

OPINION ARTICLE

Do we realize the full impact of pollinator loss on other ecosystem services and the challenges for any restoration in terrestrial areas?

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Pollinators are key agents for ecosystems and humankind concerning biodiversity, agriculture, climate change adaptation, and all other ecosystem services. Particularly in industrialized countries pollinator diversity is in decline. The bulk of research is on entomological or plant-pollinator network related topics, but the broad range of impacts of pollinator loss on coupled human and natural systems is not yet studied. As 87% of all flowering plants depend on pollinators, they are basic for all ecosystem services to some extent. Therefore, pollinator loss might cause simultaneous degradation of ecosystem services inducing counterproductive human responses and interlinked poverty spirals. The interaction of climate change, a main risk factor for pollinators, and unadvised human responses to pollinator decline are rarely studied. Tipping points of pollinator loss are not yet identified. Can counterproductive human responses to pollinator deficiency upscale pollinator decline toward a pollinator-loss syndrome in the course of climate change? The article argues for research on the impacts of pollinator loss on other ecosystem services, useful and counterproductive human strategies on pollinator-loss induced degradation, and the integration of pollinator protection into all terrestrial restoration efforts.

Key words: ecosystem services, interdisciplinary, poverty, simulation, tipping points

Implications for Practice

- Loss of 87% of pollinator-dependent flowering plants and its consequences on all other ecosystem services should be explored in benchmark ecosystems.
- Human responses on such simultaneous loss of ecosystem services should be simulated to avoid worst-case scenarios like a pollinator-loss syndrome.
- Pollinator protection should be included in any kind of terrestrial restoration project to promote long-term sustainability.

The pollination services of wild pollinators are recognized by entomologists, biologists, and ecologists (IPBES 2016), but the majority of individuals involved in their management like politicians and farmers focus more on honeybees. However, Nabhan and Buchman (1997) estimate that wild pollinators provide around 85% of global pollination services. Wild pollinator species are common resources like glaciers, large parts of rangelands, lakes, oceans, and forests. Though wild pollinators are an important agricultural production factor (Gallai et al. 2009), they are not classified as livestock (FAO 1994) and agricultural research mostly neglects the production factor common pool pollinators (Christmann & Aw-Hassan 2012).

Pollinators are in decline on all continents (except Antarctica, which does not host them; Hassan et al. 2005) due to habitat loss, agricultural practices, climate change (Biesmeijer et al. 2006; Burkle et al. 2013; Dirzo et al. 2014; Goulson

2014; IPBES 2016; Potts et al. 2016a, 2016b; Hallmann et al. 2017; Ashbacher 2018; Glaum 2018; Hallmann et al. 2018; Sánchez-Bayo & Wyckhuys 2019; Schweiger et al. 2019), and common lack of knowledge among farmers (Kasina et al. 2009; Munyuli 2011; Hanes et al. 2013; Christmann et al. 2017). Dainese et al. (2019) showed that richness of service providers such as pollinators has higher positive impacts than their abundance. Though pollinators have remarkable adaptive capacity and robustness (Møller et al. 2012), in some areas or cropping systems (e.g. almond orchards in California; Maoxian County/Sichuan) the decline of native pollinators exceeded already the threshold (Partap & Ya 2012). Restoration may lead to higher pollinator diversity: Breland et al. (2018) state that restoration does not automatically induce better pollination as well, whereas Barral et al. (2015) report on very high recovery of pollination service after restoration. Little is known about the capacity of farmers and local communities to restore landscapes efficiently.

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Potts et al. (2016a) clearly stated there is “a mismatch [...] between scientific evidence of impact and conservation, and management responses.” Since most wild pollinators have a limited radius of activity (on average 50–2,000 m around their nests) (Kohler et al. 2007) pollinator protection depends on local management and action by hundreds of millions of local farmers and protagonists in nearly the entire terrestrial area of our planet, especially in agricultural landscapes (Christmann et al. 2017).

