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Accounting for land use, biodiversity and ecosystem services in life cycle assessment: Impacts of breakfast cereals

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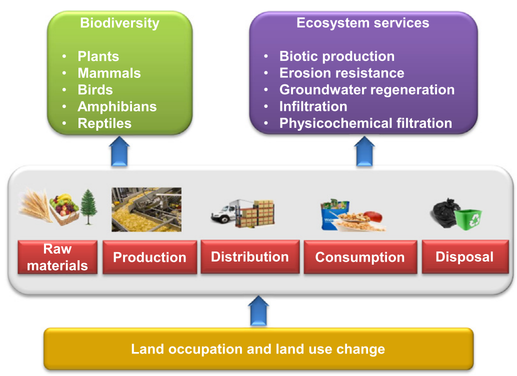
HIGHLIGHTS

- Different methods considered, identifying challenges and future research needs.
- Biodiversity impacts assessed for mammals, birds, plants, amphibians and reptiles.
- Ecosystem services assessed include biotic production, erosion and groundwater.
- Cocoa is the major hotspot for biodiversity loss and land use for ecosystem services.
- Consumption with milk increases some of the ecosystem service impacts by 4–5 times.

GRAPHICAL ABSTRACT



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ABSTRACT

This study considers the life cycle impacts of land use on biodiversity and ecosystem services associated with the production of a ubiquitous food type: breakfast cereals. For biodiversity, the impacts on five taxonomic groups have been assessed: mammals, birds, vascular plants, amphibians and reptiles. For ecosystem services, the potential loss in the following ecosystem services of soil has been considered: biotic production, erosion resistance, groundwater regeneration, infiltration and physicochemical filtration. The findings indicate that the main hotspot for the biodiversity loss is cocoa cultivation for all taxonomic groups, with a contribution of 27–67%. Cocoa is also a major contributor (35%) to the loss of biotic production, while rice is the largest contributor to erosion (34%), reduction in groundwater replenishment (43%) and physicochemical filtration (23%). Corn is the main cause of the infiltration reduction, accounting for 44% of the impact. Unlike the biodiversity impacts, which are almost entirely caused by agricultural activities, non-agricultural land use occurring in other life cycle stages (transport, packaging and manufacturing), has significant contribution to the reductions in groundwater replenishment and infiltration. The impacts on ecosystem services are almost entirely driven by land occupation, while the biodiversity impacts are caused by both land use change and occupation. The identification of cocoa as the main hotspot is unexpected as it is used only in very small quantities (<5% by mass) in breakfast cereals. Its high contribution to the impacts is partly due to the land use change in the ecoregion of the Eastern Guinean forests, which are home to a relatively large number of endemic species. The paper also discusses the limitations of the impact assessment methods for evaluating the biodiversity and ecosystem services and highlights the need for further development of indicators and methods to assess the land use impacts in life cycle assessment.

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Nomenclature

BPLP	biotic production loss potential
BPP	biotic production potential
CFs	characterisation factors
CRP	climate regulation potential
EP	erosion potential
FWRP	freshwater regulation potential
GRRP	groundwater regeneration reduction potential
IRP	infiltration reduction potential
LCA	life cycle assessment
LCIA	life cycle impact assessment
LUC	land use change
LULUC	land use and land-use change
PFRP	physicochemical filtration reduction potential
SAR	species–area relationship
SHSM	species habitat suitability model
WPP	water purification potential

1. Introduction

Land use by agri-food systems can have significant impacts on biodiversity as well as the structure and functions of ecosystems. According to the *Millennium Ecosystem Assessment* report (WRI, 2005), habitat destruction caused by land use and land-use change (LULUC) is one of the five main drivers of terrestrial biodiversity loss, together with climate change, invasive alien species, overexploitation of resources and pollution. Two main impact pathways for LULUC have been proposed by UNEP-SETAC (Koellner et al., 2013): i) biodiversity damage potential; and ii) ecosystem services damage potential. Biodiversity is a complex and heterogeneous concept, involving multiple levels of life (e.g. genes, species, ecosystems), various biological attributes (e.g. composition, structure, function) and a multitude of spatial and temporal dynamics (Curran et al., 2011). The term ecosystem services conceptualises how ecological processes support human well-being (Othoniel et al., 2016). The services provided by ecosystems include provision of food, fibre, biomass and freshwater as well as regulation of carbon sequestration, soil degradation or erosion and water purification (WRI, 2005).

