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PERSPECTIVE

The role of nature's contributions to people in sustaining international trade of agricultural products

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Abstract

1. Nature's contributions to people (NCP) are essential for the production and trade of agricultural, forestry and fishery commodities. Often, there is a spatial disconnect between consumers and the natural systems where the commodities are produced. Traded agricultural products are therefore dependent on nature and NCP in their region of origin.
2. The dependencies of agricultural products on NCP are, however, insufficiently recognised by consumers and are rarely considered in global environmental governance and trade policies along value chains.
3. Here, we synthesise studies highlighting dependencies of agricultural products on NCP in their origin locations to identify opportunities and challenges in quantifying their contribution in sustaining trade flows.
4. We suggest three methodological steps for quantifying NCP dependencies in international agricultural trade: spatial mapping of NCP supply and demand, linking NCP to agricultural trade flows, and tracing trade flows. Each methodological step requires further development and harmonisation to enable a complete accounting of how international agricultural trade depends on NCP.
5. Given the lack of knowledge and data on how NCP support agricultural trade, social and environmental trade-offs of natural resource management are currently hard to quantify. Quantifying the role of NCP dependencies of traded agricultural products can support their sustainable management, contribute to supply chain accountability and serve as input to sustainable natural resource governance and foster responsibility and equity in supply chains.

KEYWORDS
dependencies, ecosystem services, international agricultural trade, Nature's contributions to people (NCP), supply chains, telecoupling

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1 | INTRODUCTION

Nature underpins the production of agricultural, forestry, and fishery commodities globally (IPBES, 2019). This 'dependency' of commodity production on services provided by nature is captured through the concepts of nature's contributions to people (NCP; IPBES, 2019) and ecosystem services (ES) (see Section 2.1 for definitions). Through trade, production systems are ecologically connected (i.e. telecoupled; Liu et al., 2013) to consumer locations around the world. In other words, there is a spatial disconnect between consumers in the importing regions and the natural systems enabling production in the region of origin (Beery et al., 2023). For example, coffee and chocolate enjoyed by people in Germany depend on NCP—such as pollination by insects—in exporting countries like Colombia and Côte Ivoire (Kleemann et al., 2020; Lautenbach et al., 2012). However, consumers in Europe are mostly unaware of how the availability of coffee in their supermarkets is strongly dependent on the proper functioning of ecosystems in distant regions (Laroche et al., 2020).

NCP are heterogeneous in their distribution across the globe, and oftentimes, products exported from economically poor and tropical countries to high-income nations are more dependent on NCP than the other way around, thus exacerbating the inequities between exporting and importing countries (Chaplin-Kramer et al., 2019). Consequently, international trade is also a potential multiplier of inequalities regarding the distribution and access to NCP between people (Dorninger et al., 2021).

A better understanding of the dependencies on NCP of international agricultural trade is directly relevant for policy making in both exporting and importing countries. For example, a better quantitative understanding of how NCP supports exports can help design sustainable resource management strategies. For the importing country, a better understanding and appreciation of the NCP dependency of their consumption in the producing country can help assess risks, vulnerabilities and uncertainties associated with relying on NCP dependent imports and device strategies to make their supply chain more resilient.

Furthermore, it can be especially relevant for environmental policy when domestic regulation and trade liberalisation open avenues for the exploitation of natural resources in economically poor and environmentally sensitive countries for export purposes (Pascual et al., 2017). While there is evidence that trade liberalisation leads to increased overuse of NCP (Abman & Lundberg, 2020; Eisenbarth, 2022), findings also suggest that there are ways to mitigate such impacts (Abman et al., 2021), but a first step towards such mitigation measures is acknowledging and quantifying the role of NCP in supporting international trade. Recent assessments on biodiversity and NCP make explicit the need to consider the telecoupled nature of agricultural systems and their dependence on nature in distant ecosystems as an essential lever for sustainable development (Dasgupta, 2021; IPBES, 2019; Willemen et al., 2020). New policy developments open a window of opportunity to better consider NCP dependencies in global environmental governance and trade policies (CBD, 2022; IPBES, 2022). For example, Target 5 of the Kunming-Montreal Global Biodiversity Framework aims at ensuring that by 2030 trade in wild species is done sustainably. Target 15 highlights the importance of businesses to monitor, assess and transparently disclose their risks, dependencies and impacts on biodiversity along their supply and value chains and provide the information needed to promote sustainable consumption practices (CBD, 2022). And finally, Target 19 pledges for countries in the Global North to support conservation with US$ 20–30 billion per year in countries in the Global South (CBD, 2022). At the European Union level, the European Biodiversity Strategy (EC, 2020) goes a step further and states that biodiversity provisions in all trade agreements (with the EU) should be fully implemented and enforced. The EU regulation on deforestation-free products aims to minimise the consumption of products that caused deforestation in the country of origin (EC, 2021), which could prevent the depletion of NCP in exporting countries. The draft European Supply Chain Act requires EU companies to audit their suppliers throughout the global supply chain, including all direct and indirect business relationships (EC, 2022), which can help reveal and quantify the role of NCP in trade transactions.

