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Impacts of Global Food Systems on Biodiversity and Water: The Vision of Two Reports and Future Aims

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Recent reports from the EAT-Lancet Commission and the Intergovernmental Panel on Climate Change have highlighted the environmental impacts of food systems and the means of mitigating these impacts in the future. Here, we reflect upon the reports' findings on the effects of agricultural production on biodiversity and water resources and present essential areas for future research.

Introduction

By 2050, almost 10 billion people will need to access an adequate quality and quantity of food. This must be done while minimizing the environmental damage caused by the food system. Many UN Sustainable Development Goals (SDGs) are linked to this aim: SDG 2 (zero hunger), 6 (clean water and sanitation), 13 (climate action), 15 (life on land), and others (e.g., SDGs 1 [no poverty], 12 [consumption], and 14 [life below water]). Although agriculture provides nutrition to an increasing share of the world's population, it is a major driver of negative impacts on the environment. Agricultural production is the greatest threat facing species classed as threatened by the International Union for Conservation of Nature.[1] Indeed, it causes major degradation and fragmentation of habitats as a result of its widespread use of land (30% of ice-free land surface[2]) and inputs (fertilizer, pesticides, and irrigation). In addition, agriculture is the most water-intensive sector, accounting for 90% of freshwater consumption and 70% of withdrawals from freshwater bodies.[3] In many regions, irrigation has led to the overexploitation of rivers, lakes, and aquifers.[4] The use of inputs such as pesticides and fertilizers is also known to damage freshwater and coastal ecosystems. Some of the current agricultural systems are unsustainable because the associated environmental impacts hinder future agricultural production.

Two recent reports have gathered scientific knowledge on the status of land and food systems, as well as on possible future socio-economic pathways, and detail how the environmental and health outcomes of the global food system could be improved. The Intergovernmental Panel on Climate Change (IPCC) Special Report on Climate Change and Land (SRCCL) focuses on the major challenge of achieving carbon-neutral societies (i.e., mitigating and adapting to the impacts of climate change) and aims to understand the risks and opportunities related to land, where terrestrial biodiversity and people live and source much of their food (Figure 1).[5] The report looks not only at how climate change affects land processes but also at how these processes feed back to influence climate change (via increased greenhouse gas [GHG] emissions). The EAT-Lancet report focuses on a subset of this goal (centered on food systems) and presents a broader challenge (by considering human health and environmental impacts other than climate change): providing food for all in a healthy and sustainable manner (Figure 2).[6] The report calls for a radical transformation of the global food system.

Here, we reflect on how these two reports address the impacts of current and potential future food systems on water resources and biodiversity. We first summarize potential solutions to reduce the impacts of food systems on water and biodiversity, as identified by the reports. We then discuss knowledge gaps and suggest areas for future research aimed at delivering food security while conserving functioning biodiversity and maintaining the availability and quality of freshwater resources.

Improving Biodiversity and Water Outcomes of Agriculture

Both reports consider the environmental impacts of food production and consumption. They highlight that observed damages to freshwater resources and biodiversity make agriculture unsustainable because these resources are essential for food production (through the provision of pollination, pest control, and nutrients, as well as rainfall and irrigation). The routes to impacts—habitat change and/or degradation, overuse of fertilizers and pesticides, and unsustainable irrigation (relying on overexploited water sources)—are relatively well understood. Both reports outline various strategies that aim to reduce these impacts of food production.

Change Human Diets

Reducing the consumption of animal products would reduce the land and water use required for growing feed for livestock, thereby potentially alleviating water stress and sparing land for natural habitats. However, these impact reductions depend on how much land and/or water use is required for producing an alternative diet (e.g., the proposed planetary health diet[6]) with globally many more fruits, vegetables, nuts, and pulses and less meat and dairy. These diet shifts would reduce GHG emissions (especially from ruminant products), thereby mitigating climate change and its impacts on water availability and biodiversity. The SRCCL highlights that vegan and

