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Article

Biodiversity Loss and the Ecological Footprint of Trade

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Abstract: Human pressure on ecosystems is among the major drivers of biodiversity loss. As biodiversity plays a key role in supporting the human enterprise, its decline puts the well-being of human societies at risk. Halting biodiversity loss is therefore a key policy priority, as reflected in the 2020 Aichi Biodiversity Targets under strategic goal A. The Ecological Footprint has become a widely used metric for natural capital and ecosystem accounting, and is frequently cited in the sustainability debate, where it is often used for tracking human-induced pressures on ecosystems and biodiversity. Given its potential role as an indirect metric for biodiversity-related policies, this paper breaks down the Ecological Footprint into its components and analyzes resource and ecosystem service flows at an international level. We discuss its usefulness in tracking the underlying drivers of habitat impacts and biodiversity loss. We find that: China is a major net importer of all biomass biocapacity components; the largest net exporters of forest biocapacity are not low-income countries; a very high proportion of the Ecological Footprint of fishing grounds is traded internationally; Singapore and at least three Middle East countries are almost wholly reliant on net imports for the cropland biocapacity they consume.

Keywords: Aichi Targets; biodiversity monitoring; Ecological Footprint; biocapacity; human pressure; displacement

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1. Introduction

Human societies' well-being ultimately depends on the integrity of the biosphere [1,2] as all economic activities depend on ecological assets, such as productive land and marine areas, and the services and resources they produce [3,4]. However, as long as humanity's appetite for the Earth's ecological assets continues to outstrip the rate at which nature can regenerate these assets, biodiversity will become increasingly and ever more perilously under threat [5]. Moreover, biodiversity's key role in supporting the human enterprise lies in the fact that it underpins all other boundaries [1]. This, in turn, likely puts the entire human enterprise at risk as profound changes in the biosphere integrity could cause irreversible changes to the Earth System and push it out of the current Holocene state [6]. Halting biodiversity loss should thus be an urgent priority for scientists and policymakers.

The last few decades have seen fundamental changes in the society–nature relationship. Although these changes have likely contributed to noticeable socio-economic [7] and well-being improvements [8,9], they have increased human-induced pressure on ecosystems, potentially leading to a worsening of the state of ecosystems [10]. Several studies have found that humans appropriate a significant proportion of the Earth's Net Primary Productivity [11,12]—with such appropriation increasing two-fold over the last century [13]—and that global extraction and use of biomass, fossil energy carriers, ores and minerals has increased eight-fold from the early 20th century onward [14]. More recently, it has been argued that four out of nine critical planetary thresholds have been already passed [2] and a critical planetary-scale transition is likely approaching [15].

As human demands upon the Earth's ecosystems rapidly increase [16–18], the future ability of the biosphere to provide for humanity and the many other species is being degraded. Globally, biodiversity is declining at an unprecedented rate and human pressure on ecosystems is a major underlying driver of this decline [19–23]. At the same time, leaders' efforts to slow or reverse global biodiversity decline have not been sufficient [19] and the 2010 biodiversity Targets [24] have not been met as increasing society's responses have not managed to counteract growing pressures. The renewed Aichi Biodiversity Targets will also likely not be met by 2020 [10] and "efforts need to be redoubled"—especially in reducing pressures (particularly in Targets 4, 5, 8, 9 and 10)—if biodiversity and ecosystem services are to be maintained and extinction risk averted. A need thus exists to better understand the multiple anthropogenic pressures driving biodiversity loss and the consumption-driven displacement of such pressures across the world [5].

Decision makers face a challenge in navigating through a wealth of disparate information. As such, an analysis of multiple human pressures through a consistent lens would provide a useful guide to assess whether the whole system is moving towards or away from sustainability. Currently, no single metric is available which is able to provide such a comprehensive view. Nonetheless, lacking such a comprehensive metric, Ecological Footprint Accounting (EFA) can be used as a first approximation to depict human pressure on Earth's ecosystems [25–27]. EFA sets a specific ecological budget—biocapacity—and then measures the extent to which human demands on renewable resources and ecological services—the Ecological Footprint—approach or exceed this budget [28]. Where the Ecological Footprint for a specific ecosystem service (e.g., forest products) exceeds that ecosystem's biocapacity, human demand for that ecosystem's annual flow of service exceeds its rate of supply, putting exceptional pressure on that ecosystem and therefore indicating potential habitat loss and/or degradation.

The Ecological Footprint is currently listed as a category "C" indicator for use in monitoring Target 4 of the Strategic Plan for Biodiversity 2011–2020 [29]. To further its adoption, this paper builds and expands on the recent analysis by Galli *et al.* [5] and discusses the role of EFA as a proxy for tracking the underlying drivers of habitat and biodiversity loss at regional and national scales.

The total Ecological Footprint and Biocapacity of nations have been quantitatively analyzed for correlation with indices closely associated with biodiversity loss in previous studies [30] but we undertake a qualitative analysis to explore the links between international trade in components of the Ecological Footprint and the displacement of associated types of pressure on ecosystems. In the current globalized world, access to key life-supporting resources and pressure on the environment are often mediated through international trade [22,31,32]; tracking flows of natural resources from the point of origin to the point of consumption is thus a necessary step in identifying leveraging points to help reduce human pressure on habitats and species.

As such, we first review historical trends in global biocapacity, and the patterns of biocapacity embodied in international trade as an indicator of the geographic flow of pressure on ecosystems where human consumption is driving demand for biocapacity across borders. Then, we provide an overview of global trade patterns by identifying the major net importers and net exporters of the Ecological Footprint of carbon and the overall biomass Footprint (the components that represent demand for biomass materials, separated from other services such as waste absorption). Finally, within each of the four components of the biomass Ecological Footprint, we link patterns of trade in biocapacity with causes and measures of biodiversity loss (e.g., habitat degradation, habitat loss, species decline, *etc.*) associated with the consumption of each kind of biocapacity.

2. Methods and Materials

2.1. What Do Biocapacity and the Ecological Footprint Measure?

Biocapacity measures the ability of the planet to supply the renewable ecological resources and services used by humanity. This productivity is measured as a flow of materials and waste absorption available for human utility. With virtually all life on the planet fueled by the energy of the sun, the biologically-productive surface of the Earth is a fundamental limiting factor to the availability of ecosystem services, and consequently biocapacity is measured in mutually exclusive (The term 'mutually exclusive' can cause some confusion when land cover is conflated with ecological services, or when area is conflated with global area. For instance, forest biocapacity represents the potential for use of trees that can either be cut down for biomass, or remain in place for carbon sequestration—they cannot be both harvested and remain in place. Secondly, when an area provides two kinds of land cover combined such as a hectare which is mixed 1/2 grassland and 1/2 forest land; this is measured as 1/2 hectare providing grazing biocapacity and 1/2 hectare providing forest biocapacity—limitations in practice may be the resolution of the land cover definitions from the data sources (primarily UN FAO) where some small portion of a different land cover type may be allowed within the other land cover classifications.) types of biological productivity which compete for physical area [27,28]. Each area of the Earth is not equally capable of providing the same amount of renewable resources, so land area is weighted by the provisioning capacity, and normalized by an area of global average productivity per area [28,33,34].

The Ecological Footprint measures the amount of the world's biocapacity that is required to provide the ecological resources and services appropriated by humans. Comparing total demand to total supply tells us whether the amount of the Earth's biocapacity consumed is greater than, equal to, or lesser than the amount produced in a given period.

Total biocapacity and the total Ecological Footprint are made up of five land types providing essential provisioning resource and one regulatory ecosystem service [33]: cropland provides food and fiber; forest land provides timber, other forest products, and the absorption of anthropogenic CO_2 waste emissions; grazing land provides livestock feed; marine and inland waters provide fish products; and built-up land provides area for human infrastructure [5].

2.1.1. How Are the Ecological Footprint and Biocapacity Measured?

Conceptually, both biocapacity and the Ecological Footprint measure resource flows expressed as the global area available, and global area required, to produce these flows, respectively.

Biocapacity is measured in global area which is area adjusted by local productivity relative to land of world average productivity. For each of its five components, the normalization of an area of land is done in two steps: first, the area is weighted by the relative biological productivity compared to world average within the same land type by means of Yield Factors; then, the results are further weighted by the relative productivity of each land type compared to an area of land with world average productivity by means of Equivalence Factors [35].

Thus, biocapacity is calculated as:

$$BC = A_i \times YF_i \times EQF_i$$

where *A* is geographic area of land type *i*, YF is the yield factor of land type *i*, and *EQF* is the Equivalence Factor which is a calculated value of the relative productivity of world average land type *i* compared to world average of all bioproductive land.

The Yield Factor further breaks down as:

$$YF = \frac{Y_{n,i}}{Y_{w.i}}$$

where $Y_{n,i}$ is the average yield of land type *i* in region *n*, and $Y_{w,i}$ is the average yield of land type *i* for the world.

The Footprint converts the amount of primary product (or waste sequestration) demanded into the amount of the world's bioproductive capacity used to create that good (or service).

The Ecological Footprint is calculated as:

$$EF_j = \frac{P_j}{Y_{w,j}} \times EQF_i$$

where P_j is the amount of the primary product *j* appropriated, $Y_{w,j}$ is the world average yield of that product, and *EQF* is the Equivalence Factor which is a calculated value of the relative productivity of world average land type *i*—where the primary product is produced—compared to world average productivity of all bioproductive land.

