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Equity and the Conservation of Global Ecosystem Services

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Abstract: This article provides a first rough sketch of how to conceptualize countries' present and historical contributions to the loss of global ecosystem services, i.e., ecosystem services of which the delivery is global and omnidirectional, and discusses the implications of questions concerning the international distribution of responsibilities. On the basis of limited empirical data about past and present land conversion, some first calculations suggest that keeping converted land in a converted state, thus preventing ecosystems recovery, may contribute more to current loss of global ecosystem services than new conversion of ecosystems. Moreover, many developing countries in the tropics may contribute more to the loss of global ecosystem services, in both absolute terms and per capita, than many developed countries in temperate zones. This would make finding an equitable arrangement for international allocation of responsibilities for biological conservation far more complex than for mitigating greenhouse gas emissions, raising new and challenging questions for normative theorists.

Keywords: ecosystem services; common but differentiated responsibilities; equity; indicators; economic instruments; global commons

1. Introduction

The earth's ecosystems provide many services to humanity. The Millennium Ecosystem Assessment distinguishes four types of services: provisioning services such as food, water, timber and fibre; regulating services affecting climate, floods, disease, wastes and water quality; supporting services such as soil formation, photosynthesis and nutrient cycling; and cultural services providing recreational, aesthetic and spiritual benefits [1]. In terms of delivery, each of these services has different spatial characteristics [2–5]. Provisioning services are generally provided in situ, while supporting services such as pollination are provided regionally. Some ecosystem services are even provided globally and omnidirectional, i.e., the benefits are reaped independent from the proximity to the location of the ecosystem. Examples of such global ecosystem services are climate regulation, through the uptake of CO_2 and evaporative cooling performed by vegetation [6], the maintenance of biodiversity, given its importance for underpinning ecosystem functioning [7], the provision of fundamental scientific knowledge, information for the development of crops and new medicines, education information, and cultural or artistic inspiration [8]. Last but not least, people derive satisfaction from the mere knowledge that nature exists [9], for example because natural ecosystems provide a sense of continuity and understanding of our place in the universe [10,11].

Global ecosystem services, i.e., services that are provided globally and omnidirectional, are generally public goods. Public goods are non-excludable, i.e., they are provided to all or to no one at all, and non-rival, i.e., reaping benefits by one person does not prevent others from doing the

same. As public goods, the conservation of these ecosystem services offers a global social dilemma. Ecosystems after all do not only provide non-excludable services, but also services that can be privately appropriated and consumed or sold on markets, such as food, water, timber and fibre. Converting natural ecosystems to agricultural land, for example, can increase the provision of such excludable services. Although modest conversion from mires and primary forests, for example, can enhance biodiversity and increase regulating services such as groundwater recharge, more radical conversion is often at the expense of the provision of global ecosystem services. Since landowners have little private interest in conserving global ecosystem services, decisions regarding land use have often been to the detriment of ecosystem protection [4]. Over the past three centuries, roughly 12 million km^2 of forests and woodlands have been cleared, while grasslands and pastures have diminished by about 5.6 million km^2 [12,13]. Over the past 50 years, humans have changed ecosystems more rapidly and extensively than in any comparable period in human history [1]. Globally, rates of deforestation are declining but are still alarmingly high [14] (p. 51).

Collective action problems on a local and small scale, where there is direct interaction between the participants, may be solved by mutual consultation [15]. The solution of global social dilemmas requires "mutual coercion, mutually agreed upon", however, as Garret Hardin emphasized in *The Tragedy of the Commons* [16]. Just as in the case of the protection of a stable global climate—the other prime example of a global public good—the protection of global ecosystem services requires the formulation of global targets, translated to quantitative national responsibilities. At the 1992 Earth Summit in Rio de Janeiro, the Convention on Biological Diversity (CBD) was therefore initiated simultaneously with the Framework Convention on Climate Change (UNFCCC). The UNFCCC was followed by the Kyoto Protocol in 1997 that allocated national quantitative obligations to reduce greenhouse gas emissions to the industrialized countries. In 2015, at the 21st Conference of the Parties to the UNFCCC, both industrialized and developing countries have forwarded Intended Nationally Determined Contributions. As yet, however, no national quantitative obligations have been allocated for the conservation of ecosystems, nor are they being negotiated. In 2010, signatories to the CBD adopted a ten-year strategic plan, including the so-called Aichi targets, which mainly comprises aspirations for achievement at the global level such as Target 5: "By 2020, the rate of loss of all natural habitats, including forests, is at least halved and where feasible brought close to zero, and degradation and fragmentation is significantly reduced." Parties are invited to set their own targets, taking into account national needs and priorities.

