Impacts of global food systems on biodiversity and water: the vision of two reports and future aims.

Carole Dalin[1]* and Charlotte L Outhwaite[2]

[1] Institute for Sustainable Resources, Bartlett School of Environment, Energy and Resources, University College London, London, United Kingdom

[2] Centre for Biodiversity and Environment Research, Gower Street, University College London, London, United Kingdom

* Corresponding author: c.dalin@ucl.ac.uk

Summary

Recent reports from the EAT-Lancet Commission and IPCC have highlighted the environmental impacts of food systems and means to mitigate these 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 adequate quality and quantity of food. This must be done while minimising the environmental damage caused by the food system. Many U.N. 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. 1: no poverty, 12: consumption, 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 IUCN[1]. Indeed, it causes major degradation and fragmentation of habitats due to its widespread use of land (30% of ice-free land surface[2]) and inputs (fertiliser, 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. In many regions, irrigation has led to the overexploitation of rivers, lakes and aquifers. The use of inputs such as pesticides and fertilisers are also known to damage freshwater and coastal ecosystems. Some of the current agricultural systems are unsustainable as the associated environmental impacts hinder future agricultural production.

Two recent reports have gathered scientific knowledge on the status of land and food systems, and on possible future socio-economic pathways, detailing how the environmental and health outcomes of the global food system could be improved. The 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[3] (Figure 1). The report not only looks at how climate change impacts land processes but also at how these processes feedback to influence climate change (via increased greenhouse gas (GHG) emissions). The EAT-Lancet report focuses on a subset of this goal (centred on food systems) and presents a broader challenge (considering other environmental impacts than climate change, and human health): to provide *food* for all in a *healthy* and *sustainable* manner[4] (Figure 2). 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 summarise 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.

Improve 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 provision of pollination, pest control, nutrients; rainfall and irrigation). Routes to impacts are relatively well understood: habitat change/degradation, overuse of fertilisers/pesticides and unsustainable irrigation (reliance on overexploited water sources). Both reports outline various strategies that aim to reduce these impacts of food production.

Change human diets.

Reducing consumption of animal products would reduce the land and water use required to grow feed for livestock, thereby potentially alleviating water stress and sparing land for natural habitat. However, these impact reductions depend on how much land/water use is required to produce an alternative diet (e.g. the planetary health diet proposed by EAT), with much more fruit/vegetables, nuts/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 veg(etari)an 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.

By reducing food loss and waste, food production can decrease and so could its environmental impacts. There are opportunities to reduce food loss and waste all along the supply chain, from the farm – including post-harvest losses – to the food retailers and at the household level. Reduced waste, and so 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[5].

Sustainable intensification of agriculture.

Both reports support the implementation of sustainable intensification: the increase of 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, since closing yield gaps means that less land will be needed to produce the same number of agricultural products, reducing deforestation and degradation, which will reduce pressures on biodiversity. If agricultural land expansion is necessary, expanding into secondary or managed habitat (rather than primary) 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 using buffer strips and field margin planting. Agricultural water use can also be reduced with improved management. It is recommended that drought-tolerant crop varieties are selected in arid regions and only deficit and supplemental irrigation used. Precision agriculture techniques are recommended to be scaled up and subsidised. This would include management of crop cultivars used, appropriate timing and rotations of cropping and other practises with the aim of increasing crop water use efficiency. Importantly, overall irrigation water use needs to be controlled to avoid the efficiency paradox leading to increased total water use. Practises to prevent nutrient loss, e.g. nitrogen-fixing cover crops, soil erosion control, no or low tillage, and improved nutrient use efficiency will help to reduce impact of fertiliser and pesticide application on water quality.

Pathways to a sustainable future.

The IPCC SRCCL has a focus on the implications of future scenarios on nature's contribution to people, including 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 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 IPCC report for detail[3]). Most options based on land management responses that do not increase competition for land, or are based on value chain / risk management, can work across challenges (IPCC SRCLL), including eradicating poverty and hunger while promoting health, well-being, clean water and biodiversity. 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 (for example, reduced carbon sequestration by land systems) and lead to the loss of biodiversity. Importantly, many response options are also scale specific.

Both reports agree that there is no one single option: multiple actions are required to stay within planetary boundaries and both production side (e.g. sustainable intensification, food loss reduction) and consumption-side (e.g. dietary change, food waste reduction) measures are needed to achieve sustainable and healthy food systems. Most importantly, this is a global problem, so coordinated change across regions and scales is required to address it.