In the case of the carbon component of the Ecological Footprint (hereafter referred to as carbon Footprint (The term "carbon footprint" is widely used as shorthand for the amount of anthropogenic greenhouse gas emissions; within EFA however, it is used to refer to the amount of productive land and sea area required to sequester anthropogenic carbon dioxide emissions. (See [26] for additional information.)) [26]), P_j is the amount of anthropogenic CO_2 emitted during production of product *j* which the Earth's living resources would have to absorb in order for it not to accumulate in the atmosphere.

For further details on the Ecological Footprint methodology see Borucke *et al.* [33].

2.1.2. The National Footprint Accounts: A Key Implementation of Ecological Footprint and Biocapacity Accounting

National Footprint Accounts (NFA) [33] follow a consumer-based approach and calculate the Ecological Footprint by allotting it to final consumers. To calculate the Ecological Footprint of consumption—often referred to simply as Ecological Footprint—the domestic Ecological Footprint (Ecological Footprint of production) is summed with the two sides of trade so that imported materials and waste are attributed to the importer, and exported materials and waste are not attributed to the producer. In this way, the Ecological Footprint of consumption is calculated as follows:

$$EF_c = EF_p + EF_i - EF_e$$

where EF_p is the Ecological Footprint of all production activities within the nation, EF_i is the Footprint embodied in imports from outside the nation, and EF_e is the Footprint embodied in exports from the nation. On the global level there is no trade, so $EF_c = EF_p$.

For further details on the NFA accounting structure as well as data needs and processing see Borucke *et al.* [33] and Galli *et al.* [5].

The National Footprint Accounts use international trade data to track flows of embodied biocapacity into and out of national borders. For bilateral trade analysis, Environmentally Extended Multi-Regional Input-Output analysis (EE-MRIO) for the Ecological Footprint (EF-MRIO) has been used here to supplement the primary NFA results and track the flows of embodied biocapacity between country of origin and final consumers. EF-MRIO uses financial flows between sectors and nations/regions from the Global Trade Analysis Project 8.0 (GTAP 8 includes data representing the years 2004 and 2007 only.) We use the 2007 as the closest available year to calculate bilateral flows of biocapacity in trade (GTAP 8) [36] as a proxy for flows of biocapacity. Detailed Ecological Footprint of production results from the NFA are allocated to sectors in each region's economy, and associated through sector/international exchanges, thus providing quantitative measures of the flows of each component of the Ecological Footprint between all included regions in the GTAP dataset. Ewing *et al.* [37] and Weinzettel *et al.* [22] are recommended as background reading on EF-MRIO. Research on the comparability and limitations of process-based *versus* input–output-based analysis is discussed in Kastner *et al.* [22,38].

3. Results and Discussion

3.1. Global Biocapacity Flows

According to the 2014 Edition of the National Footprint Accounts, since the 1970s, humanity has been in ecological overshoot [34,39], each year consuming more than the annual flow of biocapacity produced by the Earth (Figure 1). A global biocapacity deficit (ecological overshoot) indicates that humanity is living beyond the earth's regenerative capacity (Note that overshoot is a state where the demand for ecosystem flows (resource provisioning and regulatory services) exceeds supply of those flows, resulting in liquidation of stocks of natural capital [34]. The Ecological Footprint is not land use *per se*, and overshoot is not using more land than is available (which is clearly impossible)). The consequence of continued ecological overshoot is alteration and damage to Earth's ecosystems [28,40], which ultimately poses a major threat to biodiversity [41,42]. Projections of pressures on biodiversity and ecological overshoot suggest that the impacts of anthropogenic pressure will continue increasing in the future, both in the short [10] and long run [43].

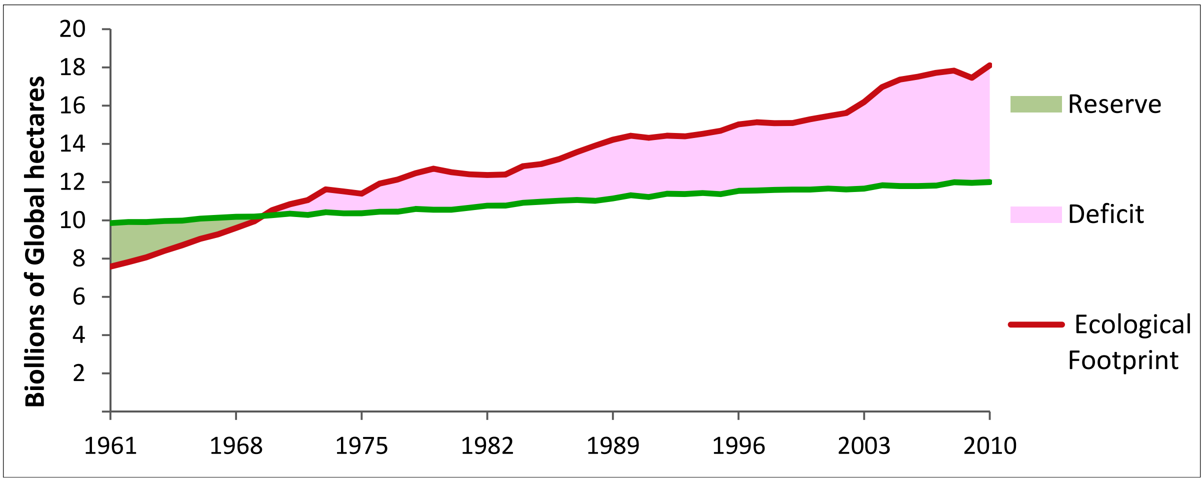

Figure 1. Global Ecological Footprint and biocapacity 1961–2010.

Human demand for the Earth's resources competes for land and ecological services with other species [41,42,44], and as humans are taking an increasing portion of these resources for themselves [45], less biocapacity remains for other species. To the extent that it does conflict, human demand for natural resources fragments native habitats and likely affects the survivability of existing flora and fauna, thus contributing to biodiversity loss [15,23,42,46]. The Convention on Biological Diversity identified increased levels of demand as one of four underlying causes of biodiversity loss to address, stating that "it is unlikely that ecosystems can be kept within safe ecological limits given current patterns of consumption" [23].

3.1.1. Net Importers and Exporters Show the Flows of Pressure in International Trade

Internationally displaced pressure on ecosystems can be monitored and identified by tracking the net flows of biocapacity in international trade [5]. At the national level, countries that export biomass products are exporting embodied biocapacity; countries that export products with an embodied carbon

Footprint are exporting a demand for the Earth's capacity to absorb that waste. Countries that import these products are then responsible for this consumption of biocapacity or demand for sequestration. EFA allows us to track which countries demand the most from the rest of the world (net biocapacity importers), and those which provide the world with biocapacity (net biocapacity exporters). It should be noted that, while some portion of national infrastructure is linked to the supply of goods and services for exports, current National Footprint Accounts do not include trade in embodied built-up land area [47]; consequently, the built up land Footprint is not a part of the trade analysis in this paper.

Moreover, different components of the Ecological Footprint track different typologies of impacts on ecosystems and habitats and require policy interventions at different governance scales. For instance, preventing climate-change-related risks likely requires international agreements and actions on CO_2 emissions reduction while remedial interventions to tackle biomass-related issues (e.g., deforestation and land use change) are most likely best implemented at the national (or sub-national) level.

3.1.2. Trade and the Carbon Component of the Ecological Footprint

Anthropogenic emissions of CO_2 are altering the carbon cycle and, in turn, the Earth's climate [48,49]. Changes in the Earth's climate, in turn, affects the habitats of many species on the planet by altering ecological factors such as flowering and hatching times [47], rainfall [50], frequency and intensity of natural disturbance [50,51], all of which are integral to ecosystem functioning and species interaction and survival [47,52].

Anthropogenic CO_2 emissions have a diffuse impact on the world's ecosystems and the species that inhabit them through climate change and related impacts [53], so direct links between drivers of emissions through trade and specific impacts on biodiversity are difficult to identify. Nevertheless, identifying the origins of demand for those emissions provides some insight on the drivers of climate-change related biodiversity loss.

Trade in the carbon Footprint shows where carbon emissions produced in one country are being driven by consumption elsewhere (see Figure 2). Around 2.5 billion global hectares of carbon Footprint were traded in 2010, accounting for about 35% of the carbon Footprint for all nations (The carbon component of the Ecological Footprint for the world includes the Footprint of emissions from anthropogenic forest fires and other sources that are not currently allocated to individual nations at this point. Thus, its global value is ≈25% higher than the sum of all individual nations' values (see [33] for further details)).

China and the USA, the two nations with the highest carbon Footprint of production (the Footprint of carbon emissions produced by the nations), account for 40% of the sum of all nations. When looking at the carbon Footprint of consumption (thus including trade), these two nations account for 36% of the total. The USA is also the second highest net importer of carbon (after Mexico), with more than a third of its imported carbon Footprint coming from China. France is the third highest net importer, and Saudi Arabia and the Russian Federation the second and third highest net exporters of carbon Footprint after China.