There are various factors complicating biological conservation relative to the mitigation of climate change [17,18], but two factors are particularly problematic for determining the international allocation of responsibilities in the case of the CBD. The first is technical: international allocation of measurable obligations to prevent ecosystem services losses requires indicators with which to express such obligations. In the case of climate policy, the indicator defining what the obligation entails is simply the emission of carbon dioxide, expressed in kilograms or tonnes. Emissions of other greenhouse gases, such as methane, can be expressed in carbon dioxide equivalents by means of so-called global warming potentials. There are no such indicators for expressing the loss of global ecosystem services, which could then be translated into ecosystem service loss reduction goals. Through CBD governance and advisory bodies, the global biodiversity community has identified a suite of 17 headline indicators for assessing and communicating progress at a global level, such as 'Trends in extent, condition and vulnerability of ecosystems, biomes and habitats' [19]. None of these indicators are as yet sufficiently reliable for use in allocating national targets, however. After all, a reliable indicator should have global coverage and be spatially-explicit; it should be sufficiently accurate and be capable of being validated and verified by independent organisations. This is because, in the case of the provision of a global public good, the efforts required from each nation are determined by the efforts taken by other nations. Therefore, the willingness to cooperate depends upon being able to accurately monitor each other's contributions.

The second factor is political. According to Principle 7 of the Rio Declaration on Environment and Development, the responsibilities of States to conserve, protect and restore the health and integrity of the Earth's ecosystem are "common but differentiated". They depend, first, on the pressures exerted (both currently and historically) by States on the global environment and, second, on States' financial and technological capacities for reducing such pressures. While a society's contribution to climate change correlates strongly with the technologies and financial resources it commands, this is not obviously so in the case of loss of global ecosystem services. Developing countries not only harbor some of the world's most important sources of ecosystem services [20] and biodiversity hotspots [21], such as the Amazon rainforest, but are also putting increasing pressures on them. This distinguishes the challenge posed by ecosystem service loss from the challenge of climate mitigation and complicates the international allocation of responsibilities. Also, at a theoretical level, there is a remarkable scarcity of normative reasoning about the international allocation of conservation responsibilities, particularly in comparison to the immense body of literature relating to climate justice (see e.g., [22] and references therein).

The purpose of the present paper is therefore to provide a first rough sketch of how to conceptualize countries' historical and present contribution to the loss of global ecosystem services, and discuss some preliminary implications for normative reasoning about the international distribution of responsibilities to prevent ecosystem service loss. While this paper advances a way to conceptualize the loss of ecosystem services, it also reveals limitations in the normative principles used to reason able the allocation of responsibility for climate mitigation. Note that the focus on the issue of ecosystem services by no means implies an anthropocentric worldview [9]. There are good reasons to protect ecosystems for the sake of the non-human organisms that comprise them. Although including the benefits of conservation to non-human nature itself will imply more stringent conservation targets and may imply a different spatial focus of priorities than if we only focus on human benefits, this will not alter the main analysis of this paper, which is structured as follows. Section 2 conceptualizes present and historical contributions to the loss of global ecosystem services. Section 3 offers some interim empirical observations about these contributions. Section 4 considers the implications for a fair international distribution of responsibilities, while Section 5 presents conclusions.

2. Conceptualization of Present and Historical Contributions

When determining countries' contributions to the loss of global ecosystem services historical and present contributions should be distinguished. First, Article 11 of the CBD calls for (economic) incentive measures for the conservation and sustainable use of biological diversity. Since historical contributions lie in the past and thus cannot be changed, it only makes sense to direct incentive measures to present contributions. Second, the extent to which people can be held responsible for present and historical contributions is different: in contrast to present contributions, historical contributions may have been performed in ignorance or by ancestors, for example, which may diminish their relevance for the present allocation of responsibilities (see for this discussion in the case of climate policy, e.g., [22]).

According to the Millennium Ecosystem Assessment, the most important direct drivers of change in ecosystems are land conversion leading to habitat change, climate change, invasive species, overexploitation and pollution [1,14]. Mere knowledge of the strength of these drivers, however, is insufficient to assess countries' contribution to the loss of global ecosystem services. First, the quality and quantity of global ecosystem services that an area provides is location-specific, meaning that the impact of the aforementioned drivers is highly variable across geographical space. Converting a hectare of the Congo rainforest will result in a higher loss of global ecosystem services than converting a hectare of the Sahara desert. Therefore, a country's contribution to the loss of global ecosystem services depends not only on the intensity of the drivers as such (e.g., converting a hectare of land), but also on the quality of the ecosystems affected. Second, the loss of global ecosystem services cannot be observed directly: a country's contribution to this loss is established against a counterfactual baseline of the global ecosystem services that would have been provided had the country not changed the

ecosystems. Third, the consequences of human interventions extend into the future. Left undisturbed, ecosystems could provide services virtually indefinitely. Therefore, human interventions imply the loss of global ecosystem services for potentially very long time periods although ecosystems also have the capacity to recover, if damage does not cross a threshold of irrecoverability.

For the purpose determining how to allocate responsibility for preventing ecosystem service losses, we must first be able to quantify the ecosystem service losses associated with the drivers of ecosystem change. Toward this end, we now turn to conceptualizing present and historic contributions to ecosystem service losses. Note that the approach followed builds on the natural resource damage assessment (NRDA), developed in response to regulations promulgated in 1986 by the US Department of the Interior concerning liability for releases of hazardous substances and oil [23–26]. Furthermore, note that 'global ecosystem services' refers to the ecosystem services that are provided globally and omnidirectional, i.e., that the benefits are reaped independent from the proximity to the location of the ecosystem; it does not refer to the sum of all ecosystems services that are produced globally.

