potentially leading to further marginalization of already vulnerable indigenous populations.

3.2.3. Cooperation in sustaining the local commons. Cooperation and collective action are one of the ways in which natural resources are sustained in cases where these resources are shared and used by groups of people. If individual and collective interests do not align, if trust is low, or if enforcement is not feasible or desirable, then individuals (or groups of people) might free-ride on others' attempts to sustainably manage and use a shared resource. As a result, individual actions can lead to the overexploitation and depletion of natural resources. Cooperation is key to prevent such a scenario. A large body of work therefore aims to understand what factors promote or diminish cooperation in groups, and a considerable part of that research is devoted to the implications of inequality within those groups (114)—both in the contexts of local common pool resources and local public goods (see 115 for a classification of goods). However, few cooperation or participation studies investigate a direct link between inequality in groups and proenvironmental behavior (see, e.g., 116 for an exception). Instead, the focus is on understanding the link between inequality and cooperation, with the implicit assumption that cooperation leads to sustainable resource use or improved environmental quality.

For instance, Olson (117) postulated the theory that groups characterized by relatively high inequality in the extent of interest in a common good are most likely to cooperate and sustain the good, given that those with high stakes in the process have a vested interest in its success. Several other theoretical studies in the following decades supported this theory (e.g., 118). Others argue that inequality should have an adverse effect on cooperation (e.g., 119). Theoretical work also suggests that the relationship between inequality and cooperation might be U-shaped (a positive quadratic); i.e., a common resource will be sustained at either low or high levels of inequality (120).

On the other hand, empirical evidence from a sample of rural cooperatives in Paraguay supports the theory of a U-shaped relationship, but in reverse: Moderate levels of inequality were found to be the most favorable condition for cooperation, representing a negative quadratic relationship (121). Other empirical studies suggest that economic inequality and horizontal inequalities based on ethnicity or class hinder cooperation and collective action. This may be because of reduced

reciprocity and trust, capacity to build consensus, or internalization of social norms—all of which are crucial factors for initiating and maintaining cooperation (122–125). This empirical work largely indicates that inequality within groups has a negative effect on cooperation around shared resources. In addition, experimental studies highlight that it matters whether or not this inequality in the group is observable for everyone, i.e., whether the level of (artificially created) inequality is public information (126). Economic inequality might only have a significant effect if group members know how well off everyone is within the group. This public information has been found to reduce voluntary contributions of all group members to sustain a local shared good—no matter their relative position (126).

Furthermore, it matters whether participants can engage in face-to-face communication during these cooperation experiments (127). It has been shown that communication can drastically improve the outcomes of cooperation and reduce the negative effects of inequality (109). However, experimental evidence further suggests that the improvement in cooperative behavior may also be influenced by the real-life wealth distribution in the group: Poorer group members tend to be less willing to cooperate (128).

Finally, effective cooperation depends on knowledge sharing. Often, technical-scientific knowledge is available primarily to those with training to understand it, which can lead to "elite capture" of decision-making processes (129). Using ultimatum field experiments in which participants received unequal levels of information when bargaining over the allocation of water, Pfaff et al. (130) demonstrated that fully informed participants accrued the vast majority (80%) of scarce resources, with less informed actors obtaining far fewer resources. Thus, even when everyone has an equal "seat at the table," information asymmetries make bargaining outcomes more unequal. Inequality in information and knowledge may therefore bias the outcomes of environmental decision making, and can lead to decisions that degrade the environment (131), or that unfairly harm marginalized groups.

3.2.4. Market concentration. In resource management systems with a high level of market concentration, a small number of powerful firms or actors dominate the total production of a certain resource. High market concentration thus implies a high level of inequality between firms or actors that use and manage the resource. Whether such inequality results in actions that are beneficial or detrimental to the biosphere is highly context-dependent.

In fisheries, for example, high market concentration may result in a situation in which a small fraction of the fleet is able to claim a large fraction of the total catch—a development that has been observed at national (132–134) and global scales (135). This inequality means that a small number of actors has disproportionately high stakes and influence in sustaining the shared resource. Theoretical predictions suggest that these powerful actors may decrease their harvest effort to enhance the stock and, hence, profitability, especially if other actors are less able to take advantage of the increased stock levels due to technological, financial, or institutional limits to access (136, 137). In this case, the impact on the biosphere is positive.

Dominance of a few actors within a specific resource management system may have several additional consequences. As the status of the natural resource improves (e.g., healthier fish stocks), higher profits allow for further accumulation of capital, as well as investment in improving extraction or harvest technologies. When such investments allow firms to exploit cost advantages due to an increased scale of production, they further reinforce the trend of market concentration (138). This concentration of wealth and influence also leads to higher lobbying power, which can be used to sway policy decisions, thus strengthening the feedbacks between market concentration, capital accumulation, and management of the resource. As an example, the implementation of certification schemes such as the Marine Stewardship Council can promote the sustainable harvest of marine resources through the implementation of rules and monitoring (139), but it can

also exclude marginal actors given the cost of compliance with the certification regime (140–142). Hence, certification can directly influence resources and promote sustainability, but it can also reinforce market concentration and increase social and economic inequalities.