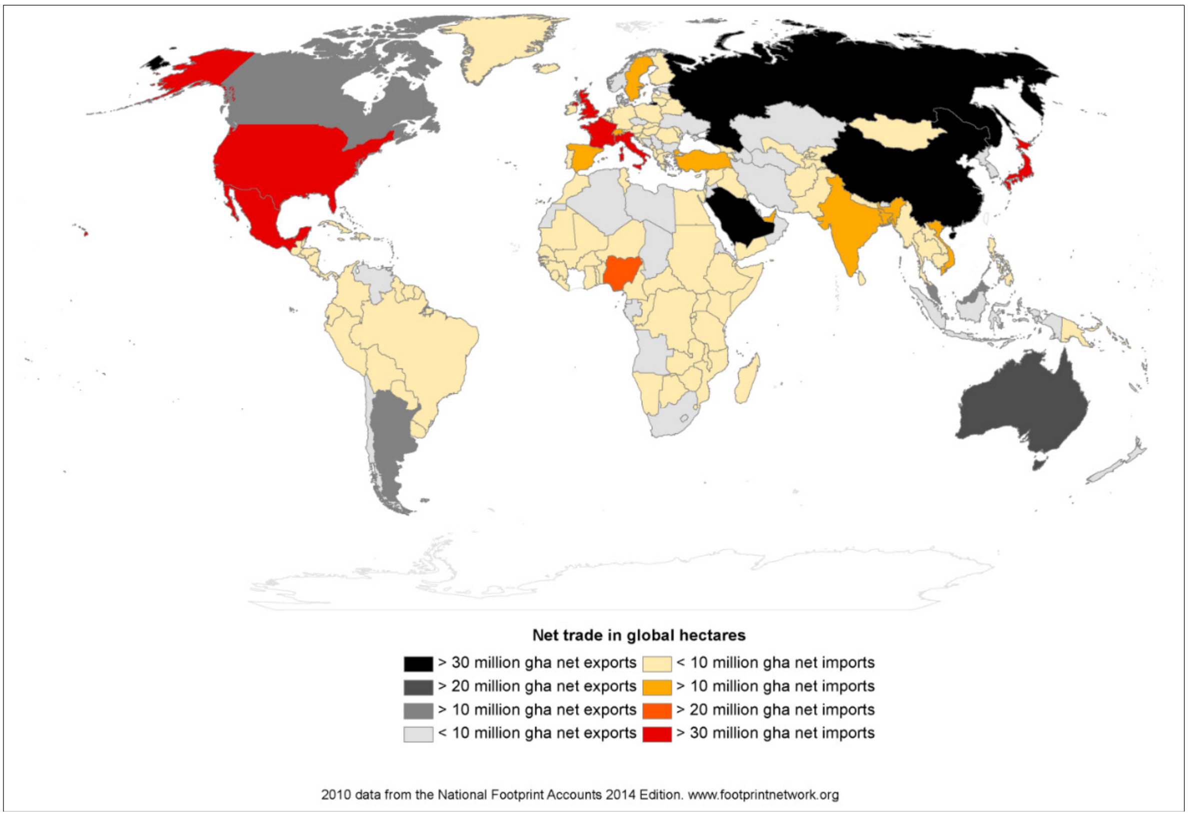

Figure 2. Net trade in the embodied carbon Footprint.

3.1.3. Trade and the Biomass Ecological Footprint

The terms biomass biocapacity, and biomass Footprint, refer to all the renewable resource components of the Ecological Footprint (cropland, fishing grounds, forest land, and grazing land) collectively, excluding the services of CO_2 waste absorption and area for infrastructure. Trade in biomass biocapacity represents direct material flows—harvested biocapacity traded among nations; thus, it has the most direct implications for displaced pressure on ecosystems.

Figure 3 shows the many nations which are drawing on the direct biological resources of other nations (net biomass Footprint importers), and those which are overall global 'suppliers' of biomass biocapacity. The top three net importers of biomass biocapacity are China, Japan and Italy. The top three net exporters are Brazil, Canada, and Argentina. Low-income countries with limited biocapacity are not among the main biocapacity traders; however, the reliance of local populations on local resources without the ability to rely on imports could also threaten local ecosystems and biodiversity.

China has the largest biomass Footprint of production, 14% of all nations combined. This is predominantly from cropland production which, at almost 650 million global hectares, accounts for 61% of the total biomass Footprint for China (see Section 3.2.1 below). China also has the largest biomass Footprint of consumption, nearly twice that of the next largest biomass consumer, the USA. Moreover, China is the biggest net importer of biomass biocapacity, while the National Footprint Accounts show that it is also maintaining a small overall reserve in domestic biomass biocapacity. The USA, second largest biomass consumer, is also the fourth largest net *exporter* of biomass biocapacity. Nevertheless, the National Footprint Accounts show that the USA maintains around 30% reserve in domestic biomass biocapacity. Globally, ≈2.7 billion gha of biomass are imported, and ≈7.8 billion gha are consumed, implying that while displacement of pressure on ecosystems through trade is very significant, the majority of demand for biomass biocapacity is within national borders.

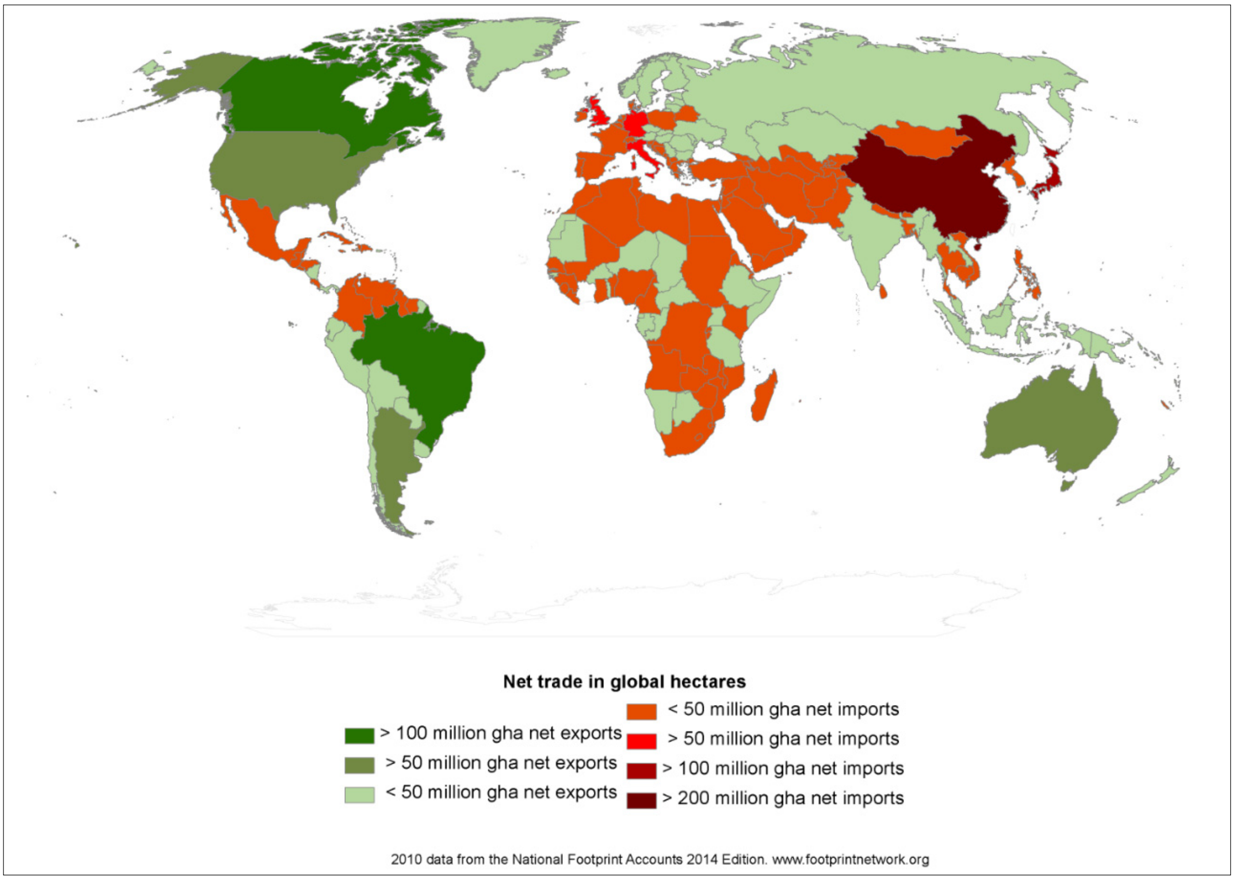

Figure 3. Net trade of biomass biocapacity by nation.

3.2. Component Biocapacity Flows

As the biomass Footprint tracks demand on different ecosystem types driven by diverse human activities, this section provides a further breakdown of its constituent subcomponents to show the different patterns of human resource demand that characterize each of the considered ecosystems and their links with biodiversity trends.

3.2.1. Cropland

Humans have appropriated more land for agriculture than any other land use. Over the last two decades, cropland area has grown by nearly 40 million hectares. Cropland and grazing land together now account for almost 40% of global land area [54]. At the same time, in areas where agriculture is highly efficient, expansion of agricultural areas has slowed or stopped, while in some cases having little to no suitable land remaining limits expansion [42]. As a direct cause of habitat loss, agriculture has been identified as a major driver of biodiversity loss worldwide [42,46]. In addition to direct habitat loss, some agricultural practices used to improve yields are known to threaten biodiversity by damaging surrounding ecosystems [55,56] through processes such as nutrient and pesticide runoff. Globally, agricultural practices vary based on multiple factors, such as available technology, cost, historical traditions, environmental conditions, and type of crops grown; these are all factors which affect the type, magnitude and location of environmental impacts [57].