2.1. Present Contribution to the Loss of Global Ecosystem Services Due to Land Conversion

Figure 1 illustrates the loss of global ecosystem services (expressed in euros per year) that can be attributed to the conversion of the natural vegetation of a certain area to agricultural land in the year conversion occurs (t_p). In this example, it is assumed that in subsequent years, agriculture is continued and the land thus kept in a converted state (the solid line after t_p). Moreover, radical conversion is assumed where enhancing provisioning services such as food is clearly at the expense of global ecosystem services. The *x*-axis denotes time (t), while the *y*-axis denotes the global ecosystem services provided by the specific area (in €/year). Although conversion increases the provision of other services such as food, the figure only shows the changes in global ecosystem services. The reason is that only global ecosystem services require (global) regulation.

The shaded area denotes the present contribution in year t_p, i.e., all global ecosystem services that are lost in year t_p and later years attributable to the act of land conversion in year t_p. The top of the shaded area is demarcated by the global ecosystem services that would be provided by the area if, instead of land conversion at t_p, man's influence were completely and permanently removed, i.e., if the vegetation were to develop towards future natural vegetation [27–30]. Of course, the 'future natural vegetation' is a counterfactual baseline which by definition cannot be observed in reality and is therefore uncertain and speculative.

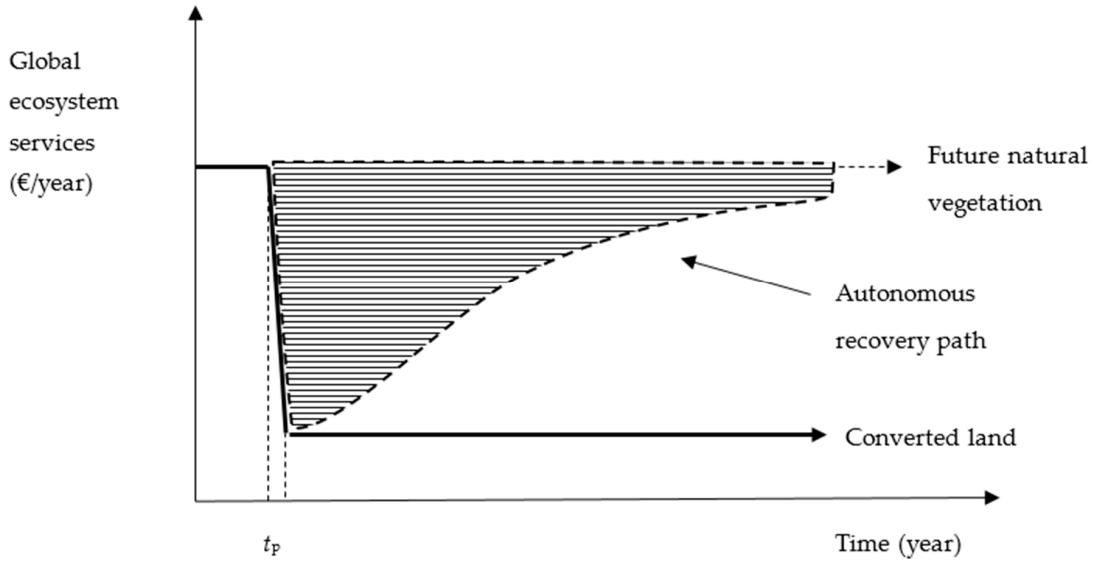

Figure 1. Loss of present and future global ecosystem services (shaded area) due to land conversion in year t_p.

The underside of the shaded area is demarcated by nature's capacity to recover autonomously once human interventions or activities have been discontinued. The ecological functions and other characteristics of the area prevailing prior to degradation can often recover [31,32]. The temporal trajectory and rate of recovery will depend on numerous variables, such as ecosystem type, severity of degradation, environmental constraints and restoration activities [33–36]. Ecosystem recovery will typically take several decades or centuries [37]. If human pressures are too intense, species have become extinct and tipping points reached, ecosystems may irreversibly shift to states with less capacity to generate ecosystem services [38]. Particularly if agricultural regions are distant from the sources of the seeds and forests that would drive such regeneration, if habitats are fragmented or if irreversible changes have occurred, the original ecosystems will not fully recover [32]. In the case of such irreversible losses, autonomous recovery will result in global ecosystem services that are (far) inferior to those existing prior to human intervention. Not only will global ecosystem services be lost, also the long-term capacity to provide provisioning services such as food might become depleted [39].

Active restoration activities may accelerate the recovery process. Nevertheless, autonomous recovery determines the present contribution because any acceleration of recovery due to ecological restoration depends on future decisions, perhaps by other actors, and therefore does not determine present causal responsibility. The difference between autonomous recovery and active ecological restoration will be small in areas where the soil is still relatively unaffected, but large in areas where land degradation has been ongoing for a considerable period of time [40]. Any gains in global ecosystem services relative to the path of autonomous recovery due to ecological restoration are attributable to the actor responsible for restoration in the year that restoration takes place.

