This is a repository copy of Linking global drivers of agricultural trade to on-the-ground impacts on biodiversity.

White Rose Research Online URL for this paper:
http://eprints.whiterose.ac.uk/152881/

Version: Published Version

Article:
Green, Jonathan Michael Halsey orcid.org/0000-0002-5003-0203, Croft, Simon, Durán, A. Paz et al. (9 more authors) (2019) Linking global drivers of agricultural trade to on-the-ground impacts on biodiversity. Proceedings of the National Academy of Sciences of the United States of America. ISSN 1091-6490

https://doi.org/10.1073/pnas.1905618116

Reuse
This article is distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivs (CC BY-NC-ND) licence. This licence only allows you to download this work and share it with others as long as you credit the authors, but you can’t change the article in any way or use it commercially. More information and the full terms of the licence here: https://creativecommons.org/licenses/

Takedown
If you consider content in White Rose Research Online to be in breach of UK law, please notify us by emailing eprints@whiterose.ac.uk including the URL of the record and the reason for the withdrawal request.
Linking global drivers of agricultural trade to on-the-ground impacts on biodiversity

Jonathan M. H. Greena,b,1, Simon A. Crofta, América P. Durana,b,c,d,2, Andrew P. Balmfordb, Neil D. Burgessd,e, Steve Fickf, Toby A. Gardnerea, Javier Godara, Clément Suavaetb, Malika Virah-Sawmymb,g, Lucy E. Youngb, and Christopher D. Westa

aStockholm Environment Institute York, Department of Environment and Geography, University of York, York YO10 5NG, United Kingdom; bLuc Hoffmann Institute, WWF International, 1196 Gland, Switzerland; cConservation Science Group, Department of Zoology, University of Cambridge, Cambridge CB2 3QZ, United Kingdom; dUnited Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), Cambridge, CB3 0DL, United Kingdom; eCenter for Macroecology, Evolution, and Climate, University of Copenhagen, 2100 Copenhagen, Denmark; fStockholm Environment Institute, 115 23 Stockholm, Sweden; gGeography Department, Humboldt-Universität zu Berlin, Alfred-Rühl-Haus, 12489 Berlin, Germany; and hWWF UK, Science, The Living Planet Centre, Rufford House, Woking GU21 4LL, United Kingdom

Edited by Carl Folk, Royal Swedish Academy of Sciences, Stockholm, Sweden, and approved September 26, 2019 (received for review April 2, 2019)

Consumption of globally traded agricultural commodities like soy and palm oil is one of the primary causes of deforestation and biodiversity loss in some of the world’s most species-rich ecosystems. However, the complexity of global supply chains has confounded efforts to reduce impacts. Companies and governments with sustainability commitments struggle to understand their own sourcing patterns, while the activities of more unscrupulous actors are conveniently masked by the opacity of global trade. We combine state-of-the-art material flow, economic trade, and biodiversity impact models to produce an innovative approach for understanding the impacts of trade on biodiversity loss and the roles of remote markets and actors. We do this for the production of soy in the Brazilian Cerrado, home to more than 5% of the world’s species. Distinct sourcing patterns of consumer countries and trading companies result in substantially different impacts on endemic species. Connections between individual buyers and specific hot spots explain the disproportionate impacts of some actors on endemic species and individual threatened species, such as the particular impact of European Union consumers on the recent habitat losses for the iconic giant anteater (Myrmecophaga tridactyla). In making these linkages explicit, our approach enables commodity buyers and investors to target their efforts much more closely to improve the sustainability of their supply chains in their sourcing regions while also transforming our ability to monitor the impact of such commitments over time.

Sustainability in supply chains will need clear and measurable targets, pathways to achieve them, and accountability (12, 14). Moreover, commitments of different stakeholders do not operate in isolation and when aligned can reinforce one another. However, the lack of methods and data to integrate policy and business perspectives prevents the design and implementation of strategies to create opportunities or regulate for more sustainable business (12, 15).

Here we combine state-of-the-art material flow, economic, and biodiversity models that link demand, trade, production, and impact. We use a species-level estimate of loss, which allows us to differentiate habitats that host the most vulnerable species from those that do not but which would appear similar or identical if broader classifications (e.g., “forest” or “natural vegetation”) were used. Our results reveal the impacts of agricultural commodity trade on biodiversity with unprecedented spatial, sectoral, operational, and taxonomic resolution.