Our analysis shows that 27% of global cropland biocapacity is traded internationally. China, the highest net importer of crop biocapacity, is still sourcing the greatest part of its consumption from local ecosystems with net imports making up just 15% of its total cropland Footprint. Japan, the second highest net importer of cropland biocapacity, conversely appears to be heavily reliant on the biocapacity imported from outside its borders, with 81% of its consumption represented by net imports. Italy, the third highest net importer, appears to be exchanging low Footprint intensive crop products in exports for high Footprint intensive crop products in imports as the difference in mass of crop products on each side of trade is much less than the Footprint results. Although not amongst the highest net importers on an absolute level, it is notable that countries such as Singapore, Qatar, Kuwait, and the UAE rely almost wholly on imports for crop biocapacity, having very little within their own borders. Singapore and the UAE also export significant amount of cropland biocapacity, with Singapore re-exporting around 50% of imports and the UAE re-exporting around 40%.

As shown in figure 4, USA, Argentina, and Brazil are the top three net exporters of cropland biocapacity. At the same time, USA is a major recipient of the cropland biocapacity exports of both Argentina and Brazil. The USA and Brazil net exports of cropland biocapacity are just around 25% of the cropland Footprint produced in each country, but Argentina has one of the two highest proportions of net exports coming from domestic cropland biocapacity along with Uruguay, where 62% of domestic biocapacity went to net exports.

Figure 4. Net trade in cropland biocapacity: arrows sized by magnitude of embodied biocapacity show the flows into the highest three net importers and out of the highest three net exporters.

3.2.2. Fishing Grounds

Persistent overfishing has not only led to the decline of many species, it has also changed the trophic structure of marine ecosystems at a global scale. Increasing global demand for fish products has led to overexploitation of fish species beyond the capacity for these fisheries to recover [19,58,59]. According to the FAO, approximately 29% of fish stocks assessed in 2011 were fished at biologically unsustainable levels [60]. Another study of 1793 previously unassessed fisheries showed that 64% were overfished, and 18% completely collapsed [61]. Mean trophic levels of the world's fisheries has declined over time [62] and the total biomass of predatory fish—fish used for human consumption—declined by 54% between 1970 and 2010, while the biomass of small fish increased [63].

Our analysis shows that the three biggest net importers of fishing grounds biocapacity are Asian countries (*i.e.*, Japan, China and Thailand), importing mostly from the local Asia Pacific region, but also northern Europe (see Figure 5). Imports into these three countries make up 19% of all global fishing grounds biocapacity imports. Global imports of fishing grounds biocapacity make up a significant proportion (≈60%) of the global fishing grounds Ecological Footprint of consumption, suggesting that global trade in fish products is highly significant in driving the harvest of fish and related impacts on biodiversity.

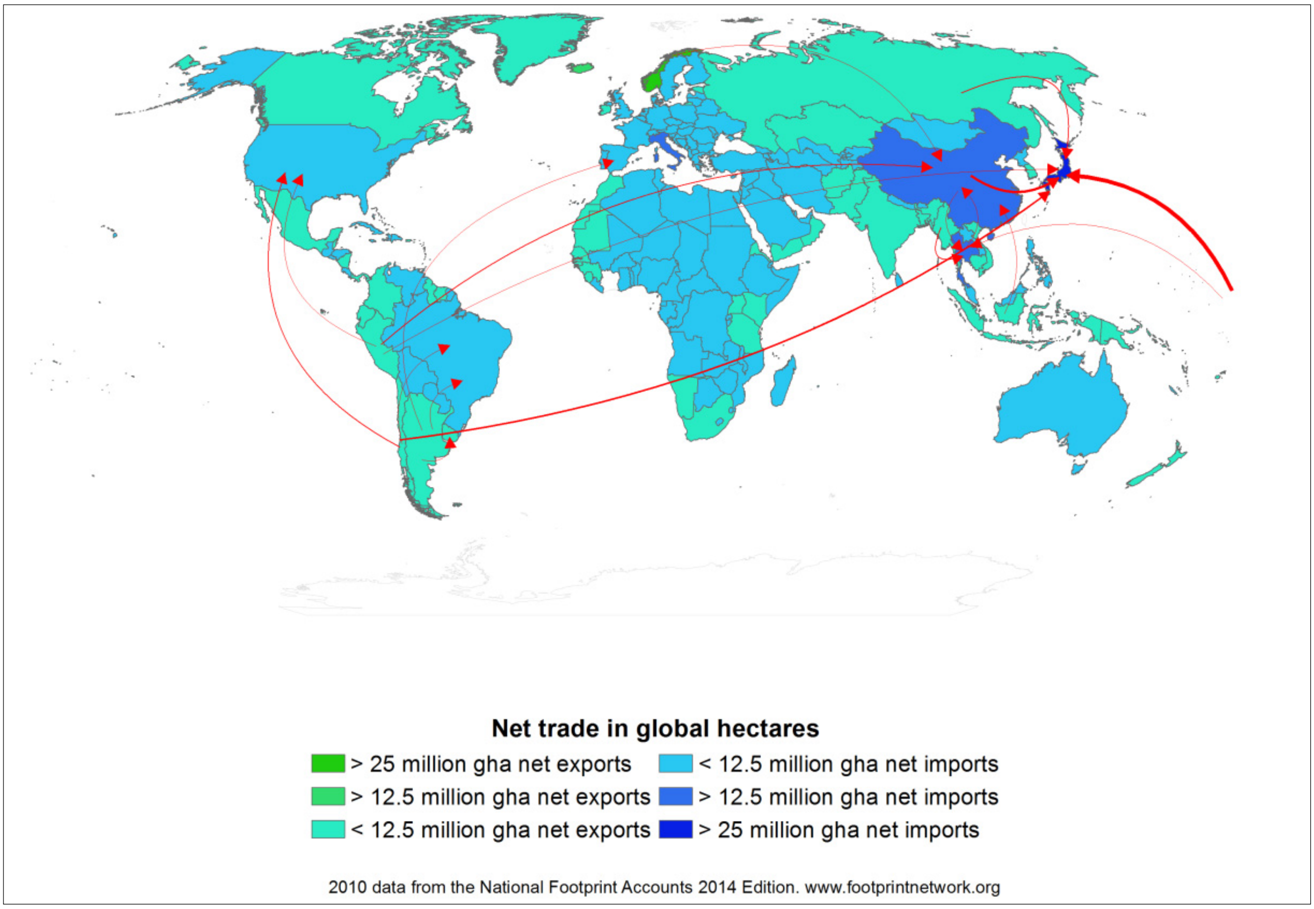

Figure 5. Net trade in fishing grounds biocapacity: arrows sized by magnitude of embodied biocapacity show the flows into the highest three net importers and out of the highest three net exporters (arrows from the Pacific are exports from a number of island nations combined).

The top three net exporters of fishing grounds biocapacity are Norway, Peru, and Chile, with their exports amounting to 16% of all exports of fishing grounds biocapacity.

The major net exporting countries show higher levels of fisheries collapse compared to the largest net importing countries. According to the Sea Around Us Project [62], Norway shows collapse in ≈45% of 84 species assessed, Chile shows collapse in stocks of >30% of the 70 species quantified, and Peru shows collapse in ≈40% of the 50 species quantified. The three largest importers seem to be in a slightly different situation in terms of stock collapse. Japan is showing collapse in the stocks of <20% of the 137 species quantified. China is showing collapse in 30% of 150 species, while Thailand shows collapse in <10% of 59 species.

There is significant complexity in the trade flows of fishing grounds biocapacity, with the largest absolute importers overlapping significantly with the largest absolute exporters, and in some cases, large flows of fishing grounds biocapacity going both ways between countries. While China and Thailand are amongst the highest net importers of fishing ground biocapacity, they are also large exporters in absolute terms—the highest and third highest in the world, respectively—and they have a significant trade in fishing grounds biocapacity going both ways between them.

3.2.3. Forest Land

Demand for forest products is a direct driver of habitat destruction and fragmentation [22,64]. Tropical rainforests contain a high concentration of Earth's biodiversity; covering only 7% of the Earth's terrestrial surface [65], they provide habitat for at least two-thirds of the world's terrestrial species. Due to this high species-richness, global forest biodiversity is especially sensitive to tropical deforestation [65] as they are threatened by deforestation, habitat degradation, climate change, and invasive species [66]. Industrial logging in temperate and boreal forests is also highly implicated in biodiversity loss, where intact forest ecosystems may be especially important to biodiversity [67]. While regulations and recommendations for improved logging practices are being promoted, the effectiveness of regulation and large scale sustainable forest-management practices have been brought into question [68,69].

Demand for forest products also has indirect impacts on biodiversity, as forest biomes play a major role in climate regulation. Tropical and boreal forests have been emphasized as having a particularly strong climate regulation role, and maintaining or building land cover of these and all forests have been identified as an important factor in living within planetary boundaries [2].

Trade in forest biocapacity accounts for approximately 37% of the world's forest Footprint. The top net exporters of forest land biocapacity are upper-middle and high-income countries rich in forest biocapacity, with the largest being Canada, Russian Federation, and Sweden (Figure 6). The top net importers are China, the UK and Italy.

In absolute terms, countries with large areas of temperate and boreal forest and countries with a greater ability to manage forestry practices are the main suppliers of forest biocapacity into the global market. While this does not support the hypothesis that the overharvest of forests linked to biodiversity loss is mainly driven by high-income countries liquidating the natural assets of low-income tropical countries, there is some question as to the extent of unreported trade in the products of illegal logging [69–71] which may be somewhat skewing the underlying data.