2.2. Present Contribution to the Loss of Global Ecosystem Services Due to Keeping Land Converted

If after an initial act of land conversion in the previous year (t_{p-1}), human activities are terminated and ecosystems are given the opportunity to recover, the present contribution to the loss of global ecosystem services in year t_p is defined as zero. The fact that in year t_p, the global ecosystem services are still below their natural level is after all attributed to the act in year t_{p-1} (see Figure 1). Moreover, one cannot take credit for nature's ability to recover. Therefore, the human decision to give ecosystems the opportunity to recover can neither be counted as a contribution to global ecosystem service gains.

If in year t_p cultivation is continued, however, there is indeed a contribution to global ecosystem service losses. Since ecosystems have a capacity for (partial) recovery, one does not only contribute to global ecosystem service losses by changes in land use but also by preventing recovery. Figure 2 therefore depicts the contribution to global ecosystem service losses resulting from maintaining land in a converted state in year t_p, i.e., the loss due to global ecosystem services being prevented from recovering. The shaded area is demarcated by the two paths of autonomous recovery starting at the beginning and the end of year t_p respectively, i.e., when cultivation is terminated at either t_p or t_{p+1}.

Farmers may persist in centuries-old farming practices, for example. One year's continuation of a converted state implies one year's loss of global ecosystem services, although that loss will be spread out over time. However, the present contribution does not include the maintenance of a reduced state if the land has undergone desertification as a result of overexploitation centuries ago and if terminating present activities would not result in complete ecological recovery. It should be noted in this context that maintaining land in a converted state can itself undermine the capacity of an ecosystem to recover. In that case, the path of autonomous recovery starting at t_{p+1} in Figure 2 will be less steep than the path of autonomous recovery starting at t_p.

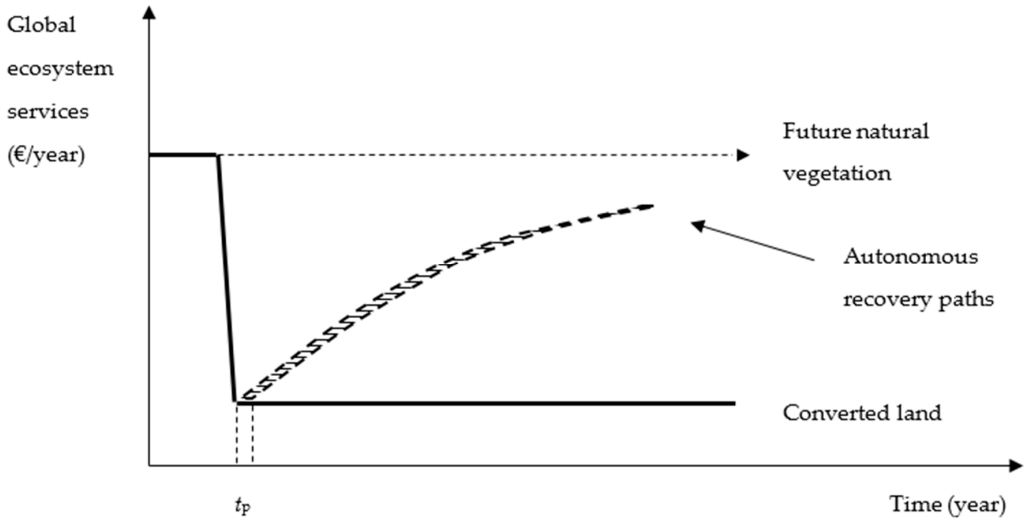

Figure 2. Loss of present and future global ecosystem services (shaded area) due to keeping land converted in year t_p.

2.3. Historical Contribution to Global Ecosystem Service Losses

While Figures 1 and 2 show contributions to global ecosystem service losses due to acts and decisions in the present, Figure 3 shows the historical contribution in the present (year t_p) due to human activities in the past, i.e., before year t_p. This historical contribution to global ecosystem service losses due to past activities is the analog of the historical or accumulative build-up of greenhouse gases in the atmosphere. Just as it is physically impossible to remove from one day to the next all the atmospheric carbon emitted by humans in the past, it is physically impossible to 'repair' ecosystems at short notice. Recovery—if possible at all—takes time. We are therefore left with fewer global ecosystem services than would be available had there been no degradation in the past. It should be noted that this definition of historical losses takes into account only global ecosystem services that will be lost in the future due to past human activities and not global ecosystem services that have already been lost in the past. Therefore, the shaded area in Figure 3 starts at the present, t_p.