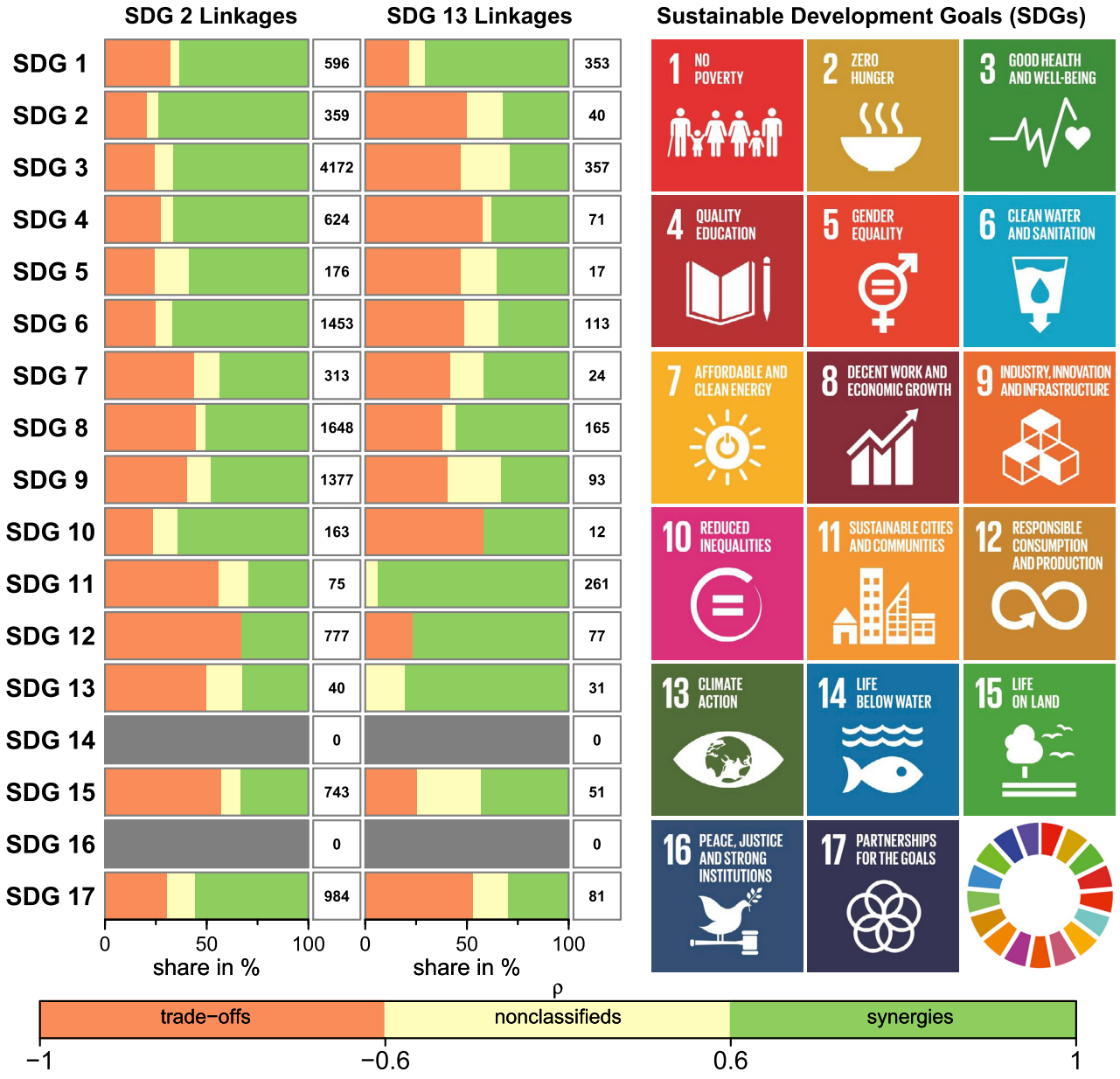

Figure 1. Synergies and Trade-offs between SDGs 2 (Zero Hunger) and 13 (Climate Action) and Other SDGs

The following legend is reproduced exactly as it appears in the IPCC SRCCL: Intra and inter-linkages for SDG 2 (Zero hunger) and SDG 13 (Climate action) at the global level using the official indicators of Sustainable Development Goals that consists data for 122 indicators for a total of 227 countries between the years 1983 and 2016 (United Nations Statistics Division 2016) and applying a statistical approach.[7] Pradhan et al. defined synergy and trade-offs as significant positive ($\rho > 0.6$, red bar) and negative ($\rho < -0.6$, green bar) spearman correlation between SDG indicators, respectively. The ρ between 0.6 and −0.6 is considered as nonclassifieds (yellow bar). The correlation between unique pairs of indicator time-series is carried based on country data, e.g., between "prevalence of undernourishment" (an indicator for SDG 2.1) and "maternalmortality ratio" (an indicator for SDG 3.1). The data pairs can belong to the same goal or to two distinct goals. At the global level, intra-linkages of SDGs are quantified by the percentage of synergies, trade-offs, and nonclassifieds of indicator pairs belonging to the same SDG (here, SDG 2 and SDG 13) for all the countries. Similarly, SDG interlinkages are estimated by the percentage of synergies, trade-offs, and nonclassifieds between indicator pairs that fall into two distinct goals for all the countries. The grey bar shows insufficient data for analysis. The number of data pair used for the analysis is presented in the grey box. Note: here we focus on three interacting goals: 2 (zero hunger), 6 (clean water and sanitation) and 15 (life on land). This graphic shows the relatively high share of synergistic interactions among SDGs 2 and 6, and while synergies exist among 2 and 15, most interactions between these two goals are qualified as trade-offs. Figure 5.16 from the IPCC SRCCL.[5]