The three highest net importers of forest biocapacity account for 43% of net imports. Tracking of transformed forest products is limited by data availability in the National Footprint Accounts, so further analysis would be required to better understand to what extent these imports represent demand for final consumption as opposed to materials in manufactured products for ongoing export.

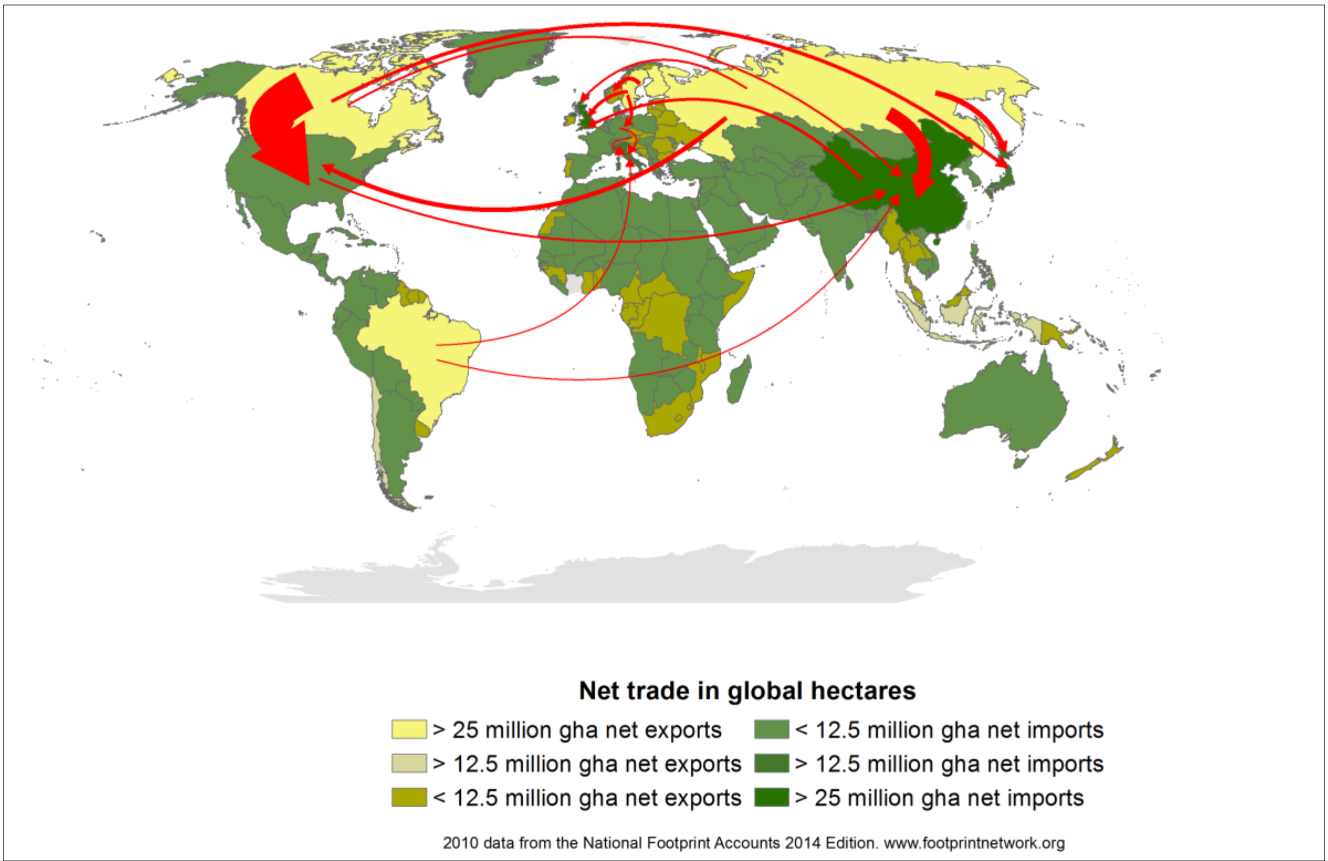

Figure 6. Net trade in forest biocapacity: arrows sized by magnitude of embodied biocapacity show the largest flows into the highest three net importers and out of the highest three net exporters.

Local consumption also appears to be a significant driver of demand for forest biocapacity. Figure 7 shows where local demand is above or within locally available forest biocapacity. This figure suggests a pressure in tropical African and Asian countries not apparent when looking exclusively at the international forest product trade flows. Notably, data on harvest of forest products used in the National Footprint Accounts does not distinguish between harvest from plantation and re-growth or old growth forest, which is likely an important factor in assessing the impact logging practices have on biodiversity.

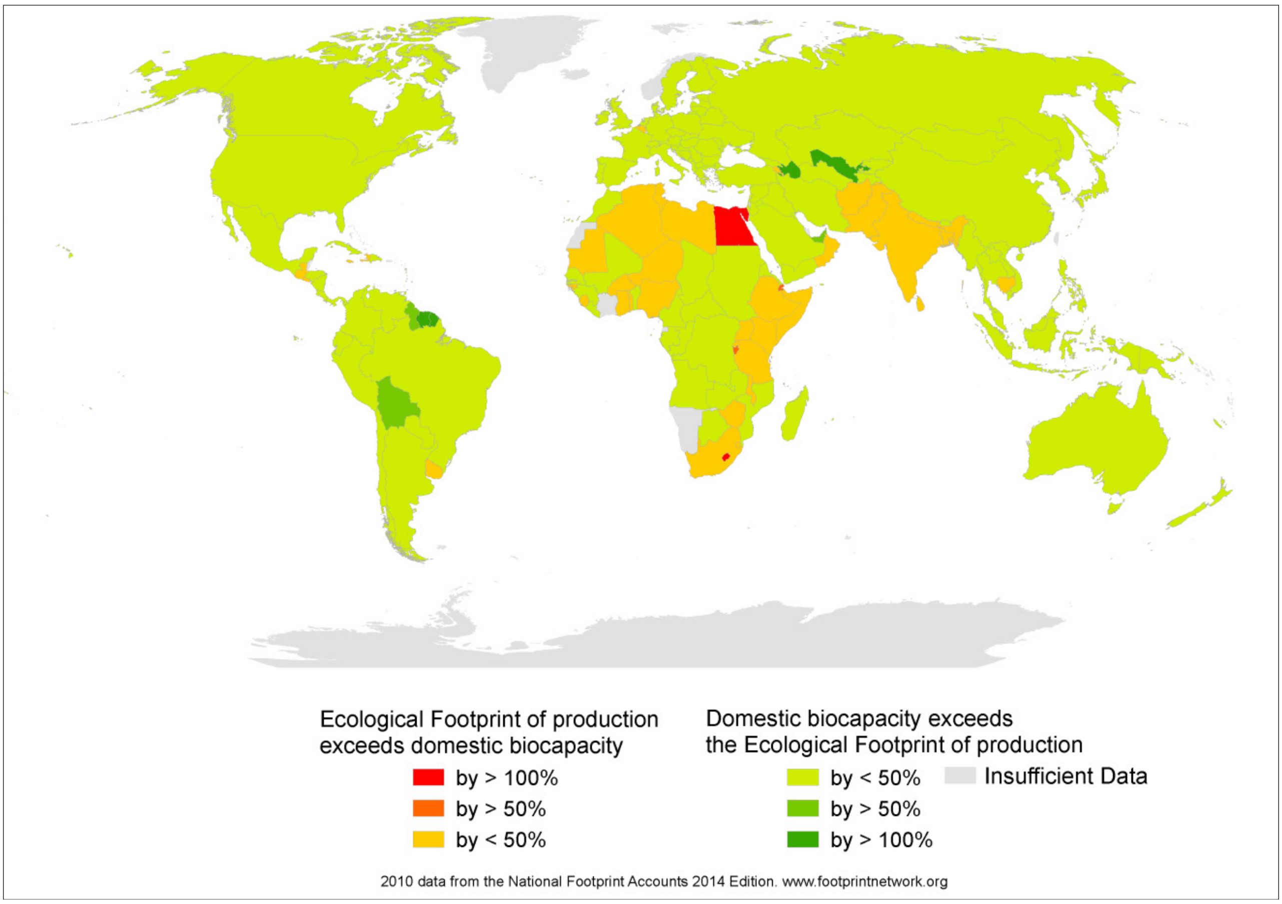

Figure 7. Ecological deficit ($EF_p > BC$) or reserve ($EF_p < BC$) for forest land, by nation.

3.2.4. Grazing Land

While the literature provides a complex picture of the biodiversity impacts of livestock grazing—including that properly managed grazing systems do not necessarily diminish biodiversity, and can even preserve and enhance plant diversity [72]—high grazing intensity is associated with local biodiversity loss, and a reduction of grazing intensity is associated with increased heterogeneity of both plant [73] and animal species [74]. The effects of grazing on rangeland biodiversity include the removal of biomass, trampling and destruction of root systems, and replacement of wild grazers by livestock [75]. Although grazing land conversion has historically been linked to tropical deforestation [76], this practice has significantly declined in favor of more sustainable systems [77].

At the same time, the impacts of livestock agriculture often associated with grazing may be more significantly linked to crop agriculture and greenhouse gases. Livestock agricultural systems have transitioned in the last hundred years from predominantly free-range feeding, to industrial systems with more than 90% of feed coming from crops and crop by-products from outside the farm [78]. Caro *et al.* [79] have analyzed the contribution of countries' consumption of livestock products to global CH_4 and N_2O emissions and found that trade is likely to contribute to increasing GHGs emissions when meat production is re-located to cheaper, environmentally-inefficient countries. The greenhouse gas impacts of livestock production are also well documented [18,80], contributing perhaps more than 15% of human associated emissions [81].