We use our framework to answer 4 questions that together provide information for reducing biodiversity losses associated with agricultural commodity demand. First, which countries and sectors drive impacts? Understanding the role of specific

Significance

Agricultural commodity production causes significant biodiversity losses, yet our globalized supply chains mean that these losses are incurred far from the places of eventual consumption. Public and private sector actors are making an increasing number of commitments to reduce their environmental impacts; to date, however, we have had limited understanding of 1) impacts at high spatial and taxonomic resolution and 2) particular consumption drivers and supply chain actors mediating trade and consumption. Without these, it is difficult to devise solutions. We link 3 state-of-the-art models to provide practical insights on the impacts of soy grown in the Brazilian Cerrado, an exceptionally biodiverse savannah that hosts some 5% of the world’s species.

Author contributions: J.M.H.G., A.P.D., A.P.B., T.A.G., M.V.-S., L.E.Y., and C.D.W. designed research; J.M.H.G., S.A.C., A.P.D., S.F., J.G., C.S., and C.D.W. performed research; J.M.H.G., S.A.C., S.F., J.G., and C.S. analyzed data; and J.M.H.G., S.A.C., A.P.D., N.D.B., T.A.G., J.G., M.V.-S., L.E.Y., and C.D.W. wrote the paper. The authors declare no competing interest.

This article is a PNAS Direct Submission.

This open access article is distributed under Creative Commons Attribution-NonCommercial-NoDerivatives License 4.0 (CC BY-NC-ND).

Data deposition: Trase data are freely and publicly available at https://trase.earth.

1To whom correspondence may be addressed. Email: jonathan.green@york.ac.uk.
2Present address: Instituto de Ciencias Ambientales y Evolutivas, Universidad Austral de Chile, Valdivia 5090000, Chile.

This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1905618116/-/DCSupplemental.
consumption patterns and the responsibilities of consumers around the globe helps inform national and international policy making. Second, what are the relative roles of different commodity traders? Detailed supply chain information can help to identify and develop partnerships for solutions. Third, what are the impacts on high-profile species and important species assemblages? Highly resolved information on biodiversity impacts can galvanize support from consumer groups and provide information for particular interventions around specific species and risk hot spots. Fourth, how do government and private commitments overlap? Understanding the commitments of diverse actors along the supply chain can help identify where commitments coincide and hence where actions might be aligned to reinforce one another.

We work through our framework using the example of Brazilian soy production. Brazil is one of the world’s largest producers and exporters of soy, a globally important commodity embedded within many food products, particularly because of its use as a source of protein in animal feed. In Brazil, soy production is closely associated with the Cerrado (16, 17), which is the largest savannah region in South America and hosts some 5% of global biodiversity, including over 4,800 plant and vertebrate species found nowhere else (18). It is also one of the world’s most important frontiers of agricultural expansion, with many of its species facing dire threat (16–20). Our approach produces insights into the connections between markets, soy traders, and biodiversity losses at the point of production. We consider these in the context of 2 high-profile collective commitments: the New York Declaration on Forests, a voluntary declaration by private-, public-, and third-sector parties with a commitment to end forest loss by 2030 (21), and the Amsterdam Declaration, a commitment by 7 European countries to eliminate deforestation from agricultural commodity chains (22). These commitments are a recognition that things need to change; meeting them, however, requires a dramatic scaling up of action.

**Results**

**Which Countries and Sectors Are Driving Impacts?** Information that identifies the relative roles of different countries—and sectors within them—can guide coherent action among consumer nations to drive more sustainable production practices and provision of support to key industry actors (6). The top 10 countries importing embedded soy from the Cerrado are Asian, European, and North American (Table 1). However, while international demand, especially from China, drives more than half of soy’s impacts on endemic Cerrado biodiversity, the domestic market is responsible for the greatest share of any country, with consumption across all of Brazil driving 45% of soy-related impacts (Table 1 and SI Appendix, Table S1). We consider these findings against country-level commitments to 2 key declarations that aim to support companies in eliminating deforestation from agricultural commodity supply chains. The first is the New York Declaration on Forests. This has been signed at the national or local government level by most of the countries with the greatest soy-linked biodiversity impacts in the Brazilian Cerrado, but the 2 countries with the greatest impact are notably absent (Table 1). The second is the Amsterdam Declaration, for which 5 of the 7 European signatories are among the top 10 importers of soy-driven biodiversity impacts in the Cerrado: Italy, France, Germany, the United Kingdom, and the Netherlands (Table 1).

