International trade causes large net economic losses in tropical countries via the destruction of ecosystem services

Article *in* AMBIO A Journal of the Human Environment · March 2016

DOI: 10.1007/s13280-016-0768-7

Will Symes

National University of Singapore

Felix Lim

The University of Sheffield

L Roman Carrasco

National University of Singapore

This is a preprint version. The copyedited final article can be found at:

http://link.springer.com/article/10.1007/s13280-016-0768-7?wt_mc=internal.event.1.SEM.ArticleAuthorOnlineFirst

Please cite as:

Chang, J., Symes, W.S., Lim, F.K., Carrasco, L.R. (2016) International trade causes large net economic losses in tropical countries via the destruction of ecosystem services. Ambio.

Title page

International trade causes large net economic losses in tropical countries via the destruction of ecosystem services

J. Chang[1], W.S. Symes[1], F.K. Lim[1], L.R. Carrasco[1,*]

[1]Department of Biological Sciences, National University of Singapore,14 Science Drive 4, Singapore 117543, Republic of Singapore.

[*]Email: dbsctlr@nus.edu.sg. Tel: +6591377291. Fax: +65 67792486.

Junning Chang

Address: Department of Biological Sciences, National University of Singapore,14 Science Drive 4, Singapore 117543, Republic of Singapore. e-mail: chang.junning@u.nus.edu.

Will Symes

Address: Department of Biological Sciences, National University of Singapore,14 Science Drive 4, Singapore 117543, Republic of Singapore. e-mail: wsymes@u.nus.edu

Felix Lim

Address: Department of Biological Sciences, National University of Singapore,14 Science Drive 4, Singapore 117543, Republic of Singapore. e-mail: limkiatseongfelix@gmail.com

L. Roman Carrasco

Address: Department of Biological Sciences, National University of Singapore,14 Science Drive 4, Singapore 117543, Republic of Singapore. e-mail: dbsctlr@nus.edu.sg

Word count: 5620

Acknowledgements

We are thankful for research funding from a Tier 2 grant from the Ministry of Education of Singapore, WBS R154000574112.

Abstract

Despite the large implications of the use of tropical land for exports ("land absorption") on ecosystem services (ES) and global biodiversity conservation, the magnitude of these externalities is not known. We quantify the net value of ES lost in tropical countries as a result of cropland, forestland and pastureland absorption for exports after deducting ES gains through imports ("land displacement"). We find that net ES gains occur only in 7 out of the 41 countries and regions considered. We estimate global annual net losses of over I$1.7 trillion (I$1.1 trillion if carbon related services are not considered). After deducting the benefits from agricultural, forest and livestock rents in land replacing tropical forests, the net annual losses are I$1.3 and I$0.7 trillion respectively. The results highlight the large magnitude of tropical ES losses through international trade that are not compensated by the rents of land uses in absorbed land.

Keywords: conservation planning, ecological footprint analysis, international trade, tropical deforestation, underpriced exports.

Introduction

From 2000 to 2012, 2.3 million square kilometres of forest were lost globally with 32% of this loss occurring in the tropics (Hansen et al. 2013). Forest conversion from crop and livestock production accounts for 55% of forest loss (European Commission 2013) and leads to the loss of a wide range of ecosystem services (ES) (de Groot et al. 2010) and high carbon dioxide emissions (Karstensen et al. 2013). Tropical forests are also both essential for the maintenance of tropical biodiversity (Gibson et al. 2011) and the terrestrial biome with the highest value of ES per unit of area (de Groot et al. 2010). As such, conversion due to agricultural expansion in tropical countries poses a threat not only to biodiversity, but also to the stability of their ecosystems and the global climate (Karstensen et al. 2013).

Since the late 20th century, global trade volume has grown exponentially due, *inter alia*, to the liberalisation of trade policies and decreasing transport costs with technological improvements (United Nations Conference on Trade and Development 2012). International trade produces, in theory, net benefits globally by enabling countries to trade according to their comparative advantage (Andersson and Lindroth 2001; Ricardo 1817). This creates opportunity for specialisation, allowing countries to optimise the use of their natural endowments and productive technologies to increase global agricultural yields (Andersson and Lindroth 2001; Smith 1776; Steen-Olsen et al. 2012). As such, global market integration, together with improvement in agricultural productivity, should reduce cropland demand (Hertel et al. 2014; Lambin and Meyfroidt 2011).

The globalization of agricultural production results in the use of land within a country for the production of exports and the use of land abroad to supply domestic consumption. These processes have been called land absorption and land displacement respectively (Meyfroidt et al. 2010). Here we adopt the perspective of tropical countries and refer to land absorption as land used for exports by the tropical country. We refer to land displaced as the land used elsewhere to produce the goods associated to the imports by tropical countries. Land absorption becomes problematic when economic systems fail to reflect the actual economic value of environmental systems. ES in biomes such as tropical forests are often not captured by markets. As a result, a market failure occurs whereby the value of ES lost when forests are replaced by other land uses, are not internalised in the price of the traded goods. Subsequently, higher-than-optimal amounts of ES are traded off for agricultural land (Brown and Pearce 1994). Furthermore, the displacement of the environmental costs from the production of traded goods, allows the value of ES lost to be off-shored. This encourages unsustainable levels of consumption in importing countries via a geographic disconnect between consumers and these costs (Lambin and Meyfroidt 2011).

Attempts to quantify the consequences of market externalities generated from the production of internationally traded goods have resulted in the concept of ecological footprint. An ecological footprint is the area of ecologically productive land, such as cropland, pastureland and forestland which is required to, *inter alia*, provide energy, material resources and absorb waste (Andersson and Lindroth 2001; Wackernagel and Rees 1995). This allows the environmental impacts of products to be traced and attributed back to consumers (Steen-Olsen et al. 2012).