The patterns in the global trade of grazing land biocapacity identified by our analysis show that China, Italy, and the Russian Federation are the three highest net importers. Much of those imports are coming from Australia and Brazil; China is in turn supplying significant grazing land biocapacity to Italy and the Russian Federation (see Figure 8). While China is supplying almost 80% of its own final demand for grazing land biocapacity through local ecosystems, both Italy and the Russian Federation rely on net imports for almost 90% of their final demand for grazing land biocapacity.

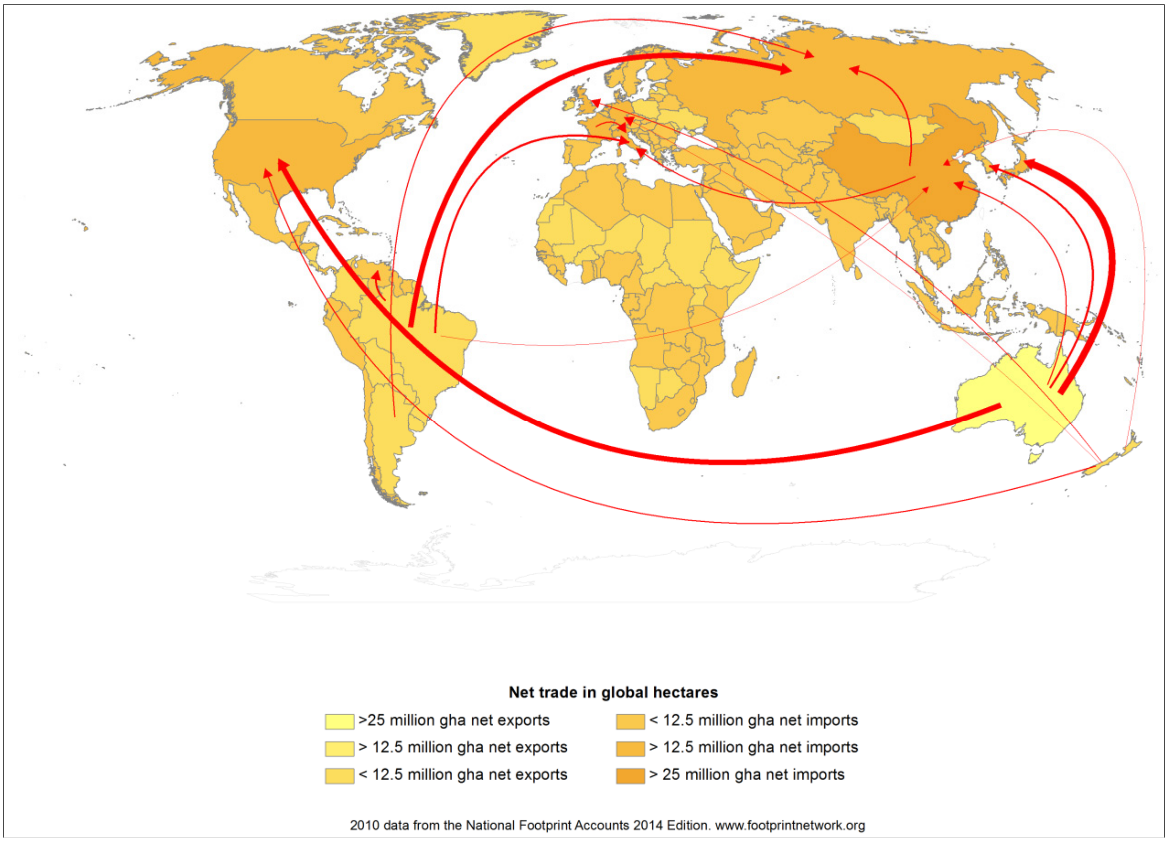

Figure 8. Net trade in grazing land biocapacity: arrows sized by magnitude of embodied biocapacity show the flows into the highest three net importers and out of the highest three net exporters.

Australia, New Zealand and Brazil are the largest net exporters of grazing land biocapacity. All three countries are among the six highest net exporters of total biomass biocapacity, with the net exports of grazing land accounting for 69%, 41%, and 12% of that total, respectively. Brazil and Australia have the highest and third highest grazing land biocapacity respectively, while China, the largest net importer, has the second highest grazing land biocapacity of all countries. Seventy-two percent of Australia's domestic grazing land Footprint leaves the country as net exports, compared with only 6% of Brazil's.

4. Conclusions

The increase in consumption levels that human societies have witnessed in the last decades is placing unprecedented demands on the biosphere's provisioning services and is contributing, among other factors, to the degradation of land and water resources, habitat fragmentation or loss, climate-induced habitat-shifts as well as a decline in the number of species and their richness to the extent that we might be already beyond safe operating limits in key planetary systems.

Ecological Footprint Accounting tracks an important element of human pressure on the biosphere; demands for the limited supply of the Earth's resources provisioning and regulatory ecosystem services. Through an analysis of the components of the National Footprint Accounts and specific elements of trade, this paper has illustrated the role of the Ecological Footprint as an indicator and potential predictor of habitats' fragmentation and loss. Indeed, international trade links consumption in one country to biodiversity loss in another, displacing pressure on biodiversity through the global supply chain.

We found that, in 2010, almost 35% of the carbon Footprint was embodied in international trade, with China being the largest net exporter and Mexico the largest net importer. We found that approximately 2.7 billion gha of biomass Footprint was imported (out of the nearly 8 billion gha consumed) with China being the largest net importer and Brazil the largest next exporter. Although displacement of pressure on ecosystems through trade is very significant, the majority of demand for biomass biocapacity places pressure upon ecosystems within national borders.

Looking at the individual components of the biomass Footprint linked to different kinds of biodiversity threats, we found that the highest flows of cropland Footprint embedded in trade flows were mobilized by China as the largest net importer (≈12%), and USA as the largest net exporter (≈18%); global trade in fish products was found to be highly significant in driving the harvest of fish and related impacts on biodiversity; upper-middle and high-income countries rich in forest biocapacity are the largest net exporters, predominantly supplying other high- and upper-middle income countries; most of the grazing Footprint embedded in trade is again mobilized by China as the largest net importer (≈8%), and by Australia as the largest net exporter (≈29%). Moreover, in some cases, the largest exporters of biocapacity from a given ecosystem type were found to be major importers of another ecosystem type. For instance, the Russian Federation, which is the third largest net importer of embodied grazing land, is also the second largest net exporter of forest biocapacity. Indeed China—the second highest net importer of fishing grounds and highest net importer of the other three biomass land types—supplies large amounts of embodied biomass biocapacity to the other major importers, making this country a significant hub of global biocapacity flows for all the ecosystem types.

In the last decade, biodiversity loss has not been reduced despite an acknowledged increase in policy responses. Among the reasons for this is that society responses so far have been mostly symptom-related, focused on addressing the state of biodiversity (e.g., by putting in place more protected areas for preserving habitat loss) rather than being cause-focused and directly addressing the primary anthropogenic drivers putting pressure upon ecosystems and habitats. Increased effort could thus be made to complement traditional policy responses with policies directly tackling the human drivers of habitats and biodiversity loss (*i.e.*, consumer behavior). Moreover, our analysis of the global biocapacity flows can be used to identify pressures along global supply chains to help prioritize areas of intervention; in several instances, Ecological Footprint results seem to indicate that pressure on ecosystems and the consequent habitat loss in a given country could be more effectively addressed by reducing the demand for resource provisioning and regulatory ecosystem services elsewhere.

To conclude, we believe that EFA offers significant scope for additional research on useful links to pressure on biodiversity. Further investigation of the results described in the overview in this paper could provide additional insight into the dynamics of the interrelations between factors such as biocapacity reserve/deficit status and net or absolute trade, national income, proximity of trade partners, historic states and trends of biocapacity and Ecological Footprint. Quantitative analysis of the relations between Ecological Footprint components and losses in biodiversity would yield additional useful results if appropriate global indices of biodiversity threats and loss become available. Additionally, analysis of detailed elements underlying each of the Ecological Footprint component results could be used to further explore relationships between human and natural systems at other scales. Given the wide variability in types of human pressure on biodiversity, and the resulting spatial variability on these relationships, analyses of Ecological Footprint flows along with complementary tools and metrics in a broader framework such as telecoupling [82], could ease the quantifying and categorizing of complex interactions with greater detail.

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Author Contributions

Alessandro Galli, Elias Lazarus and David Lin, conceived the paper and designed the research; Elias Lazarus, David Lin, Jon Martindill, Jeanette Hardiman and Louisa Pitney compiled and analyzed the data; Elias Lazarus, Louisa Pitney and Alessandro Galli produced the maps and all authors wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Mace, G.M.; Reyers, B.; Alkemade, R.; Biggs, R.; Chapin, F.S.; Cornell, S.E.; Díaz, S.; Jennings, S.; Leadley, P.; Mumby, P.J.; *et al.* Approaches to defining a planetary boundary for biodiversity. *Glob. Environ. Chang.* **2014**, *28*, 289–297.
2. Steffen, W.; Richardson, K.; Rockstrom, J.; Cornell, S.E.; Fetzer, I.; Bennett, E.M.; Biggs, R.; Carpenter, S.R.; de Vries, W.; de Wit, C.A.; *et al.* Planetary boundaries: Guiding human development on a changing planet. *Science* **2015**, *347*, 1259855.
3. Costanza, R.; Kubiszewski, I.; Giovannini, E.; Lovins, H.; McGlade, J.; Pickett, K.E.; Ragnarsdóttir, K.V.; Roberts, D.; de Vogli, R.; Wilkinson, R. Development: Time to leave GDP behind. *Nature* **2014**, *505*, 283–285.
4. Daly, H.E. Toward some operational principles of sustainable development. *Ecol. Econ.* **1990**, *2*, 1–6.
5. Galli, A.; Wackernagel, M.; Iha, K.; Lazarus, E. Ecological Footprint: Implications for biodiversity. *Biol. Conserv.* **2014**, *173*, 121–132.

