doi:10.1038/nature11145

International trade drives biodiversity threats in developing nations

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Human activities are causing Earth's sixth major extinction event[1]—an accelerating decline of the world's stocks of biological diversity at rates 100 to 1,000 times pre-human levels[2]. Historically, low-impact intrusion into species habitats arose from local demands for food, fuel and living space[3]. However, in today's increasingly globalized economy, international trade chains accelerate habitat degradation far removed from the place of consumption. Although adverse effects of economic prosperity and economic inequality have been confirmed[4,5], the importance of international trade as a driver of threats to species is poorly understood. Here we show that a significant number of species are threatened as a result of international trade along complex routes, and that, in particular, consumers in developed countries cause threats to species through their demand of commodities that are ultimately produced in developing countries. We linked 25,000 Animalia species threat records from the International Union for Conservation of Nature Red List to more than 15,000 commodities produced in 187 countries and evaluated more than 5 billion supply chains in terms of their biodiversity impacts. Excluding invasive species, we found that 30% of global species threats are due to international trade. In many developed countries, the consumption of imported coffee, tea, sugar, textiles, fish and other manufactured items causes a biodiversity footprint that is larger abroad than at home. Our results emphasize the importance of examining biodiversity loss as a global systemic phenomenon, instead of looking at the degrading or polluting producers in isolation. We anticipate that our findings will facilitate better regulation, sustainable supply-chain certification and consumer product labelling.

Many studies have linked export-intensive industries with biodiversity threats, for example, coffee growing in Mexico[6] and Latin America[7], soya[8] and beef[9] production in Brazil, forestry[10] and fishing[11] in Papua New Guinea, palm oil plantations in Indonesia and Malaysia[12], and ornamental fish catching in Vietnam[13], to name but a few. However, such studies are neither systematic nor comprehensive in their coverage of international trade. They also do not link exports to consuming countries, and miss threats more difficult to connect to specific exports, such as agricultural and industrial pollution.

Our approach provides a comprehensive view of the commercial causes of biodiversity threats. Using information from the International Union for Conservation of Nature (IUCN) Red List on threat causes, we associated threatened species with implicated commodities; for example, *Ateles geoffroyi* (spider monkey) is endangered and threatened by habitat loss linked to coffee and cocoa plantations in Mexico and Central America. Using a high-resolution global trade input–output table, we traced the implicated commodities from the country of their production, often through several intermediate trade and transformation steps, to the country of final consumption (Methods). This is the first time, to our knowledge, that the important role of international trade and foreign consumption as a driver of threats to species has been comprehensively quantified.

We calculated the net trade balances of 187 countries (Supplementary Information section 1) in terms of implicated commodities (Supplementary Information section 2). Countries that export more implicated commodities than they import are net biodiversity exporters, and importers vice versa. A striking division exists between the world's top ten net exporters and net importers of biodiversity (Fig. 1 and Supplementary Information section 3). Developed countries tend to be relatively minor net exporters, but major net importers of implicated commodities. This is probably due to environmental policies that effectively protect remaining domestic species and that force impacting industries to locate elsewhere. Among the net importers a total of 44% of their biodiversity footprint is linked to imports produced outside their boundaries. In stark contrast, developing countries find themselves degrading habitat and threatening biodiversity for the sake of producing exports. Among the net exporters a total of 35% of domestically recorded species threats are linked to production for export. In Madagascar, Papua New Guinea, Sri Lanka and Honduras, this proportion is approximately 50–60%.

Examining exporters and importers in unison shows that primarily the USA, the European Union and Japan are the main final destinations of biodiversity-implicated commodities. For the five selected exporting countries shown in Fig. 2, export activities are linked to between 50 and 60% of all domestically recorded biodiversity threats.