Tracing the ecological footprint of agricultural imports involves identifying and quantifying the extent of the land used for their production. Since agricultural products require the conversion of biomes to agricultural land, unaccounted ES values and agricultural rents are traded off.

The trade-offs between biodiversity and economic benefits stemming from agricultural land are recognised (Lenzen et al. 2012), and there have been attempts to calculate the opportunity cost of biodiversity conservation in terms of agricultural benefit lost (Naidoo and Iwamura 2007). Efforts have also been made to trace ecological footprints embodied in trade with the use of international trade databases such as the Global Trade Analysis Project (GTAP) (Hertel 1997). This allows constructing multiregional input-output (MRIO) models. MRIO models trace the footprint of biomass and land use associated with trade and have also been used to show a relationship between affluence and land use displacement (Weinzettel et al. 2013). As such, MRIO models make it possible to analyse the effects of trade on the amount of land displaced and absorbed around the world (Meyfroidt et al. 2013; Weinzettel et al. 2013).

Despite the large biodiversity conservation implications of tropical land absorption, the actual magnitude and spatial distribution of the trade-offs between international trade and ES are unknown. Recent efforts to quantify the economic value of ES in global initiatives such as The Economics of Ecosystems and Biodiversity (TEEB), mean the value of ES forgone in 10 different biomes, including tropical forests, temperate forests, woodlands and grasslands, has been estimated (de Groot et al. 2012). With the recent availability of global land absorption and displacement estimates (Weinzettel et al. 2013), it is now possible to estimate the value of ES lost to tropical land absorption due to international trade.

The objectives of this study are: (i) to quantify the net value of ES lost in tropical countries from the conversion of four different biomes (tropical forests, temperate forests, woodlands and grasslands) to cropland, forestland and pastureland as a result of land absorption through international trade while deducting ES gains through land displaced by tropical countries through imports; (ii) to compare the net ES lost with the estimated gains from agricultural, forests and livestock rents in tropical countries; and (iii) calculate in which countries the value of ES lost is lower than these gains to asses which countries are winners and losers from international trade with respect to ES.

Methods

Overview

There were three main stages to the analysis. In the first stage the scope of the study was defined and three scenarios were identified to test the assumptions underpinning the results, such as the proportion of cropland, forestland and pastureland absorbed for export and displaced through imports and the spatial distribution of ES values in both absorbed and displaced land respectively. Secondly, the value of the ES of the four main biomes considered (tropical forests, temperate forests, woodlands and grasslands) and the agricultural, forest and livestock rents received from their conversion were calculated (Table 1 shows the datasets used with their resolution). Finally, we compared the value of rent gains from land absorbed for the export of agricultural, forest and livestock products to the value of the net ES lost through trade under the different scenarios. All the maps used were compiled using ArcGIS 10.2.2.

Scope of the analysis

The analysis of land absorption was restricted to the tropical countries and regions for which data on land absorption and displaced were available (Weinzettel et al. 2013). This led to 33 countries and 8 regions (Figure 2 and Table S2 in Electronic Supplementary Material 1, ESM1). The analysis of land displacement involved all countries and regions with available data from which tropical countries import, leading to 94 countries and 18 regions (Weinzettel et al. 2013). Land absorbed and displaced data corresponded to year 2004 (Weinzettel et al. 2013). The crop yield and distribution data were taken from Monfreda et al., (2008) and Ramankutty et al. (2008). The top ten crops by value and area under cultivation in the study region and cattle (used as a proxy for livestock) were used to calculate agricultural and livestock rents. This left a list of 17 crops and livestock to be included in the analysis: banana, beans, cassava, cocoa, coconut, coffee, cotton, cowpea, groundnut, maize, millet, oil palm, rice, sorghum, soybean, sugarcane, wheat. Data on the spatial distribution of the four different biomes considered (tropical forests, temperate forests, woodlands and grasslands) were employed to evaluate the potential losses of ES due to agricultural conversion (Ramankutty and Foley 1999). All economic values were converted to 2014 international dollars (I$) using deflation and purchasing power parity conversion rates (Bureau of Labor Statistics 2010; WHO 2010).

Scenarios to characterize uncertainty in the location of absorbed land

Because the actual distribution of absorbed land versus land used for domestic production is not known, there is uncertainty regarding the proportion of each biome conversion to absorbed agricultural land. To characterize the potential range of results due to this, three different scenarios were considered.

A. ***ES net losses from historical land conversion***: the proportion of biome conversion was based on historical cropland conversion data (Ramankutty and Foley 1999). This included historical cropland inventory data from 1700 up to 2007 (Ramankutty 2012; Ramankutty and Foley 1999). The cropland distribution in 1700 was compared with the cropland distribution in 2004 to analyse the proportion of the four biomes that were converted to cropland (Figure 1). The cropland distribution map of 1700 was subtracted from the 2004 cropland distribution and overlaid with a potential vegetation map (Ramankutty and Foley 1999), showing the distribution of global biomes (Figure 1). The 15 vegetation types from the potential vegetation map were reclassified into the four biomes studied (Table S3 in ESM1) and the proportion of each biome that was converted to cropland in each country was calculated. It was assumed that the proportion of biomes in absorbed cropland was similar to the historical proportion of conversion in each biome.
B. ***ES net losses lower bound***: this scenario assumed that all the land absorbed did not contain tropical forests. As tropical forests have the highest ES value per hectare as compared to other biomes studied (de Groot et al. 2012), scenario B sets the lower bound of potential net losses. The proportion of the four biomes in the displaced agricultural land was derived using historical maps similar to scenario A (Ramankutty and Foley 1999) and the entire proportion of tropical forest was excluded and re-weighted into the remaining three biomes, temperate

forest, woodland and grassland. In the case of countries for which the total cropland area in temperate forests, woodland and grassland was lower than the cropland absorbed, the same biome proportions as scenario A were considered (e.g. in Indonesia 96% of the cropland area occurs in the tropical forest biome, leading to very low uncertainty as to what type of biome was absorbed by international trade, i.e. scenario B agrees with scenario A. The opposite situation occurs in India and Brazil where different biomes could overlay with the area of cropland absorbed, leading to higher uncertainty).