Alongside the amount of soy consumed, the impact per unit consumed also varies greatly between countries. Brazil and Italy, for example, have over twice the impact per unit of soy consumed than China, France, or the United States. The 2 largest consuming countries, Brazil and China, consume similar amounts of soy from the Cerrado but show particularly high and low impacts per ton, respectively (Fig. 1A). These differences arise from differences in biodiversity losses in the municipalities from which particular supply chains source soy. By combining high-resolution trade data with impacts on biodiversity we find that Brazilian consumer demand was met to a greater extent by municipalities in the central and southern Cerrado, where endemic richness is higher and impacts are thus greater (Fig. 1B and C and SI Appendix, Fig. S1). Chinese demand, on the other hand, was met from a more tightly concentrated area in the northeast (Fig. 1C).

By linking direct material flows to global financial data, our approach also captures both the reexports of soy (for example, much of the soy consumed in Europe arrives via ports in the Netherlands, from where it is reexported) and the consumption of soy embedded in other products, such as in meat fed on soy-derived feed. The Netherlands is a globally important trade hub, receiving much of the soy coming directly from Brazil into the European Union (EU) (Fig. 1D). However, tracking supply chains only to the country of first import greatly overestimates the country’s role as a driver of biodiversity loss, while for other Amsterdam Declaration (AD) countries their role is substantially underestimated unless we consider reexports and embedded consumption of soy (Fig. 1D).

### Table 1. The countries whose embedded consumption of soy from the Cerrado in 2011 is estimated to have the greatest impact on endemic biodiversity (domestic plus top 10 international consuming countries)

| Consuming region | Relative impact | Relative impact/mass consumed | Commitment |
|------------------|----------------|------------------------------|------------|
| Brazil           | 44.9%          | 0.87                         | *          |
| China            | 22.0%          | 0.38                         |            |
| Japan            | 2.9%           | 0.52                         | NYDF       |
| Germany          | 2.7%           | 0.49                         | NYDF/AD    |
| Spain            | 2.5%           | 0.61                         | *          |
| Thailand         | 2.3%           | 0.55                         |            |
| United States    | 1.9%           | 0.36                         | NYDF       |
| United Kingdom   | 1.8%           | 0.46                         | NYDF/AD    |
| France           | 1.8%           | 0.33                         | NYDF/AD    |
| Netherlands      | 1.4%           | 0.60                         | NYDF/AD    |
| Italy            | 1.2%           | 0.87                         | AD         |

Relative impact per unit mass of soy consumed from 0 (no impact) to 1 (greatest observed impact across all consuming regions). We highlight country commitments to the New York Declaration on Forests (NYDF) and Amsterdam Declaration (AD). Asterisks indicate local, but not national, government signatories to NYDF. See also SI Appendix, Table S1.
Sectoral drivers of biodiversity loss vary markedly between countries. In the case of AD countries, particularly Germany and the United Kingdom, our results highlight the importance of "other meat" (primarily pig and poultry) consumption (Fig. 1E). For Italy and Norway, on the other hand, dairy and beef sectors contribute a relatively larger proportion of their biodiversity footprint.

**What Are the Relative Roles of Different Traders?** For the Cerrado we estimate that between 2000 and 2010, 33% of soy’s impacts on endemic species were in Goiás State, which occupies just 16% of the biome (SI Appendix, Fig. S2 and Table S2). Of 41 traders exporting soy from Goiás in 2011, the top 10 account for 91% of exports. Disaggregating the data to the municipality level reveals the highly clustered nature of company operations (SI Appendix, Fig. S2). The largest exporter in each municipality accounts for a mean of 97% of exports. Just 5 traders account for all soy exports from the 3 most heavily affected municipalities, which together incur 56% of the state’s soy-driven biodiversity losses but cover <4% of the area.

