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Photo: https://pixabay.com/sv/photos/nyckelpigor-vete-biologisk-m%c3%a5ngfald-3649918/

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Abstract

The climate impact of food production has been lively debated over the last decades. It is e.g. well known that some products have a higher climate impact in comparison to other food products. The biodiversity impact of different food products is however less known. To steer the food production in a positive direction as well as to enable consumers, restaurants, public kitchens, and the food industry to make well-informed decisions, we need to address and measure this impact.

The aim of this study has been to examine the biodiversity impact of Nordic and European food consumption. In this report we present (1) a brief summary of biodiversity indicators linked to food production and consumption, (2) different methods to evaluate biodiversity impact of food products and (3) a literature review of studies that assess biodiversity impacts of food products and diets. Based on the literature review, we identify food products suggested to have a higher respectively lower negative impact on biodiversity and discuss what changes that could promote a Nordic diet with lower negative impact on biodiversity. Finally, we highlight knowledge gaps and possibilities for future work.

There are different methods to examine the biodiversity impact on food products, such as life cycle assessment, input-output-model, and mapping tools. Biodiversity footprints are often based on the land use (area and intensity) in combination with parameters linked to where the production takes place and thus what biodiversity values can be affected. The consumed amount of food is also often considered – a product with a low impact per kg can get a high impact when consumed to a high degree and vice versa.

Our literature review shows a variety of food products with high negative biodiversity impact. Particularly, products that are known drivers of deforestation in tropical regions, such as palm oil, coffee, and cacao – as well as meat and/or animal products that have been fed with soybeans derived from tropical regions have a high negative impact on biodiversity. On the other hand, consumption of foods as vegetables, starchy roots, and pulses – ideally with domestic origin – are examples of foods indicated to have lower biodiversity impact which would be beneficial to eat more of in the Nordic diet.

There are also examples of agricultural systems where human interference is crucial for maintaining a high level of biodiversity, for example keeping grazing animals on high-nature-value-grasslands. If these lands are abandoned or planted with forest, numerous of species will be extinct. Thus, meat linked to these grasslands can also support biodiversity, especially in the Nordic countries where there are relatively many of these landscapes left (in comparison to the rest of Europe).

As the studies reviewed varied in their scope, methods, and results, they are difficult to compare. More research is needed to confirm our conclusions. Furthermore, none of the methods are flawless and there are obvious difficulties with finding a transferable and scalable unit – like CO_2-equivalents – since biodiversity impacts are highly dynamic and site-specific. Additionally, most of the reviewed studies do not consider transformation of natural areas driven by food production, e.g., deforestation, and may therefore be underestimating the impacts. In future studies, the reference systems may also be discussed and further developed, and more taxonomic groups (e.g., arthropods such as insects) should preferably be included.

Sammanfattning

Kartläggning av den nordiska livsmedelskonsumtionens påverkan på biologisk mångfald

Livsmedelsproduktionens klimatpåverkan har länge diskuterats och beräknats vilket gett en god förståelse för vilka livsmedel som har ett högre klimatavtryck än andra. Betydligt mindre kunskap finns om livsmedels påverkan på biologisk mångfald. För att styra produktionen i en positiv riktning, och möjliggöra för konsumenter, offentliga kök, restauranger och livsmedelsindustrin att ta välgrundade beslut som leder till minskad negativ miljöpåverkan behövs mer kunskap om hur livsmedels biodiversitetspåverkan kan kvantifieras på bästa sätt.

Syftet med denna studie har varit att undersöka den nordiska livsmedelskonsumtionens påverkan på biologisk mångfald. I rapporten presenteras (1) en översiktlig kartläggning av biodiversitetsindikatorer som kan kopplas till livsmedelsproduktion och -konsumtion, (2) olika metoder för att beräkna biodiversitetspåverkan för livsmedel samt (3) en litteraturöversikt av studier som undersöker livsmedels/kosters biodiversitetspåverkan. Utifrån litteraturöversikten identifieras livsmedel som indikerats ha högre respektive lägre negativ påverkan på biologisk mångfald. Vi resonerar vidare kring vilka kostförändringar som skulle bidra till en nordisk kost med lägre negativ påverkan på biodiversitet. Avslutningsvis lyfter vi fram kunskapsluckor och framtida forskningsmöjligheter.

Det finns olika metoder för att beräkna livsmedels påverkan på biodiversitet, såsom livscykelanalys, input-output-modell och kartverktyg. Livsmedelsprodukternas biodiversitetsavtryck styrs ofta av markanvändningen, både yta och intensitet, i kombination med var produktionen sker och vilka värden för biodiversitet det givna området hyser. Konsumtionsmängden har också betydelse – en produkt som har lägre påverkan per kg kan i slutändan få hög påverkan om konsumtionen är hög och vice versa.

Vår litteraturgenomgång visar på en mängd olika livsmedelsprodukter som har hög negativ påverkan på biologisk mångfald. Speciellt produkter kopplade till avskogning i tropiska regioner, såsom palmolja, kaffe och kakao – samt kött och/eller animaliska produkter med soja från tropiska områden i foderstaten har en hög negativ inverkan på den biologiska mångfalden. Å andra sidan är konsumtion av livsmedel som grönsaker, rotfrukter och baljväxter – helst med inhemskt ursprung – exempel på livsmedel som har lägre påverkan på den biologiska mångfalden och som skulle vara fördelaktiga att äta mer av i den nordiska kosten.

Det finns också exempel på marker där mänsklig inblandning är avgörande för att upprätthålla en hög nivå av biologisk mångfald, till exempel naturbetesmarker. Om dessa marker överges eller planteras med skog kommer många arter att dö ut. Svenskt naturbeteskött kan alltså hjälpa till att upprätthålla en hög biologisk mångfald.

Då studierna hade varierande metoder, omfattning och resultat är de svåra att jämföra och mer forskning krävs för att dra generella slutsatser. Ingen av dagens metoder är felfria och det finns svårigheter med att hitta en universell enhet – motsvarande koldioxidekvivalenter – då biodiversitetspåverkan ofta är dynamisk och platsspecifik. Vidare tar många av studierna inte hänsyn till att vissa livsmedel driver på drastiska omvandlingar av naturområden, såsom avskogning, varför dessa effekter kan vara underskattade. Avslutningsvis bör även referenssystemen diskuteras och utvecklas och fler taxonomiska grupper (t.ex. leddjur såsom insekter) bör inkluderas i framtida metoder.

Content

Foreword

This report is part of the project "Scenarios and pathways toward sustainable land-use and food production for Western and the Nordic European countries, as a part of the global FABLE Consortium" funded by FORMAS via ERANET-Axis, a project run 2019-2021.

We want to thank Annie Svensson at RISE for contributions in the start-up phase of the study and the literature search. Thanks also to Sarah Jones at Alliance of Bioversity International and CIAT for reading and giving good comments!

The Authors,

April 2022

Glossary / abbreviations

BDP – Biodiversity Damage Potential

CF – Characterization factors is factors (expressed in numbers) that indicate biodiversity damage resulting from a particular land use in a given unit area

Ecoregion – A large area of land and/or water that holds a geographically distinct assemblage of species, ecological dynamics, environmental conditions etc. Chaudhary and Brooks (2018) divide the world into 804 ecoregions, while Olsen et al. (2001) suggest 867 ecoregions

High biodiversity value – regions with *higher biodiversity values* refers to regions that, according to LCA-methodologies, hold less vulnerable ecosystems and a higher number of species (including endemic species and/or red-listed species) in comparison to other regions

Hotspot product – A food product with a high negative impact on biodiversity

Land occupation – *Land use*, expressed in m^2year. After an area has been transformed (see Land transformation below) it is occupied for e.g., cropping or pasture for *n* years.

Land transformation – Initial *land use change*, e.g., from a natural to an anthropogenically-modified state or from a land use developing from extensive to intensive. This is expressed in m^2.

LCA – Life Cycle Assessment (or Life Cycle Analysis)

Low biodiversity value –regions with *lower biodiversity values* refers to regions that, according to LCA-methodologies, hold less vulnerable ecosystems and a lower number of species (including endemic species and/or red-listed species) in comparison to other regions

PDF – Potentially Disappeared Fraction

1 Introduction

Climate impact of food production and consumption has been lively debated over the last decades. For instance, we know that meat from ruminants have a high climate impact (in terms of greenhouse gas emissions, "GHG") per kilogram compared to other food products. Meat-related GHGs make up a large share of an average western person's food-related greenhouse gas emissions. When it comes to other environmental impacts, we know to a much lesser extent what foods cause the largest burdens. Biodiversity is one of the planetary boundaries we are already overshooting, and food production is identified to be one of the largest drivers of biodiversity loss (IPBES, 2019). It is therefore very important to increase knowledge on what foods cause the highest biodiversity losses in order to enable e.g., consumers, restaurants, public kitchens, and the food industry to make the right informed choices.

In this report, we have a Nordic focus. We ask ourselves; is it possible to distinguish what food products are hotspots of biodiversity impact caused by Nordic food consumption? Is it the imported bananas, coffee or wine, or something else? We will investigate this by performing a literature review and by discussing available biodiversity indicators, data on imports and production methods, and by identifying knowledge gaps. More specifically we will:

- Map available indicators for biodiversity connected to food production and consumption and describe methods that are useful for biodiversity evaluation in Life Cycle Assessments (LCA)
- Perform a literature review of studies that assess biodiversity impacts of food and/or diets and identify which are the high impact products and in what locations they are produced
- Discuss what changes that can promote a Nordic diet with lower biodiversity impact
- Discuss knowledge gaps and possibilities for future work

2 Different perspectives and units of measurements for biodiversity

According to the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), biodiversity is explained as:

> *"The variability among living organisms from all sources including terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part. This includes variation in genetic, phenotypic, phylogenetic, and functional attributes, as well as changes in abundance and distribution over time and space within and among species, biological communities and ecosystems."* [1]

There are many ways to approach the complex issue of quantifying the status, or change, in biodiversity. In figure 1, we illustrate some perspectives and how biodiversity can be quantified.