C. ***ES net losses upper bound***: this scenario assumed all the land absorbed was previously tropical forests. In the case of countries for which the total cropland area in the tropical forest biome was smaller than the land absorbed, the same biome proportions as scenario A were considered.

Cropland absorbed and displaced

Data for cropland absorbed in each country were obtained from Weinzettel et al. (2013). For countries without country-specific data, we employed the country groups used by Weinzettel et al. (2013) (Table S2 shows the countries included in each group). The proportion of land absorbed in each biome in each group was estimated using a weighted average by area of the proportions of each biome absorbed (estimated in a similar way to Scenario A) in each country constituting the group.

We translated the data on land absorbed and displaced from Weinzettel et al. (2013) from global hectares into the hectares of each country using yield factors (Ewing et al. 2008). The national yield factors were derived as the weighted average of the yield factor of each crop considered weighted by the area of each crop involved in exports. The area of exports was obtained through export volumes and average national yields (FAO 2010a). Each yield factor was estimated as the ratio of average yield for each crop globally divided by the yield of such crop in the country (using global yield maps by Monfreda et al. 2008).

Estimation of ES net losses from international trade

The annual net value of ES lost per tropical country and region *i* ($netES_i$) was calculated as the ES gained through land displaced (ES_{dis}) minus ES lost due to land absorbed (ES_{abs}):

$$netES_i = ES_{dis\_i} - ES_{abs\_i} = \sum_{j=1}^{J} A_j \sum_{k=B_1}^{B_4} P_{kj} ES_k - A_i \sum_{k=B_1}^{B_4} P_{ki} ES_k$$

where *B1–B4* represents the four different types of biomes considered namely tropical forest, temperate forest, grassland and woodland; P_{kj} is the proportion of the associated biomes converted to displaced land in country *j* among all the countries *J* where imports from country *i* lead to land displaced; P_{ki} is analogous to P_{kj} but referring to land absorbed in tropical country *i*; ES_k is the value of ES per hectare associated with biome *k* per year; A_j and A_i are the areas displaced in each country *j* and absorbed in country *i*.

We considered two types of $netES_i$, those with and without carbon related ES to represent the perspective of a global planner and the perspective of the tropical countries studied since carbon services produce global benefits not exclusively received by the exporting country. We considered three types of land absorbed and displaced: cropland, forestland and pastureland, leading to three types of ES values. Forgone ES in absorbed cropland value were done according to the proportion of biomes estimated in scenarios A–C. Forgone ES in forestland were estimated considering only the rescaled proportion of tropical forest, temperate forest and woodland biomes absorbed. Absorbed pastureland was assumed to present ES values similar to grasslands.

Gross rents from agricultural, forest and livestock products

Once the net losses of ES were calculated, we added the gross rents obtained from absorbed land to ascertain whether they could compensate for the annual losses of ES.

According to the three types of land absorbed and displaced: cropland, forestland and pastureland, we calculated rents from agricultural, forest and livestock products respectively.
Gross rents from absorbed cropland were approximated from the agricultural rents in the 17 major tropical crops considered. Adopting a conservative approach and, due to the large uncertainty associated with production costs, we assumed that production costs were zero.

The geographic distribution of yields in the 17 crops in year 2000 were compiled from Monfreda et al., (2008) and multiplied by producer prices that were obtained from FAOSTAT (FAO 2010a). The crop prices for countries without available data were approximated using the mean price of the crop by sub-regions and regions (Table S1 in ESM1). An average producer price was obtained over a five year period from 2001 to 2005 to mitigate the effect of commodity price fluctuations in a single year. Agricultural rent per hectare was calculated using a weighted average of the 17 crops based on the area of the crops used for exports in each country. These areas were estimated by converting the volume of exports in each crop back into areas using crop and livestock yields for each country (using global yield maps by Monfreda et al. 2008).

Forest rents were approximated using the benefits of sales of timber after land conversion by combining the proportion of growing stock of commercial species and total growing stock by region (FAO 2010b) with price per unit of volume of exported timber by country (FAO 2010a). This net present value of forest rent value was annualized using a 6% discount rate and a 20 year time horizon to reflect a conservatively short harvesting cycle (Table S1 in ESM2).

We estimated the rent from livestock using cattle density maps (FAO 2014) and multiplying these with carcass efficiency in each country, meat prices per country and proportion of land that was pasture (FAO 2010a; Naidoo and Iwamura 2007). Regional information was used when prices or carcass efficiency could not be obtained for a country (Table S1 in ESM1).

Results

Considering all ES lost through land absorbed and gained through land displaced from the perspective of a global planner (including all ES), international trade in the tropics led to a mean annual global net loss of I$1.7 trillion from scenario A. This estimate ranged from I$1.37 to I$2.52 trillion (scenarios B and C respectively) when uncertainty in the distribution of absorbed land was considered. If carbon related services were not considered, to represent the perspective of tropical nations, the global annual losses were I$1.1 trillion with an uncertainty range of I$0.92–1.42 trillion (scenarios B and C respectively).