However, we lack research on villagers’ readiness to take action without rewards (Christmann et al. 2017). Also, scalable, economically self-sustaining approaches for pollinator protection are rare (Kleijn et al. 2018; Christmann 2019).

When the drivers of pollinator decline reach a critical point, pollinator populations can suddenly collapse (Lever et al. 2014). Loss of pollinator species can cause cascades of extinctions (Hassan et al. 2005; Biesmeijer et al. 2006; Pauw 2007; Dirzo et al. 2014). Their loss directly affects complex network interrelations and the functional composition of flora, fauna, and habitats (Hassan et al. 2005; Christmann & Aw-Hassan 2012; Burkle et al. 2013; Dirzo et al. 2014). The functioning of ecosystems hinges on key species such as pollinators (Hassan et al. 2005; Kremen et al. 2007; Haines-Young & Potschin 2010; Dirzo et al. 2014). Increasingly, the impacts of pollinator loss on plant-pollinator networks (Lennartson 2002; Lever et al. 2014; Novais et al. 2016; Ashbacher 2018; Evans 2018; Redhead et al. 2018) and on birds (Benton et al. 2002; Goulson 2014) are assessed and modeled. Carpenter et al. (2009) stated that the decline of regulating services (e.g. pollination and biological control) “foreshadows future declines in other ecosystem services.” Declines might not be linear, but interlinked. The complexity of interlinked impacts is not yet analyzed (Gao et al. 2018).

Potential Impact of Loss of 87% of Flowering Plants Due to Pollinator Loss

The value of pollinators, pollination services, and restoration of pollinator-friendly landscapes should be reconsidered, as (1) 87 of 115 most important food crops (76%) require or benefit from pollinators (Klein et al. 2007); (2) 87% of all flowering plants need pollinators (Ollerton et al. 2011); (3) cross-pollination enhances genetic diversity (Hassan et al. 2005) and thus the development of genotypes potentially better adapted to climate change (Parmesan 2006; Christmann & Aw-Hassan 2012); (4) all ecosystem services (ES) rely to some, but different, extent on pollinators, namely the percentage of ES provided by these 87% of flowering plants.

In particular the full dimension of the fourth aspect seems to be not yet realized, even by IPBES (2016, 2018). An example can be large monocultures with frequent tillage and high load of hazardous chemicals spreading chemicals further to nature by water and wind. Such landscape management affects insect and even bird diversity and abundance in a larger region (Goulson 2014; Hallmann et al. 2017). If 87% of all flowering plants

cannot produce a sufficient amount of fertile seeds for regeneration due to pollinator loss and if lack of cross-pollination highly reduces the chances of plants to adapt to climate change, they could become rapidly extinct in the course of temperature extremes, changing temperatures and precipitation patterns, and seasonal abnormalities. This would impact all other ES to some extent.

The ES “erosion prevention and maintenance of soil fertility” for instance depends to a great extent on plants with elaborate root systems, some of which depend on pollinators (e.g. *Cornus mas*, *Tilia cordata*, *Tilia platyphyllos*, *Salix caprea*, *Acer pseudoplatanus*, *Prunus spinosa*, *Astragalus*, *Artemisia*, and *Rosa canina*). Many legumes (nitrogen fixation) depend on specific wild pollinators, e.g. Megachilidae and *Bombus*. Pollinator-dependent plants (e.g. *Phacelia* and *Trifolium*) enhance soil organic matter and support the well-being of worms, enhancing soil fertility. (Invasive) pollinator-independent plants can compensate loss of photosynthesis, soil erosion, or flood prevention to some extent, but it cannot be taken for granted that these plants will be as useful for humankind, livestock, wildlife, and ecosystems. The loss of the pollinator-dependent common mangrove *Avicennia germinans* for instance can exacerbate floods in tropical countries. Pollinator-independent plants like sedges could occupy the space, but will they provide adequate services?