Figure 1. Some different perspectives and units of measurements for biodiversity. The perspectives can sometimes overlap, and there are of course other ways to cut the cake and many other units and metrics.

On the first level we have the species, which can be measured e.g., by field surveys or satellite images and be reported in biodiversity databases. There are a number of standardized techniques for gathering data in the field, e.g., observations in transects or quadrats, or collection using traps. Besides registration of species occurrence, the abundance of each species is often included so that the evenness of species in a community can be measured. Surveillance can also focus on specific species, such as red-listed species, as well as functional diversity – i.e., the range of components/species traits

[1] https://ipbes.net/glossary/biodiversity

that influence the operation or function of an ecosystem (Tilman, 2001). The first level is fundamental, and feed data into the other levels.

Also, on the ecosystem level, actual observations of species can be used, but more often biodiversity indicators such as habitats, field size and connectivity are reported and put into frameworks, e.g for fram level assessments. For a review see e.g., Eichler Inwood et al. (2018).

Biodiversity is often also quantified with help of indicators to set and follow up targets on regional, national, or global level. Indicators are explored further in the next chapter.

Next, biodiversity can be quantified in a value chain perspective or with LCA. More on this topic is written in section 2.3. This is the level most suitable for assessments of biodiversity impacts due to diets and dietary choices, which is the focus of this report.

Biodiversity is also an important topic for many businesses, where there are frameworks to help set and follow up targets, for example the Science Based Targets for Nature[2].

Finally, biodiversity is becoming an increasingly important topic within the finance sector, being the set of institutions through which resources are directed to real economy activities in society, with influence on investments that can affect biodiversity.

2.1 Indicators for biodiversity

"*Any meaningful study of biodiversity, no matter which aspect is in question, must involve its quantitative measurement*", says Daly et al. (2018). For this purpose, we need indicators that enable comparisons between different spatial regions, land uses, temporal periods, taxa (species) and functional groups. However, there is no consensus on which indicators are more suitable and informative than others and the choice is highly dependent on the intended use. The available indicators are numerous and disparate in their ecological interpretation and mathematical behaviour.

According to Bockstaller et al. (2011), indicators can be sorted into four different categories (Figure 2): (a) simple indicators based on a causal variable or a simple combination of variables; (b) predictive indicators based on outputs from operational model; (c) predictive indicators based on outputs from complex model and (d) measured indicators based on field measurement or observation.

[2] https://sciencebasedtargets.org/about-us/sbtn

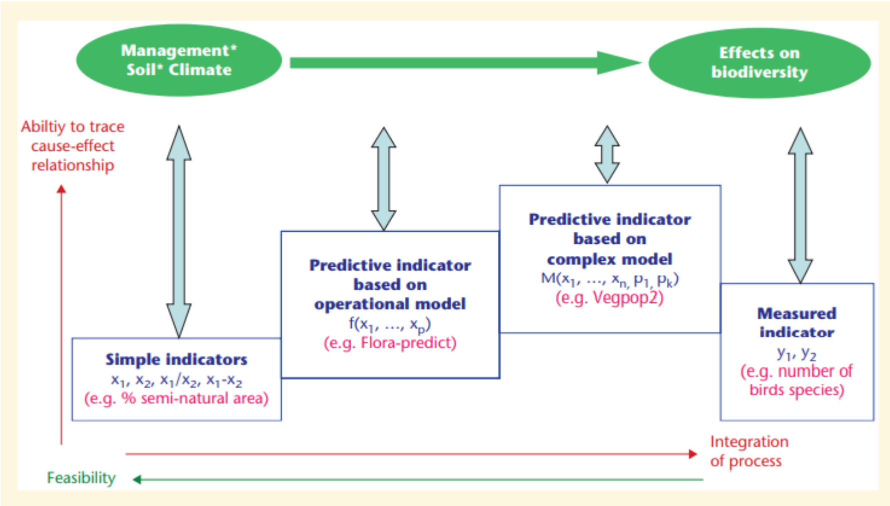

Figure 2. Indicators for biodiversity can be sorted into four different categories according to Bockstaller et al (2011).

Biodiversity indicators can also be sorted by their thought use; leading (indicators that are useful for preventative actions), coincident (indicators that measure the current state of the subject of interest) or lagging (indicators that can be used to evaluate past actions) (Stevenson et al., 2021). Further, other environmental impacts can be used as proxy for biodiversity impacts; in a study by Belgacem et al. (2021) biodiversity impact of different dietary patterns is addressed in terms of land use, water use, greenhouse gas emissions, and eutrophication impact indicators.

There is a large amount of biodiversity indicators. A review can be found in e.g., Harris et al. (2021). Worth mention in a global context is the CBD (Convention on Biological Diversity) indicator database and the indicators under the SDGs (Sustainable Development Goals) developed by the UN. Under the SDG framework, target 2.4 (Sustainable food production systems) has an indicator 2.4.1, defined as the "proportion of agricultural area under productive and sustainable agriculture", where there is a sub-indicator for biodiversity. This sub-indicator for biodiversity is reported country-wise by filling in a survey about use of agro-biodiversity-supportive practices, e.g., the share of temporary/permanent crops, natural grasslands/pastures, wildflower strips etc[3].

In this context, the indicators in the Swedish environmental objectives can also be mentioned. The framework is made up by 16 environmental goals, and although biodiversity tangents several goals it is mainly monitored by the goal "A rich diversity of plant and animal life". The progress to reach the environmental goals is followed up by use of indicators. For biodiversity, the indicators used are "Share of protected area of nature types" as listed in the EU habitat directive, red listed species index, protected forest area.

For the purpose of estimating biodiversity impact of food consumption, these types of biodiversity indicators are not very useful. We need to be able to attribute biodiversity impacts on a food item level. However, the huge efforts put into biodiversity indicators

[3] http://www.fao.org/3/ca5157en/ca5157en.pdf

contribute to a large source of datasets, that could be useful also for other purposes e.g., for integration in LCA.

2.2 Hotspot index maps

Mapping biodiversity, by e.g., creating range maps of different species across different taxa, is an essential tool for supporting goal setting as well as planning and prioritizing of conservation actions (see e.g., Jung et al. 2021). Creating maps, using spatial data, is also an approach to evaluate the biodiversity impact of commodities (such as food products) and their trade routes around the world. This has for instance been performed in Lenzen et al. (2012) and Moran & Kanemoto (2017). The purpose of these studies was to identify products and trade routes (the value chain from the production country to the final consumer), that have the greatest negative impact on biodiversity. The researchers used spatial data on threatened species from IUCN Red List and Bird Life International, as well as data on transactions between industry sectors across countries, to pinpoint specific countries (Lenzen et al. 2012) and habitats (Moran & Kanemoto 2017) that are specifically affected by threats induced by international trade.

The map on EU consumption by Moran & Kanemoto (2017) is showed in Figure 3. Thus, these studies showed how spatial data on threatened species can be linked to value chains of commodities, to examine their impact on biodiversity – in terms of number of threatened species and the level of threatening activities (such as deforestation for agricultural purposes) linked to the consumption of goods in another country.

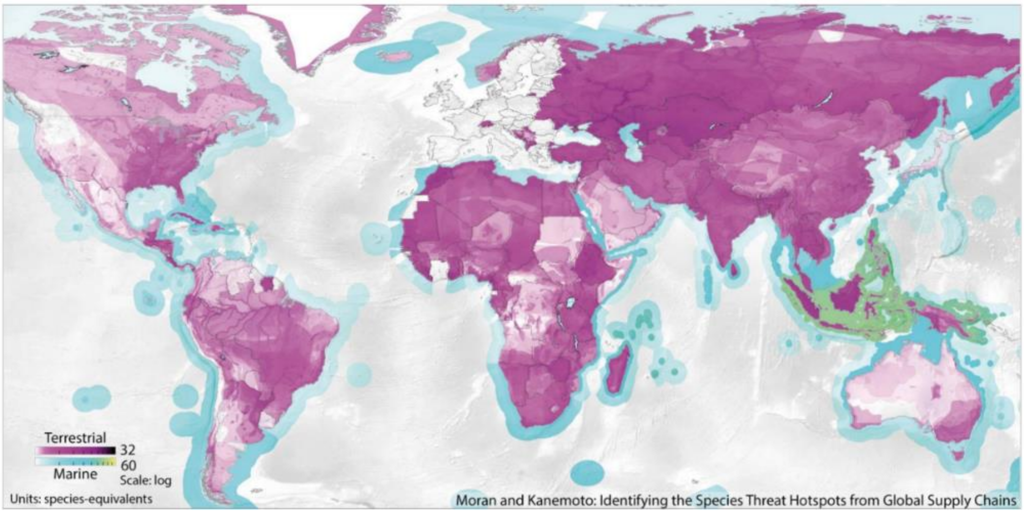

Figure 3. Hotspot index map of EU consumption (Moran & Kanemoto 2017).

2.3 Biodiversity impacts in LCA

There are several developed methods for quantifying biodiversity impacts in product level LCAs. However, most methods have limited geographical scope (restricted to certain locations, or global scale without meaningful results) and are restricted to only one organism group (e.g., plants or birds). Several frameworks are also developed for a specific purpose and not generally applicable. For a review of methods see e.g., Gabel et al. (2016) and Crenna et al. (2020).

2.3.1 Midpoint or endpoint?

In LCA, potential impacts can be assessed by two types of indicators: midpoint and endpoint (Figure 4). Midpoint indicators reflect intermediate impacts e.g., global warming, eutrophication, or ozone depletion. Endpoint or damage indicators address areas of protection, i.e., human health, ecosystem quality and resource depletion, which are caused by midpoint impacts. Biodiversity can be a midpoint indicator expressed e.g., as potentially disappeared fraction (PDF) due to a certain land use change or land use. Biodiversity can also be part of the endpoint indicator ecosystem quality (Vidal Legaz et al., 2017), estimating the effect of midpoint impact categories on the ecosystems (Figure 4).