Considering the gross rents from agriculture, forest and livestock products in absorbed land, the global annual net losses when considering all ES were reduced to I$1.26 trillion (uncertainty range of I$0.92–2.08 trillion). If carbon ES were not considered, global losses reduced to I$0.67 trillion (uncertainty range of I$0.47–0.97 trillion).

Although global aggregate estimates point towards net losses of ES, there were marked differences among countries (Figures 1, 2 and 3) chiefly driven by the ratio of land absorbed vs. displaced and the proportion of biomes associated to these (Tables S1–S6 in ESM2). Unless otherwise stated, we focus now on the results in scenario A, considering all ES (perspective of the global planner) and no deduction of agricultural, forest and livestock rents (Table S1 in ESM2). The results for other no carbon and land use rents scenarios follow in parallel (Tables S2–S6 in ESM2, Figures S1–S6 in ESM1). Under this scenario, only 7 out of the 41 countries and regions presented net overall gains of ES through trade. When considering cropland, forestland and pastureland separately, 11, 16 and 18 countries and regions out of 41 presented net gains respectively (Table S1 in ESM2).

Large countries such as Brazil, Indonesia, Thailand, India, Malaysia and Vietnam present large losses which represented 79% of the global ES loss estimate. These countries have in common large areas of absorbed land destined to exports than are much greater than the land displaced through their imports (e.g. Brazil and Indonesia present 70 and 14 millions of global hectares of cropland absorbed and 9.4

and 11 millions of hectares of cropland displaced respectively, Table S1 in ESM2). On a per capita basis, the top countries in terms of net losses were however quite different. The largest net ES losses occurred in Botswana (I$8100 per capita), Malaysia (I$6100 per capita) and Paraguay (I$5787 per capita) that are countries with small populations relative to their large areas of land absorbed.

While most of the land absorbed was associated to the tropical forest biome with high ES values, land displaced corresponded, in large proportion, to countries outside the tropics with low ES values. This led to low overall ES gains through imports, e.g. in the case of Indonesia cropland absorbed and displaced translate into I$98 thousand millions lost and I$31 thousand millions gained, more than proportionally widening the gap between gains and losses with respect to differences in cropland displaced and absorbed (Table S1 in ESM2). All countries and regions but Malawi and Vietnam showed a more than proportional widening of the gap between cropland absorbed and displaced when ES were considered (e.g. the ratios of cropland absorbed and displaced for Brazil and Malaysia were 7.48 and 1.48 and the ratio of ES lost to land absorbed and gained through land displaced were 14 and 3 respectively).

Other countries and regions, by contrast, presented net gains of ES through trade (Figures 1–3). Some of these were: Mexico, Caribbean countries, Venezuela, Bangladesh, Senegal and Nigeria (Figures 1–3). These countries have in common smaller areas of land absorbed than the areas they displace through trade (e.g. 7, 3 and 2 millions of global hectares of cropland absorbed vs. 27, 6 and 5 millions of global hectares of land displaced occur in Mexico, Nigeria and Bangladesh respectively, Table S1 ESM2).

The inclusion of gross rents obtained from agricultural, forest and livestock products was not able to compensate the net losses of ES through trade in most cases (Figure 3). The country exceptions were Colombia, Guatemala, Mozambique and Peru that were characterized by low net ES lost and high agricultural, forest and livestock rents able to compensate these net ES losses (Table S1 in ESM2).

About half of the countries and regions presented inconsistencies in the direction of ES gains or losses across cropland, forestland and pastureland absorbed (Figures S1–S6 in ESM1), i.e. countries such as Colombia, Ecuador and Ethiopia presented net losses through cropland absorbed and displaced but net gains through forestland, reflecting marked differences in agricultural and forest products exports, imports by countries and their corresponding rents (Figures S1–S6 in ESM1).

Discussion

Our results show large economic losses resulting from the loss of ES due to land absorbed in tropical nations. These losses are not compensated by gains of ES embedded in imports through land displaced in the majority of the tropical countries analysed. These net ES losses are neither compensated by gains in agricultural, forest and livestock rents in most countries even if carbon-related ES (a large proportion of the ES value of tropical forests) are not considered.

Most countries that presented top net losses such as Brazil, Thailand, India, Vietnam and Indonesia were countries with large areas of land absorbed and, in comparison, small areas of land displaced. This suggests that the global demand in agricultural and forestry products leads to the conversion of large tracks of tropical forests with high ES values in export-oriented tropical countries. The lack of compensation of ES loss by agricultural, forest and livestock rents suggest that, due to diminishing marginal returns, these countries may be converting increasingly less optimal land for agriculture at the expense of high valuable land for ES.

Countries presenting large net losses were typically export-oriented countries supplying large volumes of agricultural products and timber to temperate high-income countries and emerging economies. For instance 13%, 8% and 8% of the trade footprint in Brazil and 21%, 16% and 7% in Indonesia corresponded to the USA, Germany and China respectively (Weinzettel et al. 2013). These countries are also characterized by a large area of their tropical forest biome converted to agriculture and by large agri-businesses being a major driver of deforestation. The opposite was found in the majority of

African countries where smaller net losses or even net gains (e.g. Senegal, Nigeria) were estimated from land absorbed minus displaced. Countries with net gains presented, by contrast, large areas of land displaced, smaller areas of land absorbed and higher imports from neighbouring tropical countries.