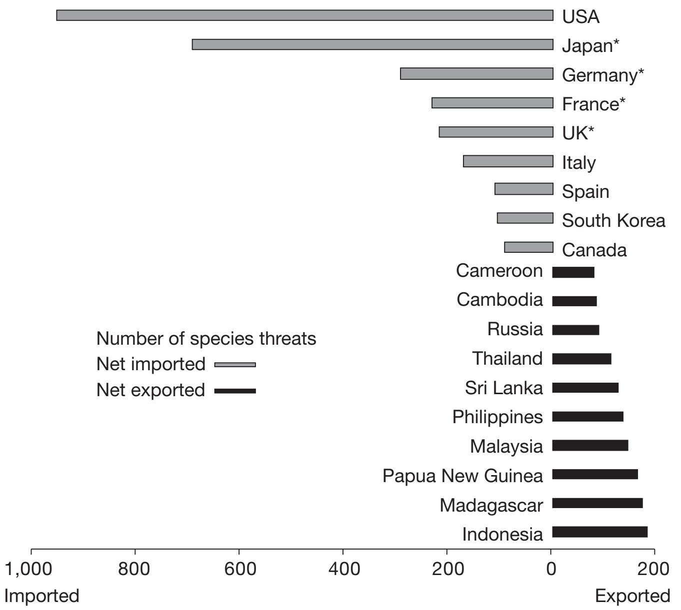

Figure 1 | Top net importers and exporters of biodiversity threats. In importer countries marked with an asterisk, the biodiversity footprint rests more abroad then domestically; that is, more species are threatened by implicated imports than are threatened by domestic production.

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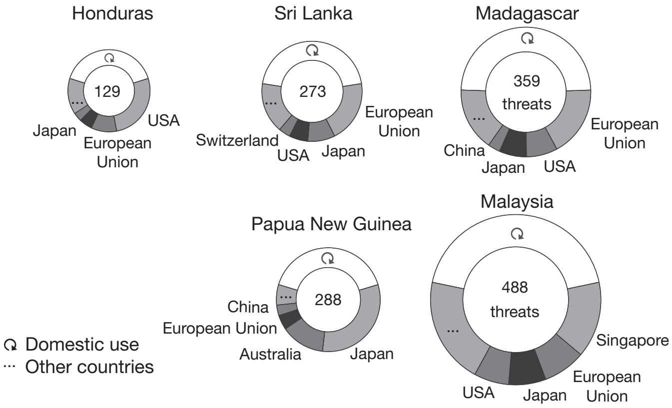

Figure 2 | Selected net exporters. Selected net exporters and final destinations of biodiversity-implicated commodities.

Further examination of the commodity content of these trade activities shows that threats to species are often facilitated by supply chains involving more than two countries or producers, and that major supply chains originate in developing countries rich in biodiversity and with export-oriented agricultural, fishing and forestry industries (Supplementary Information section 4). Coffee, a top-ranking commodity, is threatening species in Mexico, Colombia and Indonesia. Agriculture also affects habitat in Papua New Guinea (where coffee, cocoa, palm oil and coconut growing are linked to nine critically endangered species including the northern glider, *Petaurus abidi*, the black-spotted cuscus, *Spilocuscus rufoniger*, and the eastern long-beaked echidna, *Zaglossus bartoni*), Malaysia (the main export products are palm oil, rubber and cocoa; 135 species are affected by agriculture) and Indonesia (the main crops are rubber, coffee, cocoa and palm oil, affecting 294 species including *Panthera tigris*, the Sumatran serow, *Capricornis sumatraensis*, and Sir David's long-beaked echidna, *Zaglossus attenboroughi*). Fishing and forestry industries cause biodiversity loss directly through excessive and illegal resource use and indirectly through bycatch and habitat loss. Such impacts occur not only in developing countries such as the Philippines (affecting 420 species, 28 of which are critically endangered) and Thailand (affecting 352 species, 28 critically) but also in the United States (affecting 450 species, 63 critically). Biological resource use is not the only threat. In China, pollution is responsible for one-fifth (304 out of 1,526) of all threats. Consumers in the United States and Japan are the largest beneficiaries of these trade flows. Finally, most species on the Red List suffer several different threats. For example, the vulnerable round whipray, *Himantura pastinacoides*, is under threat in Indonesia owing to chemical pollution and loss of its native mangrove habitat to shrimp aquaculture, logging and coastal development.