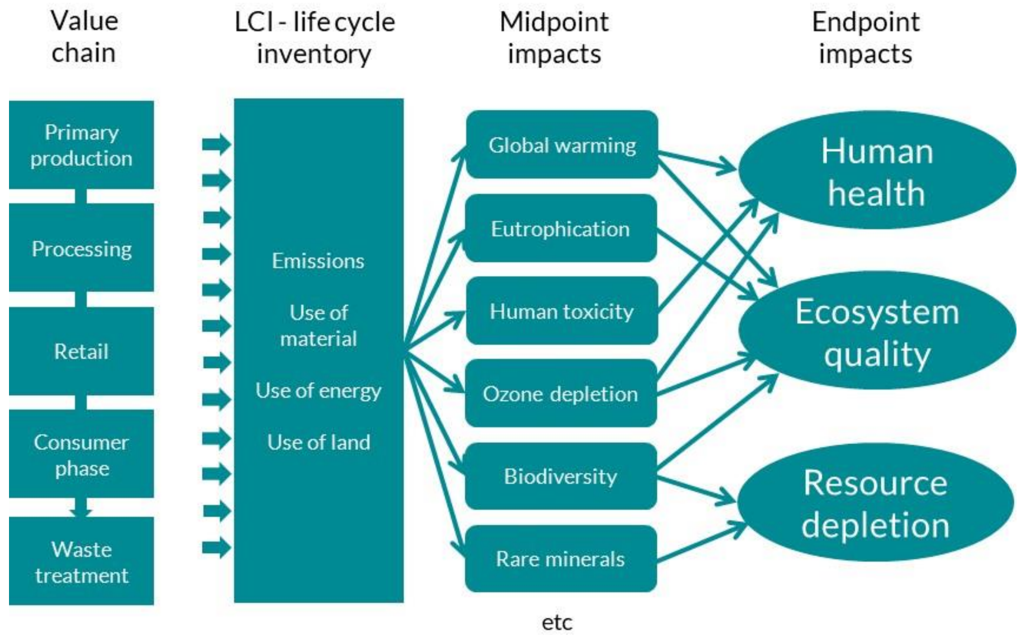

Figure 4. Schematic illustration of the LCA process, from mapping of value chain to data inventory, to impact assessment on midpoint and endpoint level. Results from an LCA can be presented as midpoint, endpoint or on both levels.

A promising midpoint method was developed by a research group in Switzerland (Chaudhary & Brooks, 2018), and this is also the method that is recommended for use in LCA by the UNEP-SETAC Life Cycle Initiative, which is a forum for science-based decision and policy support. The Chaudhary & Brooks method provides Characterization Factors (CFs)[4] for potential biodiversity loss in 804 different ecoregions for mammals,

[4] In LCA characterization factors (CFs) are used to convert emissions to impacts. For e.g. global warming, the CF for methane is 30, allowing you to convert methane emissions to CO2-equivalents. For biodiversity, the CFs are used to convert land use to biodiversity impact.

birds, amphibians, reptiles and plants, and a taxa-aggregated unit resulting from different types of anthropogenic land use. The method covers forest, cropland, pasture, and urban land use, at different levels of land use intensity. The CFs are developed based on e.g., data on global land use intensity maps, WWF Wildfinder database and International Union for Conservation of Nature (IUCN) red list habitat classification scheme. The method provides CFs for land transformation (e.g., for deforestation situations) and land occupation, and these reflect the potential biodiversity loss of human disturbance as in comparison to natural (primary) vegetation in the chosen ecoregion.

The Chaudhary & Brooks method has global coverage and is practical and easy to use but has its flaws. The method allows for three intensity levels of land use: intensive, low, and minimal. However, the difference in CFs between the levels is very small, so there is e.g., a very little difference between conventional and organic agriculture. The reason for the small difference is the reference land use (primary vegetation, in a world without humans). Most species are assumed to already been wiped out once the natural vegetation of a region is cleared to make way for pasture/cropland, so there is little effect on how the land is used after this clearing. In other words, the method only shows negative biodiversity impacts. Improvements or positive contribution to biodiversity e.g., by a varied crop rotation or grazing of high value natural grasslands, cannot be accounted for with this method. Another negative aspect of the methodology is that it does not include insects, or other arthropods, as one of the taxonomy groups that is assessed. Further, the method only covers land use, consequently fish and seafood are not included.

Endpoint CFs for biodiversity are e.g., developed by Huijbregts et al (2016) in the ReCiPe framework, allowing you to translate midpoint indicators to endpoint. While it can be argued that it makes more sense to calculate the “final” impacts there are also several disadvantages, e.g., endpoints have an anthropocentric focus, it brings a high level of uncertainty to the results, and endpoint results are difficult to communicate.

2.3.2 Reference situation

Choice of reference situation is a decisive factor in biodiversity assessments and something of a philosophical issue that needs to be discussed. The assessments on biodiversity impacts using LCA is mainly quantified as the difference between the quality of a given ecosystem in the present state and a reference situation (Vrasdonk et al. 2019). Thus, a reference state is needed to assess the changes derived from a land use intervention in an ecosystem.

Reference situation is a broad concept and there are different kinds of approaches. Often, some kind of “natural” state is used as a reference, which could be (1) historical (original, unmanaged state), (2) natural counterfactual (hypothetical state that would have appeared without any human impact) or (3) a re-naturalization state (hypothetical state that reflects a situation *after* all human interventions stops) (Vrasdonk et al. 2019). Hence, naturalness is reflecting an ideal state for biodiversity in these cases (Lindner et al. 2021). It could also reflect a target reference situation, i.e., a state that describes a desired direction to e.g., fulfil conservation targets (Vrasdonk et al. 2019). The quality can e.g., be manifested in the presence of threatened species, which is partly applied in

Chaudhary & Brooks (2018). The potential biodiversity loss is then quantified by a comparison between presence of species in the present land use and the reference situation, which describes an undisturbed state in the given ecoregion (Chaudhary & Brooks 2018).

To assess an appropriate reference situation is not an easy task. To use real locations as reference sites is usually difficult as most areas in the world have been impacted by humans to some degree (Vrasdonk et al. 2019; Ellis et al. 2021). Often reference situations are based on data on semi-natural land use, which is associated with some uncertainties as the "naturalness" can vary a lot between areas. To use a historical reference may also associated with great uncertainties, e.g., as most monitoring schemes started at the end of the 20th century, which result in limitations to assess the true impacts on biodiversity (Mihoub et al. 2017).

On the other hand, a completely undisturbed ecosystem may neither be ideal for all kinds of ecosystems (Lindner et al. 2021; Vrasdonk et al. 2019), nor result in realistic comparisons as humans already affected ecosystems for thousands of years (Mihoub et al. 2017). Vrasdonk et al. (2019) set out various possibilities, recommending that an appropriate reference needs to be in line with society's set goals for biodiversity. They stress that many reference situations differ significantly from conservation targets, especially those that reflect states with a total absence of human activity. For instance, CBD emphasizes a sustainable coexistence of human well-being *and* a healthy planet (CBD, 2021). Furthermore, Vrasdonk et al. (2019) emphasize that numerous threatened and protected species and biotopes are dependent on continued management, e.g., semi-natural pastures and meadows. However, some ecosystems will benefit from naturalness, such as old-growth forests and many kinds of wetlands (Vrasdonk et al. 2019). Hence, there is a need for flexibility in the process of assessing reference situations, that reflect sustainable use and can include ecosystems that benefit from more stable conditions, as well as those dependent on disturbance (natural or anthropogenic) to maintain a favourable conservation status (Lindner et al. 2021; Vrasdonk et al. 2019).

3 Review of studies that assess biodiversity impacts of foods and diets

We reviewed literature to help us identify what food items have high and low biodiversity impact per kg, and what are hotspot food products in a Nordic diet. To perform the literature review, a literature search was done in Google Scholar based on the keywords: *consumption* OR *diet* AND *biodiversity* AND *food*.

The literature search was performed in May 2021 with no restrictions for publication dates of the articles. Due to the time limits of the project, we included the first 100 articles (sorted by *relevance*) in the literature selection. Literature of relevance for this study was selected based on two criteria. We included peer-reviewed English-language scientific articles that: (1) analyse biodiversity impacts of food consumption (diets and/or on a food item level), and (2) have a Nordic or European perspective. Some additional articles were identified from reference lists of the selected articles. Articles that had a global focus but included a European and/or a Nordic perspective were however also included. In such studies our review was limited to the European and Nordic perspectives. Some of the articles included other environmental impacts (e.g., climate impact, ecotoxicology), in these cases we only focused on the biodiversity assessments. In total, nine articles fulfilled our criteria and were included in the literature review[5].

In Appendix 1, the nine reviewed papers are briefly presented (aim, methods used and main results), while we in this chapter will summarize the overall findings of which food products and origin countries suggested to have a higher negative impact (i.e., hotspot products) respectively lower negative impact on biodiversity in the reviewed studies. In this study, we have not established any thresholds to define higher and lower negative impact on biodiversity, as the examined studies' methods as well as functional units differed significantly. Instead, we will here provide an overview of the food products that are suggested by the studies to have relatively higher negative respectively lower impact on biodiversity.

3.1 Hotspot food products/areas identified in the reviewed papers

The four studies that presented the biodiversity impact per kg of food item suggested various hotspot products, such as lamb, coffee, cocoa, bananas, rice, soybeans, and nuts (Table 2). However, there were only three products that were highlighted in more than one study: coffee, nuts, and rice (Moberg et al. 2020; Karlsson & Röös, 2021; Sandström et al. 2017).

[5]Since this is a project with limited scope, we did not have the possibility to do a systematic literature review in several databases, and it is possible that literature of relevance was overlooked. Thus, this review should not be perceived as complete or to cover all aspects of importance for biodiversity impacts of foods and diets.