An example of region where large agri-businesses drive deforestation is Southeast Asia where oil palm, pulp and paper companies expand via large forest concessions that are granted by governments (Abood et al. 2014; Sandker et al. 2007). Similar patterns used to be common in Brazil, where large-scale farms utilized 50% of the deforested area while small farms accounted for only 1.5% (Chomitz and Thomas 2001). These patterns seem however to have reversed due to the effectiveness of command and control policies on large plantations (Godar et al. 2014). Teasing out exactly which type of actors are behind land absorbed as opposed to supplying the domestic market presents high uncertainty and should be a matter of future research. Satellite image analyses combined with agricultural census data may allow to identified the type of actors driving deforestation (Godar et al. 2014), but ascertaining whether the products are destined to the international market or not would still require further technical developments.

Although scaling-up the value of ES from the TEEB dataset to quantify the total economic value of ES lost involves strong caveats such ignoring the heterogeneous distribution of the value of ES (Turner et al. 1998), it is also important to illustrate the magnitude of the problem (Costanza et al. 2014). Our results on ES lost from absorbed minus displaced agriculture amount to I$1.7 trillion (uncertainty range of I$1.34–2.52 trillion) per year which is between 8 and 40% of the total value of ES lost per year through land-use change as estimated in a previous global study (Costanza et al. 2014). This suggests that land-use absorption due to international trade in the tropics is a substantial contributor to terrestrial ES loss globally.

The large losses from absorbed agricultural land in many tropical countries indicate that many agricultural, timber and livestock goods are severely under-priced, confirming the presence of large externalities borne by tropical countries for the consumption by high-income and emerging non-tropical nations (Dasgupta and Ehrlich 2013). This is the result of tropical countries bearing land absorption in areas with high forgone ES values while importing products in displaced areas with much lower ES value in temperate regions. As a result, an uncompensated transfer of ES values from tropical countries to temperate high-income countries takes place, i.e. tropical exporters are subsidizing consumption for temperate high-income countries.

To correct the market failure by including the externalities through the ES values lost into the price of agricultural products, the price would need to increase considerably for some products. For instance, conservatively, it would cost importers an additional sum of I$140 thousand millions per year to compensate for the loss of ES (excluding carbon services) in Brazil (after deducting ES gained through imports and agricultural, forest and livestock rents). Distributing this cost by the area of land absorbed and considering average yields, commodities such as soybean in Brazil would require an "ES" price premium of 280% of its price in 2004 per ton. In Indonesia, internalising ES under the same scenario would cost importers a lower gross sum of I$6 thousand millions per year (due to higher displaced land in Indonesia from other tropical countries). Oil palm, one of the key exported commodities in Indonesia, would require a 5% increase in price to internalize the value of ES lost. Consumers could potentially be willing to pay these "ES" price premiums for agricultural products in Indonesia. For instance, although the premium for certified sustainable palm oil was less than 1% over the market price for crude palm oil (Paoli et al. 2010), the willingness-to-pay for tiger-friendly margarine ranged from 37% –56% (Bateman et al. 2010) and a recent study suggests willingness to pay of 8-10% for palm oil deforestation free products by Singaporean consumers (Giam et al. 2015).

One of the limitations of our research is that we used spatially implicit values of ES. Future research should aim to use spatially explicit values of ES, which may present lower values per hectare because spatial meta-analytical models can correct for sampling bias towards high ES value sites (Carrasco et al. 2014), a correction that is not possible using the direct benefit transfer techniques employed in the spatially implicit scenarios used. Paucity of spatially explicit maps of economic value of ES for all biomes prevented us from employing this approach, which could lead to an overestimation of the value of ES by 7-28% (Carrasco et al. 2014). The use of meta-analytic methods can also avoid some of the biases generated when using homogeneous ES values. For instance, the type of valuation method used, i.e. accessibility of the forest (presence of beneficiaries is necessary for the value of the ES to be realized), scarcity of the service, spatial configuration and size of the ecosystem can all influence the value of the ES across space (Boyd and Banzhaf 2007; Polasky and Segerson 2009). It should also be noted that our analyses were restricted to economic values, leaving aside the intrinsic value of biodiversity, cultural and health values of ES that cannot be easily captured using economic valuation techniques. Given the global importance of tropical forests for biodiversity conservation (Gibson et al. 2011), our results are thus likely to be underestimating the impacts of absorbed land in the tropics.

Relatedly, due to the high uncertainty associated to production costs, especially regarding machinery, labour, fertilizer and pesticide inputs, we could not incorporate agricultural production costs effectively and instead assumed them to be zero. This assumption makes our analysis of the degree of compensation of ES losses by agriculture conservative, i.e. if production costs were included the ratio of ES losses to agricultural benefits would be even higher. It overlooks, however, the differences between countries (especially between intensive agricultural production and extensive smallholder systems) in the net benefits from agricultural activities. These differences may be large, as the benefit to cost ratios of agricultural activities will vary by country as a function of economies of scale, level of inputs (such as fertilizer and seeds), labour and transport costs.

Similarly, our analysis, using global maps (homogeneous in terms of ES), is not able to capture the food security, employment and social benefits derived through forest conversion in local communities. Even though conversion of forests to agriculture generates large net aggregate losses in countries like Brazil or Indonesia, studies on-the-ground that evaluate the fine-grain socio-economic implications of forest conversion to agriculture in specific communities, would be needed to further support governments in the evaluation of social trade-offs between agriculture and forests. Another limitation is that we used historical conversion to cropland since 1700 to ascertain the potential distribution of land absorbed. This ignores how ES values changed through time using only the contemporary values of ES across all the absorbed land.