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, there are areas of research that 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 understand the interlinkages between challenges and the synergies and 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 on biodiversity or water. Understanding feedbacks and consequences of choices will be important for determining future impact. Here, we highlight those areas that would benefit from future research with a 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 services provided by biodiversity 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 (e.g. [6–8]), 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, concluding 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 their decline due to human impacts is discussed in detail in another global report: the IPBES Global Assessment Report on Biodiversity and Ecosystem Services[9]. 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 across dimensions be? On the consumption side, some synergies have been identified such as less ruminant meat being beneficial for health (where this product is currently over-consumed) and climate change[3,4,10] (due to methane), 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 composition 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 ruminant meat and dairy products consumption and to increase intake of fruit/vegetables and nuts/pulses, especially in developed countries. Increased intake in pulses and vegetables will require significant increases in production of these foods and the associated environmental impacts need to be considered. Would agricultural expansion be needed, e.g. can current pasture be used for crops? Or can this be achieved with sustainable intensification? There is still a 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[11-14]. So, although national-level environmental impacts may not be high in the demanding region, the imported impacts may be great[15]. These impacts may result from increased production leading to the clearing of primary vegetation, or production in unsuitable areas resulting in the over-application of inputs such as fertiliser 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 likely impacting local communities. Considering the role of feedbacks of trade within the food production and consumption system 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 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 under climate change. This challenge is not one that can be met by individuals, communities or countries in isolation, but 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, cultural aspects of food systems, supporting political and behavioural 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 to effectively improve our understanding of these synergies and trade-offs and help provide solutions to the challenge of sustainably feeding the world. Ongoing research plans are aligned with our reflection, such as the IPBES project to carry out a thematic "nexus" assessment of the interlinkages among biodiversity, water, food and health. We think such effort will be highly valuable and that the underlying science, while providing already solid evidence, can be further developed to address the current knowledge gaps we have highlighted.