In addition, market concentration can increase the spatiotemporal scale at which the largest actors operate. Although this may reduce environmental externalities in cases where the scale of the large actors matches the scale of the benefits accrued from sustainable resource management practices (such as long-term planning horizons in fisheries), this is not generally true for all circumstances. In resource use systems where the benefits of sustainable management mainly accrue globally, or to downstream actors, increased market concentration is less likely to lead to proenvironmental behavior by powerful actors (143). For instance, in the case of agricultural systems, benefits from environmentally friendly resource management practices (such as limiting irrigation, fertilizers, and pesticides) typically accrue downstream of those who invest in these measures upstream. Moreover, the downstream benefits apply across multiple sectors, benefiting diverse users of lakes, rivers, and coastal regions. This provides little incentive for proenvironmental behavior to the upstream farmers, even as market concentration increases, unless some kind of compensation scheme can be implemented (144).

However, the motivations and actions of dominant actors can also change rapidly. The role that DuPont played in the establishment of the Montreal Protocol in 1987 is an example. In the 1970s, DuPont accounted for approximately 25% of the global production capacity of chlorofluorocarbons (CFCs), compounds that contribute significantly to the depletion of ozone in the upper atmosphere (145, 146). For years, the company asserted that scientific evidence for the link between CFCs and ozone depletion was insufficient, and strongly opposed regulation. In 1986, virtually overnight, it changed its position and announced the desire to phase out CFC production and support international regulation. Although partially motivated by environmental concerns, this change in position has also been linked to the company's belief that CFC regulation would create a new, more profitable market for chemical substitutes, in which it could obtain a significant competitive advantage and substantial market share (145, 147). Once again, this example highlights that powerful actors can impact the biosphere in positive or negative ways, depending on the situation.

4. DISCUSSION: INSIGHTS ACROSS FIELDS AND REMAINING RESEARCH GAPS

In this review, we highlight examples from the literature in which changes in the biosphere impact inequality and those in which inequality affects the biosphere. We identify six different pathways for these interactions within the framework of social-ecological systems, ranging from the direct impacts of environmental shocks on inequality in society to the more indirect effect of perceived inequalities on proenvironmental behavior. We show that the far-reaching impacts of global environmental change are already exacerbating inequalities at local and regional scales (Section 3.1) and that inequalities between people, corporate actors, and nations can significantly affect the way in which natural resources are managed and used (Section 3.2).

Importantly, the social-ecological systems perspective allows us to identify examples where these interactions form feedback loops, such as the case of Hurricane Katrina and its lasting exacerbation of inequalities in New Orleans (see sidebar, Hurricane Katrina). Similarly, Hurricane Mitch disproportionately affected poor communities in Honduras, but in this case the increase in inequality in the wake of the event resulted in societal changes that led to a decrease in inequality over time (71). In these two cases, different social and ecological outcomes following a similar environmental shock illustrate the context-dependency of interactions between inequality and the biosphere.

However, we found very few studies where these kinds of feedback loops are explored in any detail, which is a symptom of the one-directional way in which research on inequality and the environment has so far been approached (20, 21). Instead, examples of feedbacks between inequality and the biosphere must often be pieced together, drawing on multiple studies from different disciplines (see sidebar, Meat Consumption and Deforestation). Nevertheless, these cases illustrate that inequality is not just a socioeconomic issue that divides communities and nations; it is also a significant driving force behind social-ecological dynamics and feedbacks within the biosphere. Going forward, a social-ecological systems perspective could help identify and map the most relevant feedbacks involved in the interactions between inequality and the biosphere, thus highlighting potential points of intervention and scenarios of change (148).

The examples gathered from the literature also emphasize that interactions occur across multiple scales. Hurricanes such as Katrina and Mitch were large-scale, regional, environmental shocks that had impacts on inequality at the household level within a community, which in turn affected local ecosystems (71, 149). The sidebar titled Meat Consumption and Deforestation describes how global demand for meat drives regional deforestation in the Amazon, which results in health impacts and rising inequalities in local communities of Peru. Similarly, global environmental change affects the distribution and availability of marine resources, which can have significant impacts on economic and gender inequalities in small coastal communities in developing countries (88, 150). Another example of cross-scale interactions involving inequality and the biosphere is the 2014–2015 Ebola epidemic. The factors that contributed to the outbreak of the disease in a remote, poor, and sparsely populated region of Guinea, West Africa, are numerous and not yet fully understood, although some evidence suggests that forest degradation and loss, caused—in part—by foreign mining and timber companies, brought disease-carrying wildlife into closer contact with the people living in the area, thus sparking the outbreak (151, 152). Other evidence points toward unsustainable fishing practices, partially fueled by foreign fishing fleets, forcing communities in West Africa to shift their diets to include more bushmeat, thereby increasing exposure to zoonotic diseases such as Ebola (153). In the context of these multiscale interactions, the disease spread from a small local village across many countries, causing the loss of more than 11,000 lives, major socioeconomic upheaval, as well as a significant increase of economic inequality in the entire West African region (73).