**What Are the Impacts on High-Profile Species and Important Species Assemblages?** Quantifying how consumption drives losses of charismatic, culturally important, or valuable species and habitats can raise the profile of environmental issues and bring into focus the tangible impacts and risks of sourcing from a particular area (23). The spatial and taxonomic resolution of the component models in our framework enables fine-scale, species-specific information that is typically masked in national-level analyses. To illustrate this, we compare impacts of soy-driven habitat loss on 2 iconic species, the maned wolf (*Chrysocyon brachyurus*) and giant anteater (*Myrmecophaga tridactyla*), with impacts on endemic species, and characterize these as flows from the state in which the losses occur through to the country of final consumption of the impact-linked soy (Fig. 2). This reveals some striking patterns
resulting from differences between the threats facing different species and from differences in sourcing between consuming countries. For example, the majority of the EU’s impact on the maned wolf is in Mato Grosso, while for Brazil it is in other states. This has implications for the targeting of conservation interventions by downstream actors wanting to mitigate specific impacts associated with their activities. We also found that the giant anteater’s range has been more heavily impacted by past habitat loss than that of the maned wolf [which better tolerates pasture and arable land (17)] and that the EU has played a large role in recent losses, with impacts mostly arising in Mato Grosso. Unlike for the maned wolf and giant anteater, losses in Goiás and Distrito Federal dominate impacts across endemic species, largely due to the high number of endemics, particularly plants, found in these states (Fig. 2 and SI Appendix, Fig. S1).

How Do Government and Private Commitments Overlap? In 2011, companies with zero-deforestation commitments were responsible for ∼80% of soy imports for France, Germany, and the United Kingdom (Fig. 3 and SI Appendix, Table S3). The Netherlands, on the other hand, has a more diverse supplier base, with ∼50% supplied by traders with zero-deforestation commitments.

Fig. 2. Chord diagrams showing impacts on likelihood of persistence due to soy expansion between 2000 and 2010 for 2 charismatic species (Top) and for all endemics (Bottom Left). Losses are calculated for each municipality according to the total embedded flows of soy and then aggregated to state level for visualization. Chords show the flow from states on the left-hand side (BA = Bahia, dark blue; DF = Distrito Federal, gray; GO = Goiás, red; MA = Maranhão, cyan; MG = Minas Gerais, light green; MS = Mato Grosso do Sul, purple; MT = Mato Grosso, dark green; PI = Piauí, pink; PR = Paraná, dark olive green; RO = Rondônia, brown; SP = São Paulo, dark gray; TO = Tocantins, gold) through to the country or region of final consumption on the right-hand side (Brazil, South America, North America, European Union, India, China, and the rest of world). The proportion of remaining suitable habitat within the Cerrado for the 2 species (Bottom Right) and the mean for all endemic species. Light gray: suitable habitat lost from the preindustrial era to the year 2000; red: losses during the 2000 to 2010 study period (as represented in the chord diagrams); medium gray: losses between 2010 and 2014; dark gray: remaining suitable habitat in 2014.
most significant hubs for trade. The Netherlands is the largest
important opportunities for intervention, so too can identifying the
final consumption. However, in the same way that identifying key
estimate (e.g., the Netherlands) impacts attributed to a country
severely underestimate (e.g., Denmark and Norway) and over-
Strategy, which aims to reduce Cerrado deforestation by 95%
Mato Grosso, an important soy-producing state within the Cer-
signed key declarations at the national level (although note that
may push the sustainability bar higher for smaller or newer actors
toward their own commitments to eliminate deforestation and
15). If supporting companies make good on their commitments,
trader commitments will help identify where action should be
(12, 15). Understanding alignment between government and
supply chains vary widely in their detail, ambition, and meaning
for international supply chains that span
larly smaller volumes, such as the United Kingdom, France, and
Germany, may help the Netherlands government to encourage
currently uncommitted yet major traders such as Caramuru and
Granol to sign up to targets to eliminate deforestation from their
supply chains.