When the consumed amount of the products was considered, three (out of four) of the studies suggested different types of meat (beef, pork, lamb, chicken) to account for a large proportion of the diet's negative biodiversity impact (Table 2). Dairy products were also highlighted to have a high negative impact in two of the studies (Crenna et al. 2019; Martin & Brandao 2017). A range of plant-based products, such as coffee, oil (e.g., palm oil, olive oil, sunflower oil), and cocoa, were also suggested as hotspot products with a considerable contribution to the diets' overall biodiversity impact (Table 2).

Regarding hotspot areas, i.e., production countries for implicated foods, coffee from e.g., Colombia, Mexico, Guatemala, and Indonesia were suggested by Lenzen et al. (2012) and Sandström et al. (2017) (Table 2). Lamb from New Zealand (Moberg et al. 2020), bananas from Colombia (Lenzen et al., 2012) and palm oil from Malaysia and Papua New Guinea (Lenzen et al. 2012; Sandström et al. 2017) were also highlighted (Table 2).

In summary, hotspot products are generally resource-intensive food items that require large areas for production (primary crops, fodder crops, pastures) and/or are produced in areas that have high biodiversity values i.e., they originate from highly vulnerable ecosystems with a larger number of species – including endemic and/or red-listed species. The consumed amount is also of great importance, i.e., a food item can have a low impact per kg, but when consumed to a larger extent the weighted impact can still be considerable and be a hotspot product in a diet.

3.2 Food items with lower biodiversity impact identified in the reviewed papers

The assessment of food products with lower negative biodiversity impact is mainly based on the reported impact per kg food item (Table 2). Results showing the impact from total consumption were not considered, as a low impact from consumption of a food product may be the result of low intake levels which does not necessarily imply that the food has a low negative impact on biodiversity per kg. For instance, foods that generally make up a smaller part of a diet, such as nuts, may have a high impact per kg but as it is consumed in a small extent it has a low impact in the total diet. Identifying food items that have a low impact on consumption level might give the impression that these should be *more* consumed when the recommendation should be the opposite.

Regarding food items with lower negative biodiversity impact there was a rather good agreement in the results of the reviewed studies results. Vegetables, fruits (expect for e.g., bananas), starchy roots, and pasta were suggested by more than one study as low impact foods (Table 2).

Several studies highlighted the impact of different dietary patterns and the importance of the magnitude of the consumption of a given food item. For instance, Moberg et al. (2020) suggest fruits and greens to have a lower biodiversity impact per kg food item, while they were considered as hotspot products when the consumed amount was taken into account. Cereals and pork were other food products found in both the columns for hotspot food products and foods with lower biodiversity impact (Table 2), i.e., they are suggested to have a relative low impact per kg product but make up a large proportion of a diets' biodiversity impact as they are consumed a lot. Moreover, Moberg et al. (2020)

suggested beef to have a low biodiversity impact, as beef – and dairy products – consumed in Sweden are derived from cattle that feed on pastures and/or fodder produced in areas with relatively low biodiversity values (Moberg et al., 2020). On the contrary, beef and dairy products were suggested to be hotspot products in Crenna et al. (2019) and Martin & Brandão (2017), due to the high amount of land required for production of animal feed. This highlights that there can be great differences in impact even within a food product category, as also reflected in Tidåker et al. (2021), and that the impact is highly dependent on the input data (intended to reflect a consumption pattern in the studied country), and methods used.

Table 2. Summary of the food products suggested to have a higher (hotspot products per kg food item and per consumed amount) and lower negative biodiversity impact (per kg food item), in each of the reviewed studies. Origin countries and production method (conventional/organic) are stated when available. "–" means that results are missing for the specific category.

Authors	Hotspot food products (per kg food item)	Hotspot food products (per consumed amount)	Foods with lower biodiversity impact (per kg food item)	Scope	Method
Moberg et al. 2020	Lamb (New Zealand) Cocoa Coffee Vegetable oils Nuts Rice	Lamb Sweets, snacks, sugar etc. Coffee, tea, cocoa drinks Fruits, greens, nuts	Roots Greens Cereals Fish and seafood Pork Chicken Fruits Beef (Northern Europe)	15 food categories consumed in Sweden	Chaudhary & Brooks (2018)
Tidåker et al. 2021	Organic beans (Sichuan, China) Organic lentils (Turkey) Conventional chickpeas (Italy) *Note: the comparison is among different pulses only, so the "hotspot" products are only in relation to other pulses*	–	Organic lentils, organic grey peas and conventional beans (Sweden) *Note: the comparison is among different pulses only*	Comparison of pulses produced in six countries and different production methods (organic/conventional)	Chaudhary & Brooks (2018)
Karlsson & Röös 2021	Bananas (conventional and organic) Almonds (conventional and organic) Aspargus (south American) Quinoa (conventional and organic)	–	*Protein sources* – beans and lentils, ready-made products, soy-based, peanuts *Carbohydrate sources* – pasta, potatoes *Plant-based drinks* – almond drink, oat drink *Fruits and berries* – apples, oranges, pears, strawberries *Vegetables* – cucumber, eggplant, tomatoes Mushrooms	90 plant-based food products consumed in Sweden	Chaudhary & Brooks (2018)
Crenna et al. 2019	–	Beef meat Pork meat Poultry meat Cheese Milk	–	32 food products consumed in the EU	Process-based LCA, incl. Chaudhary et al. (2015)

		Butter Sunflower oil Eggs			
Sandström et al. 2017	*Land use* Coffee (Colombia, Mexico, Brazil, Honduras, Guatemala, Kenya, Nicaragua) Soybeans (India) Palm oil (Malaysia) *Water use* Rice (Spain) Citrus fruits (Spain) Grapes (South Africa) Plums and sloes (USA) Almonds (USA) Vanilla (Madagascar)	–	–	132 products consumed in Finland. The impact was divided into land use and water use	Chaudhary et al. (2016)
Röös et al. 2015	Lamb Beef Pork Chicken Cheese Butter Cream	–	Root vegetables Potato Fruits and berries	Examining three diet scenarios (e.g. Nordic recommendations, common Swedish diet). 20 food categories	de Baan et al. (2012)
Martin & Brandao 2017	–	Meat Milk Cereals Oil crops	*Overall suggestion; diets with reduced meat, more organic food and less imported food*	Predicting Swedish diet scenarios (e.g. BAU, reduced meat, all organic, all conventional, vegetarian) including 20 food categories	Röös et al. (2015)
Lenzen et al. 2012	–	Coffee (Mexico, Colombia, Indonesia, Papua New Guinea) Cocoa (Papua New Guinea, Malaysia, Indonesia, Colombia, Cameroon) Palm oil (Papua New Guinea) Coconut (Mexico, Colombia, Indonesia, Papua New Guinea) Bananas (Colombia) Vanilla (Madagascar)	–	Trade of commodities between ~16000 industry sectors across 187 countries. Global focus	Input-output model

4 Discussion and thoughts on future research

In this review, we have summarized findings from nine different studies which evaluated the impact on biodiversity from different food products and/or different diets. Most studies focused on food consumption in the Nordic countries (Sweden and Finland), whereas three studies examined products consumed in the whole EU (Crenna et al. 2019; Lenzen et al. 2012; Moran & Kanemoto 2017) and one study were limited to one food category (pulses) produced in different countries and regions (Tidåker et al. 2021).

Due to the limited number of reviewed studies, and the number of available studies that were consistent to our scope, it should be stressed that absolute conclusions cannot be fully drawn within this review. Although there were some similarities between the studies, they had different scopes, methods as well as input data (food products/categories based on different consumption groups, origin countries, impact categories, number of stages in the food products' life cycles etc.). Therefore, we will start this chapter with a discussion of the limitations. Thereafter, we will present conclusions from our study and discuss knowledge gaps and possibilities for future work.

4.1 The studies have different scope

As the results were presented in dissimilar ways in the different studies, e.g., per kg food product and/or per consumed amount, they are difficult to compare. The level of detail in the results presented also varied, for instance, how food products were categorized. For instance, Röös et al. (2015), Moberg et al. (2020), Martin & Brandão (2017) grouped all vegetables in one category, although there may be great differences in impact between different plant-based products as shown in Karlsson & Röös (2021) or even within the same food item category (Tidåker et al. 2021). Another example where the classifying system affected the results were in Moberg et al. (2020) where all meat besides beef were categorized in one group, even though lamb was the type of meat which accounted for the largest impact per capita. Furthermore, two studies only presented the food products with the highest negative impact (Lenzen et al. 2012; Sandström et al. 2017), whereas the other showed the relative impact of all included food products/food categories.

Most studies did not differentiate organic and conventional products in the results. In those that did, no distinct differences in biodiversity impact were indicated, a result partly affected by the selected reference situation. In other studies, it was assumed that the negative impact on biodiversity by default is larger for conventional products (Karlsson & Röös, 2021; Martin & Brandão, 2017). Additionally, the biodiversity value in the production country (or preferably at finer scales) is of great importance to assess the impact on a certain food product. However, only three of the studies explicitly linked the foods to the origin country in the results (Lenzen et al. 2012; Sandström et al. 2017; Tidåker et al. 2021) and two partly (Moberg et al. 2020; Karlsson & Röös 2021).

4.2 The studies use different methodologies

The studies used different methods – LCA, input-output model and trade analyses – but some approaches were recurring in several studies. For instance, the most common methodology to assess the biodiversity impact was by predicting extinction rates of species caused by a food products' life cycle in terms of required land use in the given ecoregions (Chaudhary et al. 2015; Chaudhary et al. 2016 or Chaudhary & Brooks 2018 (see 5.1). This method was used by five studies (Moberg et al. 2020; Tidåker et al. 2021; Karlsson& Röös 2021; Crenna et al. 2019; Sandström et al. 2017). The method is partly based on de Baan (2012), which were used in two other studies (Martin & Brandão 2017; Röös et al. 2015). The remaining two articles reviewed used input-output model and trade-flow maps visualizing threatened species and species threats derived by trade of implicated commodities (Lenzen et al. 2012; Moran & Kanemoto 2017). Although the studies had different methods, the biodiversity impact of food products was mainly assessed by the area occupied for production in combination with the biodiversity values (e.g., species richness, or number of threatened species) in the production area/country. Parameters such as climate impact, eutrophication and ecotoxicity and how they impact biodiversity were however also considered in one of the studies, although land use was the most important impact factor also in this study (Crenna et al. 2019).