In addition, the remaining species in degraded ecosystems might not be able to sustain their current level of ES, e.g. the remaining 13% of flowering plants and pollinator-independent plants will probably not be sufficient to provide adequate habitats for all species. Impoverished ecosystems are less robust in the course of climate change than ecosystems with high diversity, e.g. concerning their capacity to reduce the impacts of storms, pests, and diseases (Hassan et al. 2005; ten Brink et al. 2011; Schweiger et al. 2019). Currently, the high diversity of pollinator-dependent plants indirectly also supports the ES of pollinator-independent plants by enhancing the robustness of ecosystems.

Taking the fourth aspect into account, pollinators are basic for global benefits such as globally traded crops and food products, pharmaceuticals, raw materials, carbon sequestration, climate regulation, ecotourism, spiritual imagination, and inspiration in art and decoration. The attribution of pollination providing only local benefit (ten Brink et al. 2011; de Groot et al. 2012) might be wrong. Also, pollinators contribute to more sustainable development goals (SDGs) than to SDG 2 and 15 only (Dangles & Casas 2019); they contribute highly also to SDGs 1, 3, 6, 8, 13, and 16.

Human Responses to Loss of ES Might Be Counterproductive

When pollination fails, many plants go locally extinct and this reduces other ES. Humans’ responses can be counterproductive for the survival of pollinators, availability of other natural resources, social stability, and peace. Breeding pollinator-independent crops to avoid malnutrition (Chaplin-Kramer et al. 2014) for instance could accelerate

pollinator decline. Replacement by rented honeybees, managed bumblebees, or hand-pollination is costly (Bauer & Wing 2010), risky, and not even possible for all flower types and crops, altitudes, and weather conditions. Shift to pollinator-independent crops aggravates the local lack of pollen and nectar and can be regarded as a counterproductive response to pollinator loss.

Research is needed on willingness to pay to avoid pollinator decline and also on preferred coping strategies to pollinator-loss induced degradation among farmers and other social groups (Breeze et al. 2016; Martínez-López et al. 2018). Also, simulations based on the results of this research would be useful, in particular as responses to pollinator loss can exacerbate adaptation to climate change and vice versa. If, for example, farmers would compensate the loss of pollinator-dependent high-value crops by increased livestock production based on maize and barley, this would increase water consumption, greenhouse gas production, air and water pollution, overexploitation of natural resources and sinks, accelerate climate change, and cause higher risks for poverty for future generations. If farmers would respond to the loss of pollinator-dependent high-value crops by abandoning such areas, it can increase food insecurity, migration, and social risks for migrants and challenges in regions of immigration. Partial loss of linen, cotton, textile fibers, wood, and energy plants might accelerate the consumption of petrochemical resources, aggravate climate change, and increase not-compostable garbage. Greater run-off of precipitation due to loss of flowering plants with strong root systems can induce local inhabitants to abandon land or migrate, or induce regional governments to invest in the construction of dams. If, however, decision makers would be aware of the multifold potential impacts of pollinator decline, restoration in time could avoid such negative development.

The loss of species in flora and fauna due to deteriorated habitats can change ecosystems considerably and humans can lose the homeland they are familiar with. So, restoration projects should raise awareness that ES will be restored as far as possible, but landscape might look different. Otherwise humans can lose interest in protecting the environment. The loss of (flowering) recreational and touristic sites can raise tension in society. This should be considered ahead of time.

The poverty impacts of multifaceted simultaneous environmental deterioration as a consequence of pollinator loss have yet to be comprehensively analyzed. Global pollinator loss could cause environmental and human impoverishment in unconceivable dimensions. Current research analyzes pollinator-plant networks as referenced above. The tipping points of pollinator decline for *Homo sapiens* and identification of signals for critical transitions need to be studied as well. More research is needed also on the impact of pollinator loss on functioning of ecosystems, climate change resilience, global food chains (Bauer & Wing 2016, 2010; Oliver et al. 2015), social stability, tourism, culture, and peace. Economy-wide losses largely exceed farmer-related losses (Bauer & Wing 2010) and are understated even if the calibration focuses only on the impact of pollinator loss on agriculture (Bauer & Wing 2016).