The international trade in biodiversity-implicated commodities can be visualized using global trade-flow maps. Figure 3 illustrates the flows of implicated commodities for two countries: exports from Malaysia, and imports by Germany (this figure is available in higher resolution in the Supplementary Information, and an interactive version is available online at http://www.worldmrio.com/biodivmap/). German imports are linked to 395 species threats, and Malaysian exports to 276 species threats. Further details supporting Fig. 3 are given in Supplementary Information section 7. In Papua New Guinea, 171 listed species are threatened by exports to fewer, but larger, trade partners. Half of Papua New Guinea's implicated exports are destined for Japan. These are mostly timber and agricultural products that undergo intermediate processing in Malaysia and Indonesia (wood machining), and Hong Kong, Taiwan, Australia and Thailand (food processing). Countries producing implicated goods bound for Germany are diverse, such as Madagascar (twine, rattan, sisal, cocoa, vanilla, cloves and processed food prepared in France, Austria and the Netherlands; 18 species), Democratic Republic of the Congo and Ghana (mining inputs to Finnish metal products used in German passenger-car production; 3 and 5 species, respectively), Sri Lanka (tea, latex gloves, rubber products for automobiles and cotton clothing; 14 species), Colombia (coffee, bananas, tobacco and cocoa made into chocolate; 3 species) and Cameroon (coffee, rubber, wool, lumber and cargo pallets; 6 species).