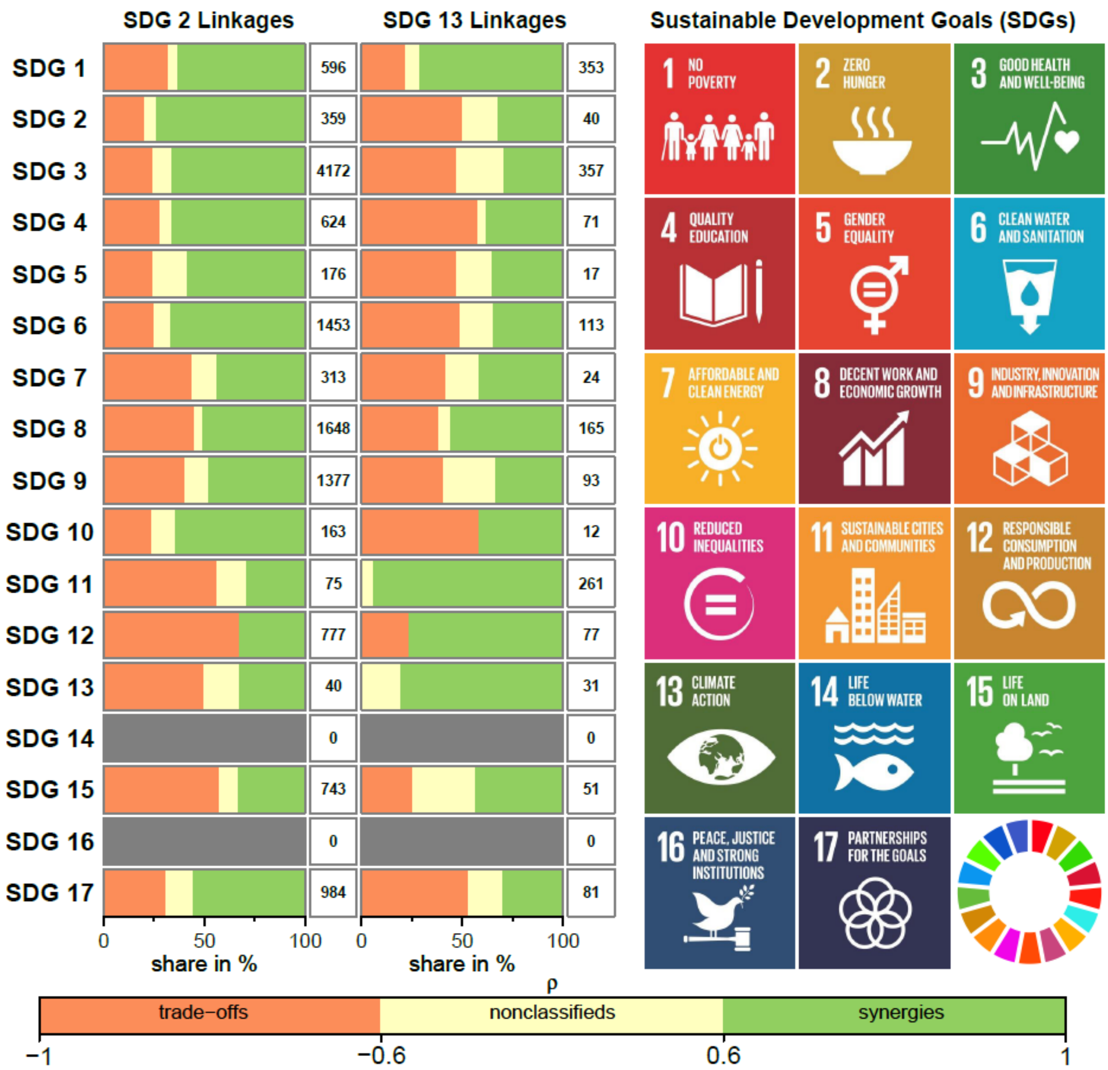

Figure 1. Intra and inter-linkages for SDG 2 (Zero hunger) and SDG 13 (Climate action) at the global level using the official indicators of Sustainable Development Goals that consists data for 122 indicators for a total of 227 countries between the years 1983 and 2016 (United Nations Statistics Division 2016) and applying a statistical approach[16]. 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*[3].

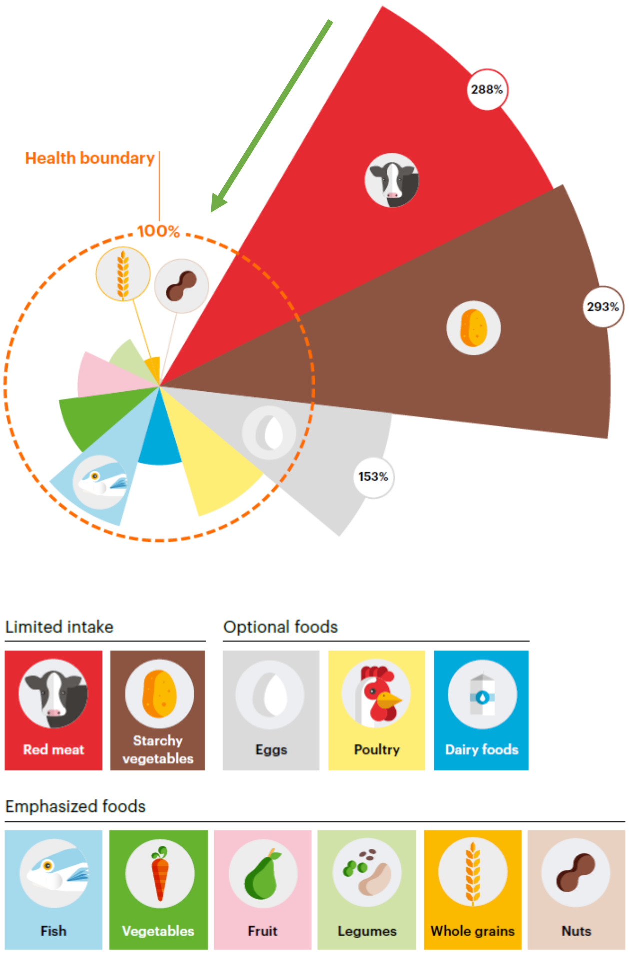

Figure 2. The "diet gap" between current dietary patterns and thresholds of the planetary health boundary, at the global level. Globally, red meat and starchy vegetables are highly overconsumed while nuts, whole grains and others are under-consumed. The recommended diet is aimed at improving health and environmental outcomes of human food production and consumption. Figure taken and adapted from the EAT-Lancet Report[4].

References

1. Maxwell, S.L., Fuller, R.A., Brooks, T.M., and Watson, J.E.M. (2016). Biodiversity: The ravages of guns, nets and bulldozers. Nature *536*, 143–145. Available at: http://www.nature.com/doifinder/10.1038/536143a [Accessed January 9, 2019].