Despite these recent policy advances, the ground reality is that dependencies of production on multiple NCP are rarely recognised by producers and consumers and not yet considered in global environmental governance, trade policies, manufacturers of final products, retailers, and other actors along the value chain (Dasgupta, 2021). This fundamental lack of recognition of such crucial dependencies increases the risk that certain NCP are overused beyond nature's capacity to provide or replenish them, potentially cascading into detrimental impacts on local and global food security and land degradation or ecosystem collapse in the long run (IPBES, 2018; Willett et al., 2019) and leading to global supply chain disruptions (WEF, 2023).

Although land, water and biodiversity impacts associated with traded agricultural goods have been extensively explored in the literature (Bruckner et al., 2019; Cabernard & Pfister, 2021; Chaudhary & Kastner, 2016; Hoekstra & Mekonnen, 2012; Lutter et al., 2016; Marques et al., 2019; Rosa et al., 2019; Weinzettel & Pfister, 2019), the role of NCP in sustaining international trade of agricultural products has rarely been quantified (Pascual et al., 2017).

In this paper, we start by exploring the current understanding on the role of material, regulating and non-material NCP in sustaining international trade of agricultural products. Although all economic sectors are (to some extent) dependent on NCP, here we focus on agricultural systems due to their high and direct dependence on NCP. To advance this task, we identify three methodological steps towards robust quantitative assessments of international agricultural trade dependencies on NCP: (1) spatial mapping of NCP supply and demand, (2) linking NCP to agricultural product flows and (3) tracing trade flows of these products. As a synthesis, we provide an outlook on how to operationalise the quantification of international agricultural trade dependencies on NCP and how to move towards providing actionable evidence to inform policy and practice.

2 | DEPENDENCIES ON NCP IN INTERNATIONAL AGRICULTURAL TRADE

2.1 | Concepts for quantifying and understanding dependencies on NCP

In this article, we bring together the frameworks that are best suited to capture the dependency of international supply chains on NCP. We build on concepts from different research strands: most importantly, research on ES and NCP, telecoupling and food systems. We use the NCP classification provided by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), whose starting point was the concept of ES and associated classification schemes (IPBES, 2017).

NCP and beneficiaries are linked through supply chains in telecoupled systems (Figure 1). Telecoupling, in our context, relates a sending system (the exporting country), where the agricultural product depending on various NCP is produced, and a receiving system (the importing country), where the final benefits are enjoyed (e.g. through consumption in importing nations) (Friis & Nielsen, 2019; Liu et al., 2015). The NCP dependency considered in this paper underpins the production of the commodity within the sending system (Figure 1). Our agricultural systems focus encompasses actors and activities involved in agricultural production, aggregation, processing, distribution, consumption and disposal (Ingram, 2011).

2.2 | The role of NCP in sustaining the international trade of agricultural products

2.2.1 | Agricultural trade dependencies on material NCP

Nature's material contributions to people refer to the biomass production (across trophic levels) for energy, food, feed, material or medicinal use, as well as the beneficial contributions of genetic information contained in living organisms (IPBES, 2017). In our framework, any biomass material that is a central input to the production process of agricultural, fisheries and forestry products internationally trade can be considered to generate a NCP dependency. This definition will cover a wide range of inputs, from plankton and low trophic level fish sustaining seafood trade, to grass sustaining milk or beef production, to the genetic diversity in bananas that can support a sustainable supply of the fruit. This wide variety highlights the complexity of supply chains, as well as their common dependence on photosynthetic and heterotrophic organism growth. Here, we summarise two examples of such dependencies of agricultural and fisheries products on biomass inputs.