6. Steffen, W.; Broadgate, W.; Deutsch, L.; Gaffney, O.; Ludwig, C. The trajectory of the Anthropocene: The Great Acceleration. *Anthr. Rev.* **2015**, *2*, 81–98.
7. Bolt, J.; van Zanden, J.L. *The First Update of the Maddison Project*; Re-estimating Growth before 1820; Maddison Project: Groningen, The Netherlands, 2013.
8. Malik, K.; United Nations Development Programme. *Human Development Report 2013: The Rise of the South : Human Progress in a Diverse World*; United Nations Development Programme: New York, NY, USA, 2013.
9. United Nations Environment Programme (UNEP). *Global Environmental Outlook GEO 5: Environment for the Future We Want*; United Nations Environment Program: Nairobi, Kenya, 2012.
10. Tittensor, D.P.; Walpole, M.; Hill, S.L.L.; Boyce, D.G.; Britten, G.L.; Burgess, N.D.; Butchart, S.H.M.; Leadley, P.W.; Regan, E.C.; Alkemade, R.; *et al.* A mid-term analysis of progress toward international biodiversity targets. *Science* **2014**, *346*, 241–244.
11. Imhoff, M.L.; Bounoua, L.; Ricketts, T.; Loucks, C.; Harriss, R.; Lawrence, W.T. Global patterns in human consumption of net primary production. *Nature* **2004**, *429*, 870–873.
12. Vitousek, P.M.; Ehrlich, P.R.; Ehrlich, A.H.; Matson, P.A. Human Appropriation of the Products of Photosyntheseis. *Bioscience* **1986**, *36*, 368–373.
13. Krausmann, F.; Erb, K.-H.; Gingrich, S.; Haberl, H.; Bondeau, A.; Gaube, V.; Lauk, C.; Plutzar, C.; Searchinger, T.D. Global human appropriation of net primary production doubled in the 20th century. *Proc. Natl. Acad. Sci.* **2013**, *110*, 10324–10329.
14. Krausmann, F.; Gingrich, S.; Eisenmenger, N.; Erb, K.-H.; Haberl, H.; Fischer-Kowalski, M. Growth in global materials use, GDP and population during the 20th century. *Ecol. Econ.* **2009**, *68*, 2696–2705.
15. Barnosky, A.D.; Hadly, E.A.; Bascompte, J.; Berlow, E.L.; Brown, J.H.; Fortelius, M.; Getz, W.M.; Harte, J.; Hastings, A.; Marquet, P.A.; *et al.* Approaching a state shift in Earth's biosphere. *Nature* **2012**, *486*, 52–58.
16. Haberl, H. The global socioeconomic energetic metabolism as a sustainability problem. *Energy* **2006**, *31*, 87–99.
17. Rockström, J.; Steffen, W.; Noone, K.; Persson, Å.; Chapin, F.S.; Lambin, E.F.; Lenton, T.M.; Scheffer, M.; Folke, C.; Schellnhuber, H.J.; *et al.* A safe operating space for humanity. *Nature* **2009**, *461*, 472–475.
18. Nelson, G.C.; Bennett, E.; Berhe, A.A.; Cassman, K.; DeFries, R.S.; Dietz, T.; Dobermann, A.; Dobson, A.; Janetos, A.; Levy, M.A.; *et al.* Anthropogenic Drivers of Ecosystem Change: An Overview. *Ecol. Sci.* **2006**, *11*, 29.
19. Butchart, S.H.M.; Walpole, M.; Collen, B.; van Strien, A.; Scharlemann, J.P.W.; Almond, R.E.A.; Baillie, J.E.M.; Bomhard, B.; Brown, C.; Bruno, J.; *et al.* Global Biodiversity: Indicators of Recent Declines. *Science* **2010**, *328*, 1164–1168.
20. Lenzen, M.; Moran, D.; Kanemoto, K.; Foran, B.; Lobefaro, L.; Geschke, A. International trade drives biodiversity threats in developing nations. *Nature* **2012**, *486*, 109–112.
21. Loh, J.; Green, R.E.; Ricketts, T.; Lamoreux, J.; Jenkins, M.; Kapos, V.; Randers, J. The Living Planet Index: Using species population time series to track trends in biodiversity. *Philos. Trans. R. Soc. B Biol. Sci.* **2005**, *360*, 289–295.

22. Weinzettel, J.; Hertwich, E.G.; Peters, G.P.; Steen-Olsen, K.; Galli, A. Affluence drives the global displacement of land use. *Glob. Environ. Chang.* **2013**, *23*, 433–438.
23. Secretariat of the Convention on Biological Diversity. In *Global Biodiversity Outlook 4*; Secretariat of the Convention on Biological Diversity: Montreal, QC, Canada, 2014.
24. Secretariat of the Convention on Biological Diversity. In *Handbook of the Convention on Biological Diversity*; Earthscan Publications: London, UK; Sterling, VA, USA, 2001.
25. Bastianoni, S.; Niccolucci, V.; Cranston, G.; Neri, E.; Galli, A; Wackernagel, M. Sustainable Development: Ecological Footprint in Accounting. In *Encyclopedia of Environmental Management*; Taylor & Francis: Florence, KY, USA, 2013; pp. 2467–2481.
26. Galli, A.; Wiedmann, T.; Ercin, E.; Knoblauch, D.; Ewing, B.; Giljum, S. Integrating Ecological, Carbon and Water footprint into a "Footprint Family" of indicators: Definition and role in tracking human pressure on the planet. *Ecol. Indic.* **2012**, *16*, 100–112.
27. Galli, A. On the rationale and policy usefulness of Ecological Footprint Accounting: The case of Morocco. *Environ. Sci. Policy* **2015**, *48*, 210–224.
28. Wackernagel, M.; Schulz, N.B.; Deumling, D.; Linares, A.C.; Jenkins, M.; Kapos, V.; Monfreda, C.; Loh, J.; Myers, N.; Norgaard, R.; *et al.* Tracking the ecological overshoot of the human economy. *Proc. Natl. Acad. Sci.* **2002**, *99*, 9266–9271.
29. Convention on Biological Diversity (CBD); United Nations Environmental Programme (UNEP). *Report of the Eleventh Meeting*; CBD: Hyderabad, India, 2012; p. 288.
30. Vačkář, D. Ecological Footprint, environmental performance and biodiversity: A cross-national comparison. *Ecol. Indic.* **2012**, *16*, 40–46.
31. Lambin, E.F.; Meyfroidt, P. Global land use change, economic globalization, and the looming land scarcity. *Proc. Natl. Acad. Sci.* **2011**, *108*, 3465–3472.
32. Peters, G.P.; Minx, J.C.; Weber, C.L.; Edenhofer, O. Growth in emission transfers via international trade from 1990 to 2008. *Proc. Natl. Acad. Sci.* **2011**, *108*, 8903–8908.
33. Borucke, M.; Moore, D.; Cranston, G.; Gracey, K.; Iha, K.; Larson, J.; Lazarus, E.; Morales, J.C.; Wackernagel, M.; Galli, A. Accounting for demand and supply of the biosphere's regenerative capacity: The National Footprint Accounts' underlying methodology and framework. *Ecol. Indic.* **2013**, *24*, 518–533.
34. Monfreda, C.; Wackernagel, M.; Deumling, D. Establishing national natural capital accounts based on detailed Ecological Footprint and biological capacity assessments. *Land Use Policy* **2004**, *21*, 231–246.
35. Galli, A.; Kitzes, J.; Wermer, P.; Wackernagel, M.; Niccolucci, V.; Tiezzi, E. An Exploration of the Mathematics behind the Ecological Footprint. In *Ecodynamics: The Prigogine Legacy*; Brebbia, C.A., Ed.; WIT Press: Southampton, UK, 2012; Volume 1, pp. 249–256.
36. Aguiar, A.; McDougall, R.; Narayanan, B. Global Trade, Assistance, and Production: The GTAP 8 Data Base. Availabile online: http://www.gtap.agecon.purdue.edu/databases/v8/v8_doco.asp (accessed on 6 May 2014).
37. Ewing, B.R.; Hawkins, T.R.; Wiedmann, T.O.; Galli, A.; Ercin, A.E.; Weinzettel, J.; Steen-Olsen, K. Integrating ecological and water footprint accounting in a multi-regional input–output framework. *Ecol. Indic.* **2012**, *23*, 1–8.