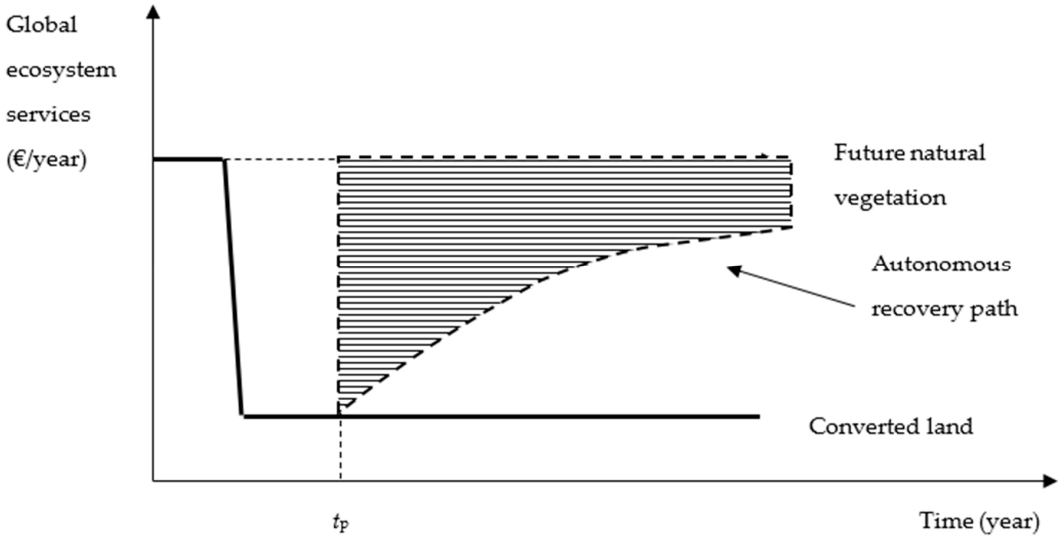

Figure 3. Historical loss: present and future loss of global ecosystem services (shaded area) after year t_p due to human interventions before year t_p.

The top of the shaded area is demarcated by the services that would have been provided in the absence of human intervention, i.e., the services provided by the present natural vegetation of the particular area. Present natural vegetation is the vegetation that would be present today had the area not been affected by humans, yet acknowledging earlier (non-human-influenced) climatic changes, natural species migration and other natural events since prehistoric times [27–29]. 'Present naturalness' differs from 'potential naturalness', which Peterken defines as the state that would develop if human influence were completely removed and the resulting ecological succession were accomplished in a single instant (see also [41,42]). In other words, potential naturalness is what present naturalness would eventually become. Of course, the 'present natural vegetation' is a hypothetical construct which cannot be observed in reality. Remnants of actual real vegetation with natural or near-natural characteristics ('past naturalness') may be taken as a reference here, even though such remnants do not necessarily represent the present natural vegetation [30]. Also note that even without human influence, the earth's ecosystems are dynamic, and that therefore the global ecosystem services provided by natural vegetation do not necessarily remain constant through time.

3. Some Interim Empirical Observations

Although it is not yet possible to provide reliable quantitative data concerning the present and historical contribution of the various countries to the loss of global ecosystem services, a highly simplified proxy can be used to offer some quantitative examples to illustrate the concepts proposed in the paper. This proxy proceeds from the assumption that the provision of global non-excludable ecosystem services is proportional to the carbon stock in living biomass, although the correlation is of course far from one-to-one [43–45]. Moreover, this provision of services is of course proportional to time. In plain terms, a 'green' area will generally provide more global ecosystem services than a desert, and the longer it is green the better. The unit of a country's contribution to the loss of global ecosystem services is therefore the loss of a year that a tonne of carbon would otherwise have existed, i.e., a lost t C·year. To determine the lost ecosystem services, a lost t C·year should be monetarily valued, but since we are only comparing countries' contributions, this valuation step is omitted. So the shaded areas in Figures 1–3 are not expressed in €, but in t C·year.

The Global Forest Resources Assessment 2015 of the Food and Agriculture Organization (FAO) provides figures on the carbon stock in living forest biomass for different countries for the year 2015, and the annual change between 2010 and 2015 [46]. The carbon stock of the potential natural vegetation is estimated on the basis of [13,47]. In this simplified approach, it is assumed, moreover, that once human intervention is terminated, the provision of global ecosystem services recovers autonomously and fully in 50 years and linearly in time (i.e., the shaded area in Figure 1 is a triangle). In that case, the contribution due to initial conversion is 25 times larger than the contribution due to keeping the same area of land converted in the subsequent year. Based upon the aforementioned data and assumptions, historical and present contribution to the loss of global ecosystem services have been given in Table 1 for two tropical (developing) countries and two developed countries.

Table 1. Historical and present contribution to the loss of global ecosystem services in 2015 (in Gt C·year).

Country	Historical Contribution	Present Contribution Due to New Conversion	Present Contribution Due to Continuation of a Converted State
Brazil	−1300	−2.0	−54
Indonesia	−560	−6.8	−23
Germany	−30	0	−1.1
United States	−500	0	−21

On the basis of the previous conceptual analysis and preliminary calculations, a number of qualitative observations can be made that are relevant to debates about the appropriate distribution of

responsibilities involved in protecting global public goods, such as ecosystem services. Please note, however, that these observations only refer to causal contributions and therefore say little about moral responsibility without taking countries' capacities and other circumstances into account as well. This is discussed in Section 4.