Our first example focuses on one of the most important traded commodity groups that depends on material NCP: seafood. The value of international seafood trade exceeds the trade value of sugar, maize, coffee, rice and cocoa combined (Asche et al., 2015). This trade consists of aquaculture and capture fishery products,

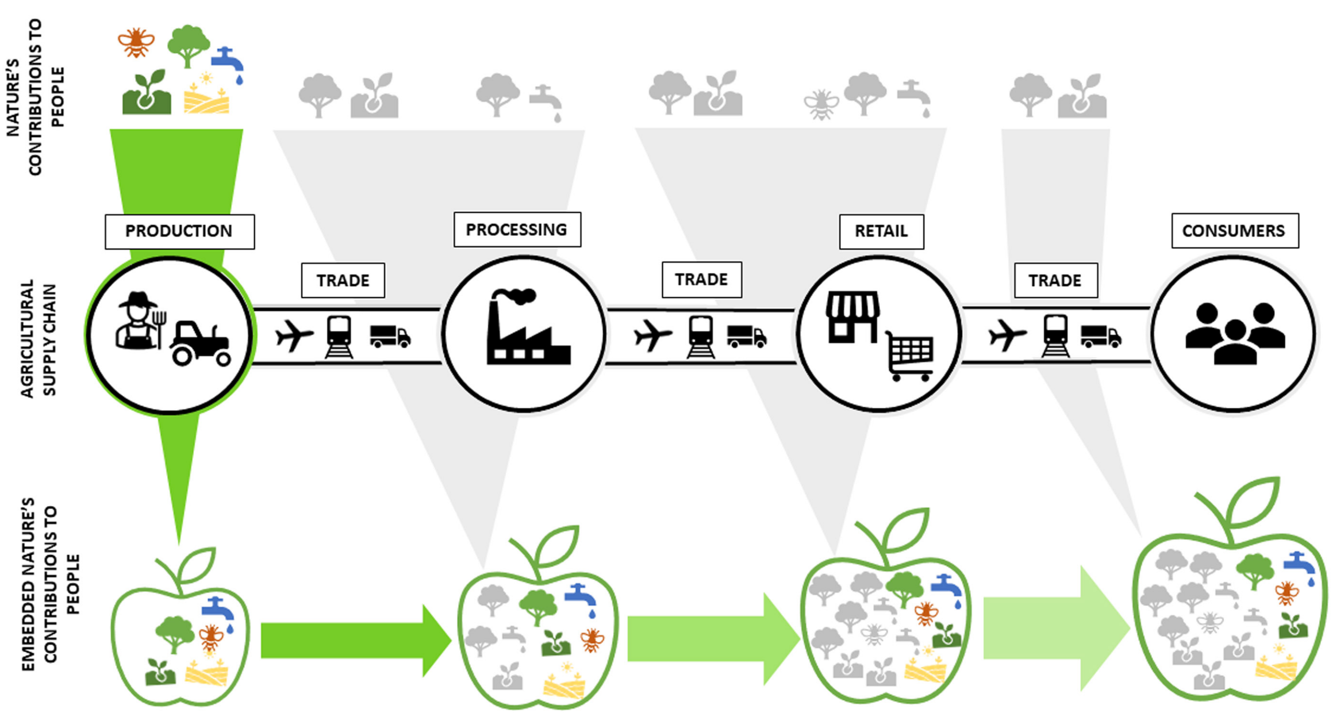

FIGURE 1 Conceptual scheme of NCP supporting international agricultural trade. The top row refers to all direct NCP types (material, regulating and non-material) that are necessary for an agricultural supply chain. The middle row represents an international supply chain of agricultural products, from the producer to the consumer. The bottom row represents the direct NCP, from the first row, which sustains the provision of agricultural products and their flow through the supply chain. The NCP in grey represent those that are necessary for other stages of the agricultural supply chain (top row) than production but that are not covered in this paper.

both of which depend on material NCP. For example, forage fisheries on average contribute about twice as much value (11.3 billion USD) via the material services embedded in predator capture fish products as they contribute via direct catches (5.6 billion USD) (see Pikitch et al., 2014). However, Pikitch et al. (2014) did not calculate how these contributions propagate through trade networks to consumers. Dependencies on material NCP can also result from the use of low-trophic-level fish as bait to catch high-trophic-level fish. For example, significant amounts of Southern African pilchard are embedded in tuna products from international pole fisheries via this route, and Atlantic herring is embedded in New England lobster (Nissar et al., 2022).

