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Linking global drivers of agricultural trade to on-the-ground impacts on biodiversity

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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.

supply chain | agricultural commodity | biodiversity impacts | telecoupling | species

Species are being lost at 1 to 2 orders of magnitude above background rates (1), with greatest losses resulting from habitat conversion and degradation, particularly appropriation for agriculture (2–4). Much of the impact of food crop production in biodiverse tropical regions is associated with commodities destined for export (5), and as much as 80 to 99% of the biodiversity impact of food crop consumption in industrialized countries is incurred abroad (5). Work linking biodiversity threats to global financial flows at the country level indicates that at least 30% of threats to globally threatened species are linked to international trade (6–8). Growing recognition of the role of global consumption in driving remote environmental damage elsewhere (9–11) has led to a number of private- and public-sector commitments to reduce these impacts, particularly in agricultural commodity supply chains (12). However, our ability to monitor in practically useful detail whether governments or businesses are making progress toward these commitments has been limited.

To devise and monitor solutions for sustainable production and consumption we need to know the location of production areas to a high degree of spatial accuracy and understand the biodiversity impacts of production in these places. Crucially, we must also understand how impacts are connected to globalized supply chains and the key actors involved (13). Progress on

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.

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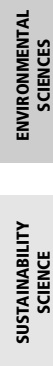
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Data deposition: Trase data are freely and publicly available at <https://trase.earth>.

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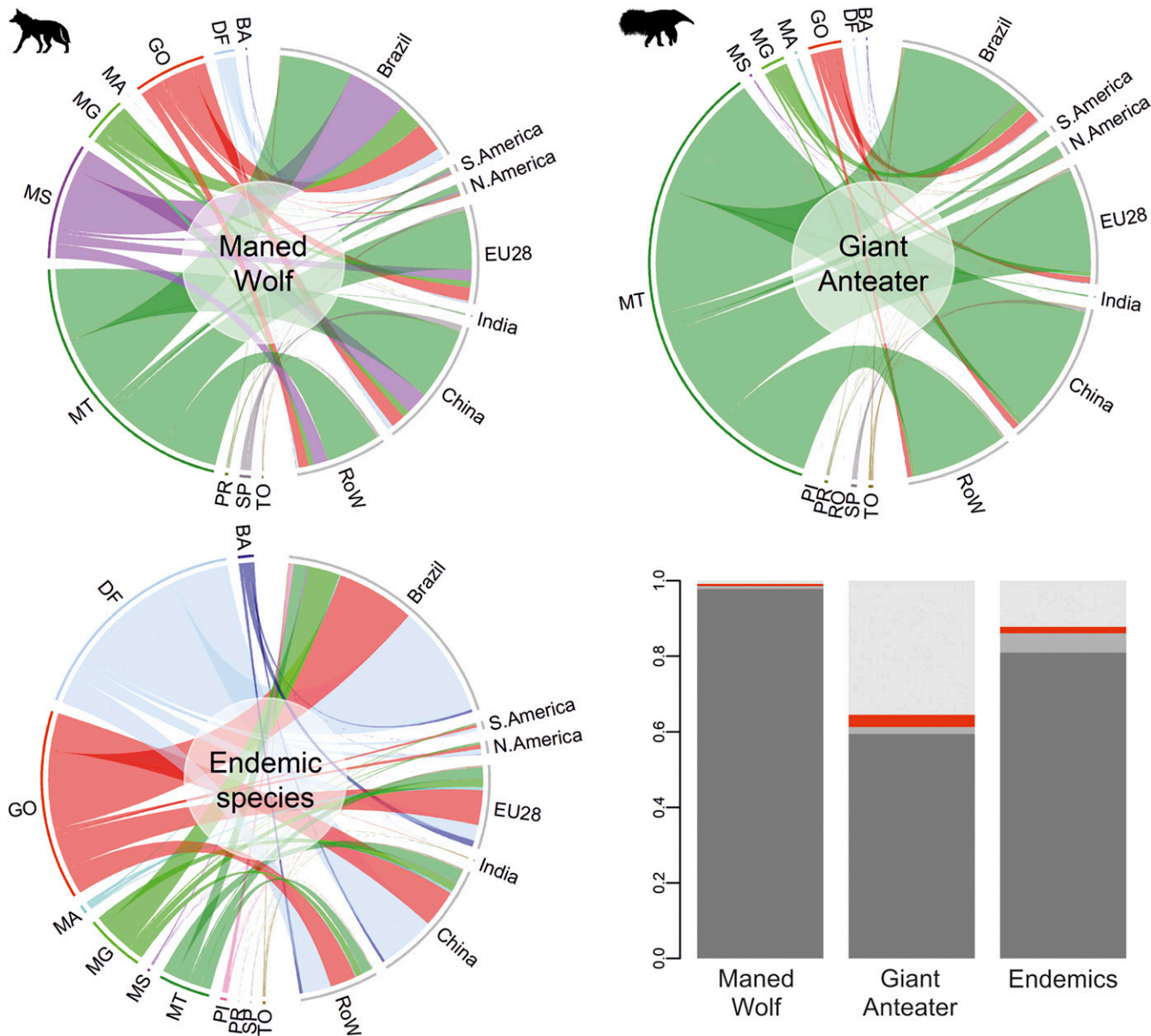