vegetarian diets have a large climate-mitigation potential and show no negative impacts across other challenges associated with food production—such as stopping land degradation and ensuring food security. So far there has not been a global estimation of the role of diet changes for climate-change adaptation.

Reduce Food Loss and Waste

Reducing food loss and waste could decrease food production as well as its environmental impacts. Opportunities to

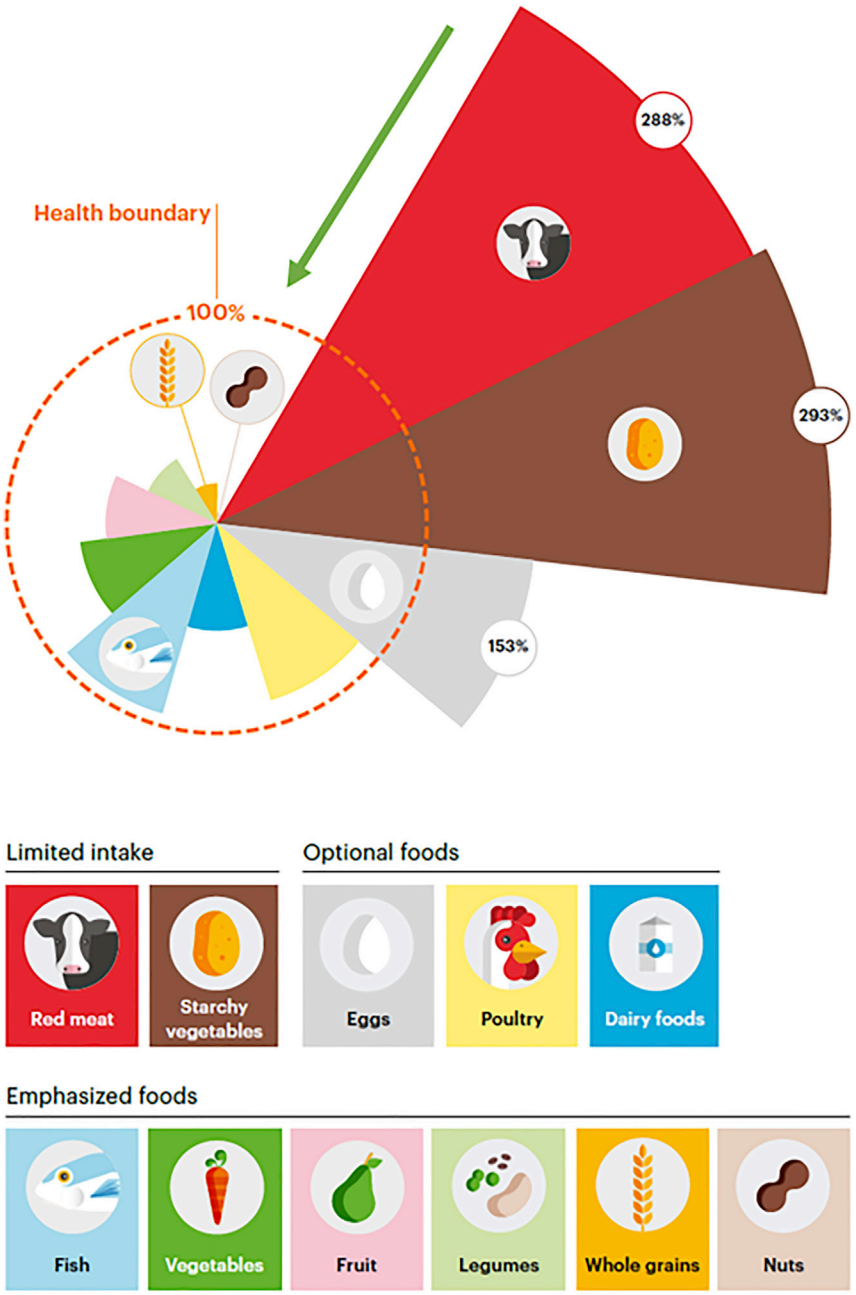

Figure 2. The "Diet Gap" between Current Dietary Patterns and Thresholds of the Planetary Health Boundary at the Global Level