The importance of assessing the land use impacts on biodiversity and ecosystem services through life cycle assessment (LCA) is widely recognised; however, the task remains difficult. A number of studies have attempted to develop biodiversity indicators and spatial models to quantify them (for a review, see Curran et al., 2016). The most notable life cycle impact assessment (LCIA) models for biodiversity have been developed using species–area relationship (SAR) model of biodiversity loss (de Baan et al., 2013a,b; Chaudhary et al., 2015) and species habitat suitability model (SHSM). The latter, proposed by de Baan et al. (2015), provides characterisation factors (CFs) for mammals based on their conservation status and global rarity but, due to a very large data demand of this approach, global coverage was not achieved and taxonomic coverage was restricted to mammals. By contrast, the CFs provided by the same authors in an earlier study (de Baan et al., 2013a,b) quantify regional and endemic species loss in all global ecoregions for mammals, birds, vascular plants, amphibians and reptiles. Chaudhary et al. (2015) further developed this approach by including more data and weighting regional species loss with a spatially-resolved factor that combines the rarity and threat level of species (based on Verones et al., 2013), thus developing an indicator of global species extinctions. The study also provided CFs for land occupation and land use change for 804 ecoregions and six land use classes: intensive forestry, extensive forestry, annual crops, permanent crops, pasture and urban land. The UNEP-SETAC Life Cycle Initiative recommended this approach as the best practice for identification of hotspots for land-use biodiversity impacts in LCA (UNEP-SETAC, 2016).

For ecosystem services, several indicators and their characterisation factors have been proposed in various studies; for a review, see Othoniel et al. (2016) and Vidal Legaz et al. (2017). For example, the indicator 'climate regulation potential' (CRP), proposed by Müller-Wenk and Brandão (2010), considers CO_2 transfers between vegetation/soil and the atmosphere in the course of terrestrial release and re-storage of carbon due to land use. Brandão and Milà i Canals (2013) provided a characterisation model for impacts of land use on biotic production potential (BPP). The model uses soil organic carbon as an indicator of soil quality, as a proxy indicator for the biotic production capacity of the soil. Saad et al. (2013) proposed CFs for three major ecological functions: erosion potential (EP), freshwater regulation potential (FWRP) and water purification potential (WPP). These indicators have been further developed in the LANCA® (LANd use indicator value Calculation tool) (Bos et al., 2016). Further discussion of these indicators is provided in the next section.

A few studies have assessed impacts of food products on biodiversity and ecosystem services using some of the above mentioned methods. These include margarine production in the UK and Germany (Milà i Canals et al., 2013) as well as milk and pork in Sweden (Nordborg et al., 2017). Both studies used the aforementioned UNEP-SETAC impact pathways for LULUC (Koellner et al., 2013) and assessed six mid-point categories for ecosystem services: CRP, BPP, FWRP, EP and WPP through infiltration and physicochemical filtration. For the margarine study, biodiversity damage potential (BDP) was considered using the approach suggested by de Baan et al. (2013a). In addition, some studies have also assessed land-use impacts of individual crops from particular countries using different methods. For instance, de Baan et al. (2015) assessed impacts of tea, coffee, and tobacco in East Africa using the SAR approach and SHSM. Chaudhary et al. (2016) applied their own biodiversity impact assessment method to global agriculture, pasture and forestry. A global analysis of biodiversity loss by IRP (2017) found that about 10% of global species were lost because of agricultural crop production, grazing of pasture and wood extraction.

This study focuses on breakfast cereals which represent an integral part of diet in many countries (CEEREAL, 2015). As their production is heavily reliant on land use, the effects on biodiversity and ecosystem services are highly relevant. While the life cycle environmental impacts of breakfast cereals have been reported previously (Jeswani et al., 2015), their influence on biodiversity and ecosystem services remains unknown, thus warranting further study. Recently developed LCIA methods have been applied for these purposes, as detailed in the next section.

2. Methods

2.1. Goal and the scope of the study

The main goal of the study is to quantify the impact of land use on biodiversity and ecosystem services associated with the production of breakfast cereals. The products considered are ready-to-eat breakfast cereals and snacks manufactured by Kellogg Europe. This is one of the leading producers of breakfast cereals in Europe with a market share of over 35% (CEEREAL, 2011; Kellogg, 2013). The functional unit is defined as the 'annual production (388,000 tonnes) of ready-to-eat breakfast cereal products'. As indicated in Fig. 1, the scope of the study is from 'cradle to grave', including:

- agricultural production of cereal grains and other ingredients;
- processing of ingredients, such as corn, wheat, rice, sugar, cocoa, fruits and nuts, to produce different breakfast cereals;
- production of packaging materials and packaging;
- transport of ingredients, packaging materials, products and waste along the life cycle; and
- management of waste in different life cycle stages.