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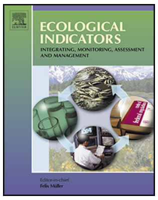

On the suitability of input–output analysis for calculating product-specific biodiversity footprints

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ABSTRACT

Recently it has been estimated that one third of biodiversity threats are driven by consumer demand from outside the country in which the threat occurs. This occurs when the production of export goods exerts pressure on vulnerable populations. While population biologists have in cases been able to establish links between species threats and the causative industry(s), little has been done to trace this biodiversity footprint from the directly implicated industry out to final consumers, a step that would open a wider variety of policy responses. Here we investigate the suitability of multi-region input–output (MRIO) analysis for tracing out links between particular species threats, directly implicated industries, and the countries and consumer goods sectors ultimately driving these industries. Environmentally extended MRIO models are understood to provide reliable results at a macroeconomic level but uncertainty increases as the models are used to investigate individual sectors, companies, and products. In this study we examine several case studies (nickel mining in New Caledonia, coltan from the Democratic Republic of Congo, cut flowers from Kenya, and forestry in Papua New Guinea) in order to understand how and when MRIO techniques can be useful for studying biodiversity implicated supply chains. The study was conducted using the Eora global input–output database that documents >5 billion global supply chains. Calculating the biodiversity footprint at this level of detail, between specific threats, supply chains, and consumer goods, has not been done before. These case studies provide interesting insights in their own right and also serve to highlight the strengths and weaknesses of using input–output analysis techniques to calculate detailed biodiversity footprints. We conclude that MRIO analysis, while no panacea, can be useful for outlining supply chains and identifying which consumption sectors and trade and transformation steps can be subjected to closer analysis in order to enable remedial action.

1. Introduction

The planet is currently undergoing its sixth great extinction event (Chapin et al., 2000; Butchart et al., 2010; Dirzo et al., 2014; Tittensor et al., 2014). Species loss is occurring at a rate of two or more orders of magnitude greater than before the Anthropocene (Pimm et al., 1995), and humans and their domesticated animals currently account for >97% of terrestrial vertebrate biomass (Smil, 2002). Yet despite full awareness and considerable research into the problem of biodiversity loss there are few clear stratagems for ameliorating the situation. In terms of tractable policies, saving species seems to be proving a far more difficult goal than reducing GHG emissions. This is because protecting biodiversity is both an ecologically and an economically complex challenge. To begin with, measuring ecosystems' health is difficult. There is no clear consensus on any single best way to measure biodiversity health. Next, it is often difficult to attribute species threats to specific human activities – a necessary prerequisite for organizing any socio-political response. Then, even in cases where a policy has been established, economic and social interests often collide with protection goals (Chapman et al., 2003; Luck et al., 2004) and illegal and unreported activity thus continue to drive further species loss. Adding further to this complexity is the fact that in today's globalized economy purchasers in households, business, and governments are often far removed from the ecological impacts their consumption ultimately drives. Often consumers cannot directly see how their actions impact individual species.

It is this last point – supply chain opacity and complexity – that we investigate here. We use environmentally extended input–output analysis to evaluate the supply chains of biodiversity-implicated commodities. We present four case studies (nickel mining in New Caledonia, coltan from the Democratic Republic of

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Congo, cut flowers from Kenya, and forestry in Papua New Guinea) and use these techniques to try and identify clear links between a particular biodiversity threat, a causative industry, and the key supply chains leading out from that industry to final consumers of implicated products. Identifying such threat pathways allows all the actors along a supply chain – traders, companies, governments, and households – to contribute to reducing the magnitude or ecological intensity of a product's supply chain.

Using input–output (IO) techniques to trace environmentally important flows is not new. The basic techniques have been developed and refined since their introduction in the 1940s. IO is regularly used to calculate carbon footprints, trace substances of concern, and unravel the linkages between consumers and the raw resources their consumption requires (Graedel and Allenby, 1995; Graedel et al., 2002; Reck et al., 2008; Peters et al., 2012; Reck and Graedel, 2012; Graedel et al., 2013). What is new is using IO techniques to trace biodiversity-implicated commodities. In a seminal study on biodiversity footprints Lenzen and colleagues (Lenzen et al., 2012b) used IO accounting and found that one third of the species threats recorded on the IUCN's Red List of Threatened and Endangered Species were ultimately driven by consumption demand outside the country in which the threat was exerted.

Lenzen et al.'s study worked in the aggregate, looking at over 3000 individual species threats and 15,000 industries across 187 countries. In this study we use the same methods but look in depth at few selected species, industries, and trade flows. The aim is to determine whether IO methods are suitable for investigating individual species threats and related implicated product flows. Policy responses to biodiversity threats, especially when linked to traded products, will require a high level of industry and product detail, a fact recognized by the European Commission (Lammerant et al., 2014) and in the active interest in the biodiversity footprint. IO methods could also be used to bolster green supply chain and green certification programmes. With the selected case studies we seek to ask whether IO methods are appropriate, and robust enough, for studying individual species – industry – supply chain links. The case studies were selected to provide a "best case" of use of MRIO techniques to biodiversity-implicated products through supply chains. The cases were chosen for having clear links between species loss and a particular industry, and good trade data on that industry's onward flows.