3.1. On a National or Global Scale Keeping Land Cultivated May Contribute More to the Loss of Global Ecosystem Services Than New Land Conversion

In Section 2.2, it was explained that since ecosystems have a capacity to recover once human intervention is terminated, preventing this recovery counts as a contribution to the loss of global ecosystem services. As Figures 1 and 2 show, if a certain area of land is newly converted, this contributes much more to the loss of global ecosystem services than if the same area is kept converted in a subsequent year. Nevertheless, on a national or global scale, keeping land cultivated may well contribute more to the loss of global ecosystem services than new land conversion. The reason is that the present area already under cultivation is orders of magnitude larger than the area brought into cultivation each year [48] (p. 23): while from 2010 to 2015, 0.088 million km^2 of natural forest were converted per year [46] (p. 18), over the past three centuries roughly 12 million km^2 of forests and woodlands have been cleared, while grasslands and pastures have diminished by about 5.6 million km^2 [11,12]. This is also reflected by the calculations presented in Table 1: on a national scale, the present contribution due to keeping already cultivated land cultivated is much larger than the present contribution due to new land conversion.

Therefore, any international distribution of responsibilities and any efficient incentive scheme must address this substantial present contribution due to keeping land that has been converted in the past in a cultivated state. This contribution is not well captured, however, by the five principal drivers cited in the Millennium Ecosystem Assessment: land conversion leading to habitat change, climate change, invasive species, overexploitation and pollution [1] (p. 47). 'Land conversion', after all, only includes new conversion (Figure 1 in Section 2.1), i.e., a change in the situation, and not the continuation of an already converted state (Figure 2 in Section 2.2). As has been explained in Section 2.2, however, the continuation of an already converted state also should be counted as a contribution to the loss of global ecosystem services. It is therefore recommended to extend these five drivers with continued land use.

3.2. All Countries Contribute to the Loss of Global Ecosystem Services

Since keeping land converted contributes to the loss of global ecosystem services (Section 2.2), virtually all countries contribute even if there is no net change in the ecosystems and no new land is brought under cultivation on their territory. This holds true, for example, for many European countries where forests were converted to farmland and human settlements many centuries ago. This observation is not changed by the fact that, in many developed countries, ecosystems are even recovering: since autonomous recovery is defined as a zero present contribution (see the start of Section 2.2), areas within a country where such autonomous recovery occurs do not offset the present contribution to service loss that is due to other areas where land is kept converted.

3.3. Not All Land Should Be Restored to Its Natural State

The fact that countries contribute to the loss of global ecosystem services by maintaining land converted by no means implies that all land should be restored to its natural state. Over and against this contribution due to maintaining land in a converted state are benefits, such as the ecosystem service of food production, which also add to human wellbeing. Whether decisions should be made to restore land to its natural state thus depends on weighing up the costs of losing the provisioning services resulting from land conversion and the benefits of regaining the (global) ecosystem services that are provided by land in its natural state. Reconverting and restoring traditionally intense farming regions, for example, would not make economic sense if such farming is relatively profitable and the

chances of ecological recovery are poor. This is no different from the case of climate change: although every emission of carbon dioxide implies pressure on the global climate, this does not mean that all emissions should be prevented. An important question, however, is how the gains and losses of ecosystem service recovery should be made comparable or prioritized. This issue is particularly complicated if one wishes to include non-human benefits in the weighing process and wider human values such as existence values. It should be noted, though, that economic valuation is not necessarily incompatible with the inclusion of such values [9].

3.4. Historically, Many Developing Countries in the Tropics May Have Contributed More to the Loss of Global Ecosystem Services Than Many Developed Countries

Many developed countries in temperate zones have cultivated a much larger percentage of their land than developing countries in the tropics such as Brazil and Indonesia [13]. The latter countries, however, may have contributed more to the loss of global ecosystem services than many developed countries. The reason is simply that tropical countries harbor some of the world's most important sources of ecosystem services [20] and biodiversity hotspots [21]. According to Myers et al. [21], as many as 44% of all species of vascular plants and 35% of all species in four vertebrate groups are confined to 25 hotspots comprising only 1.4% of the land surface of the Earth, predominantly tropical forests. In other words, what has been lost in such hotspots is generally much more valuable per hectare. That a tropical country such as Brazil may have contributed more to the loss of global ecosystem services than a developed country such as Germany is also reflected in Table 1 where t C·year has been used as a proxy for the production of global ecosystem services. Note that the largest historical losses in developing countries are of relatively recent origin. Brazil's Amazon forest, for example, remained largely intact until the 'modern' era of deforestation began with the inauguration of the Transamazon Highway in 1970 [12,49].