Conclusion

Our analyses point towards severely under-priced agricultural commodities implying high environmental costs in the form of ES losses that are largely borne by tropical countries, i.e. tropical nations subsidize the consumption of importing nations. Without incorporating these costs into the international trade of agricultural and forestry commodities produced in the tropics, beyond optimal deforestation levels will continue. Our results thus question the capacity of international trade to reflect the true value of tropical products, demonstrating that international trade leads to large net losses of ES that are not compensated by imports nor agricultural, forest and livestock rents.

References

Abood, S.A., Lee, J.S.H., Burivalova, Z., Garcia-Ulloa, J., Koh, L.P., 2014. Relative contributions of the logging, fiber, oil palm, and mining industries to forest loss in Indonesia. Conservation Letters.

Andersson, J.O., Lindroth, M., 2001. Ecologically unsustainable trade. Ecological Economics 37, 113–122.

Bateman, I.J., Fisher, B., Fitzherbert, E., Glew, D., Naidoo, R., 2010. Tigers, markets and palm oil: market potential for conservation. Oryx 44, 230–234.

Boyd, J., Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. Ecological Economics 63, 616-626.

Brown, K., Pearce, D.W., 1994. The causes of tropical deforestation: the economic and statistical analysis of factors giving rise to the loss of the tropical forests. UBC Press, Canada.

Bureau of Labor Statistics, 2010. CPI Inflation Calculator. United States Department of Labor. Available at: http://data.bls.gov/cgi-bin/cpicalc.pl.

Carrasco, L., Nghiem, T., Sunderland, T., Koh, L., 2014. Economic valuation of ecosystem services fails to capture biodiversity value of tropical forests. Biological Conservation 178, 163–170.

Chomitz, K., Thomas, T., 2001. Geographic patterns of land use and land intensity in the Brazilian Amazon. World Bank Policy Research Working Paper No. 2687.

Costanza, R., de Groot, R., Sutton, P., van der Ploeg, S., Anderson, S.J., Kubiszewski, I., Farber, S., Turner, R.K., 2014. Changes in the global value of ecosystem services. Global Environmental Change 26, 152–158.

Dasgupta, P.S., Ehrlich, P.R., 2013. Pervasive externalities at the population, consumption, and environment nexus. Science 340, 324-328.

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., 2012. Global estimates of the value of ecosystems and their services in monetary units. Ecosystem Services 1, 50–61.

de Groot, R.S., Alkemade, R., Braat, L., Hein, L., Willemen, L., 2010. Challenges in integrating the concept of ecosystem services and values in landscape planning, management and decision making. Ecological Complexity 7, 260–272.

European Commission, 2013. The impact of EU consumption on deforestation: Comprehensive analysis of the impact of EU consumption on deforestion, pp. 1–98, Belgium.

Ewing, B., Reed, A., Rizk, S., Galli, A., Wackernagel, M., Kitzes, J., 2008. Calculation Methodology for the National Footprints Accounts. 2008 ed.(version 1.1); Global Footprint: Oakland, CA, 2008.

FAO, 2010a. FAOSTAT. Food and Agriculture Organization of the United Nations. Available at: http://faostat.fao.org/site/342/default.aspx.

FAO, 2010b. Global Forest Resources Assessment 2010. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/forestry/fra/fra2010/en/. Global Forest Resources Assessment 2010. Food and Agriculture Organization of the United Nations.

FAO, 2014. Livestock densities. Gridded Livestock of the World (GLW). Food and Agriculture Organization of the United Nations. Animal Production and Health. Accessed at: http://www.fao.org/ag/againfo/resources/en/glw/glw_dens.html.

Giam, X., Mani, L., Koh, L.P., Tan, H.T.W., 2015. Saving Tropical Forests by Knowing What We Consume. Conservation Letters, n/a-n/a.

Gibson, L., Lee, T.M., Koh, L.P., Brook, B.W., Gardner, T.A., Barlow, J., Peres, C.A., Bradshaw, C.J., Laurance, W.F., Lovejoy, T.E., 2011. Primary forests are irreplaceable for sustaining tropical biodiversity. Nature 478, 378-381.

Godar, J., Gardner, T.A., Tizado, E.J., Pacheco, P., 2014. Actor-specific contributions to the deforestation slowdown in the Brazilian Amazon. Proceedings of the National Academy of Sciences 111, 15591-15596.

Hansen, M., Potapov, P., Moore, R., Hancher, M., Turubanova, S., Tyukavina, A., Thau, D., Stehman, S., Goetz, S., Loveland, T., 2013. High-resolution global maps of 21st-century forest cover change. Science 342, 850-853.

Hertel, T.W., 1997. Global trade analysis: modeling and applications. Cambridge university press.