Deforestation, especially of tropical rainforest or old-growth forests, can lead to large losses of biodiversity. In the Chaudhary & Brooks (2018) methodology (which is, as mentioned, used in several of the reviewed papers), there is a possibility to use CFs for land occupation, and for land transformation. In the reviewed papers, only land occupation has been included, besides from Crenna et al. (2019) which analysed both, so there is a risk that biodiversity loss due to deforestation driven by food production is not included in most of the results. Thus, the impact might have been underestimated.

Further, the reference situation is of great importance (see section 2.3.2), however in most papers it is not clearly stated what reference situation is assumed. In the Chaudhary & Brooks (2018) methodology, the transformation impacts are based on the methodology described by de Baan (2013) which describes the original change in diversity due to natural habitat conversion including the time lag in the eventual recovery of the site back to a natural state (at some undetermined point in the future). The occupation impact captures the biodiversity loss attributed to prevent this recovery from taking place (i.e., because the site is occupied for human land use, it is unavailable for a proportion of species to occupy). In other words, the reference situation is an ideal state, with maximum biodiversity and imply no human disturbance to any degree. All impacts caused by food production are expressed as the potential biodiversity loss in comparison to this ideal state. As the reference situation in the other papers were not stated, it is difficult to make comparisons.

4.3 Knowledge gaps and outlook

When assessing the impact on biodiversity of diets, there are many factors to take into account. First of all, data on food consumption is needed, as well as the origin of the food products. However, only the origin of the food product does not give a full picture, more information about the production methods is needed.

Take for instance milk as an example (Figure 5). The milk farm itself of course has an impact on biodiversity when feed is cultivated, and pastures are grazed. Factors that the farmer can influence such as grazing pressure, crop rotation, use of pesticides and fertilizers, flower strips, hedgerows etc. can have both positive and negative impacts on the biodiversity status. However, in many cases farms also import feed from other nearby farms or from other countries. Use of soy meal is common in many animal production systems, which can be connected to deforestation and unsustainable agricultural practices. Goods such as fertilizers and fossil fuels are also imported to the farm, and the production of these can have vast negative impact on nature. Production of electricity e.g., hydropower can also have huge impacts on ecosystems. In our review, we could not find any study that included all of these product life-cycle effects for food items.

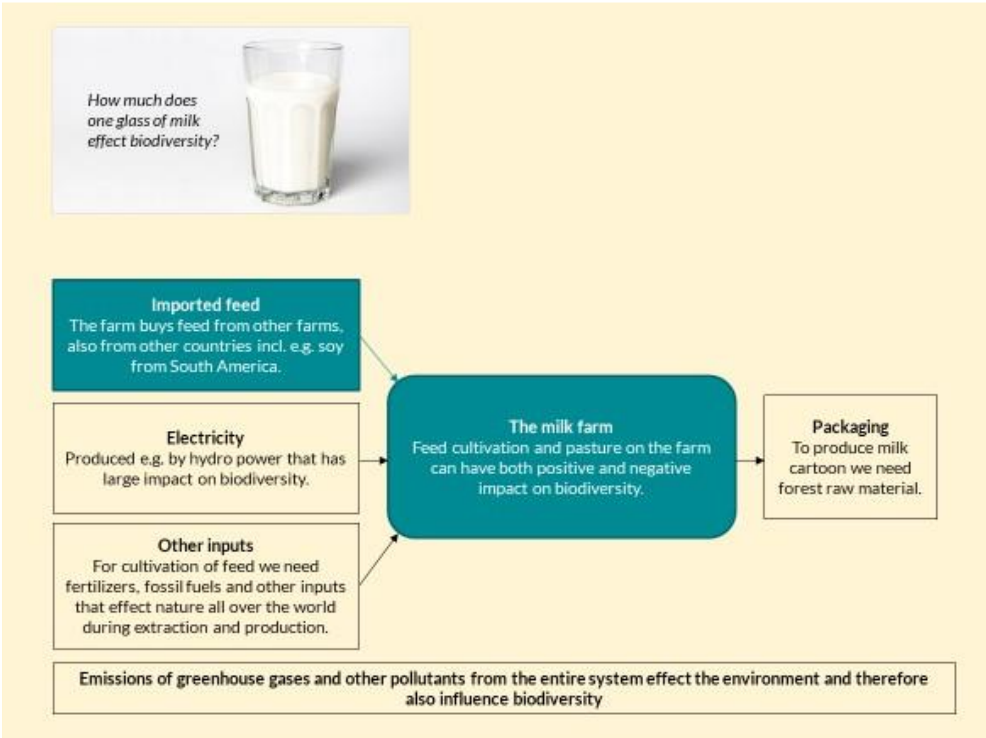

Figure 5. Examples on impact factors in the life cycle of a glass of milk. The green boxes are in many cases included in biodiversity assessment, the other boxes not.

To complicate things even more, emissions from the food system can also influence biodiversity in a longer time perspective. Greenhouse gases increases global temperature which also is a stated driver to biodiversity loss. Moreover, nutrient run-off and acidification effect biodiversity in terrestrial ecosystems, lakes and oceans, and so on. There are methods to include these kind of endpoint effects (see e.g. the ILCD-methodology) but the uncertainties are of course very large.

We also need a method to weigh all these factors into a single biodiversity score, so that biodiversity effects e.g., can be assessed in the same way as carbon footprints. However, in our review, we could not find a methodology or metric that weigh together indicators such as use of pesticides, deforestation and positive impacts due to grazing on high nature value lands. Another possible way forward would be to develop metrics that cover the 5 main drivers of biodiversity loss defined by IPBES (land use change, direct exploitation of organisms, climate change, pollution and invasive non-native species).

When studying the methods used in the reviewed papers, several gaps were identified. For example, they include a limited number of taxa groups and there are uncertainties regarding the reference situation. Moreover, most reviewed studies examined the impact on country-level, which may partly be explained by lack of data on finer scales, which will have an impact on the precision of the results – particularly in countries with numerous ecoregions. Finally, most studies only covered land-use, and do not consider marine species. In other words, there is much room for further improving biodiversity assessment methods.

4.4 Conclusions

So, what should we eat to benefit biodiversity? Our results highlight that efforts to limit the negative impact on biodiversity with our food consumption requires a focus on both what we should eat and perhaps even more importantly, what we should avoid eating. While additional studies are needed to confirm our results, the studies here indicate that caution should particularly be given to products that are known drivers of deforestation in tropical regions, such as palm oil, coffee, and cacao – as well as meat and/or animal products that have been fed with soybeans derived from tropical regions. On the other hand, consumption of foods as vegetables, starchy roots, and pulses – ideally with domestic origin – are examples of foods indicated to have lower biodiversity impact which would be beneficial to eat more of in the Nordic diet.

Finally, there are examples of agricultural systems where human interference is crucial for maintaining a high level of biodiversity, for example keeping grazing animals on high-nature-value-grasslands. If these lands are abandoned or planted with forest, numerous of species will be extinct. Thus, meat linked to these grasslands can also support biodiversity, especially in the Nordic countries where there are relatively many of these landscapes left (in comparison to the rest of Europe).

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Appendix 1. Reviewed papers

In this appendix the aim, methods used and main results of the reviewed papers is briefly presented. The nine papers are presented in an order based on the method used.

Moberg et al. 2020

Aim

The aim of the study was to assess the environmental impacts of the Swedish diet. The impacts were also benchmarked against global environmental sustainability boundaries for the food system, scaled down to per capita level.

Method

To calculate the impacts caused by the average Swedish diet, average per capita food supply was multiplied with the estimated environmental impacts per kg or litre of food. For biodiversity, the methodology in Chaudhary and Brooks (2018) was used to calculate potential species loss per kg food item. This was then recalculated to extinctions per million species-years (E/MSY) by allocating the biodiversity loss over a time horizon of 100 years, then divided by one-millionth of the total number of recognized species globally. The impact per kg food was based on weighted averages intended to be representative of the Swedish consumption to capture differences in impact due to origin country and production method.

For the benchmarking against global environmental sustainability boundaries, global environmental boundaries for the food system suggested by the EAT-Lancet Commission were used. For biodiversity, the boundary was expressed as extinctions per million species-years (E/MSY).