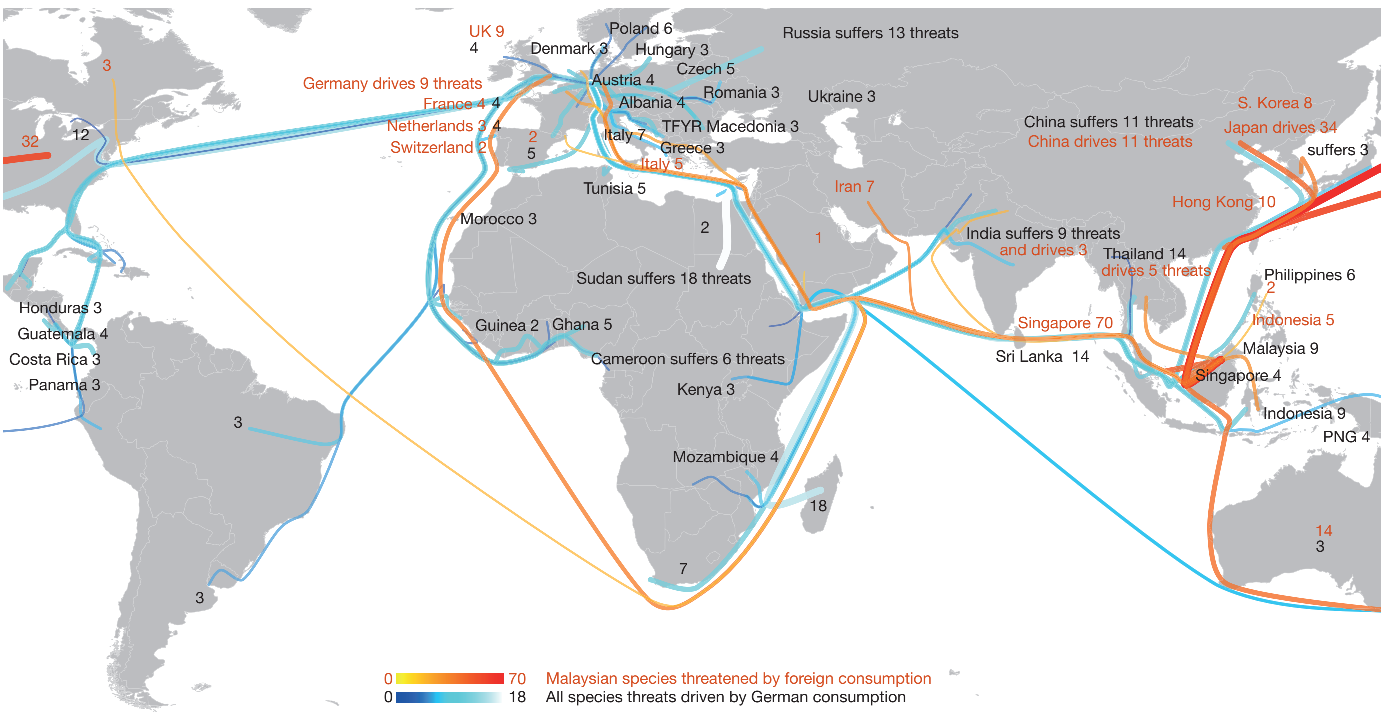

Figure 3 | Flow map of threats to species. Flow map of threats to species caused by exports from Malaysia (reds) and imports into Germany (blues). Note that the lines directly link the producing countries, where threats are recorded, and final consumer countries. Supply-chain links in intermediate countries are accounted for but not explicitly visualized. An interactive version is available at http://www.worldmrio.com/biodivmap/.

Our findings clearly show that local threats to species are driven by economic activity and consumer demand across the world. Consequently, policy aimed at reducing local threats to species should be designed from a global perspective, taking into account not just the local producers who directly degrade and destroy habitat but also the consumers who benefit from the degradation and destruction.

Allocating responsibility between producers and consumers is not straightforward, even as an academic exercise. Producers exert the impacts and control production methods, but consumer choice and demand drives production, so that responsibility may lie with both camps, and may hence have to be shared between them[14]. Notwithstanding its theoretical challenges, the consumer responsibility principle is now receiving ample attention in the climate change debate. Its political relevance is demonstrated by China's official stance that final consumer countries should be held accountable for the greenhouse gases emitted during the production of China's export goods[14]. To inform this debate, countries' carbon footprints are now being calculated using global multi-region input–output models[15]. The biodiversity footprints introduced here use identical concepts and methods. Therefore, policies to mitigate climate change and biodiversity loss may share analytical approaches and implementation protocols on the basis of supply-chain quantification.

Starting with the producers, regulating polluting and degrading industries in developing countries may be difficult if these industries have limited means and alternatives, and are vital to income and employment. These limits may not apply to multi-national producers that operate in the developing world but are controlled from a developed country. The emigration of industries as a result of tightening domestic environmental or work standard laws is well known. Such migration can be countered by extending domestic jurisdiction to producers abroad. Similar processes may be behind the stark division between net importing and net exporting countries shown in Fig. 1. Harmonizing regulation and standards among trade partners may stem the migration of habitat-intensive producers. Producer-side sustainability initiatives such as the developing[16] Roundtable for Sustainable Palm Oil can further reduce the impacts of production.

Moving from producers to traders, the 1977 Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) today protects more than 30,000 species[17]. CITES is exclusively concerned with the international trade of endangered species, be it as live specimens, parts or derived products. Indeed, trade in marine,[18] sylvan[19] and iconic endangered species[20] can be, to a degree, constrained by certification, quota and regulatory regimes. We argue that there is no practical difference in terms of imperilment between trading specimens and trading commodities whose production leads to their imperilment. The motivation for banning the first kind of trade equally applies to the second kind, and, consequently, trade in biodiversity-implicated commodities should be governed by the same control and licensing procedures.

Ending with consumers, environmental labels such as advertising dolphin-safe canned tuna, organic produce and fair trade coffee have been a well-known sight for decades. Although these examples refer to relative short, intuitively traceable supply chains, there is in principle no obstacle to extending such labelling and certification to more complex international trade routes. This is demonstrated by the United Kingdom's Carbon Reduction Label, which despite methodological shortcomings[21] requires the quantification of a product's full carbon footprint. Given the complete equivalence of carbon and biodiversity footprinting methodologies (Supplementary Information sections 8 and 9), our integration of species Red Lists with global trade databases could provide a starting point for more comprehensive biodiversity labelling schemes. However, whether sustainability-minded consumers and shareholders can be a force in mitigating the impacts they drive will depend on whether sustainability certification schemes will be able to overcome their current limited efficacy[22].