Fig. 2. Chord diagrams showing impacts on likelihood of persistence due to soy expansion between 2000 and 2010 for 2 charismatic species (*Top*) and for all endemics (*Bottom Left*). Losses are calculated for each municipality according to the total embedded flows of soy and then aggregated to state 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.

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.

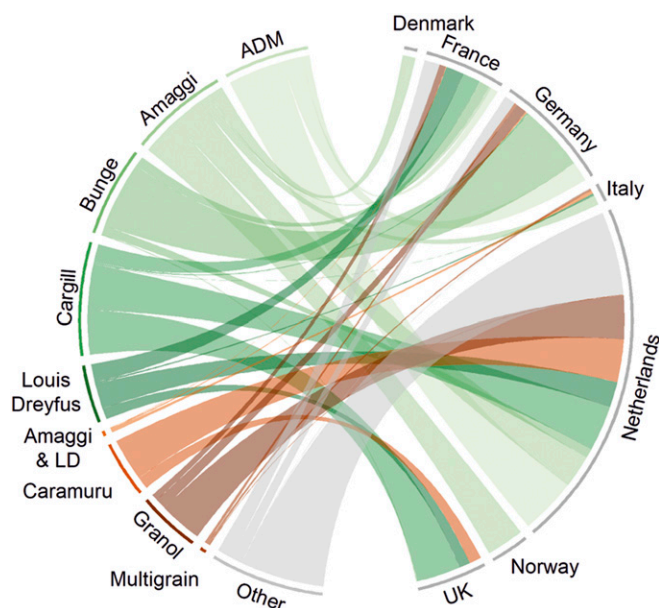


Fig. 3. Alignment of government commitments with sustainability goals of key traders. Chord diagram representing direct soy trade from the Brazilian Cerrado to the 7 countries of the Amsterdam Declaration from the largest traders in 2011 (companies shown were among the top 3 traders in 2011 for at least one of the countries; companies trading smaller volumes are aggregated and shaded gray). Green shaded chords indicate exports via companies 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 coordinated 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 Cerrado, 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 overestimate (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 important 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 underlie 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 produce more sustainable soy (Farmer Support Program) (26). In addition, governments have an important convening and financing role to play in establishing sustainable finance, including provision of credit lines to farmers who adhere to higher sustainability 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 responsibilities 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 substantially 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 biodiversity loss, modeling trade, and year-to-year variability of supply chains. The Trase Spatially Explicit Information on Production 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 considerable 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 construction (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 consider 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 assumptions might affect conclusions. We use 2011 trade data in our analyses that provide a snapshot of a dynamic system, particularly 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 between 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

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