Hertel, T.W., Ramankutty, N., Baldos, U.L.C., 2014. Global market integration increases likelihood that a future African Green Revolution could increase crop land use and CO2 emissions. Proceedings of the National Academy of Sciences 111, 13799-13804.
Karstensen, J., Peters, G.P., Andrew, R.M., 2013. Attribution of CO2 emissions from Brazilian deforestation to consumers between 1990 and 2010. Environmental Research Letters 8, 024005.
Lambin, E.F., Meyfroidt, P., 2011. Global land use change, economic globalization, and the looming land scarcity. Proceedings of the National Academy of Sciences 108, 3465–3472.
Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L., Geschke, A., 2012. International trade drives biodiversity threats in developing nations. Nature 486, 109–112.
Meyfroidt, P., Lambin, E.F., Erb, K.-H., Hertel, T.W., 2013. Globalization of land use: distant drivers of land change and geographic displacement of land use. Current Opinion in Environmental Sustainability 5, 438–444.
Meyfroidt, P., Rudel, T.K., Lambin, E.F., 2010. Forest transitions, trade, and the global displacement of land use. Proc Natl Acad Sci U S A 107, 20917-20922.
Monfreda, C., Ramankutty, N., Foley, J.A., 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Global Biogeochem. Cycles 22, GB1022.
Naidoo, R., Iwamura, T., 2007. Global-scale mapping of economic benefits from agricultural lands: Implications for conservation priorities. Biological Conservation 140, 40-49.
Paoli, G.D., Yaap, B., Wells, P.L., Sileuw, A., 2010. CSR, oil palm and the RSPO: Translating boardroom philosophy into conservation action on the ground. Tropical Conservation Science 3, 438–446.
Polasky, S., Segerson, K., 2009. Integrating ecology and economics in the study of ecosystem services: some lessons learned. Resource 1.
Ramankutty, N., 2012. Global Cropland and Pasture Data from 1700-2007. Accessed at: http://www.geog.mcgill.ca/~nramankutty/Datasets/Datasets.html.
Ramankutty, N., Evan, A.T., Monfreda, C., Foley, J.A., 2008. Farming the planet: 1. Geographic distribution of global agricultural lands in the year 2000. Global Biogeochemical Cycles 22.
Ramankutty, N., Foley, J.A., 1999. Estimating historical changes in global land cover: Croplands from 1700 to 1992. Global Biogeochemical Cycles 13, 997–1027.
Ricardo, D., 1817. On the Principles of Political Economy and Taxation: London.
Sandker, M., Suwarno, A., Campbell, B.M., 2007. Will forests remain in the face of oil palm expansion? Simulating change in Malinau, Indonesia. Ecology and Society 12, 37.
Smith, A., 1776. The wealth of nations. New York: The Modern Library.
Steen-Olsen, K., Weinzettel, J., Cranston, G., Ercin, A.E., Hertwich, E.G., 2012. Carbon, land, and water footprint accounts for the European Union: consumption, production, and displacements through international trade. Environmental science & technology 46, 10883–10891.
Turner, R.K., Adger, W.N., Brouwer, R., 1998. Ecosystem services value, research needs, and policy relevance: a commentary. Ecological Economics 25, 61-65.
United Nations Conference on Trade and Development, 2012. Development and Globalization 2012: Facts and Figures.
Wackernagel, M., Rees, W., 1995. Our Ecological Footprint. New Society. Philadelphia.
Weinzettel, J., Hertwich, E.G., Peters, G.P., Steen-Olsen, K., Galli, A., 2013. Affluence drives the global displacement of land use. Global Environmental Change 23, 433-438.
WHO, 2010. Purchasing Power Parity 2005. World Health Organization. CHOosing Interventions that are Cost Effective (WHO-CHOICE). Accessed on May 2010 at: http://www.who.int/choice/costs/ppp/en/index.html.

Tables and figures

Table 1. Variables used in the analysis, their temporal range, spatial extent, grain and source.

Variable	Temporal range	Spatial extent and grain	Source
Cropland, forestland and pastureland absorbed and displaced.	2004	Global. Country and regional level.	(Weinzettel et al. 2013)
Crop yields and crops distribution.	2000	Global. Spatially explicit maps for 17 crops.	(Monfreda et al. 2008; Ramankutty et al. 2008)
Distribution of biomes, global potential vegetation maps	—	Global. Spatially explicit maps.	(Ramankutty and Foley 1999)
Historical cropland conversion	1700-2007	Global. Spatially explicit maps.	(Ramankutty 2012)
Ecosystem services values per biome	1974-2010	Global. Spatially homogeneous.	(de Groot et al. 2012)
Yield factors to translate from global to national hectares	2001-2005	Global. Country level.	(FAO 2010a)
Export volumes	2001-2005	Global. Country level.	(FAO 2010a)
Producer prices	2001-2005	Global. Country level.	(FAO 2010a)
Growing stock of commercial timber species	2010	Global. Regional level.	(FAO 2010b)
Price of timber (using volume and value of exports)	2001-2005	Global. Country level.	(FAO 2010a)
Cattle density maps	2007	Global. Spatially explicit maps.	(FAO 2014)
Carcass efficiency, meat prices	2001-2005	Global. Country level.	(FAO 2010a)

Figure 1. Distribution of biomes (Biome) within cropland areas in year 2000 and net ES lost through international trade plus agricultural, forest and livestock rents in tropical countries (NET ES + AR expressed in $ billions).