A second example comes from the milk and dairy industry. Milk and dairy products are often produced on farms close to their consumers. However, the fodder is made not only of hay from local meadows but from all over the world in the form of concentrated feed. For example, Cederberg and Mattsson (2000) revealed that Swedish milk production currently depends on fodder crops produced in Asia, Latin America and several countries of Europe. Therefore, milk consumed in Sweden is dependent upon material NCP abroad.

2.2.2 | Agricultural trade dependencies on regulating NCP

Regulating NCP are '*functional and structural aspects of organisms and ecosystems that regulate the generation of material and nonmaterial benefits*' (IPBES, 2017). As such, many regulating NCP directly contribute to the production of biomass used as food, feed or fibres.

Agricultural crop production depends on important regulating NCP such as pollination, pest control, erosion control, maintenance of soil fertility, regulation of freshwater quality and quantity, as well as regional climate and air quality regulation.

Pollination services that benefit crop production have been well investigated (Coghlan & Bhagwat, 2022). Pollinators are essential for production of major traded food products including, for example coffee and cocoa. Pollinator-dependent crops account for >50% of crop products traded internationally, while demand for these crops is expected to grow due to lifestyle changes (Silva et al., 2021). Datasets tracing back consumption to production fields are not yet available, which currently limits our understanding of pollination dependencies. Wolff et al. (2017) quantified the trade of pollinator-dependent crops and found that the largest per capita demand resulted from the consumption of pollinator-dependent crop products in Europe. Silva et al. (2021) quantified the global virtual pollination trade and showed that higher income countries were dependent on high levels of pollination services, from lower income countries, to fulfil their consumption patterns. Relevant databases used for such large-scale analyses are, for example United Nations' FAOSTAT on crop distribution and trade and Gallai et al. (2009) on pollinator dependence rates. In turn, habitat for wild pollinators surrounding crop fields was researched on a regional (Sitotaw et al., 2022), continental (Koh et al., 2016) and global scale (Dainese et al., 2019).

Regulation of detrimental organisms and biological processes are NCP provided by organisms or ecosystems, as they regulate the geographical distribution or population abundance of species harmful to agricultural production (e.g. crop pests, pathogens, parasitic organisms) and result in health or economic benefits to humans. Although the process and mapping at the local level is very similar to that of pollination, no studies that present such dependencies in relation to international trade of agricultural products were found.

Climate and air quality regulation provided by nature, for example through forests, benefit agricultural production on the local scale. Reduction in such contributions can lead to higher concentrations of short-lived air pollutants (e.g. black carbon aerosols, methane, tropospheric ozone and hydrofluorocarbons), which in turn can reduce yields of crops such as wheat and rice (Burney & Ramanathan, 2014). Other examples of such regulating NCP on which crop production depends include reduction in wind speed by hedgerows grown along vineyards that benefits wine production by lowering erosion rates (Veste et al., 2020). We did not find any studies quantifying such dependencies on climate and air quality regulation that nature provides in relation to internationally traded agricultural products.

At regional scales, crop production and its stability are also dependent upon NCP such as regulation of freshwater quantity, location and timing. However, although some indicators (e.g. groundwater/aquifer recharge and water in reservoirs) have been used to map the biophysical supply of freshwater regulation services regionally (Castro et al., 2014; Quintas-Soriano et al., 2019), the connection with internationally traded agricultural products is hardly made. However, Dalin et al. (2017) quantified the groundwater depletion induced by the production of internationally traded food. Another example is provided by La Notte et al. (2020), who assessed the regulation of freshwater quality by the water purification service (through nitrogen removal) of lakes and rivers in Europe and showed that around 29% of the total nutrient regulation (24,406 tonnes of nitrogen removed) served the production of internationally traded agricultural products. For this, La Notte et al. (2020) linked ES accounts to a multi-regional input–output economic model. While the ES account connects biophysical quantification of water purification to the economy, the input–output model traces international trade flows from the producer to the consumer.

Finally, while soil-regulating NCP are directly responsible for the production of agricultural and forestry goods, how international trade depends on them is hitherto understudied. Studies on the natural contribution to agricultural suitability in terms of soil structure and fertility (Schröter et al., 2021) or other indicators such as vegetation cover and its capacity to avoid soil erosion and soil loss (Castro et al., 2014; Quintas-Soriano et al., 2019) did not consider their role in supporting international trade. Similarly, Xie et al. (2019) measured the transboundary effect of the ecological security barrier function of Inner Mongolia for preventing winds as NCP preventing wind caused soil erosion and found a transregional value flow of approximately 62 billion Chinese yuan (9 billion 2010 USD). However, they did not link this value flow to agricultural trade.