3.5. Tropical Developing Countries May Be Responsible for a Larger Present Contribution to the Loss of Global Ecosystem Services Than Many Developed Countries

Developing countries in the tropics such as Brazil and Indonesia may also be responsible for a larger present contribution to the loss of global ecosystem services than many developed countries, both on a national scale and per capita. According to the FAO [46], forest biomass is decreasing in Brazil while it is increasing in many European countries such as Germany. So present contribution due to new land conversion (see Section 2.1) is higher in Brazil than in Germany. It is also likely that present contribution due to keeping land converted (see Section 2.2) is much higher in Brazil than in Germany. After all, the present contribution due to keeping land converted is proportional to the historical contribution: land that has been converted in the past determines both historical contribution and present contribution due to keeping land converted. Table 1 shows that the present contribution to the loss of global ecosystem services due to keeping converted land converted is about 54 Gt C·year in Brazil against 1.1 Gt C·year in Germany. Also, per capita present contribution is much higher in Brazil than in Germany. Brazil's population is about 200 million against 80 million in Germany, meaning about 270 t C·year per capita against 14 t C·year per capita respectively.

It might be assumed that the reason why developing tropical countries have a larger present per capita contribution lies in their export of commodities such as soybeans, biofuels and timber to developed countries. The present contribution of developing tropical countries to the loss of global ecosystem services can be partly attributed to export, just as a quarter of global greenhouse gas emissions can be attributed to foreign consumption (see e.g., [50]). It should be noted, however, that conversion of natural habitats also largely serves domestic needs and development, such as domestic growth in meat consumption. This is confirmed by calculations by Erb et al. [51], who investigated pressures on ecosystems embodied in export and import, expressed in terms of the human appropriation of net primary production (HANPP). NPP is the net amount of biomass produced each year by plants, while HANPP is an aggregated indicator that reflects both the amount

of area used by humans and the intensity of land use [52]. On the basis of the results by Erb et al., Davidson [53] calculated per capita HANPP corrected for import and export. These results show that for exporting countries such as Argentina, Brazil and Paraguay, only about a fifth of per capita pressures on ecosystems, expressed by HANPP, is due to export. In other words, the lion share of the large present per capita contribution of developing countries to the loss of global ecosystem services is for domestic consumption and development.

4. Equity

These empirical observations raise new and challenging questions about the international distribution of responsibilities for environmental harms. In raising these questions, my objective is not to formulate new distributional principles, but primarily to open up points of discussion for normative theorists to engage. I will restrict myself to considering the implication of the preceding discussion for countries' present contributions to ecosystem service losses, since the difficult and contested issue of historical justice requires a full paper on its own [22,54–57].

Let us first assume that whichever concept of distributive justice one adheres to, a policy meeting standards of economic efficiency would internalize the global ecosystem service losses that are presently externalized, thereby offering incentives for landowners and countries to incorporate global ecosystem service losses in their decisions. This would be in accordance with Article 11 of the CBD that calls for (economic) incentive measures. Internalization could be achieved by imposing a global tax on contributions to the loss of global ecosystem services (see [53,58] for a discussion of why such taxes are morally preferable over subsidies such as payments for ecosystem services). Subsequently, objectives of distributive justice could be achieved through international distribution (reallocation) of the tax revenues. Such reallocation could ensure, for example, that a poor country has an economic incentive to reduce its pressure on ecosystems, but still receives more through global reallocation than it spends on internalizing costs on ecosystem services losses through taxation. Reallocation of tax revenues, however, cannot ensure that all countries profit on balance. The reason is that the global costs of ecosystem conservation include both the taxes paid for lost global ecosystem services (of course equal to the total amount that can be reallocated), and the costs made to reduce the loss of global ecosystem services, such as the opportunity costs of not converting ecosystems to agricultural land. The main question, therefore, is how the net costs of reducing the global loss of global ecosystem services should be distributed over the various countries.

The political and philosophical literature offers a variety of normative principles for the international distribution of responsibilities to protect environmental global public goods (see for overviews, e.g., [22,59]. In contemporary discussions about responsibility for mitigating global climate change, two principles stand out, however. First, the polluter-pays principle according to which those causally responsible for environmental damage should bear the costs. In international law, this principle was adopted in Principle 16 of the Rio Declaration. Second, the ability-to-pay principle, i.e., the principle that the strongest shoulders should bear the heaviest burdens [60]. İn line with the ability-to-pay principle, both the CBD and the UNFCCC recognize the legitimacy of prioritizing of developing countries' needs for the achievement of sustained economic growth and the eradication of poverty. Various moral philosophers have acknowledged this in their proposals for a fair allocation of responsibilities to mitigate climate change (see e.g., [22,53,59,61]). Both the polluter-pays principle and the ability-to-pay principle are reflected in Principle 7 of the Rio Declaration that the responsibilities of States to conserve, protect and restore the health and integrity of the Earth's ecosystem depend, first, on the pressures exerted by States on the global environment and, second, on States' financial and technological capacities for reducing such pressures. In the UNFCCC of 1992, this has led to the acceptance of the principle that "the developed country Parties should take the lead in combating climate change and the adverse effects thereof", noting that "the largest share of historical and current global emissions of greenhouse gases has originated in developed countries, that per capita emissions

in developing countries are still relatively low and that the share of global emissions originating in developing countries will grow to meet their social and development needs."

Another distributional principle, particularly popular in the debate on climate policy, is that people are entitled to an equal per capita share of global atmospheric resources or that people hold an equal per capita right to put pressure on the global environment [62–67]. Since the emission of greenhouse gasses correlates strongly with wealth, an equal per capita reallocation of revenues of a global tax on carbon emissions would imply a substantial transfer of funds from developed to developing countries. In the case of climate policy, the idea of equal per capita rights is therefore (largely) consistent with both the polluter-pays principle and the ability-to-pay principle [66].