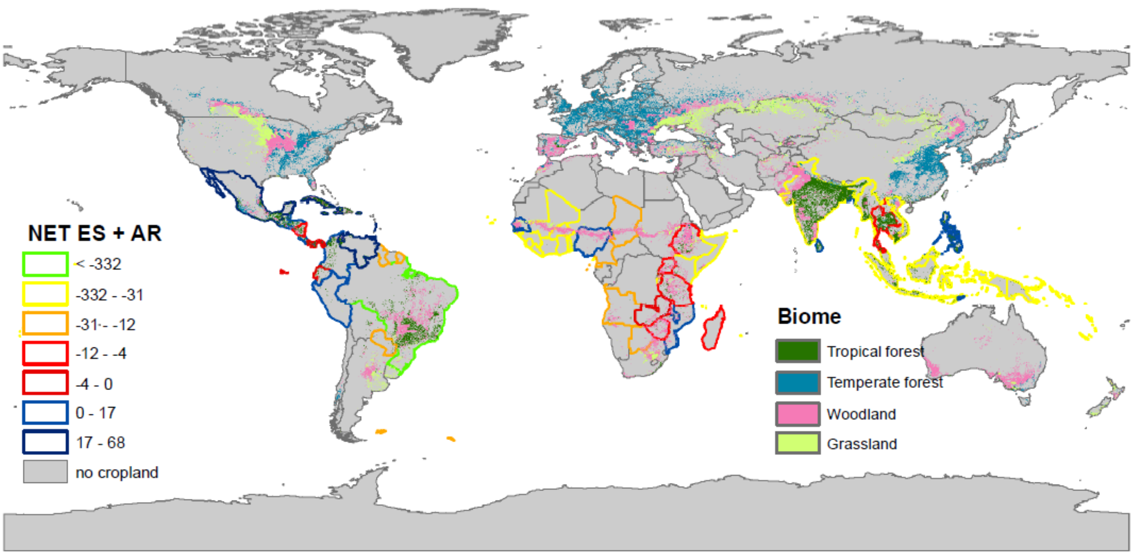

Figure 2. Net gains of ES through land displaced via imports minus net losses through land absorbed through exports in tropical countries and regions in the year 2004. Two types of ES groups are considered: one that considers all ES ("With Carbon") and one that excludes the value of carbon related services ("Without Carbon"). This represents the perspectives of a global planner and national planners in tropical countries respectively. Error bards correspond to scenarios B and C and circles correspond to scenario A.

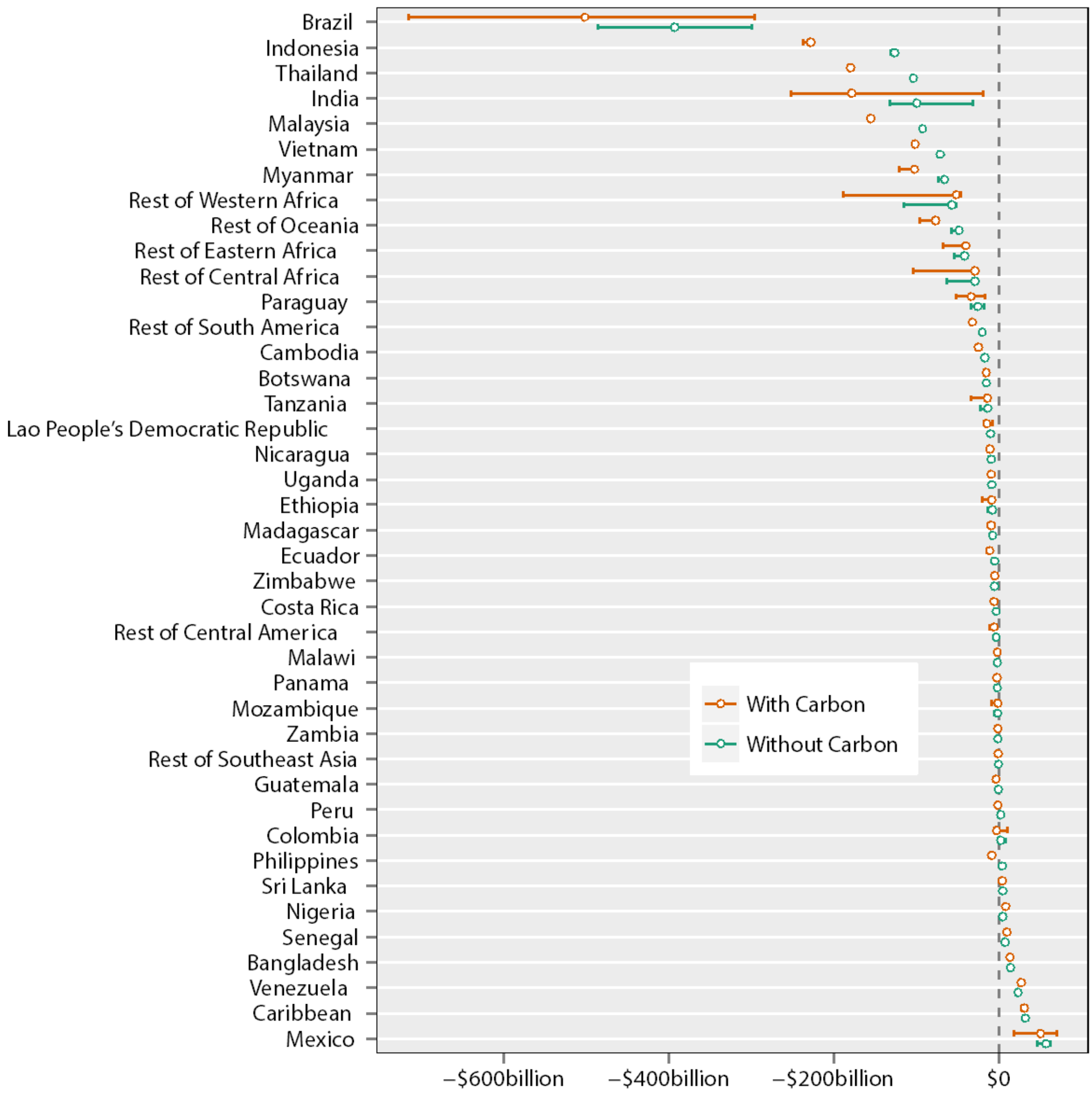

Figure 3. Net gains of ES through land displaced via imports, agricultural, forest and livestock rents minus net losses through land absorbed through exports in tropical countries and regions in the year 2004. Two types of scenarios are considered: one that considers net ES losses (displaced minus absorbed, “Net ES”) and one that adds agricultural, forest and livestock rents to the net losses of ES (“Net ES + AR”). Error bars correspond to scenarios B and C and circles correspond to scenario A.