To combat biodiversity loss, policies aimed at producers, traders and consumers must be implemented in parallel. This is reflected in the reinterpretation of the wedge approach[23] for biodiversity stabilization, which considers wide-ranging measures on human population, consumption, endowment funds to underpin permanence of habitat refuges, economic accounting of habitat degradation, reclamation of degraded lands, empowerment of local peoples and transformation of human attitudes to nature[24]. We suggest a new wedge: suppressing trade in at-risk commodities. Granted, such a policy reform would be difficult to implement given the importance of international trade. However, Article XX of the General Agreement on Tariffs and Trade (GATT) allows "measures relating to the conservation of exhaustible natural resources", thus providing a framework to support measures regulating biodiversity-implicated goods[25]. Reducing the volume of trade in implicated commodities and implementing protective policies at the production, trade and consumption points in the supply chain could have a significantly higher impact in preventing biodiversity loss than the CITES controls. Raising consumers' awareness of the biodiversity footprint of the products they buy also helps with most of these measures. Mexico's spider monkey, *Ateles geoffroyi*, is listed in the CITES as a protected species, but its survival would be more certain if consumers could see that the coffee encroaching on its home were listed as a biodiversity-implicated commodity as well.

METHODS SUMMARY

We integrated the IUCN Red List of Threatened Species[26] plus a compatible list of threatened bird species from Bird Life International[27] with a new high-resolution global multi-region input–output database[28]. The combined threat lists (excluding natural disaster, intrinsic factors and invasive species) provide country-wise information on 166 anthropogenic threat causes. We considered only endangered, critically endangered and vulnerable species. This data set covered 6,964 Animalia species and 171,825 country, species and cause records.

We linked these threats to a multi-region input–output table containing the domestic and international monetary transactions between 15,909 industry sectors across 187 countries. Using a binary concordance matrix, we attributed each threat cause to one or more industry sectors that exert the respective threat. We could not distinguish legal from illegal activities (for example, fishing, forestry and hunting), as data were unavailable. For species threatened by climate change, responsibility was allocated to all sectors worldwide. We then normalized the concordance matrix by weighting threat assignments by the gross industrial output of sectors for all causes except for climate change, where the weights are based on the sectors' greenhouse gas emissions. This normalization ensured that threat causes were not double-counted. We weighted all threat causes equally as there are no data with which to weight threat severity. Finally we determined biodiversity footprints using Leontief's standard input–output calculus[29]. These biodiversity footprints quantify threats caused directly and indirectly as a consequence of the expenditure of a final consumer. For example, the United States' biodiversity footprint contains the number of species threatened in Mexico caused indirectly by consumer spending on Mexican coffee beans in the USA. Such international indirect threats are facilitated by complex, multi-stage, global supply chains, which can be traced, extracted and ranked using structural path analysis. Further details are available in Supplementary Information sections 8, 9, 10 and 11.

Received 18 December 2011; accepted 16 April 2012.

1. Chapin, F. S. *et al.* Consequences of changing biodiversity. *Nature* **405,** 234–242 (2000).
2. Pimm, S. L., Russell, G. J., Gittleman, J. L. & Brooks, T. M. The future of biodiversity. *Science* **269,** 347–350 (1995).
3. Donald, P. F. Biodiversity impacts of some agricultural commodity production systems. *Conserv. Biol.* **18,** 17–38 (2004).
4. Naidoo, R. & Adamowicz, W. L. Effects of economic prosperity on numbers of threatened species. *Conserv. Biol.* **15,** 1021–1029 (2001).
5. Mikkelson, G. M., Gonzalez, A. & Peterson, G. D. Economic inequality predicts biodiversity loss. *PLoS ONE* **2,** e444 (2007).
6. Perfecto, I., Mas, A., Dietsch, T. & Vandermeer, J. Conservation of biodiversity in coffee agroecosystems: a tri-taxa comparison in southern Mexico. *Biodivers. Conserv.* **12,** 1239–1252 (2003).
7. Philpott, S. M. *et al.* Biodiversity loss in Latin American coffee landscapes: review of the evidence on ants, birds, and trees. *Conserv. Biol.* **22,** 1093–1105 (2008).
8. Fearnside, P. M. Soybean cultivation as a threat to the environment in Brazil. *Environ. Conserv.* **28,** 23–38 (2001).