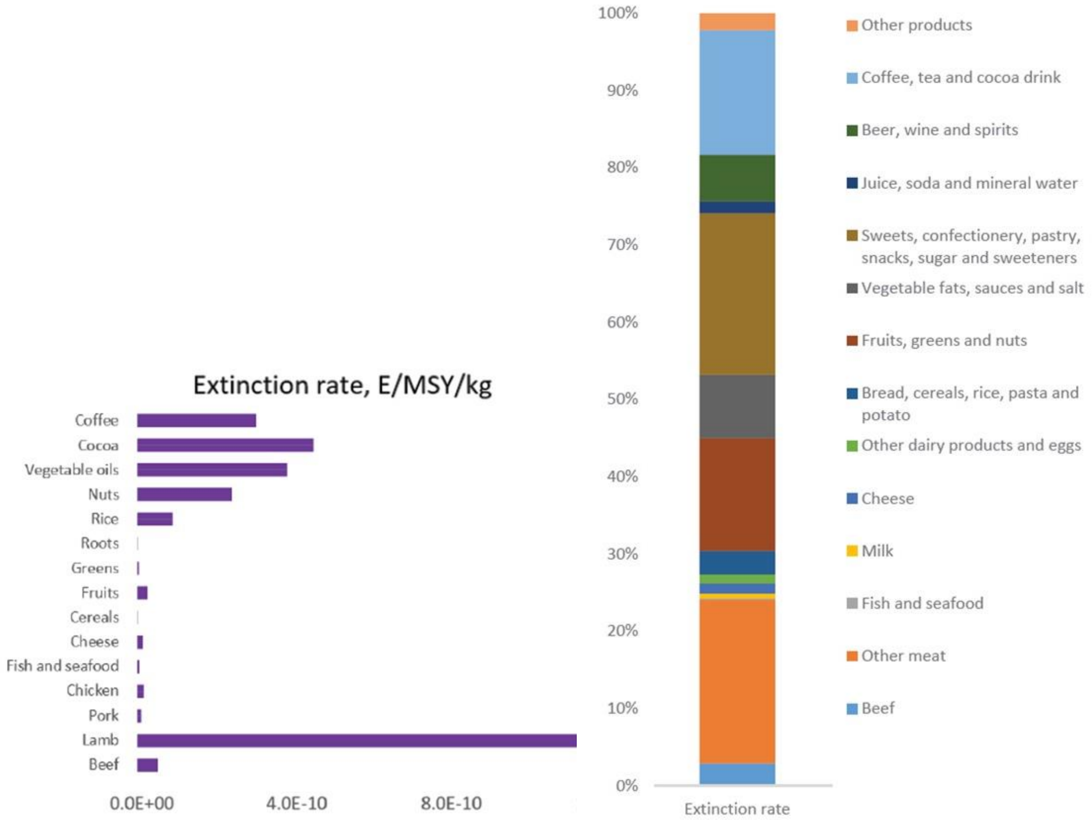
Results

The results from the study, showing impact per kg food item and relative dietary contribution by different food groups, are shown in figure 1a and 1b, respectively. The biodiversity impact per kg food is the result of how much land is needed, and the estimated biodiversity loss per m^2 of the occupied land. The high biodiversity impact per kg of olive oil, coffee and cocoa was mainly explained by the high cropland use. For products such as bananas, which are imported from South and Central America, the occupation of land for production in these areas caused high impacts due to high biodiversity loss per occupied m^2.

In general, animal products such as beef caused relatively low biodiversity impacts per kg despite high land use, due to that most livestock production for the Swedish market take place on areas with relatively low biodiversity values (Sweden and Northern Europe). However, the impacts on biodiversity loss would change considerably if production took place in areas where the land occupation causes higher biodiversity loss per m^2. As an example, lamb consumed in Sweden, which is partially based on import, was found to have the highest biodiversity impacts per kg of all food items included in the assessment. This was explained by its extensive land use (especially pasture), together with the high biodiversity loss from occupation of land for sheep production in New Zealand.

The results indicate that several plant-based products, such as vegetable oils (especially olive oil), nuts, coffee, cocoa, and rice, have a relatively high impact per kg of food (Figure 1a). When considering the dietary intake, the categories sweets etc, coffee etc, fruits etc, and other meat accounted for the largest share of the diet's total biodiversity loss (Figure 1b), which was explained by both high consumption levels and high impact per kg.

With regard to benchmarking against global environmental sustainability boundaries, the biodiversity impacts caused by the Swedish diet transgressed the global per capita boundary by six-fold.



(a) **(b)**

Figure 1. (a) Extinction rate (E/MSY/kg) per kg food, for 15 food products on the Swedish market (Moberg et al. 2020). **(b)** The relative contribution (%) by different food groups to the extinction rate from the total Swedish per capita consumption.

Tidåker et al. 2021

Aim

The aim of the study was to evaluate the environmental impact of pulses consumed in Sweden. The evaluation of production encompassed and compared five pulse crops cultivated in Sweden (yellow peas, grey peas, faba beans, common beans and lentils) as well as pulses produced abroad (China, Italy, Canada and Turkey), grown in both conventional and organic production systems.

Method

Biodiversity impact of land occupation was evaluated using CFs from Chaudhary and Brooks (2018) and the results were expressed as PDF per kg cooked pulses.

Results

The biodiversity impact of land occupation for the different pulses differed significantly, with the highest impact associated with pulse cultivation in the Sichuan region of China and in Turkey and the lowest biodiversity impact for cultivation in Sweden (figure 2). The differences between the pulse crops were mainly explained by differences in CFs for the ecoregions, while the intensity level (conventional or organic) had a marginal impact on the final score.

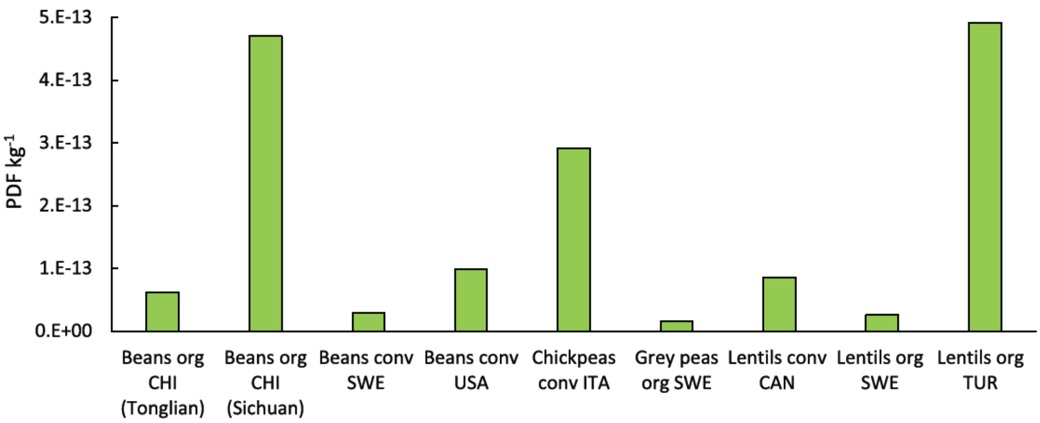


Figure 2. Biodiversity impact (PDF) per kg cooked pulses, produced either conventional (con) or organic (org), and produced in two regions in China (CHI), Sweden (SWE), Italy (ITA), Canada (CAN) and Turkey (TUR) (Tidåker et al., 2021).

Karlsson & Röös 2021

Aim

In cooperation with World Wide Fund for Nature (WWF) Sweden, this study was performed with the aim to develop a consumer guide for plant-based products to support a more sustainable food consumption in Sweden. In order to create the guide, a method was developed to compare different products/product groups within different impact categories (climate, biodiversity, water use and pesticide use), as well as calculating thresholds for a consistent evaluation.

Method

The study included 90 plant-based food products, which were divided into five categories based on their different diet functions (e.g., protein and nutrient content): protein sources, carbohydrate sources, plant-based drinks, fruits and berries and vegetables/mushrooms. The environmental impact categories were analysed using available environmental footprint data and LCA data relevant for the Swedish market. The consumer guide was constructed as a four-step traffic-light system (orange, yellow, green, green star) with defined sustainability thresholds for the different food categories, which were based on the EAT-Lancet sustainability boundaries for the food system (see Willett et al. 2019). This allowed for a consistent evaluation of the different products, while the same functional unit could be used (1 kg food at a store in Sweden). To quantify the biodiversity impact, the methodology in Chaudhary & Brooks (2018) and the unit PDF was used. Additionally, organic products (based on certification schemes) were ranked one level higher in the traffic-light system, based on the assumption that organic production is generally better in a biodiversity perspective.

Results

Regarding biodiversity impact most of the assessed food products were ranked with green stars, i.e., the lowest negative impact on biodiversity (e.g., see the evaluation for Fruit and berries in figure 3). Non-organic bananas were the most critical product (orange), followed by almonds and quinoa (both organic and inorganic) and asparagus (South American produced), which were all ranked as yellow products. However, when all impact categories were combined, several plant-based foods were ranked as orange and yellow products, e.g., asparagus (Europe), cucumber and tomatoes (if not produced in Sweden and/or organic) and nuts (e.g., cashew nuts, hazelnuts), olives and dates. This result emphasizes the importance of multi-criteria evaluations, as a product can be non-problematic regarding direct species loss but critical in other impact categories which also – directly or indirectly – affect biodiversity. Discussions of limitations and challenges of using the present method were related to e.g., different aspects of uncertainty of stating sustainability thresholds.

GROUP	PRODUCT	CLIMATE	BIODIVERSITY	WATER	PESTICIDE USE	FINAL EVALUATION
Fruit and berries						
	Apples	GREEN STAR	GREEN STAR	GREEN	ORANGE	GREEN
	Apples, Sweden	GREEN STAR	GREEN STAR	GREEN	ORANGE	GREEN
	Apples, organic	GREEN STAR	GREEN STAR	GREEN	GREEN STAR	GREEN STAR
	Bananas	GREEN	ORANGE	GREEN	ORANGE	ORANGE
	Bananas, organic	GREEN	YELLOW	GREEN	GREEN STAR	GREEN
	Oranges	GREEN STAR	GREEN STAR	YELLOW	ORANGE	YELLOW
	Oranges, organic	GREEN STAR	GREEN STAR	YELLOW	GREEN STAR	GREEN
	Pears	GREEN STAR	GREEN STAR	GREEN	ORANGE	GREEN
	Pears, organic	GREEN STAR	GREEN STAR	GREEN	GREEN STAR	GREEN STAR
	Strawberries	GREEN	GREEN STAR	YELLOW	ORANGE	YELLOW
	Strawberries, Sweden	GREEN STAR	GREEN	GREEN	ORANGE	YELLOW
	Strawberries, organic	GREEN	GREEN STAR	YELLOW	GREEN STAR	GREEN
	Strawberries, Sweden, organic	GREEN STAR	GREEN	GREEN	GREEN STAR	GREEN

Figure 3. Evaluation on climate, biodiversity, water, pesticide use and a weighted final evaluation on fruit and berries (Karlsson & Röös, 2021).

Crenna et al. 2019

Aim

The aim of the study was to, by performing an LCA, examine different food products representative to the food consumption in the EU regarding their negative impact on biodiversity. The study further presented how existing LCA-methods can be developed to improve future modelling, e.g., by including several drivers of biodiversity loss.