Can Counterproductive Human Responses Aggravate Pollinator Decline Toward a Pollinator-Loss Syndrome as a Main Driver of Global Change?

Pollinator loss can reduce various ES at the same time. This could aggravate the risk of simultaneous interrelated and interacting local poverty spirals. The interdependency of pollinator-loss induced poverty spirals might accelerate and aggravate the deterioration of coupled human and natural systems toward a syndrome. The term syndrome is used based on Schellnhuber et al.'s (1997) definition of “archetypical patterns of civilization-nature-interactions” characterized by “flowing together of many factors” and showing a “complex clinical picture.”

Compensation of partial loss of ES can be costly or take a long time (Bauer & Wing 2010; Partap & Ya 2012). Increasing costs and exacerbating risks will especially aggravate the vulnerability of one third of the global population with the lowest income (Novais et al. 2016; Narloch & Bangalore 2018). In rural areas, especially mountainous areas with frequent mudflows and floods, crop and income loss have high potential to cause (labor) migration of men and youth (Christmann & Aw-Hassan 2015). This can increase the difficulties for the remaining population (women, children, elder generation) to cope with a species-poor deteriorating environment, especially if the flow of remittances is scarce (Christmann & Aw-Hassan 2015). In mountainous areas relying on pollinator-dependent crops and diverse vegetation to prevent erosion, pollinator-population collapse could accelerate and cause the “rural exodus syndrome” (Schellnhuber et al. 1997).

When pollinator-loss induced poverty risks appear from various ends in many countries and affect the growing global population a pollinator-loss syndrome (Fig. 1) might become a main syndrome of global change. The coincidence of multifold deterioration can result in higher tensions in society and between countries. If e.g. the global loss of high-value crops surpasses a threshold, it will affect commodity exchanges (food and renewable raw materials), food industries, and global food prices (Bauer & Wing 2010, 2016). Some governments could go for military interventions to secure access to environmentally still functioning areas or to prevent the movement of ecological refugees. Counterproductive coping strategies and archetypical human responses giving preference to the well-being of one's own group or population can increase.

Implications for Restoration Efforts

Long-term restoration of rangelands, forests, and other landscapes might fail if the pivotal role of pollinators for all terrestrial ecosystems (except Antarctica) is not recognized. Neither Ockendon et al. (2018) nor IPBES (2018) reflect the basic role of pollinators for all kinds of terrestrial restoration efforts. Also, the difficulty to get the collaboration of many activists to restore large terrestrial areas for species depending on small habitats is overlooked.