Globally, red meat and starchy vegetables are highly overconsumed, whereas nuts, whole grains, and others are under-consumed. The recommended diet is aimed at improving the health and environmental outcomes of human food production and consumption. Figure adapted from the EAT-Lancet report.[6]

reduce food loss and waste exist all along the supply chain, from the farm (including post-harvest losses) to food retailers to the household level. Reduced waste, and thus less land conversion to agriculture, would be of benefit to biodiversity through the maintenance of less disturbed habitats. This will be particularly beneficial in tropical countries, where both land conversion and biodiversity tend to be high.[8]

Sustainable Intensification of Agriculture

Both reports support the implementation of sustainable intensification: increasing land productivity (e.g., closing yield gaps) with minimal additional environmental impacts. These options can help reduce current and future damages to biodiversity and water given that closing yield gaps means that less land will be needed for producing the same amount of agricultural products, thereby reducing deforestation and degradation, which will alleviate pressures on biodiversity. If agricultural land expansion is necessary, expanding into secondary or managed (rather than primary) habitats will reduce potential biodiversity impacts. Another key part of sustainable intensification is to increase biodiversity within agricultural systems with benefits for services to agriculture, including pollination and pest control. This can be achieved with buffer strips and the planting of field margins. Agricultural water use can also be reduced with improved management. It is recommended that drought-tolerant crop varieties be selected in arid regions and that only deficit and supplemental irrigation be used. Precision-agriculture techniques are recommended to be scaled up and subsidized. This would include management of the crop cultivars used, appropriate timing and rotations of cropping, and other practices with the aim of increasing the efficiency of crop water use. Importantly, overall irrigation water use needs to be controlled to avoid the efficiency paradox leading to increased total water use. Practices to prevent nutrient loss, e.g., nitrogen-fixing cover crops, soil-erosion control, no or low tillage, and improved efficiency of nutrient use, will help to reduce the impact of fertilizer and pesticide application on water quality.

Pathways to a Sustainable Future

The IPCC SRCCL describes the implications of future scenarios on nature's contribution to people, including the benefits provided by biodiversity and water. All future socio-economic pathways assessed in this report result in increased water demand and scarcity. The business-as-usual scenario is particularly detrimental to water resources and biodiversity, and scenarios involving more cropland expansion predict more severe biodiversity loss.

Evidence shows that we are on an unsafe trajectory regarding the goal of a sustainable global food system, but a range of drastic and synergistic solutions could make significant improvements in the future. Several of these solutions are mentioned in both reports (see Table 6.3

in the SRCLL for details[5]). Most options based on land-management responses that do not increase competition for land, or based on value-chain or risk management, can work across challenges, including eradicating poverty and hunger while promoting health, well-being, clean water, and biodiversity.[5] However, some trade-offs between solutions also exist. For example, many climate-mitigation options lead to increased competition for land. Where and how land is used can therefore vary greatly and could result in increased impacts on biodiversity and water. Expansion of the current area of managed land into natural ecosystems could have negative consequences for other land challenges (e.g., reduced carbon sequestration by land systems) and lead to a loss of biodiversity. Importantly, many response options are also scale specific.

Both reports agree that there is no one single option: achieving sustainable and healthy food systems necessitates both production-side (e.g., sustainable intensification and the reduction of food loss) and consumption-side (e.g., dietary change and the reduction of food waste) measures. Most importantly, this is a global problem, so addressing it will require coordinated actions across regions and scales.

Research Needs

Both the IPCC and EAT-Lancet reports present the large-scale impacts of food production on the environment and highlight the need for dramatic changes to current food production and consumption. However, certain areas of research would greatly benefit from further study. Considerable research has been undertaken on the impacts of food production and potential strategies to alleviate these impacts. However, it is not clear how these solutions scale up to the global level.

More research is also needed to elucidate the interlinkages between challenges and the synergies or trade-offs between mitigation options. Bilateral interactions and feedbacks between food production and biodiversity or water resources are less well known than the direct impacts of agriculture on biodiversity or water. Understanding feedbacks and the consequences of choices will be important for determining future impacts. Here, we highlight those areas that would benefit from future research and focus on the need to protect biodiversity and water resources in a future of increased food demand.