This paper proceeds as follows. First, we introduce IO and related methods in Sections 2 and 2.1. Then, in Section 2.2 we introduce the case studies and establish the links between biodiversity pressure and one or more specific industries in each case. Next, in Section 3 we present numeric results from the IO and trade analysis. Finally, in Section 4 we offer discussion about the results, including on reliability. Finally, Section 5 concludes.

2. Methods

2.1. Input–output analysis and structural path analysis

Input–output tables provide a database of global trade flows, as well as production and consumption recipes. Using an IO table it is possible to identify supply chains such as: "A typical $10,000 automobile purchased in the US requires $1200 worth of Japanese steel parts, the production of which in turn require $600 worth of Chinese rolled steel, the production of which in turn requires $200 worth of Australian iron ore." The techniques of input–output analysis were originally developed by Leontief (1986), and the Structural Path Analysis (SPA) (Defourny and Thorbecke, 1984; Suh and Heijungs, 2007) used to extract individual supply chains from aggregate results, has been developed and applied extensively since then (e.g. in (Lenzen, 2003, 2006; Peters and Hertwich, 2006; Wood and Lenzen, 2009). For this study we used the Eora multi-region IO table (Lenzen et al., 2012a) which covers 187 countries with a detail of 26–500 economics sectors per country for a total of S = 15,909 sectors/goods. Countries in Eora have variable levels of detail because Eora is composited from national IO tables and the original native classifications are preserved. Eora was chosen from amongst the several global MRIO tables currently available (Tukker and Dietzenbacher, 2013) because of its superior country coverage. This is an important attribute because our study requires an MRIO table that covers even smaller economies in biodiversity hotspots.

The Leontief calculus can be used to connect final consumers with upstream biodiversity impacts. Leontief originally created his methods in order to calculate how much of a given primary resource, e.g. coal, was needed, across the entire economy, to satisfy $1 of consumer demand for a particular product. By conceptualizing pollution – or, in our case, biodiversity impacts – as a necessary input to production, the same methods can be employed to determine how much biodiversity impact was exerted to produce $1 of a particular good in that year. Input–output tables are retrospective accounts; they record the production recipe and trade volumes for prior years. Improvements in technology or changes in trade patterns can change the environmental impact of a sector in future years.

One challenge in studying biodiversity is choosing an indicator with which to measure biodiversity pressure or loss. For their study on total biodiversity impact, Lenzen et al. (2012b) quantified the biodiversity impact of a sector by using the total number of species endangered due to primary production of that sector. Since in this study our focus is on determining the suitability of MRIO methods for tracing individual supply chains, we may skip the difficult question of choosing how to measure biodiversity pressure. The important thing is to determine which sector(s) are responsible for causing pressure and we do not need to measure the intensity with which that pressure is exerted. Thus to construct the environmental satellite account for the environmentally extended MRIO analysis, all sectors are given 0 biodiversity impact, except the selected sector(s) which are given a value of 1. All numeric results, then, are expressed as dimensionless percentages of the total impact.

The Leontief method has been well explained (for overviews see Wiedmann, 2009; Kitzes, 2013; Schaffartzik et al., 2014) but we briefly reiterate it here. Using the Eora MRIO table $\mathbf{T}_{s\times s}$ documenting the monetary transactions between S sectors, the biodiversity footprint $\mathbf{F}_{\mathbf{1}\times s}$ in terms of a particular implicated commodity, resulting directly and indirectly from spending $\mathbf{y}_{s\times\mathbf{1}}$ of final consumers is $\mathbf{F} = \mathbf{Q}\hat{\mathbf{x}}^{-1}\left(\mathbf{I} - \mathbf{T}\hat{\mathbf{x}}^{-1}\right)^{-1}\mathbf{y}$, where $\mathbf{x}_{s\times 1}$ denotes sectoral gross output, the $\hat{\ }$operator denotes diagonalization, $\mathbf{I}_{s\times s}$ is an identity matrix, and $\mathbf{Q}_{\mathbf{1}\times s}$ is an environmental satellite account containing the value of other resources used as input in that sector. For each case study a $\mathbf{Q}$ vector was constructed containing a single nonzero unit element flagging the environmental input to the particular sector under consideration. In this environmentally extended input–output analysis the units used in the satellite account are arbitrary; the result footprint will be expressed in the same unit as used in the satellite account. In these studies footprint was measured not according to number of species or area impacted, but merely as a share of a unit impact. The term $\mathbf{Q}\hat{\mathbf{x}}^{-1}$ contains the direct biodiversity impact of each sector's production, in terms of impact per $ gross output. The term $(\mathbf{I} - \mathbf{T}\hat{\mathbf{x}}^{-1})$ (where the sub-term $\mathbf{T}\hat{\mathbf{x}}^{-1}$ is often abbreviated $\mathbf{A}$, or technical coefficients matrix) is the classic Leontief inverse. All analysis was conducted in terms of producer's prices.

By solving the Leontief inverse as a Taylor series expansion footprints can be unravelled into individual paths. We abbreviate the terms to $\mathbf{q} = \mathbf{Q}\hat{\mathbf{x}}^{-1}$ and define a technical coefficients matrix $\mathbf{A}$, expressing production recipes in each column as composition of