2.2.3 | Agricultural trade dependencies on non-material NCP

Non-material NCP are '*nature's effects on subjective or psychological aspects underpinning people's quality of life, both individually and collectively*' (IPBES, 2017). Non-material NCP emerge to a large extent from the multiple ways of interaction between people and nature. Understanding, mapping and quantifying these intangible dependencies of agricultural systems on non-material NCP requires, even more than for material and regulating contributions, a deep understanding of the diverse values of nature and multiple experiences of people in and with nature (Pascual et al., 2023; Scholte et al., 2018).

Place-based and local knowledge that is intrinsically linked to the ecosystem, as well as other nature-related values that local producers attach to their production system and that add value to traded agricultural products, are part of the non-material NCP incorporated in those products (Pascual et al., 2023). An example of a key concept that enables attaching local values to products is *terroir*: 'the holistic combination of soil, climate, topography and the "soul of the cultivator"' (Trubek et al., 2010). For example, *terroir* has been made operational and widely used for the marketing of wine through the *Appellation d' Origine Contrôlée (AOC)* in France (Haeck et al., 2019) and, using similar labels, in Spain, Portugal, Italy, and other countries. The concept of *terroir* is also increasingly recognised and used for other products such as Comté cheese (Trubek et al., 2010), whisky (Arnold, 2020), bat-friendly tequila (Trejo-Salazar et al., 2016) or expensive fabrics (e.g. silk, Harris tweed). Consumers are willing to pay price premiums for terroir products (Haeck et al., 2019). They perceive *AOC* and other *terroir* labels as a quality guarantee (Meloni, 2018), and as a means that captures the sense of place of the production location and transfers it to the consumer (Bucher-Edwards et al., 2021). Similar emotional linkages to distant places are also observed and quantified as motivation to purchase illegally imported bushmeat in Brussels (Gombeer et al., 2021).

Evidence collected on sense of place suggests that, compared to other NCP or NCP categories, place attachment through products is mostly associated with niche or luxury products. This is also demonstrated by the range of Protected Denomination of Origin (PDO) products in Europe that is dominated by cheeses, sausages and cured meat, with fruits and vegetables comprising only a small share of PDOs (Flinzberger et al., 2022). Products with a PDO are also mainly those where uniqueness of the local knowledge needed for production plays a role. Generally, place attachment is transferred to distant regions only when premium product quality, uniqueness of place and uniqueness of local traditional knowledge come together (Bucher-Edwards et al., 2021; Charters et al., 2017). A wider range of products (including staple foods) can transfer cultural values to consumers on a local scale. This is known, for example, for quinoa (Winkel et al., 2016) and tomatoes (Ibarrola-Rivas et al., 2020) and can be attributed to the concept of home bias. Home bias describes the tendency to purchase domestic products relative to foreign products. Although price effects play a role in some places, the local sense of place and/or attachment to traditional production systems play a role as well.

A limitation is that little is known about the flow of PDOs beyond the country boundaries. Zisidis (2014) shows that there is an asymmetry between sales and production of PDOs. van Ittersum et al. (2000) hypothesise that consumers living in the region of origin or consumers who attach more value to knowing the place of origin are more likely to purchase PDOs, and moreover that PDOs (or protected geographical indications) add value to regional products. By comparing buyers and nonbuyers of PDOs, they demonstrate that attaching value to regions of origin has a stronger impact on purchasing PDOs than living in those producing regions.

The dependency of sense of place can be measured by the price premium it adds, or by the extent to which producers from a specific region use place as a marketing criterion. This can be linked to measuring or quantifying the amount of product traded over distance.

3 | METHODOLOGICAL STEPS FOR QUANTIFYING AGRICULTURAL TRADE DEPENDENCE ON NCP

Based on our analysis, we identify three methodological steps to quantify the international agricultural trade dependencies on NCP: (1) spatial mapping of NCP supply and demand, (2) linking NCP to agricultural product flows and (3) tracing trade flows of these products.

The first methodological step refers to the spatial mapping of NCP supply as well as its societal demands (Figure 2). This is a well-established field of research that is taken up in policy (Maes et al., 2018; United Nations, 2021). Mapping the supply of NCP relies on detailed information on land use, land cover and its structure (Simons et al., 2021). Mapping the societal demand for NCP requires knowledge of how much use or wish to use of a certain NCP is required or desired for the production of agricultural products. This can be approximated, for example, by the consumption of products that depend on an NCP (Wolff et al., 2017) or using the crop production area depending on an NCP (Vallecillo et al., 2019).