Fig. 3. Alignment of government commitments with sustainability goals of
key traders. Chord diagram representing direct soy trade from the Brazilian
Cerrado to the 7 countries of the Amsterdam Declaration from the largest
traders in 2011 (companies shown were among the top 3 traders in 2011 for
at least one of the countries; companies trading smaller volumes are ag-
eggregated and shaded gray). Green shaded chords indicate exports via com-
panies with zero-deforestation commitments; orange and brown shades indicate no such commitment (data from company websites as of December 2018).

Discussion
It is encouraging that many of the countries and traders most
exposed to the risks of deforestation and biodiversity loss in their
supply chains have joined high-profile declarations to eliminate
deforestation from their supply chains (e.g., refs. 21, 22, and 24).
However, company commitments to reducing deforestation in
supply chains vary widely in their detail, ambition, and meaning
(12, 15). Understanding alignment between government and
trader commitments will help identify where action should be
focused, reveal potential leverage points, and help foster co-
ordinated solutions for international supply chains that span
multiple stakeholders across the private–public interface (12,
15). If supporting companies make good on their commitments,
this would in turn help governments make significant progress
toward their own commitments to eliminate deforestation and
may push the sustainability bar higher for smaller or newer actors
in the European market. Within our analyses, the 2 countries
with the greatest overall impacts, Brazil and China, have not yet
signed key declarations at the national level (although note that
Mato Grosso, an important soy-producing state within the Cer-
rado, has committed to its Produce, Conserve, and Include
Strategy, which aims to reduce Cerrado deforestation by 95%
and to restore habitat; ref. 25).

Attributing impacts to the country of first import can both
severely underestimate (e.g., Denmark and Norway) and over-
estimate (e.g., the Netherlands) impacts attributed to a country’s
final consumption. However, in the same way that identifying key
traders operating within the supply chain can help identify im-
portant opportunities for intervention, so too can identifying the
most significant hubs for trade. The Netherlands is the largest
importer of soy in Europe and the second-largest exporter of
agricultural products in the world (26). It also processes ∼25% of
its soy imports to produce animal feed (26). These factors un-
derlie its central role in the global soy value chain and its
founding role in the Amsterdam Declaration. The Netherlands
could continue to exert disproportionate influence on trading
companies and buyers as a convening power and focal point of
private–public dialogue and partnerships (e.g., Dutch Soy
Coalition, Dutch Soy Working Group, and the Dutch Soy Platform
Initiative) (24, 26). The Dutch government has also provided
support to processors and buyers that invest in certification (Soy
Fast Track Fund), as well as to farmers to enable them to pro-
duce more sustainable soy (Farmer Support Program) (26). In
addition, governments have an important convening and fi-
nancing role to play in establishing sustainable finance, including
provision of credit lines to farmers who adhere to higher sus-
tainability criteria or support to scale up innovative solutions to
sustainability challenges (e.g., refs. 27 and 28). Our estimates of
the impacts of final consumption highlight the substantial re-
sponsibilities too of other EU countries, such as Spain, which is
not currently a signatory to the declaration but could be a focal
point for targeted political influence by existing signatories
(Table 1).

While the Netherlands may hold some influence because of its
large trade volumes, its diverse portfolio of traders could make
policy processes more complex and contested. In contrast to
other AD countries a large proportion of soy exported to (and
through) the Netherlands is from traders without zero-deforestation
commitments. Hence, even if those with existing commitments
delivered on them, this would capture just half of the Cerrado
soy traded through the Netherlands (Fig. 3 and SI Appendix,
Table S3). Working with countries that directly import substanc-
tially smaller volumes, such as the United Kingdom, France, and
Germany, may help the Netherlands government to encourage
currently uncommitted yet major traders such as Caramuru and
Granol to sign up to targets to eliminate deforestation from their
supply chains.

