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Pollinators in life cycle assessment: towards a framework for impact assessment

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A B S T R A C T

Human activities are threatening biodiversity at an unprecedented scale and pace, thus potentially affecting also the provision of critical ecosystem services, including insect pollination. Insect pollinators play an essential functional role in terrestrial ecosystems, supporting ecological stability and food security worldwide. Therefore, assessing impact on pollinators is fundamental in any effort aiming at enhancing the environmental sustainability of human production and consumption, especially in the agri-food supply chains. Different drivers are leading to pollinator populations' declines. Improving a supply-chain oriented assessment of the occurrence of pressure and impacts on pollinators is needed. However, current methodologies assessing impact along supply chains, such as life cycle assessment (LCA), miss to assess impact on pollinators. In fact, none of the existing life cycle impact assessment (LCIA) models effectively accounts for pollinators. Some LCIA models have mentioned pollination, but none has presented key drivers of impact and a proposal for integrating pollinators as target group for biodiversity protection within an LCIA framework. In order to devise a pathway towards the inclusion of impacts on pollinators in LCIA, we conducted a literature review of environmental and anthropogenic pressures acting on insect pollinators, potentially threatening pollination services. Based on the evidence in literature, we identified and described eight potential impact drivers, primarily deriving from industrial development and intensive agricultural practice: 1) intensified land use as a result of uncontrolled expansion of urban areas and modern agricultural practices; 2) use of pesticides; 3) presence of invasive alien plants; 4) competition with invasive alien pollinator species; 5) global and local climate change; 6) spread of pests and pathogens; 7) electro-magnetic pollution and 8) genetically modified crops. To account for these drivers in LCIA, there are specific modeling needs. Hence, the current study provides recommendation on how future research should be oriented to improve the current models and how novel indicators should be developed in order to cover the existing conceptual and methodological gaps.

1. Introduction

Over the last decades, human activities related to industrial development and agricultural intensification have threatened biodiversity and the provision of ecosystem services at an unprecedented scale and pace (CBD, 1992; Curran et al., 2011), almost leading to the so-called sixth mass extinction (Ceballos et al., 2015).

Ecosystem services arise when nature (in its broad definition) contributes toward meeting a human demand; they are, arguably, underpinned by biodiversity (Hooper et al., 2005; Haines-Young and Potschin, 2010). Biodiversity and ecosystem services have undergone dramatic, in some case irreversible changes: as such, also the provision of critical ecosystem services is potentially at risk (Koellner and Geyer, 2013; MEA, 2005), including those related to insect pollination. As a consequence, the overall human well-being profiting from goods and services provided by nature is also potentially threatened.

To date, different classification systems for ecosystem services are in use. They invariantly discriminate among: (i) provisioning services, i.e. the goods we obtain from ecosystems, such as water,

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timber, fish and agricultural products, which are all traded on markets; (ii) regulating and supporting services, i.e. the capacity of ecosystems to maintain a livable environment, which include the removal of pollutants from soil, air and water, or services which support crop production such as pollination and soil erosion control; and (iii) cultural services, i.e. the non-material benefits, essentially defined by human preferences, such as nature-based recreation and tourism.

Within the regulating and supporting ecosystem services (MEA, 2005; Soussana, 2014), pollination represents a critical life-support function which is crucial for planetary ecological stability and the provision of services and resources in the agri-food sector. Indeed, a broad variety of wild and domestic insects plays an essential functional role in both natural and managed terrestrial ecosystems (Kluser et al., 2010; Vanbergen et al., 2014). At the global level, insect pollinators are responsible for pollinating more than 80% of wild plant species and almost 75% of primary agricultural crops (Klein et al., 2007), providing mankind with global food supply and other fundamental goods and services.

Recently, the global biodiversity crisis has involved insect pollinator populations as well. Several authors have documented regional reductions in the abundance and diversity of wild bees and local decreases in other pollinator populations, such as hoverflies and butterflies (Aizen and Harder, 2009; Biesmeijer et al., 2006; Carvalheiro et al., 2013; Potts et al., 2015). Moreover, significant and constant declines in the number of managed honeybee colonies have been registered on a regional scale in both Europe and North America. This alarming situation may have serious implications. It would limit the future production of pollinator-dependent crops (VanEngelsdorp and Meixner, 2010), thus threatening the agricultural and economic systems human life relies on, and would considerably affect the maintenance of wild plant diversity and natural ecosystem stability. The services provided by insect pollinators form the basis of other important ecosystem services and their loss would limit the availability of goods for future generations (Singh and Bakshi, 2009). As a result, several international institutions, local authorities and non-governmental organizations have raised deep concerns regarding potential risks to global food security and natural ecosystem functioning (Allen-Wardell et al., 1998; Bauer and Wing, 2010; Steffan-Dewenter et al., 2005), thus appealing for the promotion of an environmentally sustainable development. An integrated approach is needed in the areas of agriculture and ecology that would reduce the trade-offs between food production, biodiversity and ecosystem services (Soussana, 2014).