The second methodological step consists of linking the spatial biophysical assessment with the agricultural product (Figure 2). This requires first linking the location of the NCP provision to the location where the agricultural product is produced (Serna-Chavez et al., 2014), considering the landscape structure, the distance and directionality between NCP supply and crop production, and the process of NCP flowing through the production landscape. However, current estimates of NCP dependence are frequently based on aggregated data, resulting in skewed estimates that lack the detail needed to link to the agricultural product (Anselin & Cho, 2002). It is also important to disentangle the contribution of human inputs (coproduction) from the contribution of nature (e.g. how much pest regulation is provided by natural predators and how

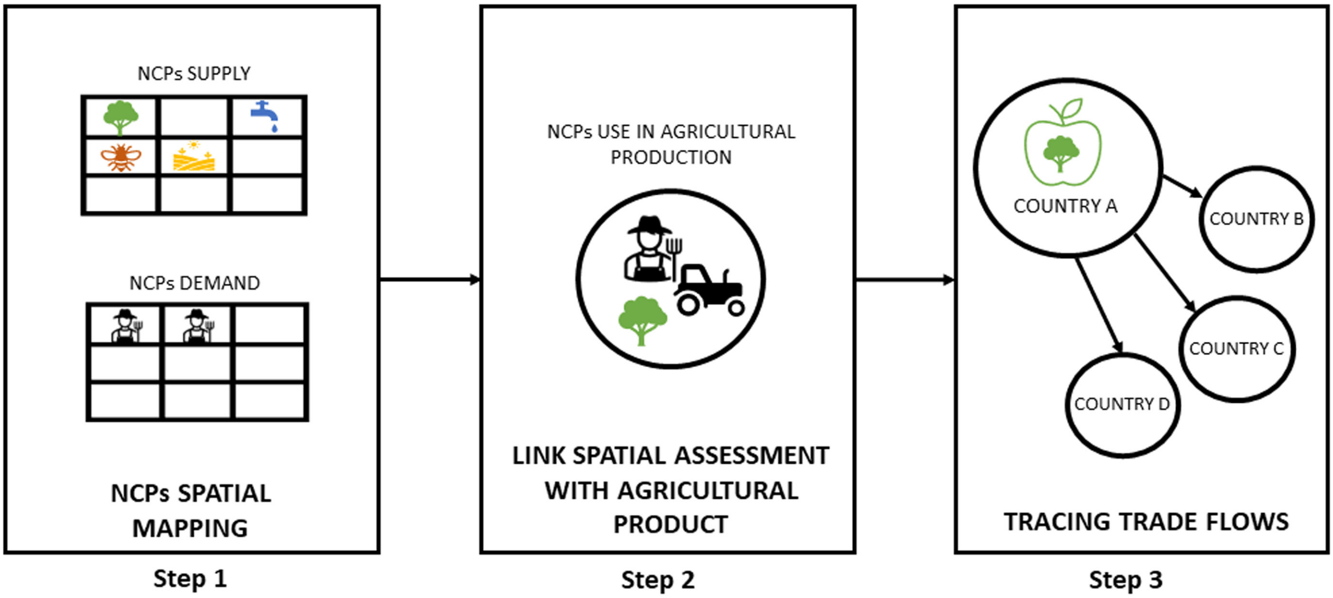

FIGURE 2 Simplified methodological steps to quantify agricultural trade dependencies on nature's contributions to people (NCP). Step 1 consists of spatial mapping of NCP's supply and demand; Step 2 consists of linking the spatial assessment with the agricultural product and Step 3 consists of tracing international trade flows; trade flows also occur between countries B, C and D but for ease of understanding, these are not represented.

much by pesticides). Such differentiation is not yet common practice in studies quantifying NCP, and will require detailed knowledge on the production function of agricultural products, such as the availability of other inputs, and the cost and potential of substituting the NCP with other, potentially human-made, inputs.