Understanding Biodiversity-Agriculture Interactions

Biodiversity-agriculture interactions at the global scale require further analysis. In particular, we need improved understanding of the biodiversity services that are essential to agricultural production (e.g., pollination services), the consequences of their loss, and the benefits of their maintenance across large scales. There have been local- and regional-scale studies of biodiversity-agriculture relationships,[9–11] but how do these synergies and trade-offs scale up? The EAT-Lancet report recommends solving the issue of competition for land between agriculture and biodiversity with the Half Earth approach, but this strategy and its consequences are still debated among ecologists. The SRCCL discusses land sharing and land sparing and concludes that both approaches are not mutually exclusive and that one or the other can be appropriate for various local contexts. The role of biodiversity in the provision of ecosystem services and the decline of these services due to human impacts is discussed in detail in another global report: the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) Global Assessment Report on Biodiversity and Ecosystem Services.[12] However, there is still scope for a greater understanding of the interactions and feedbacks within this complicated system, particularly with a focus on large scales.

Adapting Global Food Systems for Planetary Health

How can we adapt the production system at the global scale to provide healthy and sustainable food? If the mix of products grown needs to be changed to provide for healthier diets, what will the various environmental consequences be? On the consumption side, some synergies such as the fact that less ruminant meat is beneficial for both health (where this product is currently over-consumed) and climate change (due to methane) have been identified,[5,6,13] but other environmental impacts of alternative products or farming systems, such as on water or biodiversity, are not always well integrated. Dietary analyses are predominantly comparing the effects of different product compositions of diets with a focus on GHG-emission intensity for the SRCCL and with a focus on health outcomes for the EAT-Lancet report. This leads to recommendations such as to reduce the consumption of ruminant meat and dairy products and to increase the intake of fruits, vegetables, nuts, and pulses, especially in developed countries. Increased intake of pulses and vegetables will require significant increases in the production of these foods, and the associated environmental impacts need to be considered. Would agricultural expansion be needed, e.g., could current pasture be used for crops? Or could this be achieved with sustainable intensification? There is still debate about the water and biodiversity impacts of extensive grassland versus mixtures of natural vegetation and intensive cropland, for example. Understanding how the proposed diet changes will be accomplished, and where, will be key to understanding the interactions with biodiversity and water.

The Role of Global Food Trade

International food trade plays an important role in the causation and distribution of the environmental impacts of food production. Biodiversity loss and water stress due to food production are often driven by the demand from other countries; this is particularly true for tropically grown products imported by developed countries.[4,14–16] So, although national-level environmental impacts might not be high in the demanding region, the imported impacts could be great.[17] These impacts could result from increased production leading to the clearing of primary vegetation or from production in unsuitable areas resulting in the over-application of inputs such as fertilizer and irrigation. There is the potential to restructure production and trade so that products are grown in the most appropriate regions or are managed in a more sustainable way. However, this would be a large-scale operation with interventions most likely affecting local communities. Considering the role of trade feedbacks within the system of food production and consumption and how these outside influences affect biodiversity and water on the ground is key to understanding the system as a whole.

Need for Global Action on All Fronts

The two reports present the vast evidence base for the impacts of the current food-production system on the environment and the whole-system changes that will be required in a future with not only an

increased human population but also a changing climate. This challenge is not one that can be met by individuals, communities, or countries in isolation; it will require global and coordinated action. The EAT report calls for "radical change" in the global system, and the SRCCL report states that "coordinated action to tackle climate change can simultaneously improve land, food security and nutrition, and help to end hunger." It also states that "the land that we are already using could feed the world in a changing climate and provide biomass for renewable energy, but it would require early, far-reaching action across several fronts." Implementing and delivering such socio-economic transformations is not straightforward. We believe that research on the socio-economic, political, and cultural aspects of food systems—supporting political and behavioral changes—is urgently needed.

Conclusion

Both the EAT-Lancet report and the IPCC SRCCL describe the impacts of the food production system and present potential strategies for a system that would feed the rising population sustainably. However, there is no simple fix. Multiple strategies and solutions are available, and their implementation will require a better understanding of interactions within the global food system and a coordinated global effort. Transdisciplinary approaches will be important for effectively improving our understanding of these synergies and trade-offs and helping to provide solutions to the challenge of sustainably feeding the world. Ongoing research plans—such as the IPBES project to carry out a thematic "nexus" assessment of the interlinkages among biodiversity, water, food, and health—are aligned with our reflection. We think such an effort will be highly valuable and that the underlying science, although already providing solid evidence, can be further developed to address the current knowledge gaps we have highlighted.

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