2. Ramankutty, N., Evan, A.T., Monfreda, C., and Foley, J.A. (2008). Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Global Biogeochem. Cycles *22*, n/a-n/a. Available at: http://doi.wiley.com/10.1029/2007GB002952 [Accessed October 29, 2018].

3. IPCC (2019). Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (SRCCL). IPCC. Available at: https://www.ipcc.ch/report/srccl/ [Accessed August 28, 2019].

4. Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., *et al.* (2019). Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. Lancet (London, England) *393*, 447–492. Available at: http://www.ncbi.nlm.nih.gov/pubmed/30660336 [Accessed October 16, 2019].

5. Wright, S.J. (2005). Tropical forests in a changing environment. Trends Ecol. Evol. *20*, 553–560. Available at: https://www.sciencedirect.com/science/article/pii/S016953470500251X?via%3Dihub [Accessed October 16, 2019].

6. Garratt, M.P.D., Bishop, J., Degani, E., Potts, S.G., Shaw, R.F., Shi, A., and Roy, S. (2018). Insect pollination as an agronomic input: Strategies for oilseed rape production. J. Appl. Ecol. *55*, 2834–2842. Available at: http://doi.wiley.com/10.1111/1365-2664.13153 [Accessed October 16, 2018].

7. Woodcock, B.A., Isaac, N.J.B., Bullock, J.M., Roy, D.B., Garthwaite, D.G., Crowe, A., and Pywell, R.F. (2016). Impacts of neonicotinoid use on long-term population changes in wild bees in England. Nat. Commun. *7*, 12459. Available at: http://www.nature.com/doifinder/10.1038/ncomms12459 [Accessed August 23, 2016].

8. Tsiafouli, M.A., Thébault, E., Sgardelis, S.P., de Ruiter, P.C., van der Putten, W.H., Birkhofer, K., Hemerik, L., de Vries, F.T., Bardgett, R.D., Brady, M.V., *et al.* (2015). Intensive agriculture reduces soil biodiversity across Europe. Glob. Chang. Biol. *21*, 973–985. Available at: http://doi.wiley.com/10.1111/gcb.12752 [Accessed October 29, 2018].

9. IPBES (2019). Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Bonn, Germany: IPBES secretariat).

10. Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B.L., Lassaletta, L., de Vries, W., Vermeulen, S.J., Herrero, M., Carlson, K.M., *et al.* (2018). Options for keeping the food system within environmental limits. Nature. Available at: https://doi.org/10.1038/s41586-018-0594-0.

11. Chaudhary, A., and Kastner, T. (2016). Land use biodiversity impacts embodied in international food trade. Glob. Environ. Chang. *38*, 195–204. Available at: https://www.sciencedirect.com/science/article/pii/S0959378016300346?via%3Dihub [Accessed February 1, 2019].

12. Dalin, C., Wada, Y., Kastner, T., and Puma, M.J. (2017). Groundwater depletion embedded in international food trade. Nature *543*, 700–704. Available at: http://www.nature.com/articles/nature21403 [Accessed May 23, 2018].

13. Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L., and Geschke, A. (2012). International trade drives biodiversity threats in developing nations. Nature *486*, 109–112. Available at: http://www.nature.com/articles/nature11145 [Accessed April 10, 2019].

14. D'Odorico, P., Carr, J., Dalin, C., Dell'Angelo, J., Konar, M., Laio, F., Ridolfi, L., Rosa, L., Suweis, S., Tamea, S., *et al.* (2019). Global virtual water trade and the hydrological cycle: patterns, drivers, and socio-environmental impacts. Environ. Res. Lett. *14*, 053001. Available at: https://iopscience.iop.org/article/10.1088/1748-9326/ab05f4 [Accessed October 23, 2019].

15. MacDonald, G.K., Brauman, K.A., Sun, S., Carlson, K.M., Cassidy, E.S., Gerber, J.S., and West, P.C. (2015). Rethinking Agricultural Trade Relationships in an Era of Globalization. Bioscience *65*, 275–289. Available at: http://academic.oup.com/bioscience/article/65/3/275/237019/Rethinking-Agricultural-Trade-Relationships-in-an.

16. Pradhan, P., Costa, L., Rybski, D., Lucht, W., and Kropp, J.P. (2017). A Systematic Study of

Sustainable Development Goal (SDG) Interactions. Earth's Futur. *5*, 1169–1179. Available at: http://doi.wiley.com/10.1002/2017EF000632 [Accessed October 16, 2019].