Another aspect concerns the need to carefully quantify the proportion of an indirect NCP directly contributing to the final NCP. For example, it is not enough to quantify erosion control in a certain area; it is essential to quantify how much of that erosion control actually supports the production of an agricultural product that is traded. Life cycle assessment is a tool that is used to calculate the environmental impacts of a product taking into account all stages of its life, from raw material extraction, processing, manufacture, distribution, usage, recycling and waste treatment (Taelman et al., 2023). To do so, it requires that information on all processes and inputs to a product's production is collected in what is called the inventory stage. After that, the impact assessment stage quantifies the environmental impacts. For example, to determine the environmental impact of a dairy product, one would need to know the amount of grass that was used to feed the livestock, in order to quantify land use and related biodiversity impacts of the dairy product. When accounting for NCP dependencies, this approach could be useful in quantifying dependencies on material NCP. At the moment, life cycle assessment can only account for material NCP (e.g. grass, freshwater) embedded in trade but cannot account for the contribution of regulating and non-material NCP to production processes and trade. The work on this front is still in its nascent stage (Alvarenga et al., 2020; De Luca Peña et al., 2022; Taelman et al., 2023). Ecosystem services accounting is another useful approach that can quantify the contributions of nature to the economy, following the structures and practices used in traditional economic accounting (United Nations, 2021). Compiling ES accounts requires a proper distinction between human inputs and ES inputs (United Nations, 2021).

Finally, the third methodological step concerns tracing international agricultural trade flows and quantifying their dependence on NCP. Multi-regional input–output models provide data in monetary terms of international trade relationships between countries and have been extensively used to assess environmental impacts associated with international agricultural trade (e.g. Cabernard & Pfister, 2021; Kastner et al., 2021). Recently, a multi-regional input–output model has been applied to quantify the amount of water purification in traded agricultural products (La Notte et al., 2020). Another promising approach to tracking NCP supporting traded agricultural products is linking consumption patterns to the origin of primary products using information on flows of internationally traded agricultural products (Kastner et al., 2011), available from different sources. For example, the FAOSTAT platform of the Food and Agriculture Organization of the United Nations provides detailed bilateral trade matrices of agricultural crops at the country level, while the TRASE database (https://www.trase.earth/) offers a greater level of spatial detail at municipality level and coverage of the actors involved (zu Ermgassen et al., 2020). However, TRASE thus far only addresses the trade of agricultural products related to deforestation for some countries (Godar et al., 2015).

4 | OUTLOOK

The international trade of agricultural products is strongly dependent on NCP, but we currently cannot quantify the full extent of this dependency. The spatial disconnect between end consumers in the importing regions and ecosystems in the countries of origin of products means that the magnitude of NCP in the production of globally traded agricultural commodities is not fully recognised and accounted for along the value chain (Figure 1) (Willemen et al., 2020). Existing tools allow measuring certain NCP in certain locations, but large knowledge gaps and data constraints remain in quantifying dependencies. In Step 1, methods for quantifying nonmaterial NCP are the main constraint. Conceptual understanding and quantification of the actual contribution of nonmaterial NCP to agricultural production processes can be advanced by the use of interdisciplinary methods that combine spatially explicit social-economic data with qualitative methods (e.g. text analysis or interviews). Step 2, that is linking the spatial assessment with the agricultural product, still need to better disentangle the contributions of natural and human input to a production process and become more spatially detailed. The current state of satellite imagery, artificial intelligence and computational power could already solve this bottleneck, however, data proprietary rights and privacy present some challenges. In Step 3, fine scale subnational data on trade is still a big bottleneck for most sending systems and, even the finest data that we currently have for some selected countries (at municipality level) can be coarse when talking about tracing the NCP embedded in a product. Regulations to improve transparency along the supply-chain are necessary but also creating supporting bodies that gather this data and make it publicly available. Each building block (Figure 2) requires a large amount of data that is expensive and/or time-consuming to collect. That is the reason why most previous studies are confined to selected crop types, popular NCP (e.g. pollination, pest control) and high-income western countries. More efforts are needed to measure, monitor and quantify understudied NCP in different crop types and less represented parts of the world.

A prerequisite to account for NCP dependencies is that policy makers and resource managers recognise their importance, particularly of NCP supporting the production of international traded agricultural products between two regions with a high spatial disconnect (Schulze et al., 2023). The multiple benefits of being able to quantify, map, trace, and account for these dependencies have already been recognised. For example, accounting for NCP supporting traded products has been identified as a leverage point, that is a priority point for intervention for transformative change, in the pathway towards a sustainable future (Chan et al., 2020; IPBES, 2019). Disclosing and accounting for NCP dependencies allows non-state actors to identify trade-offs among NCP as well as the potential risks of losing NCP essential to an agricultural traded product. This can guide action to avoid financial loss to the company or to support research into substitution possibilities between nature and human contributions (Natural Capital Coalition, 2016; TNFD, 2023). It could also motivate sustainable investments aimed at protecting natural capital and related NCP (TNFD, 2023).