There are several sources of uncertainty within the models
presented, for example, in modeling land cover, estimating bio-
diversity loss, modeling trade, and year-to-year variability of
supply chains. The Trase Spatially Explicit Information on Pro-
duction to Consumption Systems (SEI-PCS) model of sub-
national production and export is built from key government
statistics and data that are compiled to calculate agricultural
productivity and to collect tax revenues (29). This allows con-
siderable confidence in this aspect of the modeling. The Input
Output Trade Analysis (IOTA) model employed in the analysis
is one of several multiregional input–output models (MRIOs)
that are available globally, all of which will provide somewhat
different quantitative results due to differences in their con-
struction (30). Our results are illustrative of the impacts that
different countries might have, highlighting the heterogeneity
that is expected across the trade system. Use of such information
in risk assessment or supply chain decision making should con-
sider the assumptions made and associated limitations of the
modeling approaches. More targeted analysis (e.g., of particular
supply chains looking at specific priority species) would benefit
from further sensitivity analyses to explore how changes in as-
sumptions might affect conclusions. We use 2011 trade data in
our analyses that provide a snapshot of a dynamic system, par-
cularly in the most active frontiers of agricultural expansion.
Any intervention should be based on multitemporal analyses of
spatial patterns and trends, as well as iterative engagement with
stakeholders to ensure their accuracy and relevance. However,
because of the investments in infrastructure (such as silos and
crushing facilities) and knowledge and interdependencies be-
 tween actors, we expect traders to stay relatively connected to
particular production locations over a 3 to 5 y span, with more
significant changes occurring over longer periods (refs. 20, 31,
and 32; see supplementary analyses in SI Appendix, Figs. S3 and
S4). Understanding how the data available within our framework
might be used to help determine accountability for impacts
agricultural commodities. However, to protect forests versus endemic species. 

assessing of complementarity or trade-offs between, for example, soy drives both immediate and longer-term losses and has im-

posed into degraded land according to the level of endemicity or of 

traders hold as a nexus of global commodity flows (38, 39), 

ward movement of commodities that combines traditional input 

from consumer groups and to promote responsible consumption across supply chain actors. Higher-resolution models allow us to develop land use management strategies to target particular areas for improving yields, setting aside areas for protection in expansion landscapes, or expanding production into degraded land according to the level of endemicity or of historical impacts on biodiversity. More generally, the spatial resolution demonstrated here allows the development of more credible estimates for a suite of indicators of environmental and social impacts. This species-level metric complements, rather than replaces, other measures of biodiversity loss based on the loss of the Cerrado (or deforestation) (e.g., refs. 35 and 36). Taken together, these provide a more complete picture of how the trade in a commodity such as soy drives both immediate and longer-term losses and has impacts at scales from the very local to global. It also allows assess- 

ment of complementarity or trade-offs between, for example, protecting forests versus endemic species. 

Our approach is applicable to a wide range of globally traded agricultural commodities. However, to “catalyze a race to the top” (14), actors must also be supported by mechanisms that allow and 

occurring across a dynamic trading landscape, where impacts can occur several years prior to trading activities, deserves additional research focus.

Conclusion

Currently, many sustainability commitments are little more than statements of intent and a recognition that things need to change (12, 15). Meeting these commitments requires collective ac-
tion to be scaled up through multistakeholder partnerships, landscape-scale approaches, and public–private initiatives (12). Identifying links between the intensification and expansion of 

sourcing from multiple producing countries, sell their goods globally, and have activities that span several commodities (37). This global reach may allow suc-

cessful sustainability initiatives to quickly scale up to other regions and commodities. By enabling monitoring of shifts of traders be-

tween markets our framework can also help minimize leakage by ensuring that sustainability commitments apply across companies’ operations. Moreover, because of the dominant role that a relatively few traders hold as a nexus of global commodity flows (38, 39), 

pressure from major economies, such as the AD countries, to im-

prove environmental standards could drive improvements to the sustainability of supply chains to other consuming regions.

Methods

We compiled and integrated existing data sources, linking complementary approaches to derive information on consumption patterns driving species declines and shedding light on the supply chains involved (SI Appendix, Fig. 45). Existing MRIOs use data on intersectoral financial transactions to rep-

resent full global trade and consumption but sacrifice commodity-specific detail and spatial resolution. Conversely, material flow analyses—descriptions of the physical movement of commodities—can be used to track pro-

duction and trade of individual commodities but generally capture only a portion of the supply chain (40). We therefore developed a hybridized MRIO for soy trade that combines traditional input–output analyses with highly detailed national material flow data from the Trase model underpinning the Trase platform (36, 41) (SI Appendix). We used these to tease out the activities of producers, traders, and consumers. We linked the models to estimates of species-by-species losses of suitable habitat to derive a measure of biodiversity impact that accounts for species-specific differ-

ences in range sizes, sensitivities to land use change, and historical habitat loss (17) (SI Appendix, Fig. 55). We focused on the impacts of soy production in 2000 to 2010 using habitat loss data for 2000 to 2010 and soy trade data for 2011. We chose this allocation period (i.e., attributing 2000 to 2010 losses to 2011) because it can take several years from initial clearing of land to eventual harvesting and selling soy.