Method

The study was based on data and methods used in a previous study (Notarnicola et al. 2017), but with some adjustments and extensions. 32 food products were selected primarily based on their importance in the EU food system (mass and/or economic value). The environmental impact, including biodiversity impact, of each selected product was analysed and calculated through a process-based LCA – including the entire food production and consumption from cradle to grave. Different impact drivers such as land use, climate change and acidification, were first analysed separately and compared (midpoint). Impact on biodiversity was thereafter assessed based on endpoint indicators where the calculated environmental impact at midpoint was linked to the Area of Protection (AoP) "ecosystem quality", expressed in the unit PDF*years. In addition, a specific focus was considered to capture effects from land use/land use changes, due to its well-known impact on biodiversity loss, where CFs from Chaudhary et al. (2015) were applied (the predecessor to Chaudhary & Brooks, 2018, see 2.3.1).

Results

The study suggested that eight food products make up 75 % of the total negative biodiversity impact (all examined food products summarized), which mostly consisted of animal products such as meat (beef, pork, poultry), cheese, milk, and eggs (Figure 4). Not only do these products have high environmental impact per kg products, but they are also highly consumed in the EU.

Regarding biodiversity impact linked explicitly to land use changes, pork meat and beef meat were the products with highest impact. This is mainly due to the land occupation required for production of animal feed (e.g., barley, soybean, and grass), but impact from livestock grazing is also considered. The study further showed that land use changes (agricultural land occupation and natural land transformation) and climate change were the main impact categories that contribute most to ecosystem quality deterioration and species loss. However, the authors stressed that additional drivers should be included in future models/studies, such as agricultural practices, international trade (linked to dispersal of invasive species) and overexploitation (e.g., marine species). Additionally, they highlighted that a wider range of taxonomical groups should be included in future LCA models.

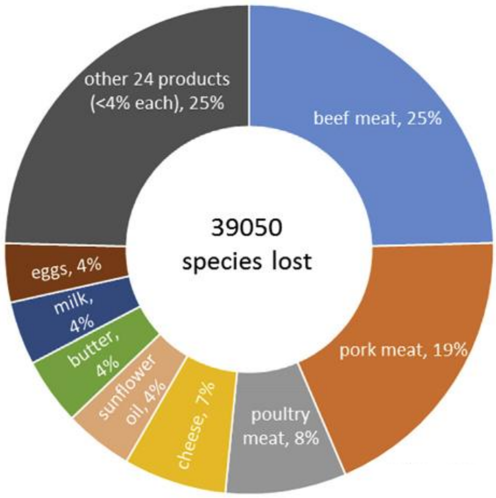


Figure 4. Relative contribution to damage on biodiversity of different food products in a European diet (Crenna et al. 2019).

Sandström et al. 2017

Aim

This study examined the development of import of food products in Finland from 1986 to 2011, both in terms of the type of commodities imported as well as the origin countries of the products. Thereafter the negative impact on global biodiversity linked to land use and water use of the studied products was analysed.

Method

The analysis was focused on crop production, both feed and food crops (450 secondary crop products converted into 132 primary products). Pastures and planted fodder crops were not included, due to e.g., pastures' varying quality, productivity and human interference worldwide respectively lack of available data on fodder crops at global scale. In order to assess the environmental impact, three variables in every source country were used; the cropland area (tons of the products converted into hectares of land), the fresh water used for irrigation (blue water) and the global biodiversity impacts linked to land and water use. The latter were assessed using CFs (Chaudhary et al., 2016, see 2.3.1), based on countryside species-area relationships for four different taxa (mammals, birds, amphibians, and reptiles) and expressed in global PDF of species in a year (gPDF a). Regarding water use, a similar approach was used which translated water consumption to e.g., wetland area loss.

Result

The study showed that the imports of food products to Finland have nearly doubled within the given period. The main imports were originated in European and Soviet Union as well as South American countries. More than 93 % of the negative biodiversity impacts linked to land and water use were related to imports and thus, allocated abroad. Coffee, cocoa, sugar and soybeans from Brazil, India, Colombia, and Indonesia were identified to cause the most severe biodiversity impacts related to land use (Figure 5). Countries such as Honduras, Guatemala, Kenya, Malaysia, and Nicaragua were also included in the top ten countries with highest negative impact. Coffee from India, Colombia, Mexico, and Brazil were also suggested to cause particularly high biodiversity threats. Regarding blue water use, rice and citrus fruits produced in Spain, USA and Egypt had the highest biodiversity impacts (Figure 6).

The authors stressed that dietary changes may reduce global biodiversity loss, as well as increasing imports of environmentally labelled/certified products from the most vulnerable regions. They also emphasized the role of global trade on biodiversity loss and other environmental issues, and requested that policies should target producers, traders, and producers in parallel to promote a more sustainable food system.

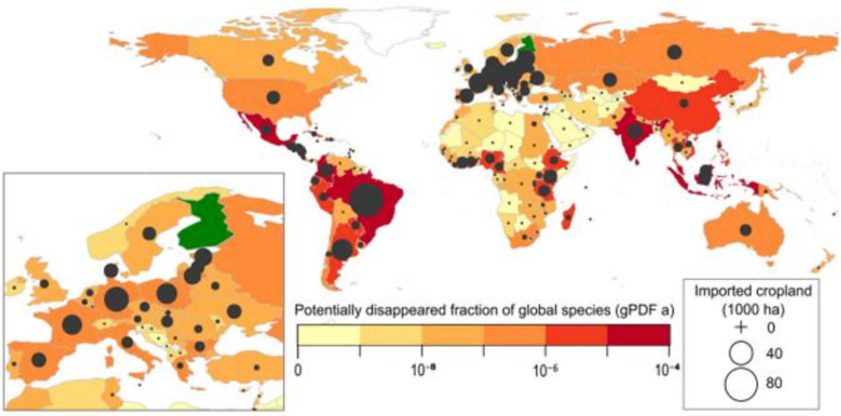


Figure 5. Imported cropland (needed for imported food products) and the impacts on biodiversity from Finnish food consumption. The circles represent the imported cropland, and the colour of the countries reflects the biodiversity impacts caused by land use (Sandström et al. 2017).

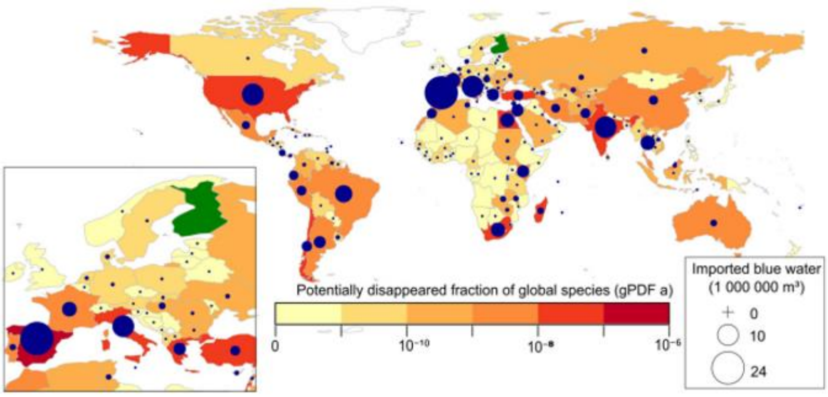


Fig. 4. Imported blue water and the impacts on global biodiversity in 2010. Bubbles represent the quantities of imported blue water and the color of the countries represents biodiversity impacts caused by blue water use (values presented as three-year means of 2009–2011).

Figure 6. Imported blue water (needed for imported food products) and the impacts on biodiversity from Finnish food consumption. The circles represent the amount of imported blue water and the colour of the countries reflects the biodiversity impacts linked to blue water use (Sandström et al. 2017).

Röös et al. 2015

Aim

Environmental impact of three diet scenarios were assessed regarding climate impact, land use and biodiversity. Nutrient intake from the diets was assessed and two alternative approaches for relating nutrient intake to environmental impact were presented.

Method

The three dietary scenarios assessed were based on the current average Swedish diet, a diet corresponding to Nordic nutrition recommendations, and a low carbohydrate high fat (LCHF) diet. Dietary impact on biodiversity was assessed as biodiversity damage potential (BDP) from land use, based on the method developed by de Baan et al (2012). The method allows to assess biodiversity impact on a global scale by differentiating species richness between different land use types based on the following data inputs: hectares of land occupied, land type classification (annual crops, permanent crops, pastures, and meadows), and biome (natural vegetation type, e.g., tropical savannah). The resulting BDP was assessed as the difference in species richness between agricultural and natural land use of the biome.

Result

The study provided ranges for BDP values per kg of all food items included in the assessment. The food products with the highest BDP were animal-based products such as lamb, beef, pork, chicken, cheese, butter, and cream. Food products with lower BDP were e.g., root vegetables, potato, fruits and berries. Some of the examined products had a relatively large variety of BDP within the food group, such as the groups *vegetables* and *coffee, tea and cocoa* where the range varied from very low BDP to medium high BDP.

No results were presented for BDP of the dietary scenarios studied, but the dietary impact on BDP was described to have similar patterns as dietary impact on climate change. Climate impact from the dietary scenarios studied was dominated by consumption of animal-based foods (65-85% of the total impact), with a smaller contribution from fruits and vegetables (8-16%), grains and potato (0-12%) and discretionary foods including alcoholic drinks, coffee, tea, cocoa, and sugar (5-13%).

The choice of method for biodiversity assessment was discussed and motivated by its applicability across land types globally, which is a prerequisite when assessing diets based on globally traded food products. Limitations of the method discussed include its inability to capture positive biodiversity effects including effects from semi-natural pasture, potential positive effects from organic production and preservation of agricultural land in forest-dominated regions such as Sweden.

Martin & Brandão 2017

Aim

In this study, implications of different dietary choices for Swedish food consumption were quantified to gain insights on impact and potential trade-offs between environmental impact categories (e.g., biodiversity, climate impact and eutrophication).

Method

The examined scenarios focused on dietary changes of reduced meat intake, increased share of Swedish food, increased share of organic food, adherence to Swedish dietary guidelines, vegan, and semi-vegetarian diets. In the scenarios with reduced meat and dairy products was substituted by an increased consumption of plant-based products such as pulses, vegetables, roots, and tubers.