As shown before, there are several laws, policies, agreements and initiatives requiring the identification of dependencies on NCP and associated risks. The actual recognition of NCP dependencies in international trade requires a stronger focus in the negotiation of international trade agreements (Kehoe et al., 2020) and national legislation. This can act as a lever for understanding how NCP support international agricultural trade (Chan & Satterfield, 2020). For example, when implementing the Kunming-Montreal Global Biodiversity Framework, countries will have to ensure that the values of nature are fully integrated in policies, regulations, planning, development processes and national accounting (Target 14). At the same time, national and subnational governments should implement the System of Environmental-Economic Accounting-Ecosystem Accounting (United Nations, 2021). This will enable the creation of the base data required to assess how international agricultural trade depends on NCP (see Section 3). On the producer side, the Corporate Sustainability Reporting Directive requires businesses at the European level to assess both impacts and dependencies on the environment (EC, 2022). The EU plans to ban biodiesel dependence on palm oil by 2030, as well as the awareness of potential deforestation consequences of the envisaged MERCOSUR trade agreement between the EU and South America, are good examples of recognising NCP dependence in international policy (Giger et al., 2021). At the global level, Target 15 of the Kunming-Montreal Global Biodiversity framework requires countries to create the enabling conditions for businesses to monitor, assess and transparently disclose their risks, dependencies and impacts on nature and provide information to consumers to promote sustainable patterns of consumption (CBD, 2022). A better understanding of NCP dependencies in different production processes can be used to benchmark products or production processes and inform consumers of the impacts they have on NCP in sending systems, while they depend on them for their consumption. This can contribute to the accountability of supply chain actors and serve as input to the governance of natural resources to promote responsibility and equity in supply chains (Gardner et al., 2019). Indirect sourcing is a ‘major blind spot for sustainable sourcing initiatives’ (zu Ermgassen et al., 2022) that should be better revealed and quantified to fully grasp the role of NCP in supporting agricultural trade and plan their sustainable use.

While the foundations for quantifying international trade dependencies exist both from a scientific and policy perspective, the linkages of data and models required to fully understand the full extent of these dependencies still need development. Funding institutions such as the Global Environmental Facility and national science funding organisations should provide adequate financial means to support the further development of measurement and monitoring of NCP dependencies. Intergovernmental institutions, like IPBES, should continue working to make knowledge on the international trade dependencies on NCP widely available. In fact, IPBES is currently undertaking a crucial methodological assessment of the impact and dependence of business on biodiversity and NCP (IPBES, 2022). The assessment's aim of ‘*categorizing how businesses depend on, and impact, biodiversity and nature's contributions to people and identifying criteria and indicators for measuring that dependence and impact*’ will contribute to bring NCP science to practice (IPBES, 2022). Another example is the ENCORE tool, developed by intergovernmental and non-for-profit institutions, that sets out how the economy depends and impacts nature (ENCORE Partners, 2023). We also call on corporate actors to take the initiative to account for NCP dependencies, for example through payments for ecosystem services (Huber-Stearns et al., 2017), other certification schemes (Tayleur et al., 2018), or disclosure frameworks like the Natural Capital Protocol (Natural Capital Coalition, 2016). In turn, researchers and nonacademic monitoring actors should adopt and, where necessary, develop science-based targets and rigorous modelling frameworks for quantifying NCP dependencies that allow quantitative distinctions between, and attribution to, different NCP required for the provision of a given good or service (e.g. using environmental-economic modelling). Finally, datasets to run assessments should be made available as open as possible to accelerate uptake in business and governance. Breaking work silos and data sharing through interdisciplinary international collaboration between industry, academia, and governments is the need of the hour. In this way, it is possible to acknowledge the dependence of international agricultural trade on NCP in the origin countries. This can support sustainable management, contribute to supply chain accountability, and foster responsibility and equity in supply chains.

AUTHOR CONTRIBUTIONS

Alexandra Marques, Catharina JE Schulp, Thomas Kastner and Thomas Koellner conceived the idea; Alexandra Marques and Catharina JE Schulp led the writing of the manuscript; Alexandra Marques and Gabriela Rabeschini conceived and developed the figures; all authors were involved in data collection (reviewing the state of the art) and analysis (synthesis). All authors critically contributed to the drafts and gave their final approval for publication.

AFFILIATIONS

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