Acknowledgments.

The material flow modeling work by the Trase initiative is supported by the Gordon and Betty Moore Foundation and the Global Environment Facility in partnership with WWF, A.P.D. and M.V.-S. were supported by the Luc Hoffmann Institute. J.M.H.G. was supported by the Luc Hoffmann Institute (with WWF-UK) and the Global Challenges Research Fund Trade, Development, and the Environment Hub project (ES/ S008160/1). S.A.C. and C.D.W. were supported by the iKnowFood project, funded by the UK Global Food Security program (Project BB/N02060X/1), and A.P.B. was supported by a Royal Society Wolfson Research Merit Award.

1. G. Ceballos et al., Accelerated modern human-induced species losses: Entering the sixth mass extinction. Sci. Adv. 1, e1400253 (2015).

2. R. E. Green, J. S. Cornell, J. P. W. Scharlemann, A. Balmford, Farming and the fate of wild nature. Science 307, 550-555 (2005).

3. D. M. Souza, R. F. Teixeira, O. P. Ostermann, Assessing biodiversity loss due to land use with Life Cycle Assessment: Are we there yet? Glob. Change Biol. 21, 32-47 (2015).

4. A. K. Duraipppah, Ecosystems and Human Well-being: Biodiversity Synthesis; A Report of the Millennium Ecosystem Assessment (World Resources Institute, Washington, DC, 2005).

5. A. Chaudhary, T. Kastner, Land use biodiversity impacts embodied in international food trade. Glob. Environ. Change 38, 195-204 (2016).

6. M. Lenzen et al., International trade drives biodiversity threats in developing nations. Nature 486, 109-112 (2012).

7. F. Ertl, M. Winter, P. Pylek, Biodiversity: Trade threat could be even more dire. Nature 487, 39 (2012).

8. D. Moran, K. Kanemoto, Identifying species threat hotspots from global supply chains. Nat. Ecol. Evol. 1, 0023 (2017).

9. P. Meyfroidt, T. K. Ruluf, E. F. Lambin, Forest transitions, trade, and the global dis-

placement of land use. Proc. Natl. Acad. Sci. U.S.A. 107, 20917-20922 (2010).

10. E. F. Lambin et al., The role of supply-chain initiatives in reducing deforestation. Nat. Clim. Change 8, 109-116 (2018).

11. J. Godar, C. Suave, T. A. Gardner, D. Dawkins, P. Meyfroidt, Balancing detail and scale in assessing transparency to improve the governance of agricultural commodity supply chains. Environ. Res. Lett. 11, 035015 (2016).

12. T. A. Gardner et al., Transparency and sustainability in global commodity supply chains. World Dev. 121, 163-177 (2019).

13. R. D. Garrett et al., Criteria for effective zero-deforestation commitments. Glob. En-

vironment 54, 135-147 (2019).

14. H. K. Gibbs et al., Brazil’s Soy Moratorium. Science 347, 377-378 (2015).

15. A. P. Durán et al., Putting species back on the map: Devising a practical method for quantifying the biodiversity impacts of land conversion. https://doi.org/10.1101/ 537897 (submitted 18 January 2019).