38. Kastner, T.; Schaffartzik, A.; Eisenmenger, N.; Erb, K.-H.; Haberl, H.; Krausmann, F. Cropland area embodied in international trade: Contradictory results from different approaches. *Ecol. Econ.* **2014**, *104*, 140–144.
39. Catton, W.R. *Overshoot: The Ecological Basis of Revolutionary Change*; University of Illinois Press: Urbana, IL, USA, 1982.
40. Goldfinger, S.; Poblete, P. *The Eecological Wealth of Nations*; Global Footprint Network: Oakland, CA, USA, 2010.
41. Vitousek, P.M. Human Domination of Earth's Ecosystems. *Science* **1997**, *277*, 494–499.
42. Millennium Ecosystem Assessment. In *Ecosystems and Human Well-being: Biodiversity Synthesis*; World Resources Institute: Washington, DC, USA, 2005; p. 100.
43. Moore, D.; Cranston, G.; Reed, A.; Galli, A. Projecting future human demand on the Earth's regenerative capacity. *Ecol. Indic.* **2012**, *16*, 3–10.
44. Chapin, F.S., III; Zavaleta, E.S.; Eviner, V.T.; Naylor, R.L.; Vitousek, P.M.; Reynolds, H.L.; Hooper, D.U.; Lavorel, S.; Sala, O.E.; Hobbie, S.E.; *et al.* Consequences of changing biodiversity. *Nature* **2000**, *405*, 234–242.
45. Smil, V. Harvesting the Biosphere: The Human Impact. *Popul. Dev. Rev.* **2011**, *37*, 613–636.
46. Foley, J.A. Global Consequences of Land Use. *Science* **2005**, *309*, 570–574.
47. Walther, G.-R.; Post, E.; Convey, P.; Menzel, A.; Parmesan, C.; Beebee, T.J.C.; Fromentin, J.-M.; Hoegh-Guldberg, O.; Bairlein, F. Ecological responses to recent climate change. *Nature* **2002**, *416*, 389–395.
48. Solomon, S.; Plattner, G.-K.; Knutti, R.; Friedlingstein, P. Irreversible climate change due to carbon dioxide emissions. *Proc. Natl. Acad. Sci.* **2009**, *106*, 1704–1709.
49. Ramanathan, V.; Feng, Y. On avoiding dangerous anthropogenic interference with the climate system: Formidable challenges ahead. *Proc. Natl. Acad. Sci.* **2008**, *105*, 14245–14250.
50. Allen, C.D.; Macalady, A.K.; Chenchouni, H.; Bachelet, D.; McDowell, N.; Vennetier, M.; Kitzberger, T.; Rigling, A.; Breshears, D.D.; Hogg, E.H. (Ted); *et al.* A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests. *For. Ecol. Manag.* **2010**, *259*, 660–684.
51. Dale, V.H.; Joyce, L.A.; Mcnulty, S.; Neilson, R.P.; Ayres, M.P.; Flannigan, M.D.; Hanson, P.J.; Irland, L.C.; Lugo, A.E.; Peterson, C.J.; *et al.* Climate Change and Forest Disturbances. *BioScience* **2001**, *51*, 723.
52. Wuethrich, B. How Climate Change Alters Rhythms of the Wild. *Science* **2000**, *287*, 793–795.
53. Climate Change 2013—The Physical Science Basis. In Proceedings of the Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, Stockholm, Sweden, 23–26 September 2013; Intergovernmental Panel on Climate Change, Ed.; Cambridge University Press: Cambridge, UK, 2014.
54. Food and Agriculture Organization of the United Nations. FAOSTAT. Available online: http://data.fao.org (accessed on 1 June 2015).
55. McLaughlin, A.; Mineau, P. The impact of agricultural practices on biodiversity. *Agric. Ecosyst. Environ.* **1995**, *55*, 201–212.
56. Matson, P.A. Agricultural Intensification and Ecosystem Properties. *Science* **1997**, *277*, 504–509.

57. Holland, J.M. The environmental consequences of adopting conservation tillage in Europe: Reviewing the evidence. *Agric. Ecosyst. Environ.* **2004**, *103*, 1–25.
58. Halpern, B.S.; Longo, C.; Hardy, D.; McLeod, K.L.; Samhouri, J.F.; Katona, S.K.; Kleisner, K.; Lester, S.E.; O'Leary, J.; Ranelletti, M.; *et al.* An index to assess the health and benefits of the global ocean. *Nature* **2012**, *488*, 615–620.
59. Swartz, W.; Sala, E.; Tracey, S.; Watson, R.; Pauly, D. The Spatial Expansion and Ecological Footprint of Fisheries (1950 to Present). *PLoS ONE* **2010**, *5*, e15143.
60. Food and Agriculture Organization of the United Nations. *State of World Fisheries and Aquaculture 2014*; FAO: Rome, Italy, 2014.
61. Costello, C.; Ovando, D.; Hilborn, R.; Gaines, S.D.; Deschenes, O.; Lester, S.E. Status and Solutions for the World's Unassessed Fisheries. *Science* **2012**, *338*, 517–520.
62. Data and Visualization. Available online: http://www.seaaroundus.org/data/ (accessed on 17 March 2015).
63. Christensen, V.; Coll, M.; Piroddi, C.; Steenbeek, J.; Buszowski, J.; Pauly, D. A century of fish biomass decline in the ocean. *Mar. Ecol. Prog. Ser.* **2014**, *512*, 155–166.
64. DeFries, R.S.; Foley, J.A.; Asner, G.P. Land-use choices: Balancing human needs and ecosystem function. *Front. Ecol. Environ.* **2004**, *2*, 249–257.
65. Bradshaw, C.J.; Sodhi, N.S.; Brook, B.W. Tropical turmoil: A biodiversity tragedy in progress. *Front. Ecol. Environ.* **2009**, *7*, 79–87.
66. Food and Agriculture Organization of the United Nations. *Global Forest Resources Assessment 2005: Progress Towards Sustainable Forest Management*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2006.
67. Mackey, B.; DellaSala, D.A.; Kormos, C.; Lindenmayer, D.; Kumpel, N.; Zimmerman, B.; Hugh, S.; Young, V.; Foley, S.; Arsenis, K.; *et al.* Policy Options for the World's Primary Forests in Multilateral Environmental Agreements: Policy options for world's primary forests. *Conserv. Lett.* **2014**, doi:10.1111/conl.12120.
68. Zimmerman, B.L.; Kormos, C.F. Prospects for Sustainable Logging in Tropical Forests. *BioScience* **2012**, *62*, 479–487.
69. Finer, M.; Jenkins, C.N.; Sky, M.A.B.; Pine, J. Logging Concessions Enable Illegal Logging Crisis in the Peruvian Amazon. *Sci. Rep.* **2014**, doi:10.1038/srep04719.
70. Lawson, S.; MacFaul, L.; Royal Institute of International Affairs. In *Illegal Logging and Related Trade: Indicators of the Global Response*; Chatham House: London, UK, 2010.
71. Tacconi, L. Illegal Logging: Law Enforcement, Livelihoods and the Timber Trade; Earthscan: London, UK, 2012.
72. Plantureux, S.; Peeters, A.; McCracken, D.I. Biodiversity in intensive grasslands: Effect of management, improvement and challenges. *Agron. Res.* **2005**, *3*, 153–164.
73. Marriott, C.A.; Fothergill, M.; Jeangros, B.; Scotton, M.; Louault, F. Long-term impacts of extensification of grassland management on biodiversity and productivity in upland areas. A review. *Agronomie* **2004**, *24*, 447–462.
74. Van Wieren, S.E. Effects of large herbivores upon the animal community. In *Grazing and Conservation Management*; WallisDeVries, M.F., van Wieren, S.E., Bakker, J.P., Eds.; Springer Netherlands: Dordrecht, The Netherlands, 1998; pp. 185–214.

75. Reid, R.S.; Bedelian, C.; Said, M.Y.; Kruska, R.L.; Mauricio, R.M.; Castel, V.; Olson, J.; Thornton, P.K. Global livestock impacts on biodiversity. *Livest. Chang. Landsc.* **2009**, *1*, 111–138.
76. Nepstad, D.C.; Stickler, C.M.; Filho, B.S.; Merry, F. Interactions among Amazon land use, forests and climate: Prospects for a near-term forest tipping point. *Philos. Trans. R. Soc. B Biol. Sci.* **2008**, *363*, 1737–1746.
77. Gasparri, N.I.; Grau, H.R.; Gutiérrez Angonese, J. Linkages between soybean and neotropical deforestation: Coupling and transient decoupling dynamics in a multi-decadal analysis. *Glob. Environ. Chang.* **2013**, *23*, 1605–1614.
78. Alkemade, R.; Reid, R.S.; van den Berg, M.; de Leeuw, J.; Jeuken, M. Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. *Proc. Natl. Acad. Sci.* **2013**, *110*, 20900–20905.
79. Caro, D.; LoPresti, A.; Davis, S.J.; Bastianoni, S.; Caldeira, K. CH_4 and N_2O emissions embodied in international trade of meat. *Environ. Res. Lett.* **2014**, *9*, 114005.
80. Garnett, T. Livestock-related greenhouse gas emissions: Impacts and options for policy makers. *Environ. Sci. Policy* **2009**, *12*, 491–503.
81. Steinfeld, H.; Gerber, P.; Wassenaar, T.; Castel, V.; Rosales, M.; de Haan, C. *Livestock's Long Shadow: Environmental Issues and Options*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2006.
82. Liu, J.; Hull, V.; Batistella, M.; DeFries, R.; Dietz, T.; Fu, F.; Hertel, T.W.; Izaurralde, R.C.; Lambin, E.F.; Li, S.; *et al.* Framing Sustainability in a Telecoupled World. *Ecol. Soc.* **2013**, *18*, 26.