The polluter-pays principle and the ability-to-pay principle may not go hand-in-hand in the case of ecological conservation, however. Given the salience of the polluter-pays principle and the ability-to-pay principle in discussions of responsibility for reducing climate change, and that the principles converge on who should bear that responsibility, the preceding analysis of ecosystem-service losses raises the important question of how to reason about responsibility for those losses when the two principles conflict. The preliminary data and calculations offered in the previous section indicate that tropical developing countries may be responsible for a larger present contribution to the loss of global ecosystem services than many developed countries. It is therefore not the case with respect to ecosystem service losses that "there is a robust correlation between ecological space usage and economic wealth", as assumed by Hayward [67] (p. 447). As explained in the previous section, this holds true even if we account for the fact that part of the ecological degradation in tropical developing countries is the result of production for export to developed countries. On the other hand, economies situated in tropical climates may face distinctive challenges related to physical geography that may hamper their development [68]. As a consequence, the idea of equal per capita rights to degrade ecosystems may deliver unfavorable results for conservation policy: in the case of a tax on ecosystem service loss, an equal per capita reallocation of the revenues may leave many developing tropical countries with large net costs. This is incompatible with the ability-to-pay principle. It is also incompatible with the principle agreed upon in the 1992 UNFCCC treaty that participation by countries in an effective and appropriate international response should be "in accordance with their common but differentiated responsibilities and respective capabilities and their social and economic conditions".

Thus, the challenge for normative theorists is how to find an international distribution of responsibilities to protect global ecosystem services that does not bring the polluter-pays principle into conflict with the ability-to-pay principle. This balance will be much harder to find than in the case of climate policy, because tropical developing countries may be responsible for a larger present contribution to the loss of global ecosystem services than many developed countries. An international distribution of responsibilities according to equal per capita rights to the environment does not appear to reconcile the two principles. Further research is necessary, however, to investigate whether present poor 'polluters' are also the beneficiaries of ecosystem degradation or that the beneficiaries are in fact more wealthy consumers in developed countries. Moreover, further research is required to discover to what extent present pressures exerted on ecosystems originate from unjust exploitation of the environment in the (colonial) past.

5. Conclusions

In this article, I have offered a first rough sketch of how to conceptualize countries' historical and present contributions to the loss of global ecosystem services. In calculating such contributions, due allowance must be made for two facts: that impacts of human interventions extend into the future, and that ecosystems have the capacity to recover. Since nature has the capacity to recover autonomously once human interventions or activities have been discontinued, such recovery is defined in the conceptual model as a zero contribution to the loss of global ecosystem services. As a consequence, not only the decision to convert land counts as a contribution to the loss of global

ecosystem services, but also the decision to continue the use of already converted land and thus prevent recovery.

To obtain a first indication of possible conclusions that can be drawn on the basis of the conceptual approach, I used data on (changes in) forest cover and carbon stock in living forest biomass (Section 3.4). The conceptual work presented in this paper is preliminary, however. Further precision and clarification would be aided by more research on the relation between these indicators and the provision of global ecosystem services, and on the options for more precise indicators, for example based upon remote-sensing techniques, such as Light Detection and Ranging (LIDAR). More precise indicators that can better distinguish between different vegetation types and forms of land conversion could also better distinguish between the kinds of global ecosystem services that are at stake. Moreover, more research is needed in the temporal development of ecosystem recovery once human interventions or activities have been discontinued. This development will be ecosystem-service specific.

Anticipating more precise quantitative data, I have drawn a number of preliminary conclusions. One of these is that, on a global scale, keeping all converted land in a converted state, thus preventing ecosystems recovery, may contribute more to current loss of global ecosystem services than new conversion of ecosystems. This contribution is not well captured, however, by the principal drivers cited in the Millennium Ecosystem Assessment that only look at changes in the state of ecosystems such as by land conversion. The second main conclusion is that many developing countries in the tropics may contribute more to global ecosystem service losses, in both absolute terms and per capita, than many developed countries. If the latter preliminary conclusion is supported by more detailed empirical research, this would have profound consequences for determining the allocation of responsibility for ecosystem service losses, and more generally, for the popular view that each of the earth's inhabitants has an equal right to natural resources and to exert pressure on the global environment. For if the per capita contribution to global ecosystem service losses is higher in tropical developing countries than in developed countries, equal per capita rights would require developing tropical countries such as Brazil and Indonesia to make large financial transfers to developed and other developing countries, which conflicts with the ability-to-pay principle popular in discussions of climate justice. Allocation principles that are deemed fair in the context of climate negotiations may therefore be considered unfair in the case of biological conservation, and vice versa. More generally, it will prove difficult to find an international distribution of responsibilities to protect global ecosystem services that does not bring the polluter-pays principle into conflict with the ability-to-pay principle. Overcoming this conflict presents an important challenge for normative philosophers.

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