Environmental impact categories assessed were climate impact, acidification, eutrophication, human toxicity, terrestrial ecosystem toxicity, land use and biodiversity. The environmental impact from the diet scenarios assessed was compared to a reference scenario representing per capita Swedish food consumption (business as usual, “BAU”). Biodiversity was assessed as BDP from land use, using the same method and data as in Röös et al. (2015) (see previous section). The method included assumptions for reduced BDP for organic production methods.

Result

A major reduction in BDP compared to the BAU scenario was shown for diet scenarios of reduced meat consumption (scenarios for reduced meat intake, vegan and semi-vegetarian diets), higher adherence to dietary guidelines, and 100% organic food consumption (Figure 7). Remaining scenarios assessed, including diets completely based on conventional food, an increased share of organic food consumption and/or a reduced share of imported food consumption had small impact on BDP. Meat contributed to about 50% of the diets total BDP in all scenarios assessed, with exception for the scenarios where meat intake was reduced or removed completely. Other food groups with a large contribution were cereals and milk responsible for about 10-15% of the diets total impact, respectively. In the vegan scenario, cereals and oil crops were responsible for the largest share of the diets total impact. Across all diet scenarios, the share of food consumption based on Swedish production varied from a minimum of 53% in the vegan scenario to a maximum of 75% in the scenario of increased Swedish food consumption. In these scenarios, the corresponding share of BDP related to imported food varied from 25-56%.

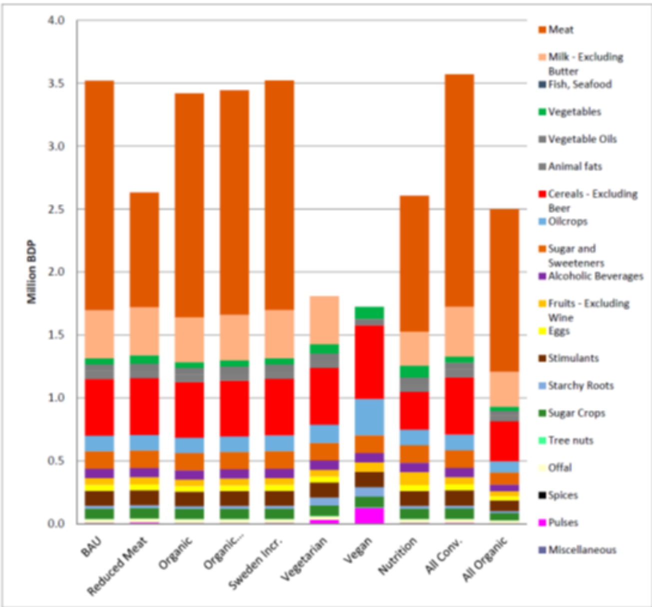


Figure 7. Biodiversity damage (expressed in million BDP) for different diet scenarios in Sweden. "Organic..." shows the scenario of *Organic Sweden* "All Conv." shows "All Conventional" (Martin & Brandão 2017).

Lenzen et al. 2012

Aim

This study examined the linkage between threatened species and international trade. More specifically, it quantified the role of international trade as a driver of species threats and evaluated the biodiversity footprint of different import countries.

Method

The authors used data on threatened species (IUCN Red list and Bird Life International) (in total 6964 species) and linked it to implicated commodities (derived from agriculture, fishing and forestry) produced and consumed worldwide. In order to evaluate the international trade of species threats they traced the commodities from the production country to the country of final consumption. The assessment was performed by combining the data on species threats with economic multi-region input-output tables, which contained transactions between approximately 16000 industry sectors across 187 countries. This resulted in an evaluation of more than 5 billion supply chains' biodiversity impact, in terms of number of threatened species and different species threats. To visualize their results, global trade-flow maps were created where the supply chain of commodities from an import to an export country and its biodiversity impact was illustrated (see Figure 8 for example of a flow map showing imports to Germany and exports from Malaysia).

Results

Overall, the authors addressed the shared responsibility of producers and consumers to commercial causes of biodiversity threats, as they found a remarkable division between the top ten net exporters versus the net importers of biodiversity[6]. A total of 44 % among the net importers' biodiversity footprint was linked to imported commodities, whereas for the net exporters (primarily developing countries) a third originated from export-oriented production. Besides USA and Japan, the EU was identified as the main final destination of biodiversity-implicated commodities.

The study further suggested that biodiversity-implicated food products are mainly produced in developing countries rich in biodiversity – mainly tropical regions – and with export-oriented industries, such as Indonesia, Malaysia and Madagascar, and that species threats are often accelerated by large supply chains. The authors suggested coffee, cocoa, palm oil and coconut as examples of food products driving species threats and high numbers of threatened species. Other highlighted products were vanilla, cloves, tea and bananas. Moreover, the authors emphasized that the fishing industry is a large driver of biodiversity loss and exemplified countries such as the USA and Philippines.

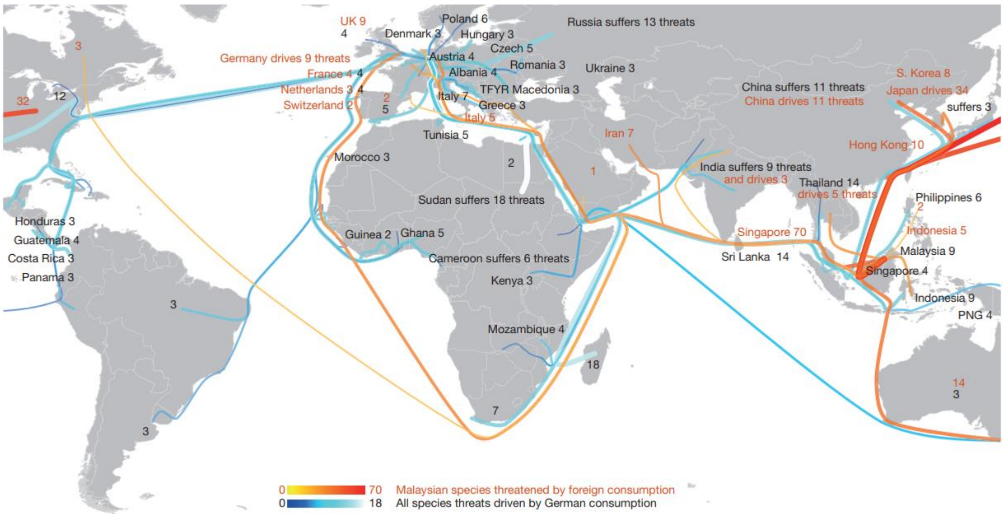


Figure 8. Flow map showing threats to species linked to exports from Malaysia (yellow/red) and imports into Germany (blue) (Lenzen et al. 2012)

Moran & Kanemoto 2017

Aim

This study aimed to assess the linkage between biodiversity threats and international trade by examining which species threat hotspots are driven by which import country as well as which consumption category(-ies). Previous studies (such as Lenzen et al. 2012) have addressed this linkage at the country level, but Moran & Kanemoto (2017) analysed these threats at a subnational level.

[6] The net exporters are countries that export more biodiversity-implicated commodities than they import and vice versa

Method

In order to link global production and consumption, the authors created a map of species threat hotspots. This was performed by combining extent-of-occurrence maps for a wide array of threatened species (based on data from IUCN and BirdLife International) and applying a spatially extended version of the biodiversity footprint method used by Lenzen et al. 2012. Anthropogenic species threats (such as agriculture, forestry, pollution, and transport) were linked to different industries and a global trade model was used to trace commodities linked to the species threats from 16000 industries around the world to final consumers. Only terrestrial and near-shore marine ecosystems were included.

Results

The results were illustrated by a map tool, showing hotspots of species threat linked to foreign consumption. Here, the results described are limited to the species threats linked to the EU consumption.

Terrestrial species threat hotspots driven by EU consumption were primarily localized in several African countries (e.g. Morocco, Ethiopia, Madagascar, Libya and Cameroon), Central and Southeast Asia and Indonesia (Figure 9). The threats to terrestrial species were however not specified in the article. Regarding marine species the authors suggested the main threats, including fishing, aquaculture and pollution, to be concentrated to southeast Asia (hotspot area) as well as islands around Madagascar (Réunion, Mauritius and the Seychelles) (Figure 9). Worth mentioning is that the analysed commodities were not limited to food products, but all types of commodities. Thus, this study scope – as well as the results – differed from the previous studies.

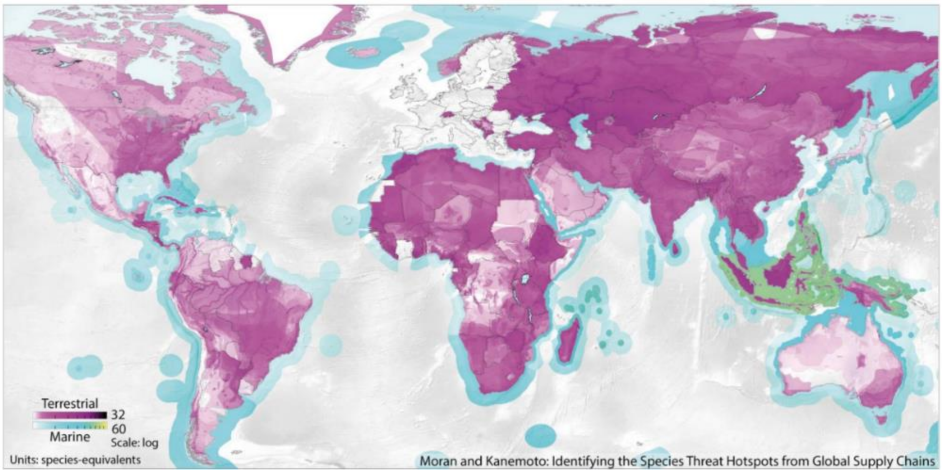


Figure 9. Global species threat hotspots caused by consumption in the EU

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