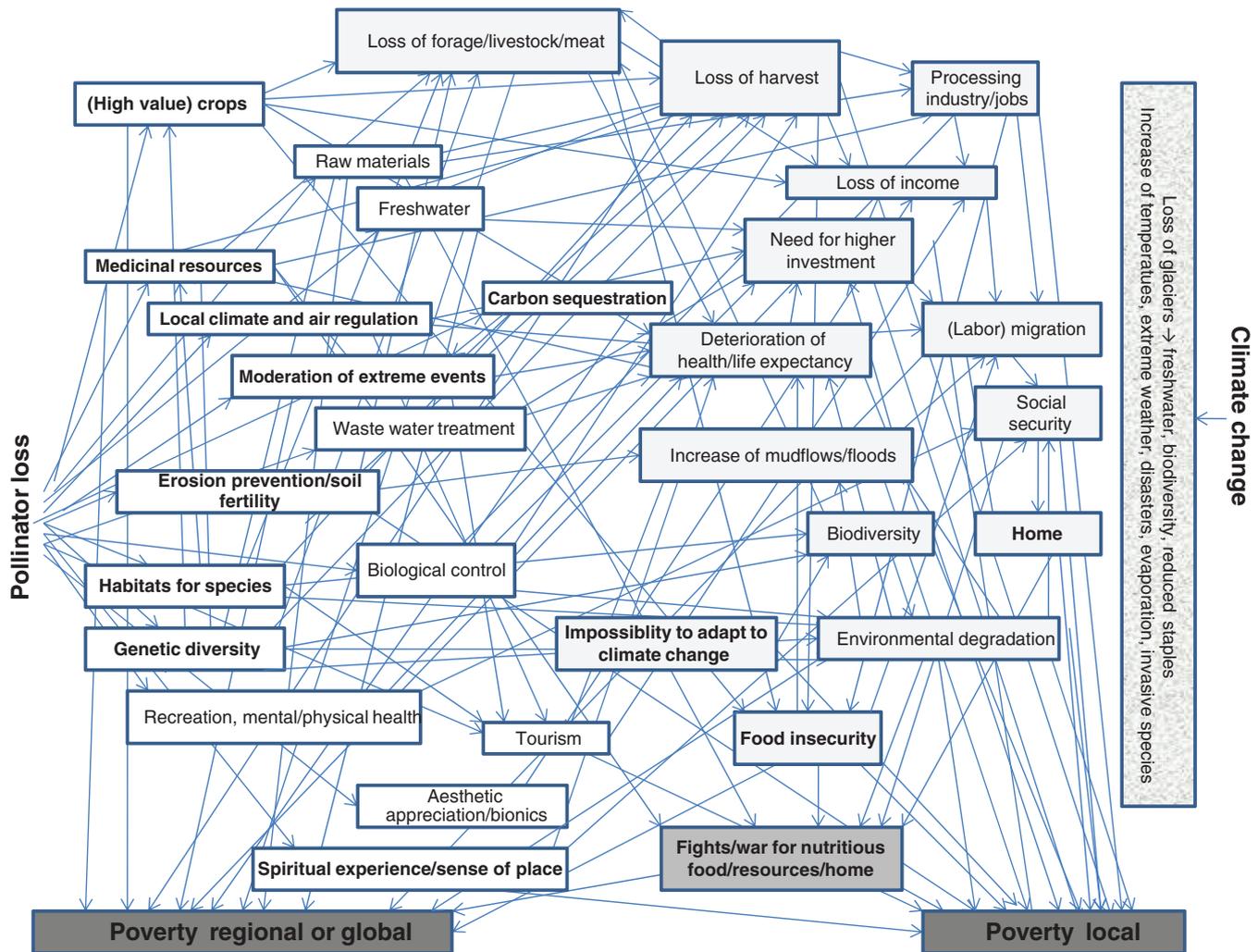


Figure 1. The pollinator-loss syndrome. Arrows: negative impacts; white boxes: ecosystem services (ES); plain gray boxes: impact of partial loss of ES; structured gray box: climate change effects, which might fuel pollinator loss or exacerbate negative effects of pollinator loss or increase dependency on pollinators.

Alternative to individual counterproductive coping strategies, governments can enhance their policies and can start timely restoration of agricultural lands for pollinators e.g. by introducing farming with alternative pollinators (FAP; Christmann & Aw-Hassan 2012; Christmann et al. 2017; Christmann 2019) or paying rewards for seeding wildflower strips.

Restoration should not focus on conservation of certain pollinator species in a region, but on restoring the ability of landscapes to host a high diversity and abundance of native and invasive pollinator species and allow their migration (Corbet 2000; Kremen & Ricketts 2000; Roubik 2000). Diverse floral resources, nesting sites and materials, water and connectivity should be integrated into all land management issues. Any restoration project should have also a clear objective on pollinator protection, conduct an ex ante assessment on pollinator diversity and an ex-post assessment.

Conclusion

It seems obvious that pollinator loss deserves similar attention as climate change, both concerning restoration and concerning complex scenarios of nonaction including different human coping strategies. Mainstreaming pollinator protection across sectors and globally is overdue (Christmann 2019). To promote higher focus on pollinators within restoration and to gain more local activists, the impacts of nonaction or counterproductive human coping strategies should be economically and environmentally modeled for some exemplary coupled human-natural systems.

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