Understanding and identifying the role of ecosystem services, their linkages with biodiversity and human activities and the pressures that endanger their provision have been the central point of recent research (MEA, 2005; Zhang et al., 2010a, 2010b). Previous studies have already highlighted the main threats leading to pollinator populations' declines and potentially menacing the provision of pollination services (Gonzalez-Varo et al., 2013; Potts et al., 2010; Schweiger et al., 2010; Vanbergen et al., 2013, 2014). Furthermore, numerous attempts have been made in order to quantify the magnitude of human interventions leading to biodiversity loss and ecosystem service depletion (Curran et al., 2011; Koellner and Geyer, 2013; Schmidt, 2008). Despite all those efforts and the link with supply chains related impacts, life cycle oriented methodologies still miss to account for them. A lack of accounting for regulating and supporting ecosystem services would overthrow the goal of Life Cycle Assessment (LCA) methodology towards sustainability (Singh and Bakshi, 2009).

The development of models and indicators for biodiversity and ecosystem services in Life Cycle Impact Assessment (LCIA) has been underway for more than a decade. To our knowledge only a few studies so far have been conducted to integrate pollinators and pollination services in the LCIA framework. Zhang et al. (2010a, 2010b) proposed a framework for an ecologically based LCA, which accounts for the contribution of a handful of ecosystem services in the life cycle of industrial activities. Nevertheless, it remains not comprehensive (Singh and Bakshi, 2009).

In an era of extreme environmental changes induced by resource exploitation, it becomes necessary assessing the sustainability of production and consumption pattern in the agri-food sector, improving the existing supporting methodologies to reach the goal of a sustainable food system (Soussana, 2014). Therefore, it is fundamental including the natural capital, particularly pollinators' biodiversity and their crucial ecosystem services, in those life cycle oriented methods, such as LCA, since none of the existing LCIA methods and models accounts for their role in a comprehensive way.

The aim of the present study is to review the anthropogenic and environmental drivers exerting pressures on pollinators. This review represents the first step towards the integration of pollinators and their services in the LCIA framework. Starting from pollination as pivotal ecosystem service and pollinators as target group for biodiversity protection, this review aims to identify the modeling needs for the impact assessment in the LCIA context. Our study represents a bridge between ecological science and global product policies. Through the implementation of LCIA models and methods capable of accounting for ecosystem services such as those delivered by pollinators, we might be able to reduce anthropogenic impacts, thus meeting the goal of a more sustainable food production and consumption system.

This review is organized as follows: Section 2 is presenting the methodology adopted for the review; Section 3 presents the results of the review and it is followed by Section 4, where we discuss how to introduce the assessment of the drivers of impact on pollinators within LCIA.

2. Methodology

We conducted a review of scientific articles and reports focusing on evidence of impact on pollinator populations and pollination services. We carried out the literature search using the bibliographic database SCOPUS and the 'ConservationEvidence.com' website, a free authoritative information resource designed to support the protection of global biodiversity. We performed a preliminary search using headings based on combinations of broader terms related to pollination issues ((pollinator* OR pollination) AND (decline* OR loss* OR threat* OR impact* OR risk*)), in order to enable an early understanding of the current forces exerting pressures on pollinator populations. Then, in order to limit the results to the explicit impact drivers resulting from the preliminary search, we refined the search using more detailed criteria. We used relevant and logical keywords referring to the specific impact driving forces as follows: 'land use change', (land OR habitat) AND (transformation* OR degradation), 'chemical emissions', 'pesticide*', 'insecticide*', (invasive OR alien) AND species', 'invader*', 'competition', 'climate change', (phenological OR spatial) AND mismatch, 'pests', 'pathogen*', 'disease', (electric OR magnetic) AND 'field*' and 'electromagnetic radiation*', (GM OR genetically modified OR transgenic) AND crops. These keyword variations were combined with the above-mentioned broader terms on pollination issues using the Boolean command 'AND'. The outputs included reviews, laboratory- and field-based studies, and scientific reports manifesting clear impacts on pollinator communities and pollination services and suggesting what ecological indicators are currently adopted to measure the effects of impact drivers on pollination systems. The great majority of the selected papers