These examples illustrate that scale is a crucial factor to consider in interactions between inequality and the biosphere. This also extends to the way in which impacts are measured and assessed. For example, a series of extreme storms might increase income inequality in coastal communities (67) but have little impact on the overall income distribution of a country, at least over longer time periods (70). Considering only the national scale, and using indicators such as a country's Gini coefficient, may therefore mask significant impacts at local levels. Furthermore, a social-ecological systems approach recognizes that there may be thresholds in some of these interactions. As shown in the cooperation literature (Section 3.2.3), the relationships between cooperation and inequality may be nonlinear, where certain thresholds in inequality result in different behavioral responses, and therefore potentially different environmental outcomes (120, 121, 154). The same may be true for thresholds in the frequency and severity of extreme events, for example, and whether these exacerbate or dampen inequality: Relatively small disasters may increase economic inequalities in a community, whereas large events may level differences between households, at least over short time periods—and depending on the indicators used to measure inequality (e.g., income versus wealth or expenditure) (155). As we explore and develop solutions to the world's most pressing challenges, we need to be aware of the (potentially nonlinear) interactions between inequality and the biosphere across multiple scales and apply interdisciplinary approaches in order to identify and measure them.

Another key research gap lies in understanding the many different dimensions of inequality, and how these relate to the biosphere. In this review, we show that gradual changes in the distribution of marine resources have the potential to exacerbate gender inequality in some parts of the world (Section 3.1.2), and that political inequality can have far-reaching consequences in global climate change negotiations and decision making (Section 3.2.1). However, most of the cases that we highlight from the literature focus on economic inequality. The salience of the large differences in per capita economic performance between countries, as well as the increasing differences within countries, combined with relatively greater availability of data on incomes, asset ownership, and other wealth indicators, has led to a focus on the economic aspects of inequality. Economic inequality, mostly measured by income, has therefore been the dominant dimension of inequality studied (15). In contrast to economic measures, data that can be used to understand social, cultural, political, or other kinds of inequality—particularly over longer time periods, and at different spatial scales—is notably lacking. The result is that we currently understand inequality and its interactions with the biosphere in a limited and one-dimensional way, when these relationships are actually multidimensional and complex. Here, inequality research might benefit from emulating recent developments in the well-being literature to measure and assess multidimensional human well-being (16, 156, 157).

In conclusion, the pathways outlined here are a first step toward a more systemic, cross-scale, and multidimensional understanding of interactions between inequality and the biosphere. Future research will need to explore these and other pathways further, as well as analyze the many context-specific differences in outcomes for both inequality and the environment. Increasing the discussion of inequality within environmental research, elevating it to equal importance as average economic outcomes, and going beyond standard economic assessment tools would begin to address the many knowledge gaps identified. Similarly, research on inequality should explicitly consider environmental drivers and feedbacks along with more established economic mechanisms. Moreover, it is crucial that we identify institutions that can deal with the scale of the challenge of understanding and addressing inequality in the context of a rapidly changing and increasingly connected planet (42). New approaches that recognize the inherent connectedness of inequality and the biosphere, the multidimensional nature of inequality, as well as the potential for cross-scale feedbacks and thresholds are needed to confront the world's dual challenge of rising inequalities and accelerating global environmental change.

SUMMARY POINTS

1. Inequality is one of the twenty-first century's most pressing challenges, and it is mainly considered to be a socioeconomic issue.
2. However, inequality and the biosphere interact in many important ways, given the intertwined nature of social-ecological systems and the far-reaching impacts of global environmental change.
3. Using a social-ecological systems approach, we identify different pathways of interaction: (*a*) The biosphere impacts inequality in society through shocks or extreme events, as well as through gradual environmental change. (*b*) Inequality has an effect on the biosphere through human actions, which can be shaped by an individual's perceptions and sense of fairness, as well as their aspirations. Beyond the individual, inequality can influence the actions of groups or institutions by shaping cooperation in sustaining the local commons, or through market concentration.

4. Most of the research considers only one-directional effects of inequality on the biosphere, or vice versa. Few studies explore feedbacks and cross-scale interactions between inequality and the biosphere.
5. Although inequality is a multidimensional concept, the majority of studies focus on economic inequality.
6. We show that interactions and feedbacks between inequality and the biosphere occur across the globe, spanning multiple spatial, temporal, and organizational scales.
7. To understand the relationships between inequality and the biosphere better, we need multidimensional measures of inequality, and approaches that recognize the complexity of potential connections and feedbacks across scales.

FUTURE ISSUES

1. Further research is needed to explore the pathways of interaction between inequality and the biosphere that were identified in this review, and analyze the context-specific differences in socioeconomic and environmental outcomes. In addition, other pathways remain to be identified and described.
2. Particular effort should be directed towards understanding cross-scale interactions and feedbacks, as well as threshold behavior in variables of environmental change and inequality.
3. Finally, there is a need to move from a narrow understanding of inequality as an economic concept toward a recognition of its multidimensionality. This requires the use of more diverse measures of inequality beyond traditional indicators of wealth and income inequality.

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