9. Nepstad, D. C., Stickler, C. M. & Almeida, O. T. Globalization of the Amazon soy and beef industries: opportunities for conservation. *Conserv. Biol.* **20,** 1595–1603 (2006).
10. Shearman, P. L., Ash, J., Mackey, B., Bryan, J. E. & Lokes, B. Forest conversion and degradation in Papua New Guinea 1972–2002. *Biotropica* **41,** 379–390 (2009).
11. Michael E, H. An assessment of the status of the coral reefs of Papua New Guinea. *Mar. Poll. Bull.* **29,** 69–73 (1994).
12. Koh, L. P. & Wilcove, D. S. Cashing in palm oil for conservation. *Nature* **448,** 993–994 (2007).
13. Giles, B. G., Ky, T. S., Hoang, H. & Vincent, A. C. J. in *Topics in Biodiversity and Conservation* Vol. 3 (eds Hawksworth, D. L. & Bull, A. T.) 157–173 (Springer Netherlands, 2006).
14. Lenzen, M., Murray, J., Sack, F. & Wiedmann, T. Shared producer and consumer responsibility – theory and practice. *Ecol. Econ.* **61,** 27–42 (2007).
15. Peters, G. P., Minx, J. C., Weber, C. L. & Edenhofer, O. Growth in emission transfers via international trade from 1990 to 2008. *Proc. Natl Acad. Sci. USA,* (2011).
16. Edwards, D. P., Fisher, B. & Wilcove, D. S. High conservation value or high confusion value? Sustainable agriculture and biodiversity conservation in the tropics. *Conserv. Lett.* **5,** 20–27 (2012).
17. Convention on International Trade in Endangered Species of Wild Fauna and Flora. http://www.cites.org (1979).
18. Villasante, S., Rodríguez, D., Antelo, M., Quaas, M. & Österblom, H. The Global Seafood Market Performance Index: a theoretical proposal and potential empirical applications. *Mar. Policy* **36,** 142–152 (2012).
19. Rotherham, T. Forest management certification around the world — progress and problems. *For. Chron.* **87,** 603–611 (2011).
20. Parsons, E. C. M. & Cornick, L. A. Sweeping scientific data under a polar bear skin rug: The IUCN and the proposed listing of polar bears under CITES Appendix I. *Mar. Policy* **35,** 729–731 (2011).
21. Huang, A. Y., Lenzen, M., Weber, C., Murray, J. & Matthews, H. S. The role of input-output analysis for the screening of corporate carbon footprints. *Econ. Syst. Res.* **21,** 217–242 (2009).
22. Blackman, A. & Rivera, J. Producer-level benefits of sustainability certification. *Conserv. Biol.* **26,** 1176–1185 (2011).
23. Pacala, S. & Socolow, R. Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. *Science* **305,** 968–972 (2004).
24. Ehrlich, P. R. & Pringle, R. M. Where does biodiversity go from here? A grim business-as-usual forecast and a hopeful portfolio of partial solutions. *Proc. Natl Acad. Sci. USA* **105,** 11579–11586 (2008).
25. World Trade Organization. WTO Rules and Environmental Policies: GATT Exceptions. http://www.wto.org/english/tratop_e/envir_e/envt_rules_exceptions_e.htm (2012).
26. International Union for Conservation of Nature. The IUCN Red List of Threatened Species. Version 2011.2. http://www.iucnredlist.org (2011).
27. BirdLife International. Threatened Birds of the World. http://www.birdlife.org (2011).
28. Lenzen, M., Kanemoto, K., Moran, D. & Geschke, A. The Eora Global Multi-Region Input-Output Tables. ISA, Univ. Sydney, Australia http://www.worldmrio.com (2011).
29. Leontief, W. & Ford, D. Environmental repercussions and the economic structure: an input-output approach. *Rev. Econ. Stat.* **52,** 262–271 (1970).

Supplementary Information is linked to the online version of the paper at www.nature.com/nature.

Acknowledgements We thank C. Pollock and M. Hoffmann from the IUCN and A. Symes from BirdLife International for advice on using the Red Lists. The work described in this paper was financially supported by the Australian Research Council through its Discovery Project DP0985522 and its Linkage Project LP0669290.

Author Contributions M.L. and D.M. conducted the analysis and prepared the figures. M.L., D.M. and B.F. wrote the paper. K.K., L.L. and A.G. prepared the data.

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