16. B. B. N. Strassburg et al., Moment of truth for the Cerrado hotspot. Nat. Ecol. Evol. 1, 99 (2017).
19. R. R. S. Vieira et al., Compliance to Brazil’s Forest Code will not protect biodiversity and ecosystem services. Divers. Distrib. 24, 434–438 (2018).
20. L. L. Rausch et al., Soy expansion in Brazil’s Cerrado. Conserv. Lett. e12671 (2019).
21. United Nations, New York Declaration on Forests: Declaration and Action Agenda. (Climate Summit 2014, UN Headquarters, New York, 2014).
22. Amsterdam Declaration, Amsterdam Declaration “Towards Eliminating Deforestation from Agricultural Commodity Chains with European Countries” (Ministry of Foreign Affairs, Amsterdam, The Netherlands, 2015).
23. A. Colleony, S. Clayton, D. Couvet, M. S. Jalme, A. C. Prévot, Human preferences for species conservation: Animal charisma trumps endangered status. Biol. Conserv. 206, 263–269 (2017).
24. Amsterdam Declarations Partnership, Overview: European National Soya Initiatives With a Focus on ADP Countries (Living document, version 9, Mekon Ecology, Leiden, The Netherlands, 2019).
25. Government of the State of Mato Grosso, Produzir, Conservar e Incluir: Estratégia de MT para mitigar Mudanças Climáticas (Climate Convention [COP 21], Paris, France, 2015).
26. J. W. van Gelder, B. Kuepper, M. Vrins, Soy Barometer 2014: A Research Report for the Dutch Soy Coalition (Profundo Research and Advice, Amsterdam, The Netherlands, 2014).
27. Partnerships for Forests, www.partnershipsforforests.com. Accessed 7 September 2019.
28. United Nations Environment Programme (UNEP), World’s first green bonds scheme to finance responsible soy production in Brazil launched [press release]. https://www.unenvironment.org/news-and-stories/press-release/worlds-first-green-bonds-scheme-to-finance-responsible-soy-production. Accessed 4 July 2019.
29. Trase, “Trace data sources: SEI-PCS Brazil soy (v.2.3), SEI-PCS Paraguay soy (v.1.1), and Paraguay Beef (v.1.0)” (Transparency for Sustainable Economies, Stockholm, Sweden, 2019).
30. A. Owen, K. Steen-Olsen, J. Barrett, T. Wiedmann, M. Lenzen, A structural decomposition approach to comparing MRIO databases. Econ. Syst. Res. 26, 262–283 (2014).
31. M.-B. Magrini et al., Why are grain-legumes rarely present in cropping systems despite their environmental and nutritional benefits? Analyzing lock-in in the French agrifood system. Ecol. Econ. 126, 152–162 (2016).
32. Trase, “Brazilian soy supply chains: Linking buyers to landscapes” in Trase Yearbook 2018, Sustainability in Forest-Risk Supply Chains: Spotlight on Brazilian Soy (Transparency for Sustainable Economies, Stockholm Environment Institute, and Global Canopy, 2018), pp. 32–38.
33. R. Sullivan, C. Mackenzie, Responsible Investment (Routledge, 2017).
34. V. Galaz et al., Tax havens and global environmental degradation. Nat. Ecol. Evol. 2, 1352–1357 (2018). Correction in: Nat. Ecol. Evol. 2, 1674 (2018).
35. F. Pendrill et al., Agricultural and forestry trade drives large share of tropical deforestation emissions. Glob. Environ. Change 56, 1–10 (2019).
36. Transparency for Sustainable Economies (Trase), Data from “SEI-PCS Brazil soy (v.2.3).” Trace. http://resources.trase.earth/documents/Trase-data-sources_release_may_2019.pdf. Accessed 7 June 2019.
37. Trase, “Exports of forest-risk commodities from South America” in Trase Yearbook 2018, Sustainability in Forest-Risk Supply Chains: Spotlight on Brazilian Soy (Transparency for Sustainable Economies, Stockholm Environment Institute, and Global Canopy, 2018).
38. J. Lee, G. Gereffi, J. Beauvais, Global value chains and agrifood standards: Challenges and possibilities for smallholders in developing countries. Proc. Natl. Acad. Sci. U.S.A. 109, 12326–12331 (2012).
39. P. Gibbon, Upgrading primary production: A global commodity chain approach. World Dev. 29, 345–363 (2001).
40. M. Bruckner, G. Fischer, S. Tramberend, S. Giljum, Measuring telecouplings in the global land system: A review and comparative evaluation of land footprint accounting methods. Ecol. Econ. 114, 11–21 (2015).
41. J. Godar, U. M. Persson, E. J. Tizado, P. Meyfroidt, Towards more accurate and policy relevant footprint analyses: Tracing fine-scale socio-environmental impacts of production to consumption. Ecol. Econ. 112, 25–35 (2015).